# STABILIZATION AND PRESERVATION OF CHARRED DOCUMENTS USING NATURAL POLYSACCHARIDES AND THEIR DECIPHERMENT

**A THESIS**

***Submitted by***

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# APPROVAL SHEET

This Ph.D. thesis entitled **"Stabilization and Preservation of Charred Documents using Natural Polysaccharides and their Decipherment"** by **Sonali Kesarwani** is approved for the degree of Doctor of Philosophy in Forensic Science.

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## CANDIDATE’S DECLARATION

I, **Sonali Kesarwani**, declare that the work in the thesis titled “**Stabilization and Preservation of Charred Documents using Natural Polysaccharides and their Decipherment**” was carried out by me in the Department of Forensic Science, School of Biomedical Sciences, Galgotias University, India. The information used for my literature review was fully acknowledged in the text and references. This thesis has not been presented in any scientific gathering, nor has it been presented for another degree at any University.

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This thesis is dedicated

wholeheartedly

to

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I wish them a healthy life !!

# ABSTRACT

Charred documents pose a significant challenge in forensic document examination, requiring specialized techniques for their stabilization and decipherment. Conventional methods for charred document examination commonly employ chemicals such as polyvinyl acetate (PVA) for their preservation; however, the use of PVA and similar chemicals presents several drawbacks, including limited availability, toxic effects, non-biodegradability, poor resistance to weather and moisture, and slow setting speed. These limitations highlight the need for alternative, more environment-friendly solutions that can effectively stabilize and preserve charred documents while facilitating their future examination and analysis. This thesis aimed to address this need by proposing a green and novel coating material synthesized from natural polysaccharides, providing a promisin
g alternative to polyvinyl acetate to stabilize and decipher charred documents.

Exploration of natural products to synthesize coating materials involves mucilage-rich resources like fenugreek seed mucilage, okra mucilage, sago, and tamarind seed powder, but optimum results couldn’t be obtained in terms of consistency, transparency, and smoothness. Further investigation disclosed pure starch as a great resource to synthesize the analog, which has proven to be an exceptionally good material for stabilizing and preserving charred documents. Furthermore, once applied to the charred documents, the synthesized analog also makes the invisible writing visible, which was an extra advantage of the synthesized product.

Synthesis of starch analog involved the microwave irradiation of an optimized amount of starch, glycerol, in the presence of acetic acid to get requisite consistency and transparency. Starch, concentration, reaction duration, and temperature of the reactions were the other parameters that were needed to regulate to get the best optimum results. Out of varied concentrations, the best result was achieved with 6% starch solution microwaved at 80 ºC for 12 minutes. In addition, the characterization of starch and its analog using ATR-FTIR spectroscopy for spectral determination and MALDI-TOF mass spectrometry for mass analysis revealed the formation of a functional peak of ether-linkage in the starch-based analog, which was further confirmed by its mass, i.e., $n[C_{35}H_{64}O_{27}]^+$ at 916.36 corresponds to the molecular mass of the synthesized starch-based analog.

Moreover, the coating of charred documents with synthesized analog involved varied types of charred documents, which vary considerably depending on the types of paper, the type and colour of ink used to make a document, and the temperature. Some other environmental factors also play an important role in charring that affects the nature of charred documents. Different paper and ink reach their maximum charring stage before their carbonized ash stage at different temperatures. In this study, documents were made using 18 different ballpoint and gel pen inks of different brands and colours on 3 types of paper viz., 75 gsm JK copier, 90 gsm bond excel paper, and 100 gsm diary paper. The combinations made on 75 gsm copier paper got maximum charred at 300 ºC, while the 90 gsm and 100 gsm were at 304 ºC and 308 ºC, respectively.

The fragile charred documents were then stabilized and preserved using the starch-based analog, and the result showed that, once the documents were coated with analog, the coating dried within 10-15 mins, and the documents gained an appreciable strength. Hence, the analog's coating aided in the preservation of fragile and brittle masses of charred documents, which can now be easily handled and used for further investigation.

Additionally, results of deciphering the content on charred documents using starch-based analog showed that the documents made with ballpoint pens, particularly black and red ballpoint inks of Linc Pentonic and Hauser Germany, gave the best results of decipherment by producing contrast and revealing the invisible texts. The G-lens also recognized successfully 100% deciphered characters in combinations from 17 to 21, i.e., BLBP Hauser Germany on 90 gsm and 100 gsm; RBP Linc Pentonic on 75 gsm, 90 gsm, and 100 gsm paper; and in combination-25 and 27, i.e., RBP Hauser on 75 gsm and 100 gsm. Moreover, the red ballpoint pen ink of Linc Pentonic manufacturer, irrespective of type and thickness of paper, showed the highest rate of success in decipherment, resulting in 100% correct character recognition using G-lens unlike the document samples containing gel pen inks.
On the other hand, some combinations were not deciphered at all, and the texts were not visible to the naked eye. For example, the blue ballpoint of the Unique EZY manufacturer showed 0% character recognition through G-lens; however, a few characters were very faintly visible to the naked eye that the G-lens could not recognized. In addition, the blue gel inks of Elkos Magic manufacturer also gave 0% character recognition via G-lens. The least significant result was shown by the red gel pen inks of all three manufacturers used in the study i.e., RG Classmate Octane, RG Elkos Velo, and RG Reynolds Jiffy on all three

types of paper i.e., 75 gsm copier, 90 gsm bond paper, and 100 gsm diary paper. This can be due to the ink formulation of red gel ink, which is a water-based solvent in gel form. Furthermore, the colour of the dyes present in the red gel ink affects the decipherment of the texts on different paper substrates. The red gel ink residue may not produce contrast after getting adhered to the starch-based analog applied on the charred documents due to their colour behaviour. Besides this, the majority of the combinations of pen and paper gave promising results of more than 70% character recognition, which can provide a sufficient hint and clarity to the questioned document examiner while deciphering the content of the document linked to any offence. This presented the great success and efficiency of a novel synthesized starch-based analog in stabilizing the charred masses of documents that either accidentally or deliberately underwent fire incidents and turns into black, carbonized, fragile, and brittle states that need processing for bringing back their original content without much compromising with their loss.

Moreover, the stabilized charred documents were further visualized under a more sophisticated instrument VSC, widely employed in forensic science laboratories for document examination. By this technique, it was observed that when the documents were viewed under VSC, even after a month of stabilization and decipherment at different light sources like, a flood light, white spot, and side light at different longpass (wavelength) like VIS, 645, 695, 715, 725 and 850, proved to provide sufficient character decipherment in the majority of combinations, while in the red gel pen inks, the decipherment was not found appreciable. This is because every ink has a different wavelength and thus absorbs light under visualization at different intensities. However, the VSC provided a sufficient clue in the document combinations with no-to-little decipherment of texts.

After the stabilization and decipherment, the documents were tested for increased strength after coating and preserving the charred documents using a Bursting Strength tester. The analysis showed that there was a significant increase in the bursting strength of stabilized and coated charred documents with that of non-coated. For example, the combination of Linc Pentonic blue ballpoint pen ink on 75 gsm paper had a bursting strength of 0.12 $kg/cm^2$, which, after getting stabilized, gained an adequate increase in strength to 0.21 $kg/cm^2$. Similarly, the bursting strength of combination BBP Linc Pentonic on 90 gsm bond paper charred at 304 ºC had risen in strength from 0.15 $kg/cm^2$ to 0.25 $kg/cm^2$. These findings demonstrate that applying starch-based analog over the charred documents made with different pen and paper combinations strengthened the charred paper surfaces by absorbing and penetrating the layers of charred masses, thus providing a better stabilization and preservation technique.

In conclusion, the study on deciphering charred documents using ballpoint and gel pen inks of different colours and brands on various paper grades has yielded significant findings. The utilization of a starch-based analog, G-lens, and Video Spectral Comparator has demonstrated promising potential in enhancing the visibility and recovery of ink residues on charred surfaces. While black and red ballpoint pen inks displayed a higher success rate in decipherment, other ink types and colours, such as red gel, presented greater challenges due to variations in ink composition and colour intensity. The success of this integrated approach highlights the importance of employing multiple techniques to overcome the complexities associated with charred document analysis. Furthermore, findings demonstrate the effectiveness of this technique in uncovering hidden text and shedding light on critical details that were once lost to fire damage. This breakthrough holds significant implications for forensic investigations, offering a promising avenue for recovering and analyzing vital information from charred documents using commonly available materials. Future research endeavours should focus on further refining and expanding the application of these methodologies, thereby advancing our capabilities in forensic investigations and contributing to elucidating critical information hidden within charred documents.

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# ABBREVIATIONS

QD- Questioned Document

QDE- Questioned Document Examiner

DNA- Deoxyribonucleic acid

pH- Potential of Hydrogen

gsm- Grams per Square Meter

VSC- Video Spectral Comparator

PVA- Polyvinyl acetate

IR- Infrared

UV-Ultraviolet

ATR FTIR- Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy

MALDI-TOF MS- Matrix Assisted Laser Desorption/Ionization-Time of flight Mass spectrometry

ESDA- Electrostatic Detection Apparatus

Viz.- Videlicet means "namely"

SRL- Sisco Research Laboratory Pvt. Ltd.

OCR- Optical Character Recognition

G-lens- Google lens

Cp- Centipoise

# CHAPTER- 1

# INTRODUCTION

## 1.1. Documents

The term "document" encompasses various meanings depending on the context in which it is used. According to Collins Dictionary, a document refers to one or more official pieces of paper containing written content [1]. In other words, the document can be defined as any information made using any conventional (chalk, pen, pencil marker, etc.) or unconventional (charcoal, lipstick, vermillion, blood, etc.) writing instrument on any kind of conventional (paper, books, photographs, etc.) and unconventional (wood, stone, cupboard, tissue, skin, etc.) writing surfaces. Additionally, documents can be understood as recorded information in various formats or mediums, such as written, printed, electronic, audio-visual, or graphic materials [2]. Documents can have many forms, including books, letters, emails, memos, contracts, photographs, videos, and sound recordings [3]. Documents play a crucial role in conveying information, documenting events, establishing legal rights and obligations, and serving as evidence in legal proceedings. Their significance in society cannot be overstated, as they facilitate communication, knowledge preservation, and record-keeping across numerous fields, including business, government, and education [4].

## 1.2. Questioned Documents

Questioned document (QD) is a specialized field of forensic science that helps to investigate the document-based evidences. It deals with the analysis of documents, including handwriting, signatures, paper, ink, and printing methods, to determine their authenticity, origin, authorship, and to explore the possible alterations or forgeries [5-7].

In simpler terms, questioned documents are those that come under scrutiny in legal proceedings due to doubts surrounding their authenticity, authorship, or origin. These documents can range from forged signatures and altered papers to anonymous letters or ransom notes, regardless of whether they are handwritten, typewritten, or printed. It is a type of document whose legitimacy becomes questionable, hence the name Questioned document [8, 9]. Questioned documents portray a remarkable role in conviction and justification in a court of law [10], therefore the analysis of questioned documents is an important field that involves a range of techniques and methods for the examination of various physical and chemical properties of documents to determine their authenticity and origin. This can help provide valuable evidence, resolve legal disputes, and identify fraud in criminal investigations and civil litigation. These can include handwriting analysis, ink analysis, paper analysis, and document reconstruction.

Questioned document examiner (QDE) scrutinizes various types of documents, depending on the type, that may include handwritten (suicide notes) or typed letters, contracts, wills, checks, passports, and other written or printed materials [11]. For the execution of their jobs, the experts in questioned document examination are trained to analyze the physical and chemical properties of questionable documents and the context in which they were produced [12]. In some cases, advanced forensic methods like DNA analysis or advanced imaging technologies are utilized to identify fraudulent alterations in order to support the document evidences. The analysis of questioned documents has played a crucial role in high-profile cases such as the Enron scandal [13] and the assassination of President John F. Kennedy, where it has provided critical evidence to aid in solving the crimes and establishing liability. Still, even after the availability of trained experts and advanced techniques, the detection of forgeries and alterations poses a major challenge in questioned document examination, especially in the case of charred documents, as forgers employ various techniques to mimic the characteristics of the original document.

### 1.3. Charred Documents

A charred document is a type of questioned document that has been subjected to fire or heat damage resulting in charring or scorching of the paper. Most often, in an instance, questioned documents get burned accidentally or deliberately in order to hide one’s wrongful intention or criminal activities. “Devastating fires, whether accidental or deliberate, have a devastating effect over time on paper or other writing materials”. Emissions from fire include gases (carbon dioxide, carbon monoxide, nitric oxide, etc.) and airborne particles (soot, organic matter, etc.) [14, 15]. When a document is exposed to fire, the heat can cause the paper to burn or char and darken, by burning or due to contact with extreme heat or smoke and soot of the flame, which probably may contain crucial information, resulting in the destruction or alteration of the original text or image. During burning, one or a few sheets of paper may get completely burnt, whereas several sheets of paper stacked together may not burn completely because of the limited supply of oxygen [16]. Due to the effect of excessive heat, charred documents also become extremely fragile and brittle, even curl around the edges. Charred documents are often difficult to read, and the content of the document may be partially or completely concealed by fire damage. In such cases, deciphering the writing on burnt/charred documents becomes challenging.

Charred documents are generally made up of paper, which is made up of cellulose fibers [14, 17-19]. Each paper varies depending on the quality, thickness (gram per square meter), and tagging material, i.e., colour. In arson or other fire investigations, these paper documents with wrong intentions are basically connected to some or the other kind of crimes ranging from fraud and anonymous letters to armed robbery, extortion, ransoms, phony, insurance, financial matters, even suicide, and murder [10, 20]. If a piece of paper is completely burned, all the organic material is destroyed, and only inorganic ash remains. The appearance of this will depend on its chemical composition, which in turn will depend on the filler in the paper and also on the inorganic components of any ink that was present. Ash from inks is more likely to be visible if it derives from printing rather than writing or typewriting because printing inks have a much higher proportion of inorganic compounds. When documents get charred to ash, they will not be able to give adequate information, and only little can be done in that case because they disintegrate almost immediately. In general, the written texts are not visible on the charred documents, but further heating highlights the content to be somewhat visible. However, in that case the documents cannot be preserved as it is likely to be turned to ash [21].

Charred documents also vary in their physical and chemical composition based on the variety of paper and ink used to make such documents and also upon the condition, it got charred [22]. It is not necessary that all documents charred at any temperature range, that resulted in a carbonized ash stage, can be handled, preserved, and deciphered [23]. In forensic investigation, documents are often examined when they have not been completely burnt but are merely charred, and, although brittle, can be moved with care. Charred documents recovered from crime scenes can be in printed using printer or typewriter as well as in hand written form using some writing instruments like, pen/pencil. Documents made from ink written on paper will be heavily damaged through fire, smoke, or soot. The content of the documents, like, what was originally written on them may provide some clue to who-so-ever wrote on them.

That is why burning of documents is the most common form of destroying evidence, with a belief that once evidence of their crime has turned into ash, it cannot be retrieved. Burning of document is also governed by many factors like temperature, atmospheric condition, storage area and condition, paper quality, etc., which may prevent the entire document from being completely burnt to ashes. In such case the documents become black but not turn into ashes, making the writing that is on it unreadable to someone looking at it with the unaided eye. In this condition, writing, typewriting, or printing contrasts with the background in several ways, depending on the composition of the paper and the ink. Till now, various methods have been described to improve the contrast between the ink and paper, but most tend not to improve the clarity in terms of texts visibility. They may also damage or break up the brittle, charred fragments. Some non-destructive techniques like photography under infrared radiation is also applied for documents examination, but still, there is a great need of preservation of charred documents in such a way that the decipherment of documents will not get effected [5, 24].

Experts can use specialized techniques and equipment to try to reconstruct the original content of the document or to determine whether the document is genuine or has been tampered. Reconstructing charred documents can be a complex and challenging process, and it may not always be possible to recover the original content fully. Nonetheless, examining charred documents can provide important evidence in criminal and civil cases and help shed light on the circumstances surrounding a fire or other incident.

### 1.3.1. Types of Charred Documents

Charred documents can be classified into several types based on the extent and nature of the damage they have gone through [25], as shown in Figure 1.1. These are illustrated below:

**Partially Charred Documents**

These are documents that have been partially burned due to the presence of insufficient oxygen during burning. This leads to incomplete combustion, hence leaving some parts of the paper intact while other areas are charred or scorched.

**Completely Charred Documents**

These are documents that have been completely burned, resulting in the complete destruction of the paper.

**Document Fragments**

These are small pieces of paper that have broken off from a larger document as a result of fire damage.

**Indirectly Charred Documents**

These are documents that have not been exposed to fire directly but have been damaged by the heat and smoke generated by a nearby fire.

**Chemically Charred Documents**

These are documents that have been chemically treated with acids or other substances to mimic the effects of fire damage for the purpose of altering or destroying the information contained in the document.

**Figure 1.1: Types of Charred Documents.**

The severity or the level to which the documents will get charred in an atmosphere varies greatly and thus depends on various parameters. These are listed below:

### 1.3.2. Factors Affecting Charring of Documents

#### 1.3.2.1. Closed or Open Environment

Documents got charred in a confined and closed space (e.g., in a deed-box, metal cupboard, or box) has been known to give rise to effects differing from those produced by charring in the open air. A document kept in a closed environment undergoes charring in a limited supply of oxygen which may results in partially charred documents. On the other hand, documents burned in an open environment may undergo more complete oxidation that may result in completely charred documents [26]. Thus, it is sometimes important to distinguish between partly charred and completely charred documents. As a rule, but not always, the former can be read by the unaided eye.

#### 1.3.2.2. Type of Flame and Temperature

When papers are burned in an open flame different point of paper receives different temperature of burning. Each portion burns at its own pace that depends on the supply of oxygen at that point. these stages follow hard on each other. Each portion will burn at its own pace depending on the supply of oxygen available at that point. During burning/charring, paper undergoes various stages at different temperatures turning the paper/document from light brown to black and finally grey ash to white ash [27].

#### 1.3.2.3. Type and Quality of Ink and Paper

Another important factor to which sufficient attention is not always given is the type of paper and ink used. Where the charring is only partial, the kind of paper, and especially the amount of loading present, is an important factor [26].

Inks also vary considerably in nature. Initially, ink was crafted from a variety of natural substances, including animal fats, fruit or vegetable juices, and plants. However, contemporary ink production primarily takes place in factories, where synthetic materials such as pigments or dyes are used [28]. These modern ink formulas typically incorporate a base, such as water, to facilitate the absorption of dyes or pigments, alongside other chemical additives that influence aspects such as drying time, texture, and ink preservation [29]. Thus, ink is a mixture of different compounds which is used to colour a surface to produce an image, text, or design. Inks also have additives such as surfactant for smooth flow, fungicides to prevent fungal growth and buffering agents to control the pH and give the ink desirable writing characteristics [30]. The main components of ink are synthetic dyes and glycol-based solvents but the characteristics of the ingredients vary greatly depending on the type of ink [31]. The exact composition of pen inks is specific for each brand and manufacturer and is a trade secret.

An ink based on a mineral pigment is not easily destroyed completely by charring, although such inks are not common except in coloured illustrations, and these are seldom of importance [32]. On the other hand, inks based on volatile solvents and synthetic dyes show different characteristics when subjected to charring. Unlike mineral pigments, these inks can be easily affected or even destroyed by charring due to the surface layer of dyes left after the solvent evaporates. Writing inks typically contain iron, which deposits as iron oxide and is faintly visible after charring that can be regenerated for decipherment through some colour reactions. The contact between burning paper and ink constituents during charring often favours the reduction of ink components [26]. Typescript ink, composed of a fatty substance (e.g., oleic acid) and a pigment, follows similar behaviours. Carbon copies, consisting mainly of carbon and possibly toned with a dyestuff, pose the greatest challenge in terms of readability or visibility after charring, as there is minimal contrast between the writing remains and the paper. In contrast, blacklead pencil writing, which combines graphite and clay in varying proportions based on the pencil's hardness, often retains the outline of the original writing. The non-combustible clay in the pencil can protect the graphite, allowing the writing to be read with the naked eye in many cases.

As, the charred documents are a combination of writing instrument, for example a pen ink; and a writing surface, for example a paper. Therefore, the type of ink, its composition and the type of paper plays a very important role in the analysis of charred documents to decipher the illegible contents as a result of burning.

## 1.4. Types of Ink

There are different types of ink namely-Indian ink, Logwood ink, Iron gallotannate ink, Ballpoint pen ink, Coloured dye ink, Printing ink, Stamp pad ink, Invisible ink, Gel pen ink, Drawing pen inks, Erasable inks, Typewriter ribbon ink, etc., which vary according to their composition. Yet all of them can serve as a tool for committing a crime, regardless of the type of writing instrument in which they are applied, but the most common type of inks that are encountered commercially and in various cases are Ballpoint and Gel pen inks.

**Ballpoint pens** are most commonly used and their inks consist of viscous liquids (oil-based solvent) containing a mixture of dyes and pigments, organic solvents, additives such as antioxidants, resins, preservatives, softeners, and trace elements [33, 34].

**Gel pen** inks contain completely insoluble colour pigment rather than organic dyes. It is water-based ink in gel form which is completely insoluble in both water and strong organic solvents. Also, it contains resins, non-ionic surfactants, and other additives. Acid dyes and related organic compounds containing sulphonic groups generally used as the colouring agents in gel in inks [35, 36].

The main difference of gel pens with other writing instruments is the predominant use of pigment as the colorant rather than dyes [37]. It poses new challenges to forensic document examiners to distinguish gel pen inks from other types of writing inks, hence forming the basis of rather limited research in this specific field [38].

## 1.5. Paper and Its Types

A paper is a thin, flat sheet made from various materials, such as wood pulp, cotton, or other fibers, that is used for writing, printing, drawing, or packaging [39]. Paper is a versatile material that plays a crucial role in various aspects of our lives. Different types of paper are available in the market, each with its own specific characteristics and applications. These types are categorized based on their gsm, which determines their thickness and heaviness (Figure 1.2). Here are some common types of paper based on their gsm:

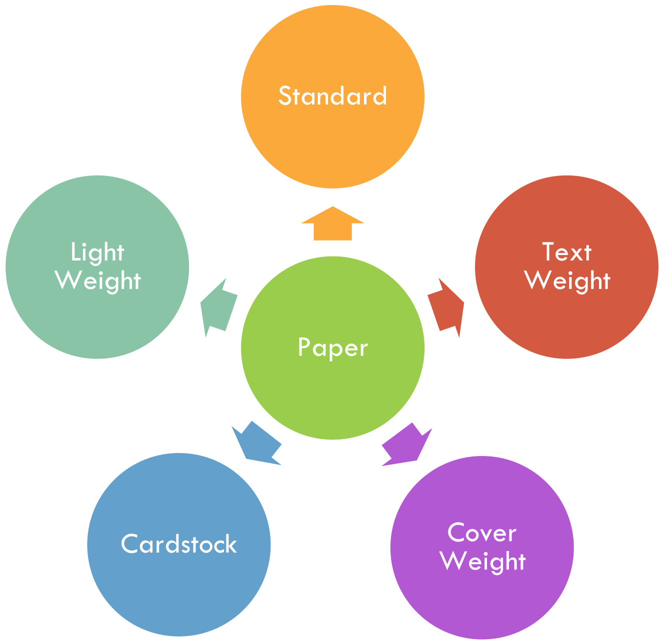



**Figure 1.2: Types of Paper**

### 1.5.1. Lightweight Paper (Below 60 gsm)

Lightweight paper, often referred to as thin paper, is frequently utilized in applications where weight and bulk are significant considerations. It is commonly seen in items such as newspapers, magazines, and flyers. The low gsm of this paper allows for easy printing and cost-effective production of large quantities [40].

### 1.5.2. Standard Paper (60-90 gsm)

Standard or regular paper falls within the gsm range of 60 to 90. It is the most commonly employed type of paper for printing documents, letters, and forms. This paper strikes a balance between weight, durability, and cost. It is also suitable for writing with various instruments such as pens and pencils [41].

### 1.5.3. Text Weight Paper (90-120 gsm)

Text weight paper is slightly heavier and thicker compared to standard paper. It offers enhanced opacity, making it suitable for double-sided printing of documents. Text weight paper is often chosen for brochures, catalogues, booklets, and other marketing materials [41].

### 1.5.4. Cover Weight Paper (120-250 gsm)

Cover weight paper is considerably thicker and more durable than standard paper. It provides a sturdy and premium feel, making it ideal for book covers, invitations, business cards, and presentation folders. Its higher gsm allows for better resistance to tearing and bending [42].

### 1.5.5. Cardstock (250 gsm and above)

Cardstock is a heavyweight and rigid paper commonly used in crafting, scrapbooking, and creating greeting cards. It comes in a wide range of colours and finishes. With a gsm of 250 and above, cardstock offers excellent stiffness and durability [41, 42].

It is essential to note that the provided gsm ranges may have slight variations depending on regional standards and paper manufacturers. These varieties of papers are thus encountered for one or the other use depending on the need, but officially the most common types of papers that are encountered are the standard paper (60-90 gsm) and text weight papers (90-120 gsm), which comprises commonly used copier paper (70-90 gsm) and bond paper (90-100 gsm). Therefore, these commonly used papers are mostly come across for forensic document examination that may even linked to cases of charred documents.

## 1.6. Examination of Charred Documents

Charred document examination is a crucial technique used in forensic science to recover information from documents that have been damaged by fire or heat. The following are the steps involved in charred document examination from the scene of the crime to the forensic science laboratory [43]:

**1.6.1. Identification and Recovery:** The first step is to identify and recover the charred documents. To prevent additional harm, it is crucial to handle the documents with caution. This entails employing protective gloves to prevent contamination and utilizing tweezers or forceps when manipulating the documents. Prior to their collection, it is advisable to photograph the documents and document their original location.

**1.6.2. Documentation:** Once the charred documents are recovered, the next step is to make a detailed note of everything related to the document's recovery, like, the location, date, and time of recovery for future reference. A chain of custody should be maintained while the process is being carried out to ensure the integrity of the evidence [44].

**1.6.3. Preservation:** Once the charred documents are recovered, it is crucial to take appropriate measures for their preservation in order to prevent additional harm. One common method is to place the documents in a plastic bag or envelope, safeguarding them against environmental factors. To avoid any potential contamination, the bag or envelope is sealed securely. Subsequently, these preserved samples are forwarded to Forensic Science Laboratories to undergo thorough examination [45].

**1.6.4. Document Physical Examination:** The next step involves examining the charred documents to determine the extent of the damage and to recover any information that may be relevant to the investigation. This may involve using specialized equipment, such as microscopes and cameras, to examine the documents in detail [2, 46].

**1.6.5. Reconstruction:** After the physical examination of the document, the subsequent step entails to reconstruct any damaged or missing areas. This restoration process can necessitate the utilization of digital imaging methods, like Photoshop, or the physical reconstruction of the document using paper fragments or alternative materials [47].

**1.6.6. Stabilization:** The charred documents should be stabilized to prevent any further damage due to their brittle nature. The methods of stabilization process include encapsulation or lamination, or in the case of charred mass as far as possible using polyvinyl acetate in acetone solution (2-3 percent) by spraying it gently over the charred masses as the charred documents are highly fragile [48], so as to prevent them from crumbling or disintegrating [46].

**1.6.7. Decipherment:** The charred documents should be examined to decipher any writing or printing on them. The examination process may include chemical tests, chromatography, or other methods to identify any ink or writing on the document.

Moreover, photographic techniques like contact process, infrared photography [49], etc., and visual decipherment methods like reflectivity techniques may be employed. The use of advanced optical techniques, such as video spectral comparator (VSC), may also be employed to reveal hidden or obscured writing [50].

**1.6.8. Analysis of Document:** The information obtained from the charred documents should be analyzed carefully to gather evidence and determine its relevance to the case. This may involve a comparison of handwriting, typewriting, printing, and other forensic techniques to identify the author of the document or to determine its origin [51].

**1.6.9. Reporting:** The findings of the examination and analysis should be documented in a report that is admissible in court. The report should be detailed and include all methods, results, and conclusions of the analysis in proper manner [52].

**1.6.10. Document Preservation and Storage:** After examination and analysis, the charred documents must be carefully preserved and stored to prevent further damage or loss. This may involve placing the documents in an acid-free envelope or container and storing them in a secure cool location. The fragility and sensitivity of charred documents necessitate innovative techniques for their stabilization and restoration, since, the most critical process in charred document examination is its handling, preservation, and stabilization, which requires careful attention to detail and adherence to established protocols to ensure the integrity of the evidence [53]. However, the sequence of steps for its examination may vary depending on the necessity and case-to-case requirement [44].

## 1.7. Conventional Stabilization and Preservation Techniques of Charred Documents

There are a number of different techniques that can be used to stabilize and preserve charred documents. These can include methods such as chemical treatments or physical stabilization techniques. The specific technique used depends on the condition of the document and the extent of the damage. Charred document stabilization and preservation is an important aspect of forensic science that helps to preserve valuable information and prevent further damage to important documents

[54]. Experiments have been conducted in separating deciphering and preserving charred and ashed papers. The handwritten, typed, printed, or stamped text on papers that have been burned black can sometimes be partially read by visual examination. This method is painstaking, time-consuming and depends on many factors, and is often unfruitful [55]. Further burning at a controlled temperature will lighten the colour of the paper and increase the contrast with the writing which is then usually easily deciphered. A further approximate 10% shrinkage can be expected from the black char to the optimum temperature of 800 °F. The paper becomes more fragile with an increase in temperature and must be stabilized [53].

Therefore, below are some of the conventional and recently used ways of stabilization of charred documents:

### 1.7.1. NEATAN Treatment

Paper burned to white ash may be so fragile that it is impossible to move without stabilization. It was found that such ash when coated with "NEATAN NEW" (Merk), used for the preservation of thin layer chromatograms, was transferred into continuous flexible sheets without significantly altering the appearance. The sheet can then be handled quite freely. The most satisfactory NEATAN application technique was found to be with an eye-dropper, allowing each drop to soak into the ash by capillary action and dry before applying the next drop to the adjoining area [53].

### 1.7.2. Lamination

Another method for preserving and making it stable is the lamination of the ashed samples. The lamination will flatten out the charred document under the pressure of the heated rollers and without breaking, makes it more legible, protects it from further damage, and makes it easy to transport or to photograph. In fact, it becomes more resistant than the original [45, 56].

### 1.7.3. Boric Acid Method

In this method, mixture of 1.2% boric acid with 0.4% sodium hydroxide is poured lightly on the charred mass with the help of an atomizer. This makes it flexible. After this, some 10% solution of formalin is sprayed which helps in unfolding the charred documents [57].

### 1.7.4. Plasticizers Treatment

Cellulose acetate solution in acetone or other like the 3% Polyvinyl acetate (PVA) solution in acetone (3 gm. polyvinyl acetate dissolved in 100 ml. of acetone) or methyl metha-acrylate (commercially known as Bedacyl ICI 40%) are the plasticizer applied by spraying or glass rod. But there are various pros and cons of every plasticizer material used. The cellulose acetate is a good plasticizer, but cannot be used as regular material here since it cannot be sprayed well which is one of the main characteristics of the stabilizing agents [58].

### 1.7.5. Cyano-acrylate Fuming (Superglue) Method

Furthermore, researchers developed an improved method of stabilizing char and ash, specifically adapting the 'superglue vapour' technique as used by forensic technicians to enhance latent fingerprints. Alkyl-2-cyanoacrylate ester is a polymer commonly found in commercial superglues. The cyanoacrylate fuming technique was initially developed to visualize latent fingerprint marks [59]. The evaporation of the cyanoacrylate ester occurs through heating, releasing its monomer [60]. The same principle was now applied to the stabilization of charred documents by the pre-treatment with moisture and cyanoacrylate fuming to see if this could increase strength and aid transportation of the charred item to the laboratory where further treatment such as the application of PVA: acetone may be affected [61].

## 1.8. Significance of Charred Document Stabilization and Preservation

Charred document stabilization and preservation is an important aspect of forensic science, as it can help to preserve vital information that can be used to solve crimes. As mentioned above, charred documents are typically those that have been exposed to fire or other extreme heat sources, such as arson or explosions, due to which the paper/documents can become brittle, fragile and prone to crumbling or disintegrating, making it difficult to handle without causing further damage. However, with proper stabilization and preservation techniques, it is possible to recover valuable information from these documents.

One of the key reasons for stabilizing and preserving charred documents is to ensure that any potential evidence is not lost or destroyed. Charred documents can contain important information related to a crime, such as handwriting, signatures, crime-suspect linking notes or other identifying features [62]. Without proper preservation techniques, this information could be lost forever, which could hinder the case proceedings. In addition, it can also help to prevent further damage to the document and ensure that it can be handled safely. Moreover, by stabilizing and preserving charred document, the documents can be stored for little longer period of time in a safe-keeping condition which can also serve as valuable evidence to be presented during case proceedings in the court of law.

As discussed, charred documents are often difficult to read or completely destroyed. However, by stabilizing and preserving the document, forensic scientists can analyze the remaining fragments of the document to identify its origin and contents, and further that can help forensic experts to reconstruct the fragments of charred documents by using various ways [63]. After reconstructing the fragments, the stabilization process helps experts to analyse those charred documents by applying various techniques to decipher and recover the lost/invisible content on them which can serve as crucial evidence for admissibility in the court of law [47].

### 1.9. Challenges Associated with Charred Documents

Charred documents can provide many cues in the investigating process; however, they pose many challenges with their examination. During the burning or charring of the document, one or a few sheets of paper may get completely burnt, whereas several sheets of paper stacked together may not burn completely because of the limited supply of oxygen [64]. In such cases, handling and deciphering the writing on charred documents becomes challenging and significantly hinders drawing accurate conclusions or making informed decisions based on the information presented in the document.

The text in a charred document may be partially or completely illegible, making it difficult to read and understand [65-67]. The degree of damage due to heat and fire may vary, and some parts of the document may be more damaged than others, which can destroy or alter the original information contained in a document, making it difficult or impossible to read. Due to the effect of excessive heat, charred documents become extremely fragile, brittle, fragmented and even get curls around the edges. Therefore, utmost care is needed in handling, preserving, and transporting charred documents from the crime scene to a laboratory for further decipherment. This makes document examination quite challenging. Furthermore, the fire residues, such as soot, ash, and other debris, can contaminate charred documents and obscure or alter the original information, which often hinders recovery of lost content through traditional methods of imaging documents, such as photography or scanning, due to the loss of contrast between the charred areas and the remaining paper [68].

Moreover, the process of restoring and deciphering charred documents can be time-consuming and require significant resources. This can be particularly challenging for questioned document examiners who have limited time due to a large number of cases in forensic laboratories, and hence charred documents may be difficult to authenticate as genuine because the damage may have altered the original appearance or the key features and content of the document that may prove its authenticity. To overcome these challenges, forensic examiners may use specialized techniques and equipment such as imaging techniques, to examine and analyze charred documents. However, even with these techniques, the quality and quantity of information that can be obtained from a charred document may be limited.

So, as we know that documents play an important role in daily life and they contain crucial information that can reveal the authenticity of such documents and the owner's identity. In cases where such document is related to any kind of fraud, particularly with documents that has been destroyed in a fire causing it to burn or burn. Many researchers have pointed towards a huge gap and challenges for questioned document examiners in handling and preserving charred documents due to their highly fragile and brittle nature. In addition, the decipherment of writings has also been found difficult due to improper handling and preservation. In recent times, most often chemicals like Polyvinyl acetate (PVA), methyl methacrylate (Bed acryl), acetone, alkyl-2-cyanoacrylate ester (superglue fuming) [69], ammonia solutions [64], etc., are being used for the purpose of charred document preservation, stabilization, and to some extent decipherment, but they pose certain demerits like less availability, chemical nature, toxic effect, low resistance to weather and moisture, poor resistance to most solvents, slow setting speed, creeping under substantial static load, etc., [70]. The current most favoured technique for stabilizing charred documents involves the application of polyvinyl acetate (PVA) dissolved in acetone [71]. However, the use of PVA may hinder decipherment under infrared (IR) and ultraviolet (UV) light and suggest some pre-processing before applying PVA over charred documents [70]. Application of PVA on charred documents is an additional challenge.

Forensic document examiners apply an array of techniques and make use of state-of-the-art equipment to conduct a variety of examinations on charred documents. However, its blackened, carbonized state renders ordinary restorative processes ineffective. Charred documents can easily disintegrate, so it is important for a permanent record to be made. The preservation of charred paper can be aided by carefully dropping a solution of plastic material on it so that it is absorbed and therefore permanently strengthened when the solvent has evaporated, but this causes the information it contains to be made less clear [5]. An entirely new approach to a unique problem is thus required. In addition, increased environmental awareness has impelled various natural polymers or biopolymers to be developed into eco-friendly materials that can replace petroleum-based synthetic materials [72-74]. Therefore, the utilization of natural polysaccharide-based stabilization and preservation has emerged as a promising approach for such purposes.

### 1.10. Natural Polysaccharide as Stabilizer and Preservative

Polysaccharides are one of the most abundant natural polymers in nature, which have the potential to replace petroleum-based polymers in forms of their environment-friendly and sustainable approach. Basically, a polysaccharide is a complex carbohydrate composed of repeating units of monosaccharides (simple sugars) linked together through glycosidic bonds formed by the polymerization of sugar (glucose) molecules. They are often large, polymeric molecules with diverse structures and functions [75]. Polysaccharide molecules have a large number of hydroxyl (-OH) groups that can bind strongly with paper fibers through hydrogen bonds. Starch, is a natural polysaccharide, derived from natural sources comprising a simple sugar-glucose assembled structure. A starch molecule is composed of two different units i.e., amylose and amylopectin. The former is a simple straight-chain glucose molecule linked with α-1,4- linkages (Figure 1.3), while the latter is a branched molecule having both α-1,4- linkages and α-1,6- linkages [76, 77], as shown in Figure 1.4.

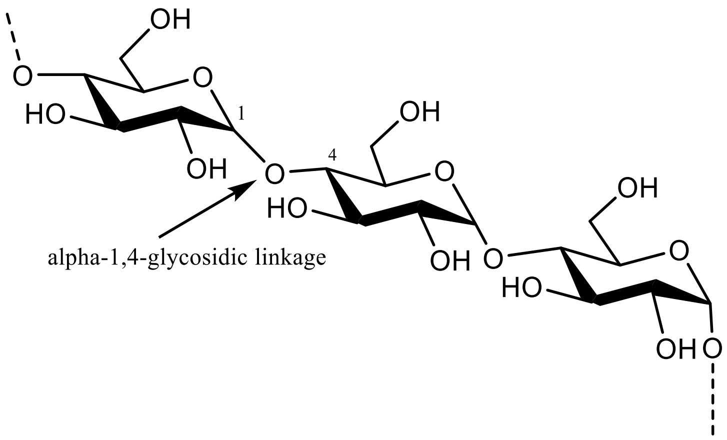



**Figure 1.3: Structure of Amylose.**

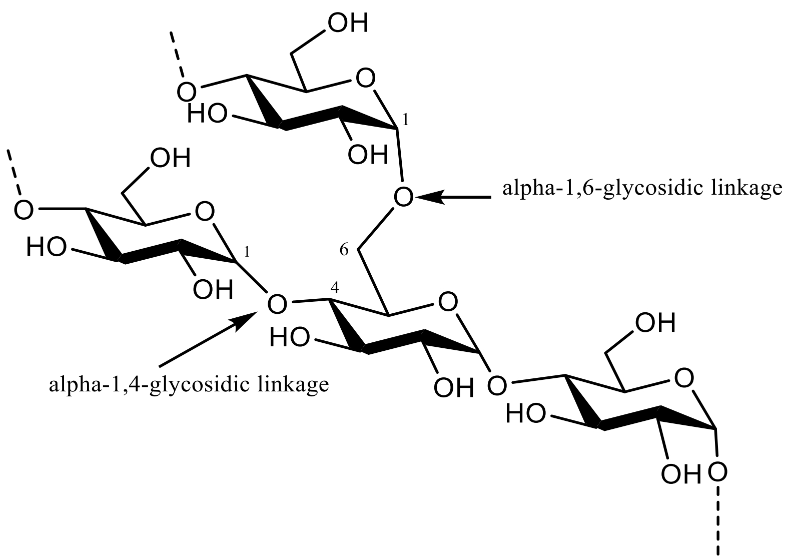



**Figure 1.4: Structure of Amylopectin.**

Chemical modification and the effect of temperature can also effectively improve the mechanical, barrier, and hydrophobic properties of polysaccharide-based coating layers and thus can further improve the related properties of coated paper. Polysaccharides can also give paper additional functional properties by dispersing and adhering functional fillers, e.g., conductive particles, catalytic particles, or anti-microbial chemicals, onto the paper surface [78].

### 1.10.1. Types of Natural Polysaccharides

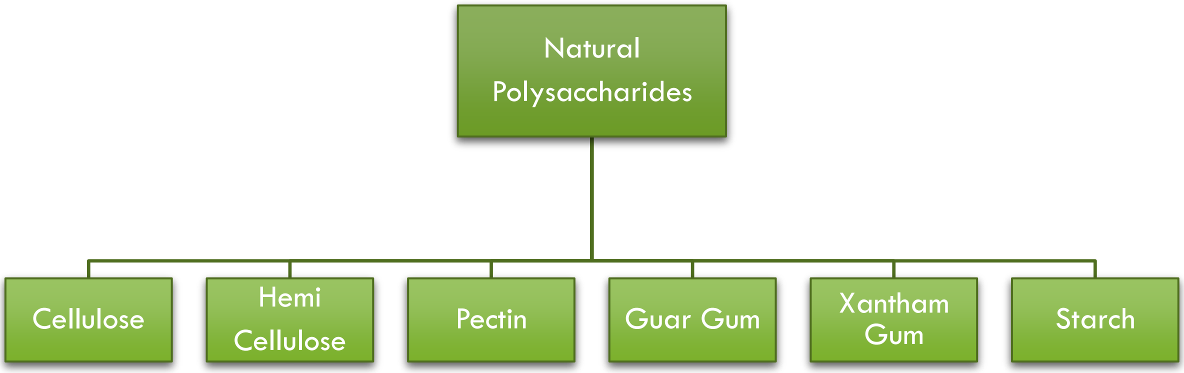



**Figure 1.5: Types of Natural Polysaccharides.**

There are numerous types of natural polysaccharides derived from various natural sources like plants, animals, and microorganisms. Some of the plants based natural polysaccharides are cellulose, hemicellulose, pectin, guar gum, xanthan gum, starch, etc. (Figure 1.5). Each of them has unique properties and applications, making them valuable in different areas and industries. Cellulose is a major component of plant cell walls and is Earth’s most abundant natural polysaccharide [79]. It provides structural support to plants and is found in high quantities in wood, cotton, and grass. Cellulose has applications in various industries, including paper and textile production [80, 81]. Hemicellulose is a complex mixture of polysaccharides that, along with cellulose, makes up the plant cell wall [82, 83]. It is found in various plant sources, including cereal grains, fruits, and vegetables. Hemicellulose has been utilized in the food industry as a dietary fiber and has potential applications in the development of biofuels and bioplastics [84]. On the other hand, pectin is a polysaccharide present in the cell walls of fruits, particularly in the peels and pulp. It is known for its gelling and thickening properties and is commonly used in the food industry as a gelling agent in jams, jellies, and other fruit-based products [85, 86]. Guar gum is derived from the endosperm of the guar bean (Cyamopsis tetragonoloba). It is a galactomannan polysaccharide and is widely used in the food industry as a thickening and stabilizing agent [87, 88]. Xanthan gum is produced by the fermentation of Xanthomonas campestris bacterium [89]. It is a polysaccharide that exhibits thickening and stabilizing properties. Xanthan gum is commonly used in food products, pharmaceuticals, and cosmetics [90, 91].

Starch is one of the most common and widely used natural polysaccharides with a chemical formula $(C_6H_{10}O_5)_n$. It is found in many plant-based foods such as potatoes, corn, and rice [92]. Starch serves as an energy storage polysaccharide in plants and has applications in the food industry as a thickening agent, stabilizer, and texture modifier [93, 94]. The majority of natural starches are amylopectin, which has the film-forming ability, but its film mechanical properties still need to be improved [95]. Being used as paper coatings, pure starch still has some other drawbacks. For instance, starch is sensitive to water vapour and usually forms a brittle coating layer [96], pure starch will also form faults in coating layers because of residual air, resulting in large surface pores. It is usually modified by gelatinization and etherification [78, 97, 98]. Starch is a natural biopolymer that has been extensively used in various industries such as food, pharmaceutical, and papermaking due to its abundance, low cost, and biodegradability [99]. Moreover, it is also being used in the archaeological conservation of documents and artifacts to shield them from further deterioration [100, 101].

### 1.10.2. Properties of Starch-based Polysaccharide as Stabilizer and Preservative

Starch can serve as protective coatings due to their unique properties and characteristics. Here are some key properties of starch polysaccharides as protective coatings:

**1.10.2.1. Barrier Properties:** Natural polysaccharides possess excellent barrier properties, forming a protective film or coating on the surface they are applied. They can create a physical barrier that prevents the penetration of oxygen, moisture, and other substances, thereby reducing the chances of spoilage, degradation, or chemical reactions [102].

**1.10.2.2. Bio-Compatibility:** Natural polysaccharides are generally biocompatible and non-toxic, making them suitable for use in various applications, including in the food, pharmaceutical, and cosmetic industries. They are safe to come into contact with and are often derived from renewable plant sources [103].

**1.10.2.3. Mechanical Strength:** Natural polysaccharides provide varying degrees of mechanical strength, which influences their resistance to deformation, flexibility, and overall stability as a coating and preservative. The mechanical strength of polysaccharide preservative is influenced by several factors, including their molecular weight, chain flexibility, and intermolecular interactions [103].

**1.10.2.4. Water Retention:** Many natural polysaccharides can retain water, which is beneficial for maintaining the moisture content of coated surfaces. This property helps prevent drying or desiccation of the coated material, which can be particularly important for preserving the quality and appearance of certain products [104].

**1.10.2.5. Film-forming Ability:** Natural polysaccharides can form cohesive and uniform films when applied to surfaces. These films have good adhesion, flexibility, and strength, providing protection to the underlying material. The film-forming ability allows polysaccharides to create a barrier against physical damage, such as abrasion or impact [105, 106].

**1.10.2.6. Anti-microbial Activity:** Some natural polysaccharides possess inherent antimicrobial properties, helping to inhibit the growth of microorganisms on the coated surface. This property can contribute to the preservation of perishable products and extend their shelf life by reducing the risk of spoilage or contamination [107].

**1.10.2.7. Biodegradability:** Natural polysaccharides are often biodegradable, meaning they can be broken down by natural processes over time. This property is advantageous from an environmental perspective, as it reduces the accumulation of non-biodegradable materials and promotes sustainability [108].

### 1.10.3. Advantages of Starch-based Polysaccharide as Stabilizer and Preservative

Natural polysaccharides can act as stabilizers and preservatives due to their ability to form protective films or coatings on surfaces, thereby preventing or reducing deterioration and extending the shelf life of perishable products [109]. These polysaccharides create a physical barrier against oxygen, moisture, and other external factors that can lead to spoilage or degradation.

Among natural or biopolymers, starch stands out as the most widely employed in the elaboration of films and coatings because of its low cost and availability. Several studies have reported on the use of starch from different sources in the preparation of films and coatings with different properties. Such work has indicated that these carbohydrates are promising materials in this regard [110-112]. Moreover, starch a natural polysaccharide is renewable and bio-degradable product that can be obtained from multiple plant sources and that had been extensively used as wet end additive, coating binder, sizing agent, adhesive, and textile size [113, 114]. A few studies had been conducted on the potential of utilizing starch as wood adhesive. Recent studies have focused on formaldehyde-free wood adhesives, which are obtained through the reaction between a cross-linker and a blend of starch with other polymers, such as starch/PVA [115], starch/tannin [116-118] and starch/isocyanates [119]. However, such wood adhesives cannot be used at room temperature because the required curing temperature is usually over 100 °C [120]. Many efforts have been exerted to develop starch-based adhesive as alternatives of petroleum-based polymers [121-123]. Moreover, the raw materials of PVA adhesives completely depended on non-renewable resources such as petroleum and natural gas. With the worsening global energy crisis, the mainly used raw materials of wood adhesives are being replaced by renewable biopolymers, such as soybean protein, natural tannin and starch [124-126].

Starch-based films are thin, transparent films made from starch and other biopolymers, and are used as packaging materials, paper coatings, and other applications. Recently, starch-based thin films have gained increasing attention over traditional synthetic films due to their unique properties such as low cost, high transparency, biodegradability [99-101, 103, 127], renewability, and excellent mechanical properties. They are attractive as sustainable and environmentally friendly alternatives to petroleum-based and synthetic coatings, which have become a significant source of pollution and environmental degradation [128]. Because of these benefits and unique properties of starch-based thin films, make them suitable for various applications in different industries [129].

The traditional methods of stabilization of charred documents in forensic science often involve physical techniques and treatments aimed at preventing further damage and preserving the integrity of the documents. However, the currently used method of stabilization of charred documents using PVA has the potential to cause discoloration or darkening over time. This can negatively impact the visual appearance and legibility of the stabilized document. Moreover, this also affects the long-term stability and aging characteristics of PVA and the stabilized document, while this may not be the case with starch-based stabilization and preservation methods. The starch film can slow down chemical reactions that lead to deterioration, extending the lifespan of the charred document. Starch-based preservation technique offers advantages such as being natural and renewable, making them environmentally friendly. Moreover, starch is biodegradable in nature, which aligns with sustainable practices of charred document preservation rather than using a synthetic polymer like PVA that may have adverse environmental effects.

Moreover, conventional methods like PVA of preservation primarily aim to protect the charred documents from physical damage and further degradation whereas starch-based polysaccharide preservation techniques offer an additional protective layer by forming a barrier against environmental factors such as light, moisture, and pollutants. The starch-based coating is compatible with adhesion with charred documents. Furthermore, Starch-based preservation techniques do not introduce toxic substances to the charred document. This helps maintain the document's integrity and minimizes the risk of chemical reactions or damage that could occur with the use of toxicity. Starch-based materials are generally considered safe to handle, reducing potential health risks for conservators and forensic professionals working with charred documents.

## 1.11. Decipherment of Charred Documents

Decipherment of charred documents refers to the process of analyzing and interpreting texts that have been damaged by fire or other sources of heat. This is a specialized field of study that requires a combination of knowledge in linguistics, paleography, and chemistry. Charred documents can be found in various contexts, such as archaeological sites, historical archives, or crime scenes. They may contain valuable information about ancient cultures, historical events, or personal records. However, their decipherment is often challenging because the heat can cause the ink or writing material to evaporate or fuse with the surface, making the text illegible to the naked eye. To decipher charred documents, experts may use a variety of techniques such as multispectral imaging, chemical analysis, and comparative analysis with known texts. They may also rely on their knowledge of the language, script, and historical context of the document. Decipherment of charred documents is important because it can reveal new insights into the past that would otherwise be lost. It can shed light on historical events, social practices, and linguistic evolution. It can also provide a deeper understanding of the people who created the documents and the cultural context in which they lived.

Before the $20^{th}$ century, writing inks contained traces of metals like iron and copper as tagging agents. Therefore, for deciphering the writing written with such inks, Blagden (1787) developed a method using potassium ferrocyanide to test the nature of ink on ancient parchment for decipherment [130]. Later, Davis (1922) proposed a method using a photographic plate to decipher the content of the charred document [131], while Mitchell (1925) used calcining method, a process of further burning of the carbonized fragment to decipher the content written with pencil or some special inks, or typewritten or printed matter [43]. Moreover, in 1935, Mitchell used infrared (IR) light with filters and plates to enhance the charred documents' content [132]. Subsequently, Radley and Grant (1940) used fluorescent oil and ultraviolet light to successfully decipher the writing on printed matter, photocopies, typescripts, and carbon copies [133]. Similarly, many other developments took place during the passing years for decipherment using chloral hydrate, 5% solution of silver nitrate, alcohol-glycerine method, etc., to decipher the content of charred printed and typewritten documents.

Over time, the development in ink composition excluded iron as its constituents because of its rusting and corrosive nature on the nib of pens, hence damaging the paper on which writing was made using such pen. Therefore, the current ink composition excludes any traces of metals and includes pigments, dyes, resins, glycerol, alcohol, oils, and fats [134]. Thus, after the documents get charred having writing made with such inks, their components like pigment, dyes, alcohol, resins, etc., burn out leaving lubricants like oils and fats on the surface of charred documents because of their high boiling point. This is how it aids in the decipherment of writings by different means. In questioned document examination, the major challenge faced by forensic practitioners is the handling and stabilization of highly fragile and brittle charred documents, hence rendering the decipherment of crucial information.

The use of thin coatings is not a new technique exploited for the decipherment of charred documents. Deciphering charred documents using thin coatings is a technique known as "palimpsest imaging" [135]. The term "palimpsest" refers to a manuscript or piece of writing on which the original writing has been erased or obscured, and new writing has been added on top [136]. To use thin coatings to decipher charred documents, a thin coating of a material such as gold or silver is applied to the surface of the document [137, 138]. This coating reflects light differently depending on the depth of the writing and can reveal previously obscured text. The process involves shining a light on the document at a certain angle, which creates shadows where the text is raised. These shadows can be captured using a high-resolution camera, which can then be processed using specialized software to enhance the contrast between the text and the background. This technique has been successfully used to decipher ancient manuscripts, including the Archimedes Palimpsest, a $10^{th}$-century manuscript containing the only surviving copies of some of Archimedes' works [139]. The technique has also been used to reveal text on charred documents from the Villa of the Papyri in Herculaneum, which was destroyed by the eruption of Mount Vesuvius in 79 AD [140]. Palimpsest imaging can be a powerful tool for deciphering charred documents, but the use of costly metals makes this procedure cost ineffective. Moreover, this technique was limited to the decipherment of documents and was not suitable for their preservation.

### 1.11.1. Techniques for Decipherment of Charred Documents

The decipherment of illegible texts after stabilization is a crucial step in charred document examination which can be done by several techniques, each with its own advantages and limitations. Some conventional techniques that were and still in some cases are being used for the decipherment of charred documents are reflected light sources [141], polar filter photography [142], infrared imaging [10, 49, 143], X-ray diffraction [144], magnetic resonance imaging (MRI) [145], chemical treatment using chloral hydrate [146], alcohol immersion method [147], etc. Moreover, the advanced methods incorporate the use of sophisticated instruments which are discussed below.

#### 1.11.1.1. Video Spectral Comparator (VSC) and other Scientific Instruments

The writing on charred documents can be improved using a Spectral Comparator (VSC) [148], Docubox DRAGON® and DOCUCENTER NIRVIS® or other light source-based scientific instruments with various features of different wavelength light conditions. A Video Spectral Comparator (VSC) imaging device allows document examiner to analyze inks, visualize hidden security features, and reveal alterations in a document [149]. It allows for the non-destructive visualization of security elements and the acquisition of reflectance measurements in both visible and shortwave near-infrared regions at focused areas in the document [150]. These imaging devices are well equipped with excellent optics including UV, IR, flood light, and spot light, in combination with high-resolution digital cameras that permit investigation from shortwave UV to IR and IR luminescence range. A research study pointed out that, compared to the flood light beam, the best improvement is visible under the source of white spot beam. Certain letters that were not clearly visible under the usual flood light and source of the white spotlight were improved by adjusting the wavelengths of the beams. Regardless of the colour of the paper, pen pressure was shown to be significant in the charred documents.

Many research that has been conducted in the past suggests that alternative light sources, such as those found in the infrared and ultraviolet wavelengths of light, can be used to visualize what has been written on paper [43], even after that paper has been burnt to the point of its contents being rendered unable to be read [49]. Using a piece of equipment that is somewhat new to the field of forensics, the Video Spectral Comparator (VSC), shows that alternative light sources can be used for these purposes. The VSC is commonly used today for document examination and ink examination [151]. It makes use of a high-quality camera as well as alternative light sources. Agencies such as the FBI and various border control organizations across the globe have been using it for more than a decade now. This technology will allow for a quick and thorough analysis of the documents burnt during research, and can potentially be used for the examination of burnt documents collected as evidence without causing any harm to the documents themselves.

Furthermore, the Docucenter Expert instrument is an advanced instrument which contains a digital camera and a combination of different light sources like ultraviolet (UV), Infrared (IR), Lumi IR, DIA, etc, integrated into a single machine by using a different range of optical rays one by one [152]. In a study, different filter of optical rays of Docucenter was used while examining the documents and when the document was visible on the screen of the computer, the image of that document was captured and then printed [153]. They pointed out that, after examining the samples of damaged documents, it becomes clear that the optical imaging technique and application of different optical instruments for revealing the handwritten contents give good results. Moreover, they suggested that an examiner can use optical instruments like Docucenter and VSC, which allow us for multi-spectral analysis of the different types of damaged documents. Therefore, it was concluded that the non-destructive technique of document examination, or recovering the illegible content of damaged documents by various means, as in the case of charred documents using the optical imaging technique is better than the chemical destructive technique. This is because, as optical rays are easily produced from different light sources that are integrated into a single instrument and these optical rays are non-destructive in nature, so causing no harm to the original document.

# CHAPTER-2

# REVIEW OF LITERATURE

This chapter provides a significant literature review of the questioned documents, particularly charred documents examination, and various techniques that are employed for their analysis. A review of pertinent literatures is firstly covered in this chapter, which elaborates on the studies conducted to assess the paper/document damage caused by fire/heat. The chapter also covers a wide array of research that has been done in areas of damage and restoration of historical and valuable documents due to charring and the major components of documents, constituting conventional and advanced techniques with their limitations.

**Ardelean and Melniciuc-Puica, 2009** conducted a study to understand the impact of fire (temperature) on the composition of old documents. The study involved analyzing three distinct types of paper: Handmade paper, aged over 120 years and composed of textile fibers clamped with gel; Industry paper, aged over 35 years, made from wooden cellulose paste and treated in an acidic environment with clamping involving colophony and aluminium sulphate; Lab-made paper, designed with a typical composition used for writing and printing. Their findings revealed interesting insights. The lab-made paper exhibited remarkable resilience against the effects of degradation, thanks to its fiber composition and the specific clamping system used, making it an ideal support material for graphic documents. Based on the research, it was concluded that the stability of paper-based documents under the influence of temperature is closely tied to the composition and structure of the paper itself [154].

Subsequently, **Khasrithong and Chitaree, 2010** aimed to recover the written contents of burnt papers using the IR Reflected Photography method. The researchers conducted an experiment using two distinct types of paper, namely cash bills (55 grams) and white plain paper (80 grams). On both paper types, the word “BURNT” was inscribed using three different types of pens: a ballpoint pen, a fountain pen, and a gel pen. Subsequently, the papers were subjected to burning, causing the written text to become charred and indistinct under standard white light conditions. However, the researchers discovered that employing infrared-reflected photography proved to be a highly effective means of recovering the obscured contents. They utilized a digital camera equipped with a straightforward infrared light source to illuminate and capture the content, rendering this method a viable and practical option for forensic document examination. The results indicated that the infrared-reflected photography method was particularly effective in recovering written contents from burnt 80-gram paper exposed to high temperatures (350 °C-380 °C). It was noted that various factors, such as burning temperatures, incident angles of the light source, and the type of ink used, could influence the success of content recovery from burnt paper samples. For instance, contents written on papers burnt at high temperatures (>350 °C) were more clearly visible under infrared light, especially when photographed at an incident angle of about 60°, which provided better contrast between the written contents and the background [49].

Further, **Su and Cheng, 2011** explored modified methods in starch-based biodegradable films and provided an overview of starch microstructures. The modified methods included physical, chemical, and enzymic modifications. The physical modification involved treatments like ultrasonic and mechanical treatment, as well as the addition of additives like plasticizers and coupling agents. Chemical modification involved various processes, including etherification, esterification, cross-linking, grafting, and oxidation. In contrast, enzymic modification encompassed debranching reactions utilizing starch debranching enzymes like pulullanase and isoamylase. The study also delved into the biodegradation of films made from starch and their potential future applications. The researchers concluded that biodegradable films based on starch not only naturally decompose through the activity of microorganisms but also use renewable resources. This is because starch raw materials, such as those derived from corn and potatoes, originate from annual plants [155].

**Schon and Schwartz, 2013** conducted a pilot study to create bioplastic using potato starch as the main polymer, glycerine as the plasticizer, water as the solvent, and vinegar as the acid. The resulting bioplastic showed flexibility and density, making it suitable for various everyday applications. They discovered that reducing the glycerine content made the bioplastic stiffer but not more breakable, and overall, the produced plastic met their expectations [156].

**Hirth and Royds, 2013** explored an innovative approach to stabilize char and ash, drawing inspiration from the "superglue vapor" technique employed by forensic experts to enhance latent fingerprints. They utilized alkyl-2-cyanoacrylate ester, a polymer commonly found in commercial superglues, for this purpose. While the cyanoacrylate fuming technique was originally designed for revealing latent fingerprint marks, the researchers adapted it as a preliminary step to stabilize charred documents. Their findings revealed that applying cyanoacrylate fumes to charred documents proved to be a straightforward and efficient process. Importantly, the polymer remained invisible, ensuring that it did not interfere with optical or other forensic examinations. Moreover, cyanoacrylate fuming added strength to delicate samples, reducing the risk of damage during transportation to the laboratory. Subsequent treatments, such as PVA: acetone, could be applied upon arrival. The researchers recommended a two-step process involving pre-humidification followed by cyanoacrylate fuming as an intermediate measure to stabilize fragile charred documents before administering further treatment with PVA: acetone. In the field, the use of a fuming wand facilitated exposing the humidified charred document to cyanoacrylate vapor, aiding in stabilization before transporting it to a forensic laboratory [61].

In **2015, Asri *et al*.** proposed the use of FTIR spectroscopic techniques to analyze ballpoint pen inks effectively. These in-situ techniques involved directing light onto ballpoint ink samples to generate FTIR spectra, which acted as "molecular fingerprints" for direct visual comparison. They analyzed ink samples from blue and red ballpoint pens of five different brands using the FTIR technique with the goal of distinguishing between the brands [157]. In the same year, **Ardelean and Melniciuc-Puica**, in a study on the practical aspects of recovering fire-damaged documents, emphasized on the severe impact of fire as a destructive element, making document restoration in such cases tedious, expensive, and delicate. The researchers highlighted the importance of prevention and understanding fire behaviour to take necessary precautionary measures [14].

In **2017, Mirza and Kesharwani** conducted a comparative study to recover written contents on different burnt papers using various techniques. They used five types of paper and a blue ballpoint pen. These papers were then subjected to smoldering in a wooden box. The burnt specimens were examined using VSC-6000 and Projectina Docubox HD with different illuminations to decipher or recover the written texts. The researchers successfully recovered the written content from exclusive bond paper, newsprint paper, photography paper, and thermal paper using various light sources, such as EPI light, Side light L, Side light R, luminescence light, and flood light. In their study, they managed to recover the contents from 12 out of 25 samples under Projectina Docubox HD. They concluded that VSC-6000 performed better than Projectina Docubox HD in terms of deciphering texts from burnt papers. However, both techniques demonstrated the ability to recover texts from burnt papers, making them valuable for forensic examination [57].

In a related study by **Ethier and Jasra, 2016** the use of the Video Spectral Comparator (VSC) as an advanced tool for detecting or recovering illegible writings and fingerprints on burnt documents was investigated. They focused on commonly used inks in many documents, particularly black and blue ballpoint pen inks. These inks are frequently used for writing signatures and notes on various documents, including legal ones, making them relevant in forensic investigations. Past research suggested that alternative light sources, like infrared and ultraviolet wavelengths, could visualize written content on paper even after the paper had been burnt beyond readability. The VSC, equipped with high-quality cameras and alternative light sources, proved effective in showcasing the use of alternative light sources for this purpose. Using the VSC, they successfully examined writing on cue cards and printer paper using black and blue ballpoint pens. Infrared and co-axial lighting were used to clearly interpret the message written on burnt paper with the blue ballpoint pen, while co-axial lighting was used for the same result with the black ballpoint pen. However, UV lighting was not suitable for examining the contents of either. Infrared lighting was also successful in visualizing latent fingerprints left on the paper before burning. The VSC offered a safe option for examining burnt documents, an essential aspect as handling such delicate materials has been problematic in the past [16].

The researchers suggested that with the limited sample size used in their study, further research on the topic should be conducted to explore other ink and paper combinations that may yield different results. The potential for alternative light sources, as demonstrated by the VSC, provides a promising avenue for effectively examining and recovering information from burnt documents, thereby contributing to the advancement of forensic document analysis.

In **2016, Moorthy and Narayan** conducted a research study in Malaysia to assess the effectiveness of a Video Spectral Comparator (VSC-6000) in enhancing text on charred documents. They employed four distinct types of writing paper and six different writing instruments to inscribe known passages on these papers. Subsequently, they subjected the handwritten documents to burning until the inscriptions became invisible. Following this, the charred documents were examined under both floodlight and white spot beam conditions using the VSC. The researchers determined that the enhancement of the writings on the charred documents was significant and suited for forensic investigation. Notably, the writings were more discernible under the white spot beam as compared to the floodlight beam. This investigation introduced a promising and effective alternative technique for improving the visibility of text on charred documents, involving the use of various VSC filters [10].

**Basta *et al.*, 2017** focused on examining the role of fire retardant-polyvinyl alcohol (PVA) systems in enhancing the performance of bagasse-based commercial paper sheets against aging and counterfeiting when exposed to burning. They considered various fire-retardant compounds, including those that chelate with PVA and those that substitute certain ions in sodium silicate. These systems were compared with the traditional fire-retardant material, ammonium phosphate. The researchers conducted mechanical and flame-retardant tests to assess the treated paper sheets' effectiveness in restoring the writing on burnt papers. The study concluded that PVA-boric acid and PVA-borax systems improved the strength qualities of the treated paper sheets, especially for Quena paper. However, the sodium silicate-$MgCl_2$ and sodium silicate-$CaCl_2$ systems resulted in a decline in paper strength. Additionally, the PVA-FR systems offered greater UV aging resistance for black ink-printed paper sheets and improved the forgery test by responding to the silver nitrate chemical for reviving the writing in burned papers [158].

Further, **AlFalasi, 2017** investigated the extended use of ESDA (Electrostatic Detection Apparatus) instrumentation for document examination. The study focused on enhancing marks on various grades of paper in terms of grams per square meter (gsm) and marks on semi-charred documents. The research findings showed that the best marks could be recovered from heavier grades of paper, and marks could be retrieved from paper exposed to temperatures up to 300 ºC just before the paper becomes carbonized [159].

**Rohatgi *et al*., 2017** conducted a study to investigate various methods for deciphering tampered documents, encompassing both common techniques and advanced instrumentation. They highlighted that forensic experts frequently encounter different types of tampered documents, including alterations, additions, obliterations, erasures, invisible writings, and charred documents. The research emphasized the importance of studying different inks and their compositions while assessing the effectiveness of existing analysis methods. The study concluded that selective techniques for analyzing tampered documents should possess qualities like affordability, ease of use, accessibility, and accuracy, and must not cause damage to the original document [160].

In a separate study, **Poggi *et al.*, 2017** proposed a new method for controlling the pH of paper, specifically designed to be compatible with most ballpoint pen drawings and manuscripts, even on folded or creased paper. The researchers noted that certain contemporary media, such as pressure-sensitive adhesives, ballpoint, rollerball pens, felt tips, and markers, are sensitive to polar solvents like water and short-chain alcohols. Additionally, they highlighted that paper has been extensively used for autonomous works, often subjected to tearing, burning, folding, perforation, twisting, or creasing, thereby emphasizing the significance of preserving the paper's topography [161].

**Howley, 2017** aimed to examine the burning of written material in ancient Rome from the Republican period until the rise of Christianity, using a book history perspective. The article explored the reasons and methods behind the burning of written material, gathering all available testimonies related to such burnings in ancient discourse. By adopting a comprehensive book-historical approach, the study revealed that differences in the treatment and use of books as opposed to documents led to distinct consequences for burning various written media in Roman society [162].

**Thomas *et al.*, 2018** conducted an experimental study on certain government and non-government documents from the UAE, such as bank cheques and credit cards, to understand the impact of heat and fire on these documents and explore methods to decipher any meaningful content from charred documents. The researchers considered bank cheques and credit cards with pre-written content using various writing instruments and inks. These documents were subjected to heat until the writings became partially or completely invisible. The charred documents were then examined under different light sources, including non-damaging sources like UV and IR, using a projectina inspec-8. The results demonstrated that the visibility of the writings on these signed documents could be significantly improved, aiding forensic investigations. Different wavelengths of light were employed, and photographic techniques were used to document the findings. The study highlighted the secure nature of bank cheques and credit cards, equipped with numerous security features that are difficult to forge accurately. It emphasized the importance of forensic examination and advanced security tools to differentiate between genuine and counterfeit documents, even in cases involving scanning, imaging, or cloning techniques [20].

**Yadav and Yadav, 2018** conducted a study focused on exploring non-destructive methods to differentiate ballpoint pen inks manufactured by various companies in India. The researchers employed two non-destructive techniques, namely VSC (Video Spectral Comparator) and FTIR (Fourier Transform Infrared Spectroscopy), both known for preserving the integrity of the documents. They applied sample ink from different brands onto blank paper and observed it under various parameters. Through VSC-filtered light examination, most of the brands could be discriminated. Additionally, IR analysis revealed that each brand's spectra were distinguishable. As a result, the study successfully differentiated among most of the brands using non-destructive methods [163].

**Gadhave *et al.*, 2018** aimed to develop an environmentally friendly stabilization method by replacing petroleum-based polymers with natural biopolymers. They created a biodegradable and renewable starch-stabilized polyvinyl acetate emulsion, achieved by graft polymerization of vinyl acetate onto starch. This innovation was prompted by the increasing global energy crisis and the need to find alternatives to petroleum resources in chemical industries. The study concluded that starch, an inexpensive, renewable product derived from abundant plants, could be an effective stabilizing medium for polyvinyl acetate emulsion, replacing conventionally used polyvinyl alcohols [123].

**Jeong *et al.*, 2018** conducted a study to introduce an eco-friendly biodegradable starch paper suitable for next-generation disposable organic electronics without requiring a planarizing layer. The researchers achieved this by forming starch papers through starch gelatinization in hot water. They enhanced the mechanical properties of the natural starch paper by adding a small amount of PVA (polyvinyl alcohol) and crosslinkers, resulting in an environmentally friendly starch paper with improved mechanical strength, stability, and solvent resistance. The study opened new research opportunities in the realm of biodegradable green electronics, facilitating the development of low-cost electronics [164].

**Kumar and Khaira, 2018** conducted a review on burnt or charred documents, highlighting the challenges in recovering content from such documents found at crime scenes. They explained that charred documents could be unintentionally destroyed due to fire or intentionally burnt by culprits to conceal evidence. In many cases, it becomes challenging to recover data from burnt documents as they may be damaged by time or external factors. However, the researchers emphasized the need for advancements in techniques and technology to improve the deciphering of content from charred documents. Despite the difficulties, they noted that there is a wide scope for future research in this field, with the potential for better methods to recover data from partially burnt documents and advancements in handling and examining charred documents [165].

**Ahn *et al.*, 2018** conducted a comprehensive study to examine the impact of fire on historical books and analyzed the changes at the endogenous level, particularly near the heavily heated edges. They found that even in charred paper areas, the fibrous structure of the papers remained preserved. These areas contained high carbon content, including carbonized cellulose and polycyclic aromatic hydrocarbons, which correlated positively with the level of heat exposure [166].

**Ni *et al.*, 2018** introduced a novel starch-based coating for food packaging papers, which enhanced their hydrophobicity and antimicrobial characteristics. They achieved this improvement by incorporating CMC, leading to enhanced compatibility between ZnO NPs and starch. Consequently, they produced a film with exceptional transparency and consistent surface roughness at a ZnO NP content of 5%. The coated paper exhibited an enhanced water contact angle (ICA) and maintained stable dynamic contact angles (DCAs) at the same NP concentration. Furthermore, the film demonstrated impressive resistance to specific solvents and improved thermal properties. As a result, the researchers successfully created an environmentally friendly, starch-based composite-coated paper with potential applications in food packaging [72].

**Rohatgi *et al.*, 2019** conducted a study to identify the most suitable non-destructive analytical technique for detecting and deciphering additions made on different types of papers using various pens and ink colours. They found that the Projectina NIRVIS docucenter, docubox HD, and docubox dragon, using infrared wavelengths ranging from 715-735 and Lumi ranging from 665-830, were highly effective for decipherment without damaging the paper surface [167].

**Jain and Parasha, 2019** aimed to determine the best non-destructive technique for deciphering illegible texts of partially charred documents, commonly encountered in arson and fire cases. They used different types of partially charred papers with varying inks (ballpoint pen, gel pen, and fountain pen) and found that blue gel pen ink on paper showed excellent results under normal light, while oblique light, diffuse light, and ultraviolet light enhanced the decipherment of ballpoint pen and fountain pen ink. UV radiation at short wavelengths also improved the decipherment of blue ballpoint pen and blue fountain pen ink on butter paper and construction paper [168].

**Li *et al.*, 2019** summarized the potential of starch-based materials as low-cost and sustainable options for enhancing the performance, durability, and strength of coated paper. They focused on the progress of starch and its derivatives in surface sizing, coating binder, and functional coatings. According to their findings, starch-based coatings have been widely used in the paper industry due to their biodegradability, availability, and affordability. The researchers suggested that further research is needed to develop starch products with varying structures, compositions, and properties for more diverse and promising applications in paper coatings. They also highlighted the potential of starch-based bio-nanocomposites to improve the performance and add new functionalities to coatings, but emphasized the need for large-scale utilization in the future [104].

**Kumar, 2019** explored the functional properties of polysaccharide-based components and their application in developing biodegradable edible films and coatings for the food processing sector. His study highlighted that these components have excellent properties such as being non-toxic, antioxidant, antimicrobial, antifungal, and containing beneficial nutrients, making them eco-friendly and suitable for various food-related applications [169].

**Abdullah *et al.*, 2019** investigated the effects of different starch-glycerol concentration ratios on the mechanical and thermal properties of cassava starch bioplastics. By varying the starch-glycerol ratio, they observed changes in the surface of bioplastic characteristics and structural integrity. Increasing the starch-glycerol concentration led to a rougher surface and stronger, more rigid structures, with corresponding changes in tensile strength and elongation at break. Moreover, the hydrophobicity of the bioplastics increased with the increase in the starch-glycerol ratio [170]. These studies demonstrate the potential of polysaccharide-based components, starch-based materials, and non-destructive techniques in various applications, including edible films, bioplastics, adhesives, and forensic documents. They highlight the importance of eco-friendly and sustainable approaches in different fields, contributing to advancements in materials and techniques.

**Sharma *et al.*, 2020** conducted a study on the effect of burning on critical documents, such as official stamps, and explored methods for deciphering the charred content. They used non-destructive light sources like UV, IR, and retro-reflective light at different wavelengths to carefully examine the charred documents. The results showed that it was possible to retrieve and decipher charred content using appropriate non-destructive techniques to facilitate further criminological investigations. The use of specific light wavelengths enhanced the visibility of the writings on the charred documents, and proper photographic techniques were used to record the outcomes of the study [171].

**Shiv *et al.*, 2020** performed research on deciphering written contents in different types of damaged documents using optical imaging techniques. They prepared ten different types of damaged samples, including water-soaked, charred, and damaged by paint, wax, and whitener. The partially charred documents were treated and stabilized using Polyvinyl Acetate and acetone spray before examination. The documents were then analyzed using the DOCUCENTRE Expert instrument with various light sources like UV, IR, and Lumi IR. The optical imaging technique provided good results, and they suggested using optical instruments like Docucenter and VSC for multi-spectral analysis of damaged documents. They concluded that non-destructive techniques like optical imaging are preferable over chemical destructive techniques for recovering illegible content, as they cause no harm to the original document [153].

**Le, 2020** focused on researching bio-plastics, particularly the production of bio-plastics from different types of starch as an alternative to petrochemical plastics. The study discussed the advantages of starch-based plastics, such as a lower carbon footprint and energy consumption compared to conventional plastics. However, they also highlighted the competition with food sources as a limitation. Despite the challenges, there is a significant demand to apply starch-based bio-plastics in various fields, including electronics, automobiles, and consumer goods manufacturing. Beyond potatoes and corn, other fruits and vegetables are also being explored as potential sources for bioplastics, expanding the global industries of starch-based materials [94].

**Li *et al.*, 2020** explored the application of various polysaccharides and their derivatives, such as cellulose, hemicellulose, starch, chitosan, and sodium alginate, in pigment, barrier, and functional paper coatings. They emphasized the importance of chemical modifications of polysaccharides to achieve specific functions. Through these modifications, polysaccharides can acquire stable conductive, fluorescent, catalytic, and other properties, opening up new possibilities for enhanced paper coatings [78].

**Sangian *et al.*, 2021** conducted a study to prepare and characterize bioplastics using cassava biomass readily available in Indonesia. They experimented with two different combinations of reactants to synthesize the bioplastics and analyzed their properties using various techniques like SEM, XRD, FTIR, TGA, and DSC. The findings revealed that bioplastics produced from the second combination exhibited a high degree of degradation, as verified through XRD analysis, indicating a low level of crystallinity. The IR spectra unveiled the presence of distinct functional groups, and the surface morphology appeared relatively even in both samples. Moreover, a decrease in sample mass was observed during the heating process [172].

In a study conducted by **Shafqat *et al.*** in **2021**, the potential of utilizing starch from various sources, including corn and rice, for the production of bioplastics was explored. Diverse bioplastic samples were prepared, incorporating different starches, plasticizers, and filler combinations, with a comprehensive investigation of their physico-chemical properties. Parameters such as moisture content, water absorption, water and alcohol solubility, biodegradability, tensile strength, and Young's modulus were assessed. Furthermore, FT-IR analysis was conducted, and the bioplastics were coated with RTV silicone to impart hydrophobic characteristics. The research emphasized that the selection of starch, plasticizers, and fillers substantially impacted the bioplastics' properties. These environmentally friendly and biodegradable materials present a promising alternative to conventional petroleum-based plastics [173].

**Gannetion *et al*., 2021** examined the characteristics of different blue pen inks using non-destructive and destructive techniques. They analyzed 20 blue pens, including ballpoint and gel pens from different brands. Microscopic examination revealed distinct optical features of the handwritten samples produced by these pens. Luminescence behavior and ATR-FTIR spectroscopy were used to discriminate ink samples with similar compositional profiles. TLC further categorized the ink samples, and the study identified 11 groups. The researchers highlighted the importance of distinguishing hybrid pens from gel and ballpoint pens in forensic document examination [174].

**Khofar *et al*., 2022** evaluated the trends and approaches of using FTIR spectroscopy, especially ATR-FTIR, in ink analysis for forensic purposes. They concluded that ATR-FTIR spectroscopy is a preferred non-destructive technique due to its direct sampling method. However, they emphasized the need for more research on ink dating using ATR-FTIR to improve its applicability in forensic analysis [175].

**Volkel *et al*., 2022** conducted an in-depth analysis to assess conservation methods for heat-damaged papers as model materials. Heat-damaged papers pose significant challenges in conservation and restoration due to the severity of the damage. The researchers successfully followed and interpreted the stages of rag paper combustion, validating their model papers' resemblance to the original counterparts. They concluded that various heating methods could be employed in conservators' workshops to prepare tailored model papers for specific applications [176]. In another study, **Volkel *et al*., 2022** focused on stabilizing and preserving historical papers damaged by fire using cellulose nanofibers (CNF). The proposed method allowed reliable preservation of the papers, enabling the retrieval of historical information. The nanofibers formed a flexible, transparent film on the surface, effectively reducing fragility, providing stability, and facilitating digitization and further handling [177].

In **2022, Gadhave** conducted an extensive review of sustainable adhesives, specifically focusing on the grafting of starch onto vinyl acetate and comonomers such as acrylamides and acrylic acid. The discussion also revolved around the incorporation of nano-fillers to improve water resistance and overall performance properties. He highlighted the transition from traditional raw materials like hydrocarbons (e.g., polyvinyl acetate) to renewable natural polymers in wood adhesives. Notably, polyvinyl alcohol, currently derived from petroleum, faces limitations due to its non-economical nature and is set to be substituted with biopolymers. Traditional wood adhesive emulsions, akin to colloids, have typically relied on polyvinyl alcohol for stabilization. However, there is growing interest among researchers in substituting polyvinyl alcohol with starch, a readily available natural polymer. Recent research has yielded a sustainable, cost-effective, biodegradable, renewable, and environmentally friendly starch-grafted polyvinyl acetate emulsion. This emulsion was synthesized through the graft polymerization of vinyl acetate monomers onto starch. Therefore, the study highlighted the potential of starch-based adhesives to replace petroleum-based raw materials in wood adhesives, as they are renewable, biodegradable, and environmentally friendly. However, challenges still exist in terms of improving properties such as water resistance and bonding strength to make starch-based adhesives more suitable for practical applications [178].

**Gagan and Ashwathi, 2022** conducted a study to investigate the correlation between ink entries on normal and charred documents using both destructive and non-destructive techniques. The examination of ink is crucial in differentiating between questioned documents. The researchers employed Thin Layer Chromatography (TLC) and UV-Visible spectroscopy as destructive techniques, along with the non-destructive technique of Video Spectral Comparator (VSC) for ink examination. Ink extracted from a normal document was compared to ink from a charred document using TLC to draw conclusions. Additionally, ash analysis was performed to understand the impact of controlled and uncontrolled combustion on paper. The results of ash analysis revealed minor variations in samples obtained after uncontrolled combustion. However, chromatographic analysis using VSC did not show any distinct band formation in the charred document samples. This led to the conclusion that clear differentiation between ink extracted from normal and charred documents could not be established. Several contributing factors were identified, including the formation of soot during uncontrolled combustion, physical and chemical changes occurring during combustion, and limitations in the ink extraction procedure from the samples [28].

Despite previous research in the field, limited information is available on the preservation of charred documents, necessitating further investigation. Therefore, **Chayal *et al*., 2023** conducted a systematic review of literature to shed light on the legal value and preservation methods of charred documents [45]. Their work aimed to help forensic questioned document scientists, law enforcement agencies, and the general public understand the methods and techniques used in examining, stabilizing, separating, detecting, investigating, collecting, preserving, preventing, and deciphering charred documents. The study suggested that to ensure the proper stabilization of suspected charred documents, it is crucial to select the most suitable method from a range of available techniques. This will involve choosing appropriate methods and techniques for fixing and hardening the documents effectively. Similarly, when deciphering the charred documents, it is essential to opt for the most suitable method from various photography techniques, including the use of different light sources like oblique light, image enhancement, polarizing filters, UV, and IR light source photography.

Sophisticated scientific instruments, such as VSC, Docubox DRAGON, and Docucenter NIRVIS, equipped with diverse light sources, offer the most effective approach for deciphering the written content on charred documents. These advanced tools open up new avenues for forensic document scientists to detect charred writings that might otherwise remain undetected using more commonly employed techniques and methods. By employing these state-of-the-art instruments, investigators can enhance their ability to identify crucial information and make valuable contributions to forensic examinations [45].

**Supangat *et al*., 2023** conducted a systematic review to summarize primary research results on deacidification methods in paper preservation. Their study aimed to provide new knowledge and insights to guide information institutions in choosing the appropriate preservation method. Through their review, they found that alkaline materials can interact with oxidized carboxyl groups in cellulose, slowing down its degeneration. The systematic review method proved effective in drawing conclusions and presenting an overview of primary research based on existing facts [179].

**Kumar and Alimohammadi, 2023** conducted a study on the effectiveness of G-lens over traditional techniques and how it can replace traditional techniques. The findings showed the power of Google Lens, the benefits of Google Lens over traditional procedures, the benefits of Google Lens in enhancing information services, and created awareness among information professionals and users regarding the use of Google Lens as a single search platform for the required resources. Moreover, the very advantage of this study was to express the usefulness of Google Lens for quick and accessible spread of information [180].

## OBJECTIVES

Objectives of the proposed research work are:

1. To explore natural polysaccharides/seed mucilage as an appropriate protective coating material for preserving charred documents.
2. To explore the advanced techniques to decipher the contents on charred document.
3. To study the stability of charred documents before and after preservation.

**Assumptions of Objective 1:** While considering the 1st objective, it has been assumed that different natural polysaccharide has properties that make them suitable as a protective coating material for preserving charred documents. These properties include their transparency for coating charred documents, their consistency or viscosity for appropriate application, their ability to get dry fast and provide sufficient strength to the stabilized charred documents, their compatibility with charred document surfaces, their potential to form a stable and durable barrier and inhibit further degradation caused by environmental factors such as moisture, oxygen, and UV radiation. Additionally, it is assumed that the application of natural polysaccharides/seed mucilage as a coating material will not significantly alter the appearance, legibility, or structural integrity of the charred documents.

**Assumptions of Objective 2:** Based on the 2nd objective, it has been assumed that the advanced techniques for the decipherment of the charred documents may involve the application of advanced imaging technologies, such as multispectral imaging, to enhance the visibility of the charred document contents. Additionally, it is assumed that specialized easily accessible software can be utilized to analyze the enhanced images and extract readable text or relevant information from the charred documents. Furthermore, it is assumed that these advanced techniques can be successfully applied to a variety of charred documents, including those with varying degrees of damage or different types of charring, to retrieve valuable information for historical, legal, or investigative purposes.

**Assumptions of Objective 3:** On the basis of 3rd objective, it has been assumed that the strength of charred documents is an indicator of their stability before and after preservation.

# CHAPTER-3

# MATERIALS AND METHODS

This research work entitled "**Stabilization and Preservation of Charred Documents using Natural Polysaccharide and their Decipherment**" was conducted in the Forensic Science Laboratory of Galgotias University, Greater Noida, during the period of 2020-2023. The study required the use of the following materials and chemicals:

**Table 3.1: List of Materials, Equipment, and Chemicals.**

| Materials and Equipment | Chemicals |
|---|---|
| Pens | Fenugreek Seeds |
| Papers | Okra |
| Beaker | Okra Powder |
| Measuring cylinder | Tamarind Seed Powder |
| Glass Rod | Sago Seeds |
| Flat Silicon Brush | Starch |
| Silicon Pad | Glycerol |
| Zipper Polyethylene bag | Acetic Acid |
| Cardboard Box | Ethanol |
| Hand Gloves | Acetone |
| Hot Plate | Sodium Hydroxide |
| Domestic Mixer Grinder | Chloroform |
| Microwave | Distilled Water |
| Video Spectral Comparator | |
| Digital Bursting Strength Tester | |
| ATR-FTIR Spectroscopy | |
| MALDI-TOF Mass Spectrometry | |

All chemicals used were of SRL (Sisco-Research Laboratory Pvt. Ltd) grade.

## 3.1. SAMPLE COLLECTION

### 3.1.1. Sampling Method

The samples for the present research were collected via the convenience sampling method. In the current research, the two most commonly used pen inks, i.e., Ballpoint pen inks and Gel pen inks were used to make the document samples under study. A total of 18 pen samples (9 Ballpoint pens and 9 Gel pens), 3 each of blue, black, and red Ballpoint pens (Figure 3.1) and Gel pens (Figure 3.2) of different brands produced by different manufacturers commercially used in India and 3 different types of paper samples having varied grades, i.e., gram per square meter (gsm) viz. 75 gsm A4 size white JK copier paper (Figure 3.3), 90 gsm A4 size JK excel Bond paper (Figure 3.4), and 100 gsm A5 size Diary paper (Figure 3.5) were purchased from stationaries of Noida (at the time of study) for research work. This type of sample collection, which is collected based on availability and selection method based on choices, is called "Convenience Sampling."


**Figure 3.1: Blue, Black, and Red Ballpoint Pen Samples.**


**Figure 3.2: Blue, Black, and Red Gel Pen Samples.**


**Figure 3.3: JK Copier 75 gsm Paper Sample.**


**Figure 3.4: JK excel BOND 90 gsm Paper Sample.**


**Figure 3.5: Factor Notes 100 gsm Diary Paper Sample.**

In the present work, all the Blue, Black, and Red ballpoint pens were denoted as BBP, BLBP, and RBP, respectively, and the different brands were denoted as 1-3 for each brand, respectively (Table 3.2).

**Table 3.2: Samples of different brands of Ballpoint Pens.**

| S. No. | Brand and Model | Colour | Reference Code |
|---|---|---|---|
| 1. | Linc Pentonic | Blue | BBP1 |
| 2. | Elkos BETTER | Blue | BBP2 |
| 3. | Unique EZY GRIP | Blue | BBP3 |
| 4. | Linc Pentonic | Black | BLBP1 |
| 5. | Elkos BETTER | Black | BLBP2 |
| 6. | HAUSER Germany XO | Black | BLBP3 |
| 7. | Linc Pentonic | Red | RBP1 |
| 8. | Elkos BETTER | Red | RBP2 |
| 9. | HAUSER Germany XO | Red | RBP3 |

Similarly, the Blue, Black, and Red gel pens were denoted as BG, BLG, and RG, respectively, and the different brands were denoted as 1-3 for each brand, respectively (Table 3.3).

**Table 3.3: Samples of different brands of Gel Pens.**

| S. No. | Brand and Model | Colour | Reference Code |
|---|---|---|---|
| 1. | Classmate OCTANE | Blue | BG1 |
| 2. | FLAIR GLASS | Blue | BG2 |
| 3. | Elkos Magic | Blue | BG3 |
| 4. | Classmate OCTANE | Black | BLG1 |
| 5. | FLAIR GLASS | Black | BLG2 |
| 6. | Elkos Magic | Black | BLG3 |
| 7. | Classmate OCTANE | Red | RG1 |
| 8. | Elkos Velo | Red | RG2 |
| 9. | Reynolds Jiffy | Red | RG3 |

## 3.2. EXPERIMENTAL METHODS

The sequence of steps that are followed for the experimental methods of the present study is shown below (Figure 3.6):

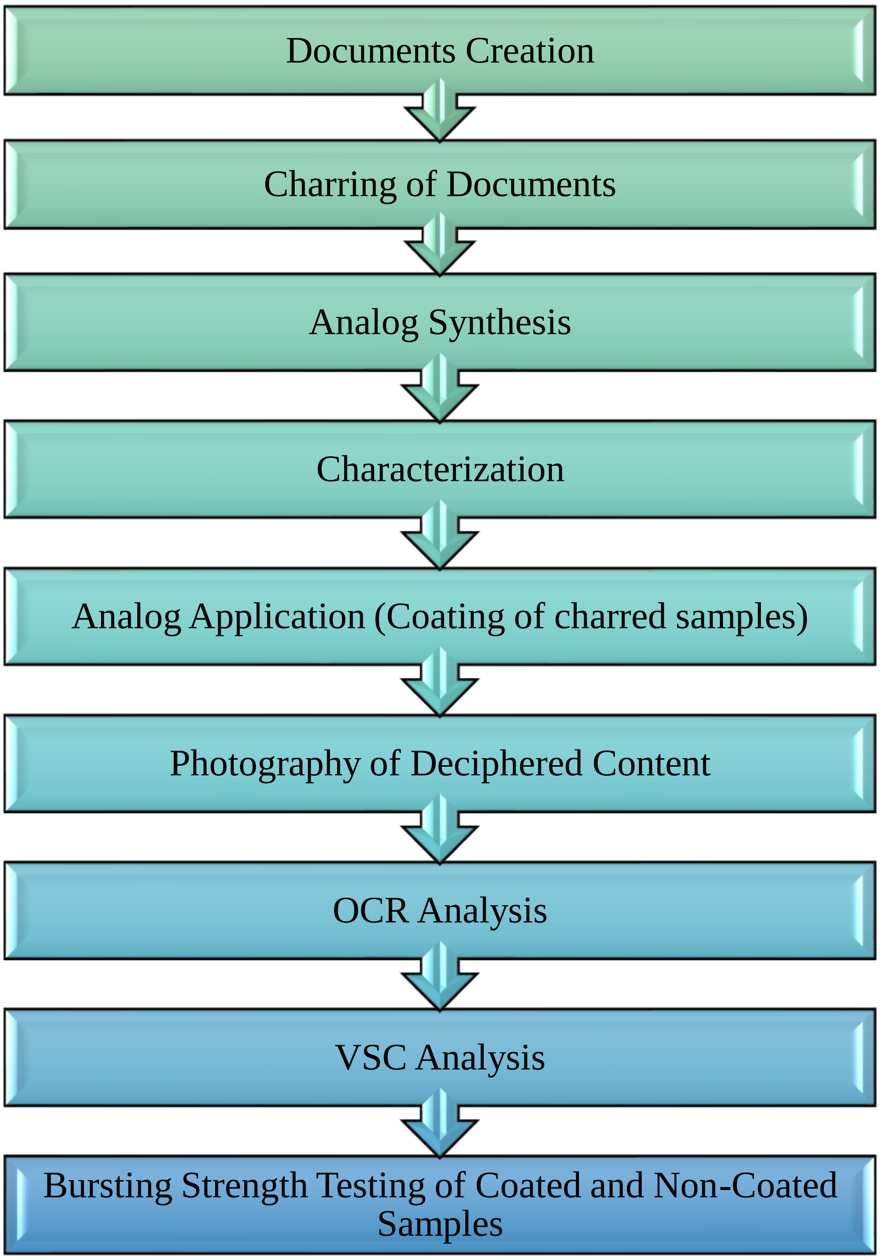



**Figure 3.6: Flow Chart of Sequence of Steps for Experimental Method.**

### 3.2.1. Sample Preparation

The preparation of samples under study was done in two steps:

#### 3.2.1.1. Documents Creation

Documents were made using each type of blue, black, and red ballpoint pens and gel pens on each type of paper viz. 75 gsm A4 size white JK copier paper, 90 gsm A4 size JK excel Bond paper, and 100 gsm A5 size Diary paper. Firstly, each A4 size paper was cut into four equal parts (7.4*5.2 cm), and A5 size was cut into 2 equal parts (10.5*7.4 cm). Thereafter, a framed paragraph of 56 characters "**Stabilization and Preservation of Charred Document using Starch**" was written on each piece of paper using each pen by the same person to ensure that even pen pressure is applied while writing since different persons apply different pressure which may impact the results. Thus, a total of 18 combinations of each set (each pen and paper) were generated. Moreover, 10 samples (5 pairs) of each combination were prepared for preventing any loss and maintaining sample integrity, thus generating a total of 540 samples. The created documents with blue, black, and red Linc pentonic ballpoint pen inks on 75gsm, 90 gsm, and 100 gsm papers are shown in Figures 3.7-3.9.

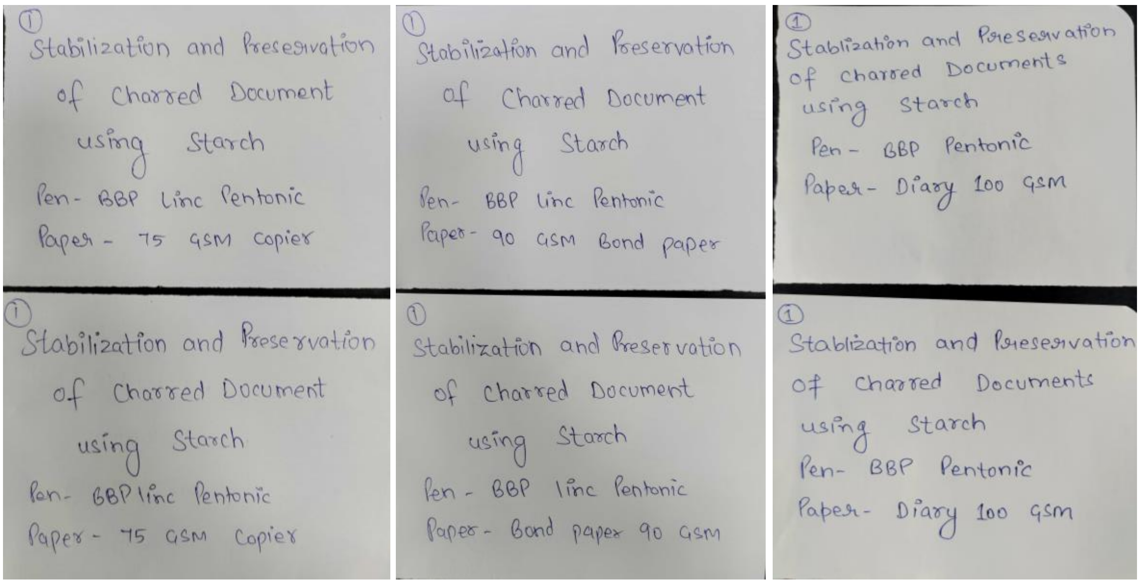



**Figure 3.7: Document samples created using Blue Linc Pentonic (BBP1) Ballpoint Pen on 75 gsm, 90 gsm, and 100 gsm paper.**

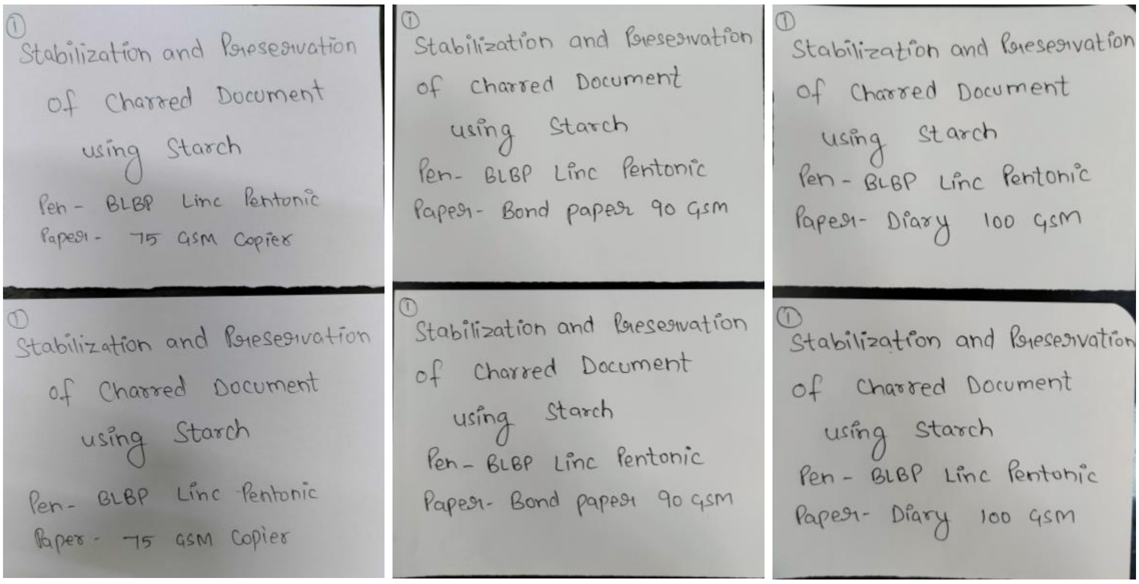



**Figure 3.8: Document samples created using Black Linc Pentonic (BLBP1) Ballpoint Pen on 75 gsm, 90 gsm, and 100 gsm paper.**

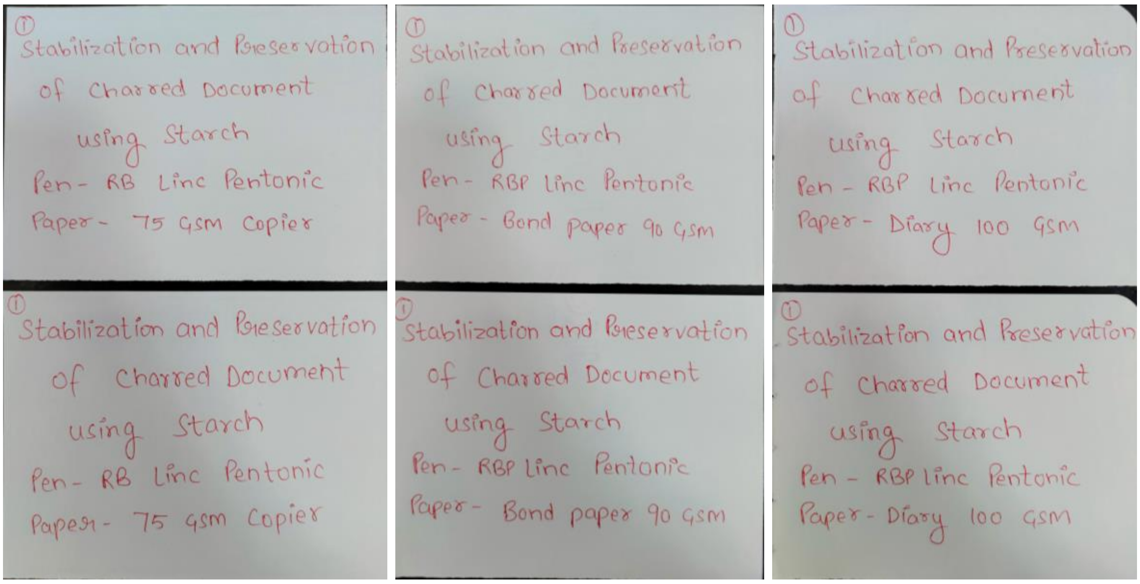



**Figure 3.9: Document samples created using Red Linc Pentonic (RBP1) Ballpoint Pen on 75 gsm, 90 gsm, and 100 gsm paper.**

Similarly, all the combinations of pen and paper of all types were made and then proceeded to the charring process.

### 3.2.1.2. Charring of Documents

The above-created documents were charred in a Thermotech brand muffle furnace [176], as shown in Figure 3.10. Charring of documents in a muffle furnace was done in order to assess the temperature at which the documents charred to a point when writing on the document become completely invisible, the document become dark brown to black-grey in colour, and become fragile enough to handle. Also, the charring was done to such a state that they did not get uncontrolled flame which gradually turn them into ash [181]. This can only be done in a controlled heating environment, which is provided in a muffle furnace.


**Figure 3.10: Muffle furnace used for charring the created documents under controlled temperature.**

Different grades of paper get maximum charred having invisible texts at different temperatures. So, each combination from each set was charred at four different stages of charring at varied temperatures (ranges from 280-310 ºC) and at energy 50 watt. This was done by firstly allowing the furnace to reach to target temperature, i.e., 280 ºC, and thereafter placing a pair of same combination of sample one at a time. In the same way, at four different charring stages, the sample was charred [176, 177]. For example, the combination of a set (BBP: Linc Pentonic+75 gsm) was charred at 280 ºC, 290 ºC, 300 ºC, and above 300 ºC, as shown in Figure 3.11.

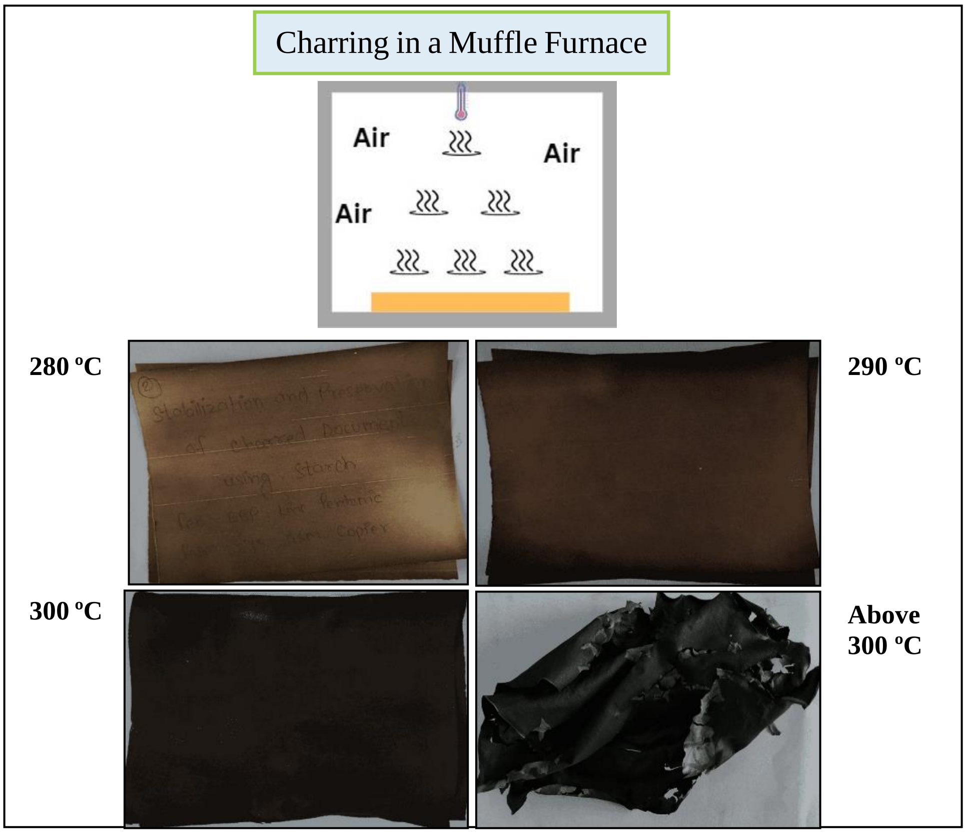



**Figure 3.11: Showing the four different stages of charring temperature of 75 gsm copier paper in a Muffle furnace.**

Similarly, all the other combinations of sets were charred at four different temperatures to examine the effect of temperature on different types of paper and ink and to evaluate the extent at which the samples get maximum charred with written content completely invisible, and fragile enough to handle.

The combinations made on 90 gsm bond paper were charred at four different temperatures, viz. 300 ºC, 302 ºC, 304 ºC, and above 304 ºC, whereas 100 gsm diary paper was charred at 300 ºC, 304 ºC, 308 ºC, and above 308 ºC. Each type of paper achieved its maximum charred stage, for example, 75 gsm copier paper at 300 ºC, 90 gsm bond paper at 304 ºC, and 100 gsm diary paper at 308 ºC with ±2 ºC standard deviation. Below and above this temperature, the documents were not in a state of handling and decipherment. Therefore, sample preservation and decipherment were done of documents charred at this temperature.

After charring the documents, the charred samples were carefully removed from the muffle furnace with the help of a tong and left to cool down. Thereafter, each charred sample had its picture taken using the mobile camera (OnePlus Nord CE 5G), to get a before and after comparison. It was then securely placed separately in an individual transparent zipper bag (Figure 3.12), which was sealed to create an airtight environment, protecting them from further deterioration. The zipper bag used helps to place the sample fragments, if any, intact and prevent from further damage. The transparency of the zipper bag allows easy visual documentation and assessment of the documents without the need for frequent opening, minimizing the risk of physical damage and exposure to potentially damaging external factors. Thereafter the charred samples were stored in a cardboard box for safekeeping, as shown in Figure 3.13, preventing the fragile samples from external factors.


**Figure 3.12: Charred Documents placed in a Zipper bag.**

**Figure 3.13: Charred Documents placed in a Cardboard box for safekeeping.**

### 3.2.2. Methods of Seed Mucilage Extraction and Polysaccharide Preservative Synthesis

In the present study, different natural polysaccharides were explored as an appropriate protective coating material for stabilizing and preserving charred documents. Therefore, five natural/green polysaccharides were extracted from their original source, namely, Fenugreek seed (Methi), Fresh okra pods (Bhindi), Okra powder (readymade from the market), Tamarind seed powder (readymade from the market), Sago seed (Sabudana), and Soluble extrapure starch. The methods of seed mucilage extraction and preservative synthesis of each polysaccharide are shown below:

#### 3.2.2.1. Fenugreek Seed

50 g of Fenugreek seeds were soaked overnight in 100 ml distilled water in a beaker. It was then ground into a fine paste in a domestic grinder and filtered using a filtration vacuum pump. The filtrate was divided into 2 equal parts. In one part, acetone was added in a 1:1 ratio, and the other half was directly heated on a hot plate at a temperature of 100 ºC to make it antimicrobial until a solution was obtained (Figure 3.14).

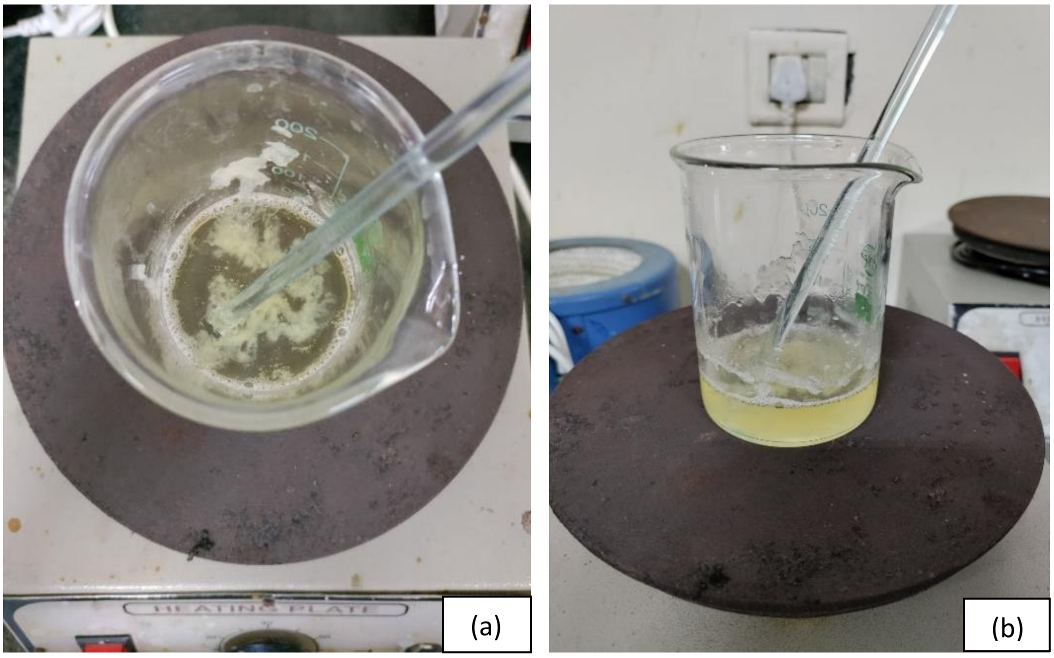



**Figure 3.14: Showing prepared (a) Fenugreek seed mucilage with acetone, (b) Fenugreek seed mucilage without acetone.**

### 3.2.2.2. Okra

#### 3.2.2.2.1. Fresh Okra Pods

Five fresh okra pods (Abelmoschus esculentus) were cut into pieces and soaked in 100 ml distilled water for 4-6 hrs. Constant stirring was done during the soaking process to perform the solid-liquid separation. Then it was filtered in a fine sieve to remove the impurities and obtain okra mucilage. Further to the filtrate, 1 ml acetone, 2 ml acetic acid, and 10 ml distilled water were added and kept on a hotplate at 100 ºC for heating and to stop microbial activity in the preparing product (Figure 3.15).

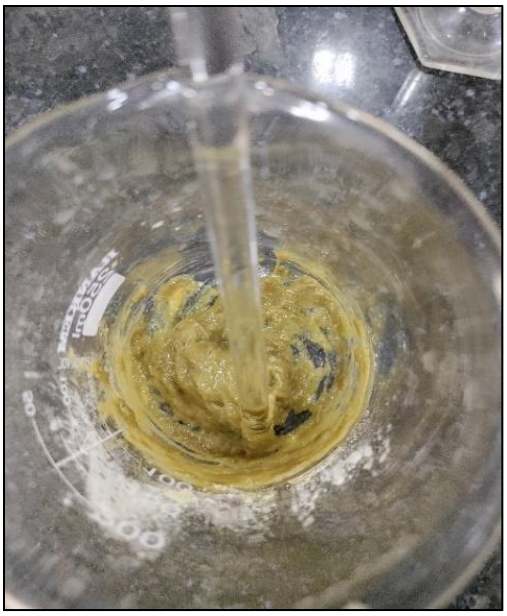


**Figure 3.15: Fresh Okra Mucilage.**

#### 3.2.2.2.2. Okra Powder

5 g of readymade okra powder was dissolved in 2 ml ethanol, 2 ml glycerol, and 20 ml of distilled water. To the obtained solution, 1 ml of acetic acid was added. The mixture was slightly heated on a hotplate at 100 ºC (Figure 3.16).

**Figure 3.16:  Okra Powder Mucilage.**

### 3.2.2.3. Tamarind Seed Powder (TSP)

3 g of TSP was dissolved in 4 ml glycerol, 2 ml acetic acid, 2-3 ml chloroform, and 20 ml distilled water. The solution was then heated on a hotplate at a temperature of 100 ºC for 20-30 mins by constant stirring until a homogenous TSP analog was obtained, as shown in Figure 3.17.

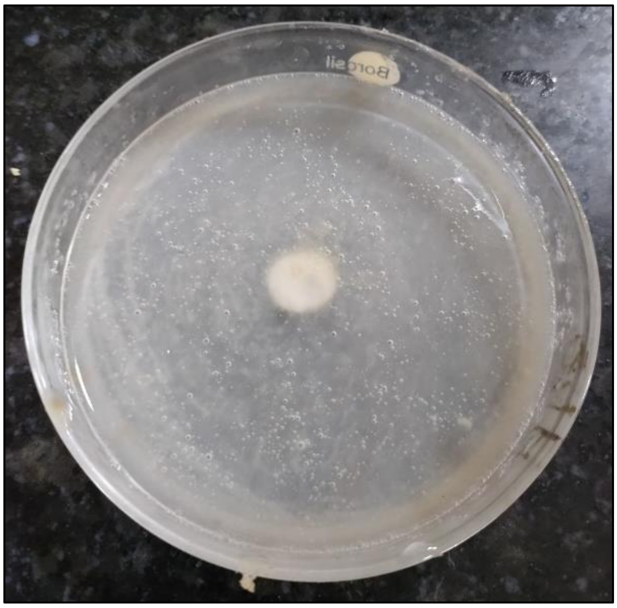


**Figure 3.17: Synthesized Tamarind Seed Powder Analog.**

### 3.2.2.4. Sago Seed

20 g of Sago (Cycas revoluta) was soaked overnight in 50 ml of distilled water. It was then ground into a fine paste in a domestic grinder and filtered using a fine sieve to remove any unground particles. The filtrate was divided into two parts; to the one part; 1 ml of glycerol, 2 ml of ethanol, and 1 ml of acetic acid were added, and to the other part along with glycerol, ethanol, acetic acid, 1 ml of sodium hydroxide (NaOH) was also added, and both of them were heated on a hotplate at a temperature of 100 ºC by constant stirring until a sago analog of polysaccharide was obtained (Figure 3.18).

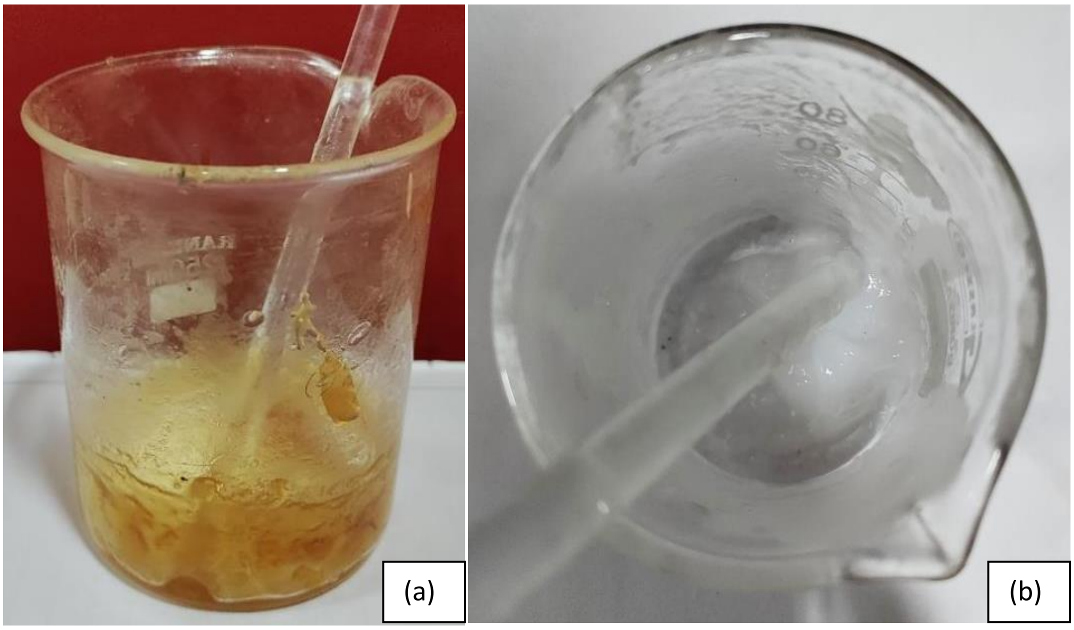



**Figure 3.18: Shows (a) Sago analog with NaOH, (b) Sago analog without NaOH.**

### 3.2.2.5. Starch

The fifth natural polysaccharide that was explored for preserving charred documents was soluble extrapure starch (SRL grade), which among all the above natural polysaccharides was found appropriate and met our requirements for a good material for stabilizing and preserving charred documents, so it was considered for the present study. The detailed method of preparation of starch-based preservative is shown below.

### 3.2.3. Synthesis of Starch-based Analog

In the current research, the synthesis of a starch-based analog as a preservative material was carried out using a microwave-assisted method in order to follow green synthesis pathways. Figure 3.19 shows the schematic representation of the reaction that takes place in the synthesis of starch-based analog. The following steps outline the procedure used for synthesizing the starch-based analog.

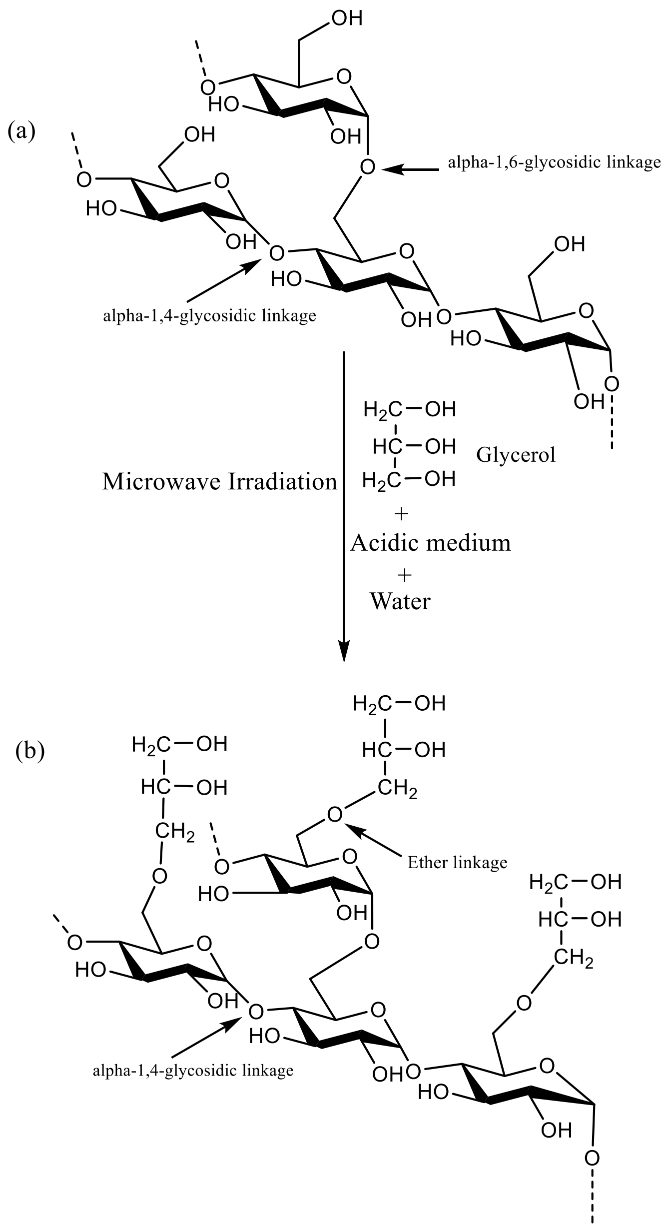



**Figure 3.19: Synthesis of starch-based analog, (a) Pure starch (b) Analog.**

### 3.2.3.1. Preparation of the Different Concentrations of Starch Solution

For preparing the starch-based analog, four varied concentrations (2%, 4%, 6%, and 8%) [182] were made in order to optimize the appropriate concentration of the desired starch analog. The 2%, 4%, 6%, and 8% of starch solution was made by adding 2 g, 4 g, 6 g, and 8 g of starch in 100 ml distilled water, respectively, in a 500 ml beaker and mixing well with a help of a glass rod to ensure a homogenous solution a shown in Figure 3.20.


**Figure 3.20: Solution of 6% Starch.**

### 3.2.3.2. Microwave Synthesis of Starch-based Analog

Current research work involved the microwave synthesis of starch-based analog as a sustainable green coating for charred documents. In order to synthesize the starch-based analog, the prepared starch solutions of desired concentration were first mixed with the requisite amount of glycerol in the presence of dilute acetic acid. The advantage of using a dilute solution of acetic acid is the low environmental impact compared with other acid solutions [183]. Then after, the reaction beaker was placed for microwave irradiation (Figure 3.21) under varied reaction condition and their optimization to get the maximum yield and desired quality product (Figure 3.22). The properties evaluated for optimization of starch-based analog included transparency, viscosity, ease of application on charred document coating, drying ability after applying on charred document, strength after charred sample gets dry, and decipherment of invisible content.


**Figure 3.21: Microwave synthesis of Starch-based Analog.**

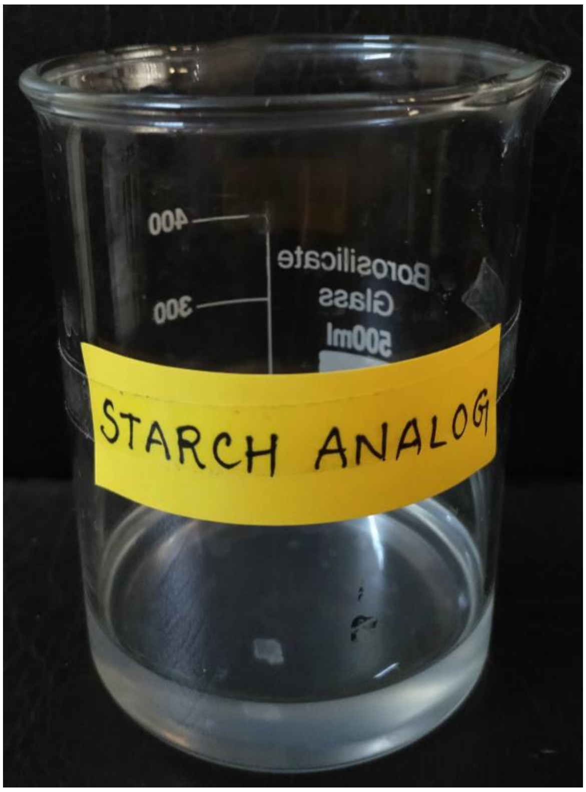



**Figure 3.22: Synthesized 6% Starch-based Analog.**

### 3.2.3.3. Cooling

Once the microwave irradiation was completed and the desired consistency of the analog was obtained, the beaker containing synthesized starch-based analog was carefully removed from the microwave using protective hand gloves. The analog was then allowed to cool down at room temperature.

### 3.2.4. Characterization

Starch and its analog were characterized by their molecular mass and functional group analysis. In order to determine the molecular mass, Matrix-Assisted Laser Desorption/Ionization-Time of Flight mass spectrometry (MALDI-TOF) was employed, whereas functional group characterization was achieved using Attenuated Total Reflectance Fourier-Transform Infrared Spectroscopy (ATR-FTIR).

A mixture of 2,5-dihydroxybenzoic acid (DHB) and Ammonium sulphate was used as a suitable matrix for MALDI-TOF analysis. The instrument was well-calibrated prior to characterization. The spectral characterization of raw solvents, like glycerol and acetic acid, was also done using ATR-FTIR of the Bruker Alpha model (Figure 3.23). The ATR-FTIR was equipped with diamond ATR crystal. ATR-FTIR analysis provides valuable insights into the molecular structure of the analog by identifying the functional groups present in the sample. Moreover, this was done in order to test the presence of different band stretching and the formation of the new analog peak after the reaction of starch and glycerol molecules in an acidic medium.

The steps of analysis are described below:

Firstly, the instrument was correctly calibrated, and the sample holder was cleaned with ethanol. Prior to the sample analysis, a background spectrum was taken to account for any instrumental or environmental noise, by setting the desired measurement conditions (wavenumber 4000-400 $cm^{-1}$) similar to the sample analysis. Thereafter, each raw chemical and pure starch powder sample was analyzed by putting a little quantity of chemicals on a clean and dry sample holder, and then the pure starch powder was kept after cleaning the surface and gently pressing it against the ATR crystal surface to ensure good contact and minimize air gaps.

After acquiring the spectrum of pure starch, the crystal was again cleaned, and then a small amount of the synthesized starch-based analog was placed on the sample holder to acquire its spectral measurements. The spectrum was recorded on the basis of the percentage transmittance (%T) against the wavenumber ($cm^{-1}$). The measurement was repeated thrice to ensure the reproducibility of the result. At last, the ATR-FTIR measurements were imported to excel (.csv) file for data processing.


**Figure 3.23: ATR-FTIR Instrument of Bruker Alpha model equipped with diamond crystal.**

### 3.2.5. Application of Starch-based Analog on Charred Documents

Firstly, the application of the varied concentration (2%, 4%, 6%, and 8%) of synthesized starch-based analog on a few charred documents was carried out to assess its coating applicability and effectiveness in preserving and stabilizing fragile charred documents. Thereafter, the best concentration of analog was applied to the whole experimental charred document samples by placing them on a silicon pad to avoid sticking to the surface [45] and applying the preservative with the help of a small silicon brush that is heat resistant and does not stick to the surface of charred documents to give a smooth, evenly coated layer of preservative. One out of each pair of charred documents of each combination, charred under the same condition in a muffle furnace was stabilized and preserved with the starch-based analog, while the second charred sample of a pair was kept separately for the comparison purpose of their physical property (strength), and visibility (decipherment) of texts before and after application of starch-based analog in and non-coated charred documents.

### 3.2.6. Drying of Coated Charred Documents

After applying the starch-based analog, the coated and stabilized samples were left to dry naturally in a controlled environment. Drying at room temperature (around 22-24 °C) allowed for the gradual removal of moisture from the coated surfaces without subjecting the charred samples to excessive heat or rapid drying conditions that could potentially cause damage. Moreover, it also ensured a gentle and controlled environment for the stabilization of the charred samples, further contributing to their long-term preservation and potential for future analysis. The drying process enabled the starch-based analog to solidify and form a stable, protective layer on the charred substrates. Over time, the coated samples underwent a gradual drying and curing process, resulting in enhanced adhesion and consolidation of the charred material.

### 3.2.7. Decipherment

The decipherment of the coated charred documents was conducted using two techniques; Optical Character Recognition (OCR) and the Video Spectral Comparator (VSC).

#### 3.2.7.1. Optical Character Recognition (OCR)

Soon after the application of starch-based analog, the images of each coated/stabilized charred document were captured using OnePlus Nord CE coated charred documents' decipherment was conducted using 5G mobile camera. Thereafter, it was subjected to Optical Character Recognition using the most easily accessible software; Google lens (G-lens), an Optical Character Recognition (OCR) tool. The OCR algorithm in google lens searched and analyzed the captured images and converted them into readable and copiable texts format [184].

### 3.2.7.2. Video Spectral Comparator (VSC)

After the decipherment via a primary technique using the OCR tool, a more advanced technique, Video Spectral Comparator; VSC-8000 of Foster+Freeman model (Figure 3.24), widely used in forensic science laboratories for invisible text decipherment was employed to reveal and decipher the invisible and faded content of coated/stabilized charred documents. The VSC utilized different light sources, such as flood light, spotlight, ultraviolet (UV), infrared (IR), and various wavelengths, to illuminate the documents. The documents were first visualized in visible light and then at different wavelengths of light in order to decipher the maximum texts. As the stabilized charred document was exposed to various wavelengths of light, the VSC-8000 captured high-resolution images. These images were displayed on a connected LCD screen. The best-resolution image of deciphered texts was then saved in a folder.


**Figure 3.24: Video Spectral Comparator (VSC- 8000) with connected LCD Display Screen.**

### 3.2.8. Bursting Strength Determination

The strength testing of both coated charred documents and non-coated charred documents was carried out using a Pacorr Digital Bursting Strength Tester (Figure 3.25). To check the strength, firstly, the non-coated charred document of the pair of each combination was placed individually on the frame of the digital bursting strength tester. Then a plunger used to apply force to the sample material was brought down, which exerted a controlled and gradually increasing force until the point of the rupture of the document. The bursting strength tester measured the force applied by the plunger at the moment of sample rupture, providing quantitative data on the strength properties of the documents. Thereafter, the coated charred document of the same pair and combination was placed individually and tested for the force applied at the moment of rupture. For each combination, tests were repeated thrice, and the mean value was calculated to ensure the accuracy and reproducibility of the results [158].


**Figure 3.25: Charred Sample under analysis using Digital Bursting Strength Tester.**

The obtained data were then analyzed to compare the bursting strength characteristics between the coated and non-coated charred documents. This step allowed for a comprehensive evaluation of the impact of the coating on the mechanical strength and structural integrity of the charred documents, providing valuable insights for their preservation and handling.

# CHAPTER-4

# RESULTS AND DISCUSSION

This chapter presents the findings and an in-depth discussion of the study focusing on the stabilization, preservation, and decipherment of charred documents. The examination of charred documents holds immense significance in forensic investigations, as it allows for the recovery and interpretation of crucial information from fire-damaged records. The primary objective of this research was to develop a novel and natural (green) stabilizing material for fragile charred documents that can aid in their preservation and decipherment, enabling investigators to uncover valuable insights that could aid in criminal investigations, historical research, and other relevant fields. This chapter presents a comprehensive analysis of the experimental results obtained through the application of some novel and various forensic techniques and explores the implications and potential applications of these findings. Through a systematic exploration of the results, this study aims to contribute to the advancement of charred document handling and preservation and enhance our understanding of the intricate processes involved in charred document content decipherment.

## 4.1. Charring of Prepared Documents

The different combinations (pen+paper) of documents were charred in a muffle furnace at different temperature ranges to get maximum charring but not exceeding its igniting state. Results revealed that the required temperature to get desired charring varies with the paper types. It was observed that in case of 75 gsm copier paper, charred at temperatures below 300 ºC had written contents visible on them, whereas, in case of 90 gsm bond paper, the content was partly visible at below 304 ºC, and in 100 gsm diary paper, the contents were visible below 308 ºC (Table 4.1). This showed that 75 gsm copier paper got maximum charred at 300 ºC, 90 gsm bond paper got maximum charred at 304 ºC, and 100 gsm diary paper at 308 ºC, as shown in Figure 4.1. In each case, below this temperature, the samples were not appropriately charred and writings were visible and above this temperature, the samples started igniting gradually in the muffle furnace which on bringing them out, started igniting more rapidly due to excess oxygen supply in the open atmosphere, that leads to uncontrolled fire, subsequently turning them into ashes. The observation of the effect of temperature/heat at each stage of charring on each combination of pen and paper is shown in Table 4.1-4.18.

**(a)**

**(b)**

**(c)**

**Figure 4.1: Shows the stage of maximum charred documents of (a) 75 gsm copier paper at 300 ºC, (b) 90 gsm bond paper at 304 ºC, and (c) 100 gsm diary paper at 308 ºC.**

As shown in Figure 4.1, once the documents get charred to their maximum stable stage of charring, the written texts became invisible to the naked eye. Moreover, the surface of the charred documents turns uneven with curly edges. This may also be due to the dehydration and charring of documents at high temperatures in a muffle furnace [185].

**Table 4.1: Illustrates the Observations on the Effect of temperature on BBP1 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 1 | **1.** | BBP: Linc Pentonic + 75 gsm Copier | 280 | Light brown to half white | Visible |
| | | | 290 | Brown in major areas while light brown in some places | Some texts faintly visible |
| | | | 300 | Dark brown-black with slightly curly edges | Completely Invisible |
| | | | Above 300 | Dark brown to blackish-grey with gradual ignition from edges, turned into ashes | Completely Invisible |
| | **2.** | BBP: Linc Pentonic + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with slightly curly edges | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into fragmented ashes | Completely Invisible |
| | **3.** | BBP: Linc Pentonic + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled and fragmented edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.2: Illustrates the Observations on the Effect of temperature on BBP2 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (°C) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 2 | **4.** | BBP: Elkos BETTER + 75 gsm Copier | 280 | Light brown to half white | Visible |
| | | | 290 | Brown to light brown in some areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curly edges | Completely Invisible |
| | | | Above 300 | Dark brown to blackish-grey with gradual ignition from edges, turned into ashes | Completely Invisible |
| | **5.** | BBP: Elkos BETTER + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with slightly ignited edge | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into fragmented ashes | Completely Invisible |
| | **6.** | BBP: Elkos BETTER + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled and fragmented edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.3: Illustrates the Observations on the Effect of temperature on BBP3 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (°C) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 3 | **7.** | BBP: Unique EZY GRIP + 75 gsm Copier | 280 | Light brown to half white | Visible |
| | | | 290 | Brown to light brown in some areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curly and fragmented edges | Completely Invisible |
| | | | Above 300 | Dark brown to blackish-grey with gradual ignition from edges, turned into ashes | Completely Invisible |
| | **8.** | BBP: Unique EZY GRIP + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with one edge ignited | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into fragmented ashes | Completely Invisible |
| | **9.** | BBP: Unique EZY GRIP + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled and fragmented edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.4: Illustrates the Observations on the Effect of temperature on BLBP1 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 4 | **10.** | BLBP: Linc Pentonic + 75 gsm Copier | 280 | Light brown to white | Visible |
| | | | 290 | Brown in major areas to light brown in some areas | Few texts very faintly visible |
| | | | 300 | Dark brown-black with slightly curled edges and irregular surface | Completely Invisible |
| | | | Above 300 | Dark brown to blackish-grey with gradual ignition from edges, turned into ashes | Completely Invisible |
| | **11.** | BLBP: Linc Pentonic + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with ignited edges | Few texts very faintly visible in oblique angle |
| | | | Above 304 | Blackish-brown with ignition from edges turning into fragmented ashes | Completely Invisible |
| | **12.** | BLBP: Linc Pentonic + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled and fragmented edges | Few texts in center very faintly visible in oblique angle |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.5: Illustrates the Observations on the Effect of temperature on BLBP2 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 5 | 13. | BLBP:Elkos BETTER+ 75 gsm Copier | 280 | Light brown to white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled edges | Completely Invisible |
| | | | Above 300 | Dark brown to blackish-grey with gradual ignition from edges, turned into ashes | Completely Invisible |
| | 14. | BLBP: Elkos BETTER+ 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with slightly ignited edges | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | 15. | BLBP: Elkos BETTER + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brow-black with curled and ignited edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.6: Illustrates the Observations on the Effect of temperature on BLBP3 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 6 | **16.** | BLBP: HAUSER Germany XO + 75 gsm Copier | 280 | Light brown to white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled and ignited edges | Completely Invisible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **17.** | BLBP: HAUSER Germany XO + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with slightly ignited and fragmented edges | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **18.** | BLBP: HAUSER Germany XO + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled and ignited edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.7: Illustrates the Observations on the Effect of temperature on RBP1 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 7 | 19. | RBP: Linc Pentonic + 75 gsm Copier | 280 | Light brown to white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with curled edges and irregular surface | Completely Invisible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | 20. | RBP: Linc Pentonic + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with slightly curled and fragmented edges | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | 21. | RBP: Linc Pentonic + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled and ignited edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.8: Illustrates the Observations on the Effect of temperature on RBP2 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (°C) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| **SET 8** | **22.** | RBP: Elkos BETTER+ 75 gsm Copier | 280 | Light brown to white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with curled edges and irregular surface | Completely Invisible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **23.** | RBP: Elkos BETTER+ 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled and ignited edge | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **24.** | RBP: Elkos BETTER + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled and ignited edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.9: Illustrates the Observations on the Effect of temperature on RBP3 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (°C) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 9 | **25.** | RBP: HAUSER Germany XO + 75 gsm Copier | 280 | Light brown to white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled edges | Completely Invisible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **26.** | RBP: HAUSER Germany XO + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled and ignited edge | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **27.** | RBP: HAUSER Germany XO + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled and ignited edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.10: Illustrates the Observations on the Effect of temperature on BG1 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (°C) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 10 | **28.** | BG: Classmate OCTANE Gel + 75 gsm Copier | 280 | Light brown to white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled edges | Completely Invisible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **29.** | BG: Classmate OCTANE Gel + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled and ignited edge | Few texts very faintly visible at oblique angle |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **30.** | BG: Classmate OCTANE Gel + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled and ignited edges | Few texts very faintly visible at oblique angle |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.11: Illustrates the Observations on the Effect of temperature on BG2 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| **SET 11** | **31.** | BG: Flair Glass Gel + 75 gsm Copier | 280 | Light brown to white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled edges | Very faintly visible at oblique angle |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Very faintly visible |
| | **32.** | BG: Flair Glass Gel + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled and ignited edges | Very faintly visible at oblique angle |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Very faintly visible |
| | **33.** | BG: Flair Glass Gel + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled and ignited edges | Very faintly visible at oblique angle |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Very faintly visible |

**Table 4.12: Illustrates the Observations on the Effect of temperature on BG3 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 12 | **34.** | BG: Elkos Magic Gel + 75 gsm Copier | 280 | Light brown to white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled edges and surface | Completely Invisible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **35.** | BG: Elkos Magic Gel + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled and ignited edges | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **36.** | BG: Elkos Magic Gel + 100 gsm Diary | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled, ignited, and fragmented edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.13: Illustrates the Observations on the Effect of temperature on BLG1 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 13 | **37.** | BLG: Classmate OCTANE Gel + 75 gsm Copier | 280 | Light brown to half white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled and ignited edges | Completely Invisible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **38.** | BLG: Classmate OCTANE Gel + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled and ignited edges | Completely Invisible in major areas, few texts very faintly visible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **39.** | BLG: Classmate OCTANE Gel + 100 gsm Dairy | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled, ignited, and fragmented edges | Completely Invisible in major areas, few texts very faintly visible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.14: Illustrates the Observations on the Effect of temperature on BLG2 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (°C) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 14 | **40.** | BLG: Flair Glass Gel + 75 gsm Copier | 280 | Light brown to half white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled and ignited edges | Completely Invisible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **41.** | BLG: Flair Glass Gel+ 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled and ignited edges | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **42.** | BLG: Flair Glass Gel+ 100 gsm Dairy | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled, ignited, and fragmented edges | Completely Invisible in major areas, few texts very faintly visible at oblique angle |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.15: Illustrates the Observations on the Effect of temperature on BLG3 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 15 | **43.** | BLG: Elkos Magic Gel + 75 gsm Copier | 280 | Light brown to half white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled and ignited edges | Completely Invisible, few texts very faintly visible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **44.** | BLG: Elkos Magic Gel + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled and ignited edges | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **45.** | BLG: Elkos Magic Gel + 100 gsm Dairy | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled, ignited, and fragmented edges | Completely Invisible in major areas, few texts very faintly visible at oblique angle |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.16: Illustrates the Observations on the Effect of temperature on RG1 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (°C) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| **SET 16** | **46.** | RG: Classmate OCTANE Gel + 75 gsm Copier | 280 | Light brown to half white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled, ignited edges and irregular surface | Completely Invisible, few texts very faintly visible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **47.** | RG: Classmate OCTANE Gel + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled, ignited edges and irregular surface | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **48.** | RG: Classmate OCTANE Gel + 100 gsm Dairy | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled, ignited, and fragmented edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.17: Illustrates the Observations on the Effect of temperature on RG2 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 17 | **49.** | RG: Elkos Velo Gel + 75 gsm Copier | 280 | Light brown to half white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled and ignited edges | Completely Invisible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **50.** | RG: Elkos Velo Gel + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled and ignited edges | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **51.** | BLG: Elkos Magic Gel + 100 gsm Dairy | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled, ignited, and fragmented edges | Completely Invisible in major areas, few texts very faintly visible at oblique angle |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

**Table 4.18: Illustrates the Observations on the Effect of temperature on RG3 with 75 gsm Copier, 90 gsm Bond, and 100 gsm Diary paper.**

| COMBINATIONS | | | Temperature (ºC) | Effect on Paper | Effect on Written Texts |
|---|---|---|---|---|---|
| SET 18 | **52.** | RG: Reynolds Jiffy Gel + 75 gsm Copier | 280 | Light brown to half white | Visible |
| | | | 290 | Brown in major areas | Faintly visible in some places |
| | | | 300 | Dark brown-black with slightly curled and irregular surface | Completely Invisible |
| | | | Above 300 | Dark brown to black with gradual ignition from edges turning into ashes | Completely Invisible |
| | **53.** | RG: Reynolds Jiffy Gel + 90 gsm Bond Paper | 300 | Light brown to half brown | Visible |
| | | | 302 | Brown in major area | Faintly visible |
| | | | 304 | Dark brown-black with curled, ignited and fragmented edges | Completely Invisible |
| | | | Above 304 | Blackish-brown with ignition from edges turning into ashes | Completely Invisible |
| | **54.** | RG: Reynolds Jiffy Gel + 100 gsm Dairy | 300 | Light brown to half yellow | Visible |
| | | | 304 | Brown in full area | Faintly visible |
| | | | 308 | Dark brown-black with curled, ignited, and fragmented edges | Completely Invisible |
| | | | Above 308 | Black to grey with ignition, turning into ashes | Completely Invisible |

As a result of charring from 280 °C to 310 °C, in a muffle furnace under a limited supply of oxygen, the paper went through dehydration, thermal scission, and gas evolution that led to the carbonization of the paper [166, 185]. Due to this, the paper structure became porous as the fibers shrink, and the sizing and fibrils of the paper get reduced. Due to the porosity, aqueous, polar, and non-polar solvents on the paper surface got well absorbed. The charring process starts at the surface, which determines interaction with preservation media.

The document charring led to the generation of fragile, brittle state of charred documents, that needed special attention for their handling, preservation, and at last, to unveil the illegible contents of the charred documents that disappeared due to the damage caused by excessive heat and smoke or carbon particle while burning. Therefore, the next aim of this study was to explore a varied range of green or natural polysaccharides that exhibits the great property of charred document stabilization, preservation, and most important recovery of the content that is lost due to excessive heat damage.

### 4.2. Exploration of Natural Polysaccharides

The exploration of natural polysaccharides as potential preservative and coating materials for charred documents has yielded diverse results. The criteria of exploration of natural polysaccharides were their availability, cost and mucilage producing ability. Among the polysaccharides investigated, like, fenugreek seeds, okra mucilage (fresh okra pods and okra powder), sago seed, and tamarind seed powder, their suitability for effective preservation and coating purposes was thoroughly examined based on several key properties, including, colour, transparency, consistency, ability to and drying capability.

The mucilage extraction and synthesis of polysaccharide showed varied results in each case for suitability and non-suitability as an appropriate coating material for charred documents stabilization and decipherment. The observed results of each polysaccharide explored are shown in Table 4.19.

**Table 4.19: The Observed Properties of Natural polysaccharides explored for Charred documents Stabilization and Preservation.**

| S. No. | Natural Polysaccharides | Observations | Suitable/Not Suitable |
|---|---|---|---|
| **1.** | **Fenugreek Seeds** | Pale yellow, mucilage coagulated, non-transparent, not appropriate for coating. | Not Suitable |
| **2.** | **Fresh Okra Pods** | Mustard yellow, thick, concentrated, slimy in texture, not appropriate for coating. | Not Suitable |
| **3.** | **Okra Powder** | Mustard yellow, concentrated, slimy, non-transparent, not appropriate for coating. | Not Suitable |
| **4.** | **Tamarind Seed Powder** | Pale yellow, non-transparent, mucus-like texture, not appropriate for coating. | Not Suitable |
| **5.** | **Sago** | Thick, opaque, mucus-like, non-transparent, not appropriate for coating. | Not Suitable |
| **6.** | **Starch Powder** | Clear, transparent, easy application, appropriate for coating, appreciable strength and decipherment on coating. | Suitable |

Therefore, based on the analysis conducted, fenugreek seeds, okra, TSP, and sago seeds polysaccharides were found to be non-suitable for the intended application. Thus, after exploring all the above natural polysaccharides, soluble extrapure starch was found to be most appropriate and were used for preservative synthesis.

### 4.3. Starch-based Analog as a Stabilizing and Preservative Material

In the current research, optimization of starch-based analog at four varied concentrations; 2%, 4%, 6%, and 8% were done in order to get the desired optimized concentration based on the properties such as transparency, viscosity, ease of application on the charred document for stabilizing, drying ability after application on charred document, strength after drying, and decipherment of invisible content.

### 4.3.1. Effect of Starch Concentration on the Synthesis of Starch-based Analog

In order to study the effect of starch solution concentration, i.e., 2%, 4%, 6%, and 8%, the requisite amount of glycerol (1 ml) and acetic acid (1 ml) was added to it and then microwave irradiated using a constant temperature (80 °C) for constant duration (12 min). Results, as shown in Table 4.20, revealed that 2% and 4% starch solution was not found adequate to produce the required consistency of the sample; an increase in the concentration from 4% to 6% was found optimum to get the best consistency of starch-based product, whereas when the concentration was increased to 8%, the viscosity of the starch-based analog got increased, and cloudy appearance was observed, which was found not suitable for coating and decipherment of charred documents.

**Table 4.20: Effect of Starch Concentration on the Synthesis of Starch-based Analog.**

Reaction Duration: 12 min

Reaction Temperature: 80 °C

| S. No. | Concentration (w/v) | Observation |
|---|---|---|
| **1.** | 2% | Transparent, low viscosity, not providing appreciable coating, strength, and decipherment |
| **2.** | 4% | Transparent, viscosity not up to mark, not providing appreciable strength and decipherment |
| **3.** | 6% | Transparent, appreciable viscosity achieved suitable for the application, provided appreciable strength and decipherment. |
| **4.** | 8% | Opaque and cloudy, high viscosity, white flaky appearance, not suitable for application and decipherment, cracks observed after drying. |

### 4.3.2. Effect of Reaction Temperature on the Synthesis of Starch-based Analog

In order to study the effect of reaction temperature i.e., 70 °C, 80 °C, and 90 °C (±2 ºC standard deviation), the starch solution was microwave irradiated using a constant concentration of starch solution (6%) for constant duration (12 min.). Results, as shown in Table 4.21, revealed that 70 °C temperature was not found to be adequate to produce the required consistency of the sample; an increase in the temperature from 70 to 80 °C was found optimum to get the best requisite product. Whereas, when the reaction was carried out at 90 °C, the viscosity of the starch-based analog increased and was found unsuitable for coating and decipherment.

**Table 4.21: Effect of Reaction Temperature on the Synthesis of Starch-based Analog.**

Starch Concentration: 6%

Reaction Duration: 12 min.

| S. No. | Temperature (ºC) | Observation |
|---|---|---|
| **1.** | 70 | Low viscosity, not appropriate for coating |
| **2.** | 80 | Optimum consistency and viscosity, appropriate for coating |
| **3.** | 90 | High viscosity, not appropriate for coating |

### 4.3.3. Effect of Reaction Duration on the Synthesis of Starch-based Analog

In order to study the effect of reaction duration, i.e., 10 min, 12 min, and 14 min (±1 min standard deviation), the starch solution was microwave irradiated using a constant concentration of starch solution (6%) for a constant temperature (80 °C). Results, as shown in Table 4.22, revealed that 10 minutes was not found to be sufficient to synthesize the required consistency of the sample; an increase in the temperature from 10 to 12 minutes was found optimum to get the best requisite consistency of product, whereas when the reaction was carried out for 14 minutes, the consistency of the starch-based analog got increased and the solution became thick which was found not suitable for coating and decipherment of charred documents.

**Table 4.22: Effect of Reaction Duration on the Synthesis of Starch-based Analog.**

Starch Concentration: 6%

Reaction Temperature: 80 °C

| S. No. | Duration (min) | Observation |
|---|---|---|
| **1.** | 10 | Low viscosity, not appropriate for coating |
| **2.** | 12 | Optimum consistency and viscosity, appropriate for coating |
| **3.** | 14 | High viscosity, not appropriate for coating |

The transparency of each optimized starch-based analog was assessed by visually comparing the clarity of the starch-based analog solutions at each concentration. Viscosity measurements were obtained using a rotary viscometer, which provided insights into the flow behaviour of the solutions. Application on charred document involved the ease of applying the starch-based analog to a charred document using a silicon brush and observing its adhesion and coverage. Drying ability after applying on the charred document was determined by the time taken to get dry and, thereafter the appearance of the coated surface. The mechanical strength of the charred document was determined by testing the bursting strength of coated and non-coated charred documents and then comparing the increase in strength because of the applied analog layer against mechanical stress.

Decipherment of invisible content was assessed by attempting to reveal any hidden or obscured information on a document treated with the starch-based analog by means of optical character recognition and video spectral comparison technique.

## 4.4. Characterization of Starch-based Analog

The synthesized 6% starch-based analog was characterized using ATR-FTIR Spectroscopy to monitor the new spectral band formation and its behavioural changes to the raw materials (pure starch powder, glycerol, acetic acid) used for its synthesis.

Figure 4.2 shows the comparison spectra of reactants (pure starch powder, glycerol, and acetic acid) and synthesized starch-based analog. As seen in Figure 4.2 (a), the ATR-FTIR spectra of pure starch powder show the presence of α-1,4-glycosidic linkage at 1143.78 $cm^{-1}$ [186] and α-1,6-glycosidic linkage at 990.79 $cm^{-1}$ and 851.51 $cm^{-1}$ [187] that represent the skeletal model of amylopectin starch ring, and the major -C-OH stretching of the primary and secondary alcoholic group at 3748.08 $cm^{-1}$ and 3271.32 $cm^{-1}$, respectively.

The spectral peak at 1018.92 $cm^{-1}$ in Figure 4.2 (b) indicates the formation of ether linkage (C-O-C) in starch-based analog other than glycosidic bonds with the involvement of the C3 hydroxyl group of glycerol and one of the C6 carbon of monosaccharide moieties of starch. After the reaction between starch and glycerol in an acidic medium, the hydroxyl (-OH) stretching in starch-based analog shifted from 3271.32 $cm^{-1}$ to 3295.90 $cm^{-1,}$ and a band of glycosidic bonds, shifted from 990.79 $cm^{-1}$ to 1018.92 $cm^{-1}$, which corresponds to C-O-C stretching, that confirms the formation of etherified starch [103, 188, 189]. However, the result from ATR-FTIR spectra of synthesized starch-based analog, where 3 molecules of glycerol got attached with one molecule of starch moiety, shows that partial etherification occurred during a condensation reaction between starch and glycerol [97].

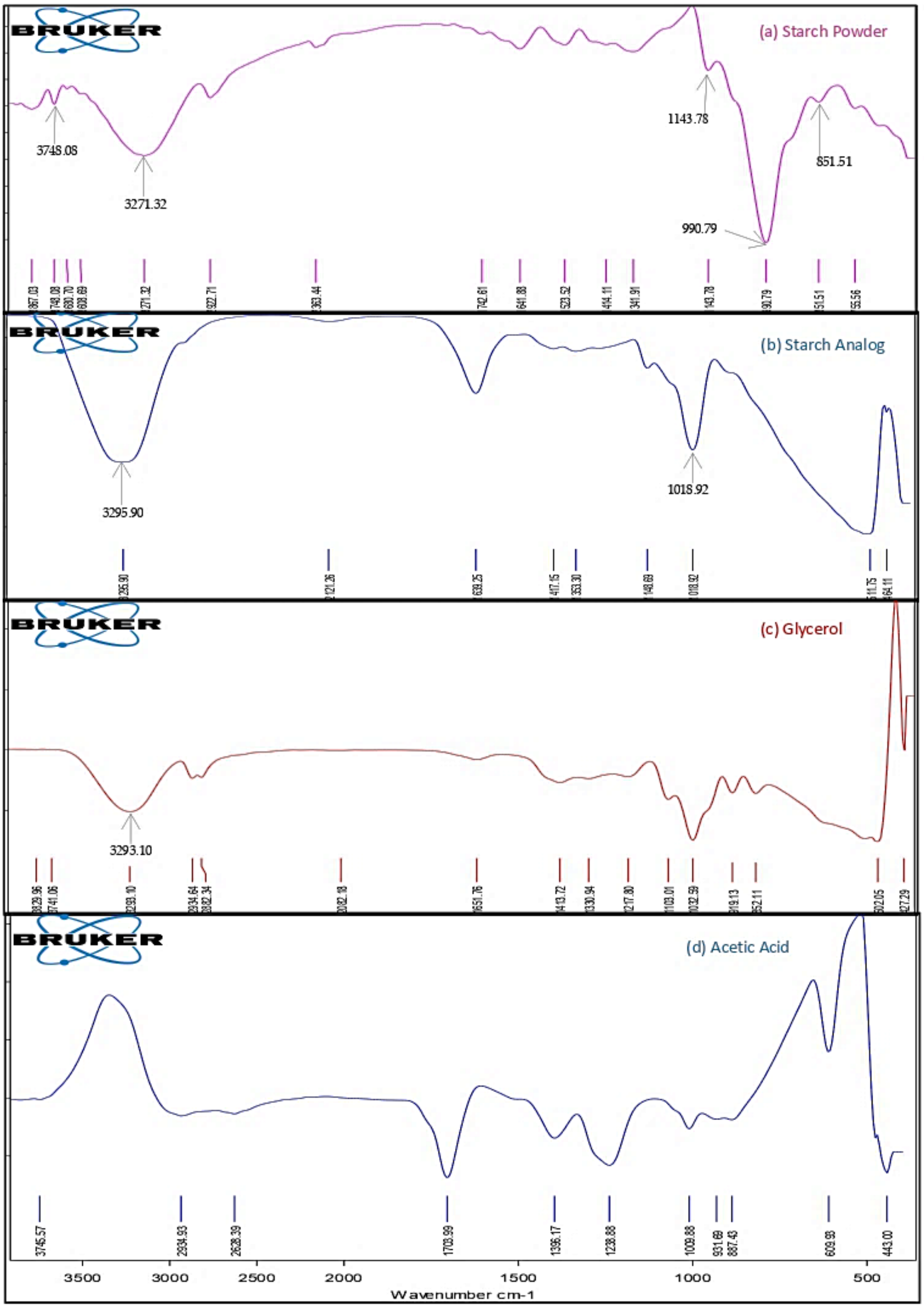



**Figure 4.2: ATR-FTIR spectra of (a) Starch powder, (b) synthesized Starch-based Analog, (c) Glycerol, and (d) Acetic acid.**

Further, the pure starch and the starch-based analog underwent mass analysis using MALDI-TOF mass spectrometry. As shown in Figure 4.3, the MALDI-TOF MS spectrum of pure starch with mass peak $n[C_{26}H_{46}O_{21}]^+$ at 694.25 was observed, which corresponds to the molecular mass of the starch used in the study, whereas, in Figure 4.4, the mass peak n[$C_{35}H_{64}O_{27}$]$^+$ at 916.36 corresponds to the molecular mass of the synthesized starch-based analog. Hence, the spectral characterization via ATR-FTIR and mass analysis via MALDI-TOF MS, confirm the structure of pure starch and synthesized starch-based analog, as shown in Figure 3.19.

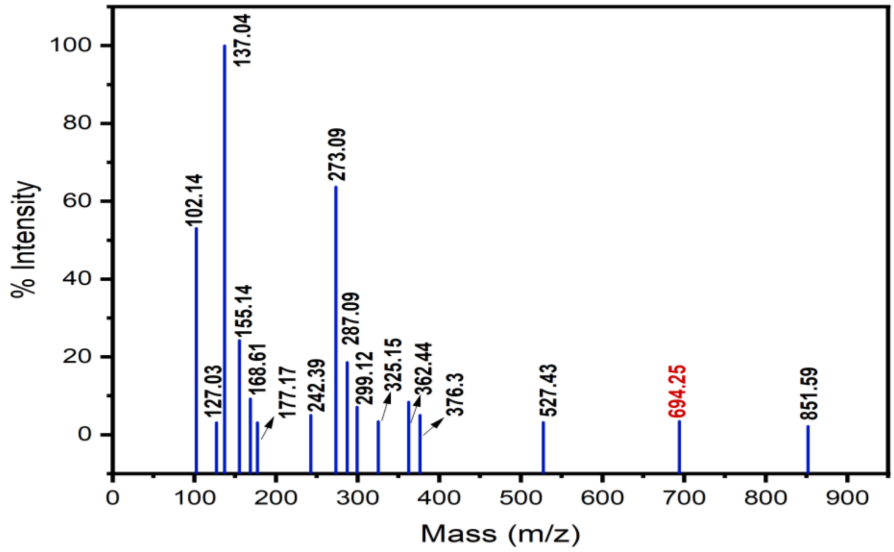



**Figure 4.3: MALDI-TOF mass spectrum of Pure starch.**

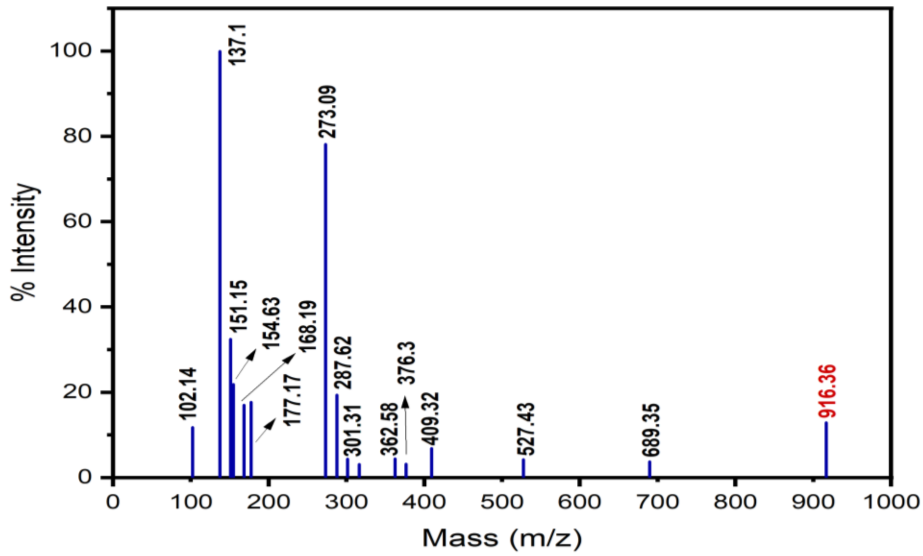



**Figure 4.4: MALDI-TOF mass spectrum of Starch-based analog.**

### 4.5. Application of Starch-based Analog on Charred Documents

After the synthesis and characterization of starch-based analog, each concentration of starch analog was applied on all three paper types to test their effectiveness on application and decipherment. Therefore, based on the experimental results, it was found that except for 8% analog, the rest were transparent in nature, whereas 8% starch analog was slightly opaque and cloudy. Applying 2% and 4% starch analog to the charred documents did not gave good results as the hydrophobic coating did not form onto the samples and did not get dry even after exposure to the air for hours.

Once it got dry, a thin film formed, which could not provide appreciable strength to the charred samples, tested by general observation and paper folding test. The decipherment of text was also insufficient as none of the text could be read by the naked eye in all three types of paper coated with 2% analog (Figure 4.5). The same was also confirmed using OCR via google lens (G-lens) (Figure 4.6). This may be due to the lower consistency of the analog. Whereas only a few texts were faintly visible to the naked eye in all three paper types coated with 4% analog (Figure 4.7), but very few could be recognized by G-lens only in 75 gsm copier paper and 100 gsm diary paper (Figure 4.8).

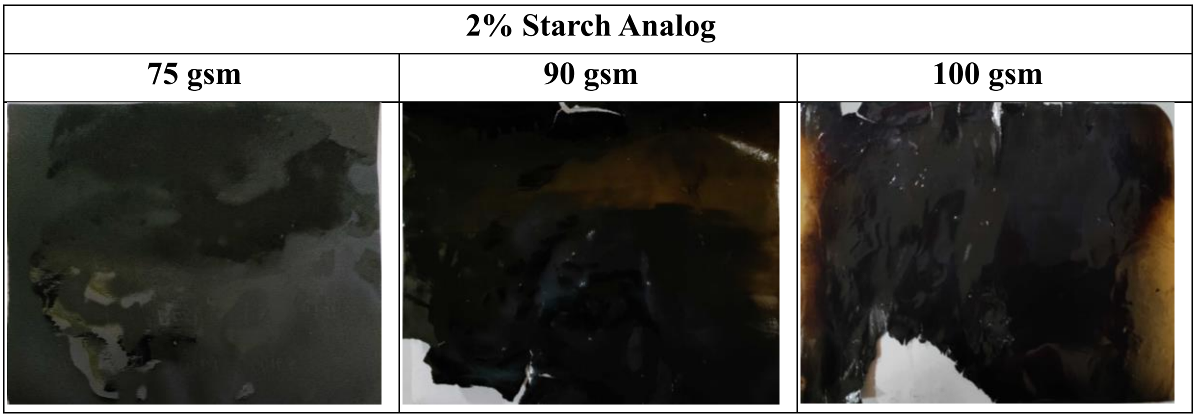
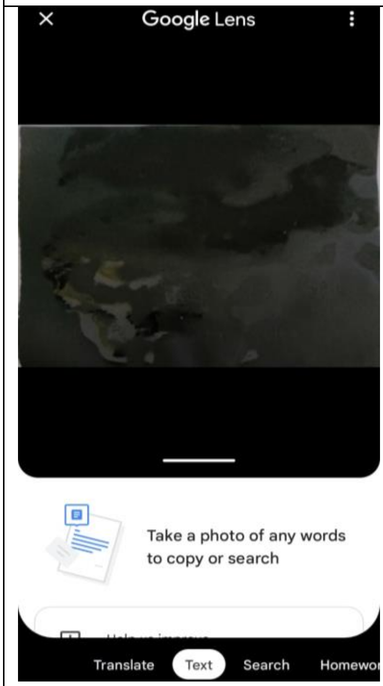
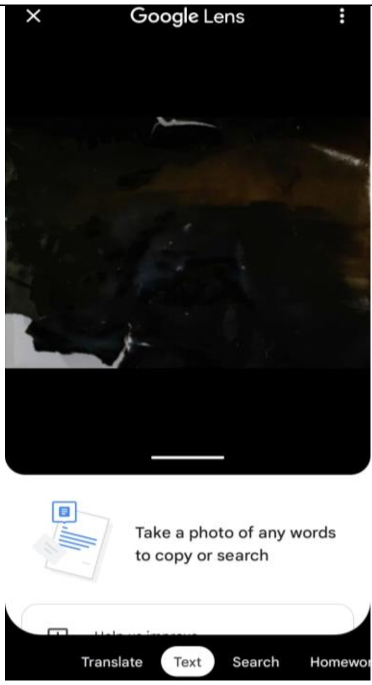



**Figure 4.5: Coated charred samples with 2% starch analog on 75 gsm copier, 90 gsm bond, and 100 gsm diary paper.**

| 75 gsm | 90 gsm | 100 gsm |
|---|---|---|



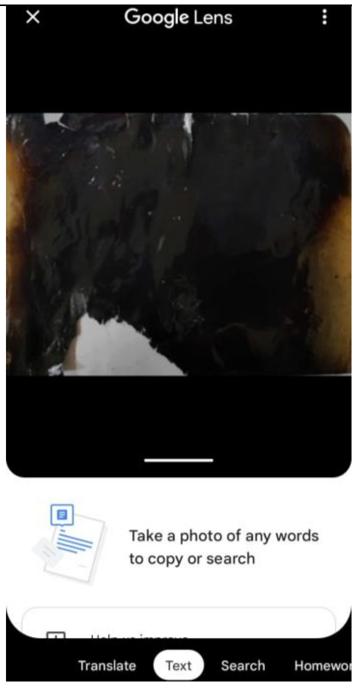




**Figure 4.6: G-lens read texts of coated charred samples with 2% starch analog on 75 gsm copier, 90 gsm bond, and 100 gsm diary paper.**

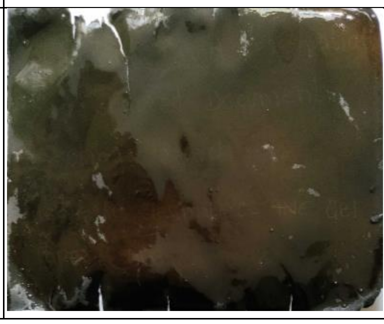
| 4% Starch Analog | | |
|---|---|---|
| 75 gsm | 90 gsm | 100 gsm |
|  |  |  |

**Figure 4.7: Coated and preserved charred samples with 4% starch analog on 75 gsm copier, 90 gsm bond, and 100 gsm diary paper.**

| 75 gsm | 90 gsm | 100 gsm |
|---|---|---|

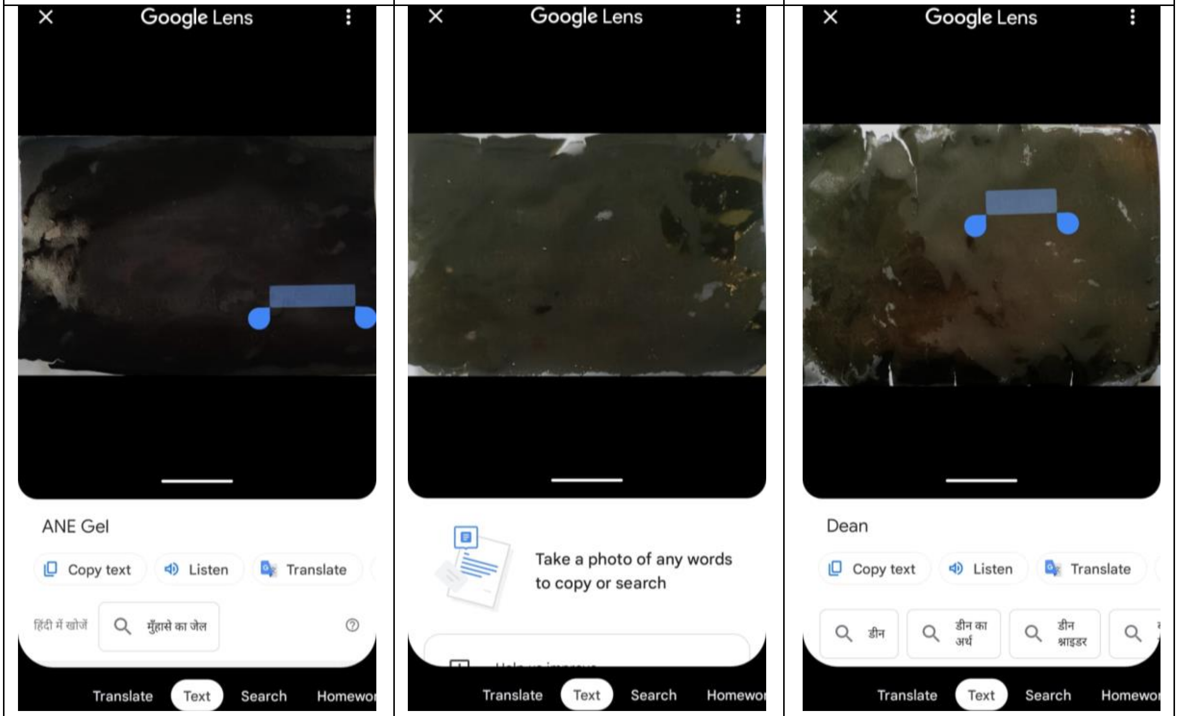



**Figure 4.8: G-lens read texts of coated charred samples with 4% starch analog on 75 gsm copier, 90 gsm bond, and 100 gsm diary paper.**

On the contrary, Figure 4.9 shows the application of 6% starch analog. In these samples, the hydrophobic film was formed like a polish that smoothens the surface and reduces the fragility and brittleness of the document through the process of rehydration. Soon after application, the texts were visible to the naked eye. This can be due to the difference in polarity of starch analog consisting of glycerol, and oils and fats in ink. The residual traces of oils and fats on the burnt paper act as a repellent to the synthesized analog. Hence, the starch analog gets absorbed by the charred paper except on the writing, leading to the differentiation due to colour contrast between the writings and the background [64]. The G-lens could also recognize all text of the statement in all three types of paper (Figure 4.10). The coating also dried in about 10-15 minutes at room temperature and provided appreciable strength to the charred document, tested by general observation and paper folding test.

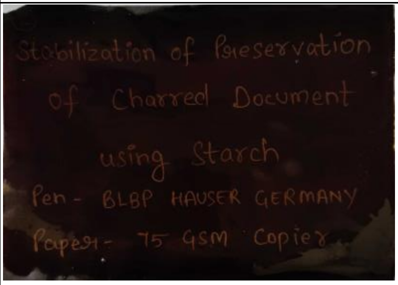
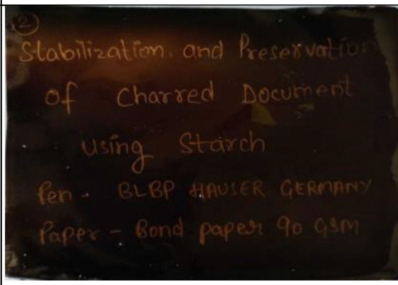
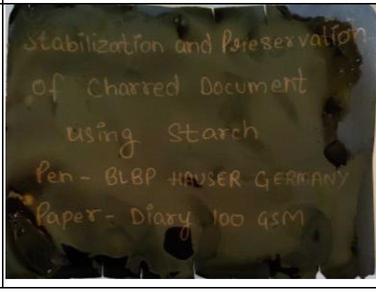
<table>
<tr><th colspan="3">6% Starch Analog</th></tr>
<tr><th>75 gsm</th><th>90 gsm</th><th>100 gsm</th></tr>
<tr>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
</table>

**Figure 4.9: Coated and preserved charred samples with 6% starch analog on 75 gsm copier, 90 gsm bond, and 100 gsm diary paper.**

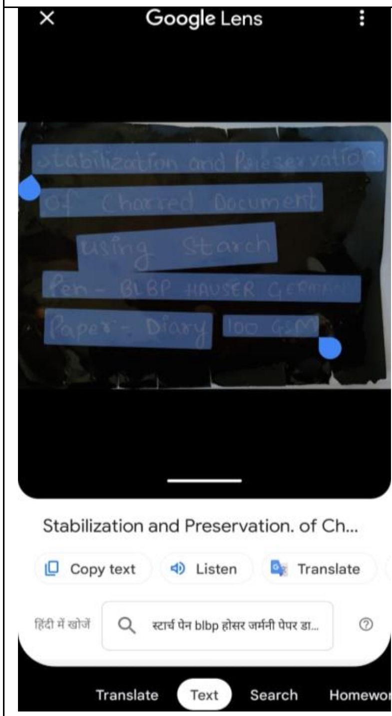
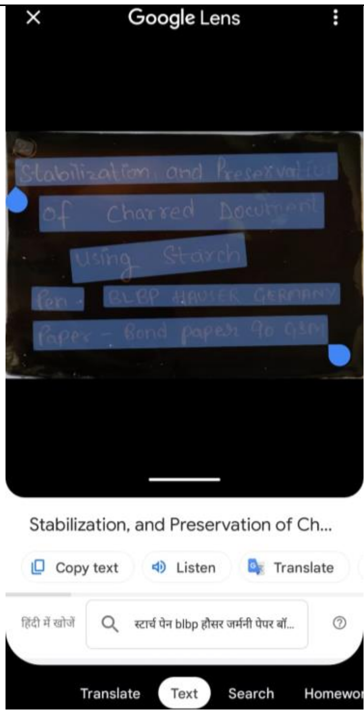
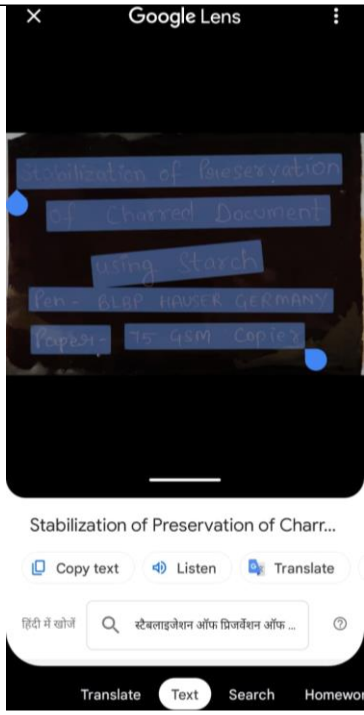
<table>
<tr><th>75 gsm</th><th>90 gsm</th><th>100 gsm</th></tr>
<tr>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
</table>

**Figure 4.10: G-lens read texts of coated charred samples with 6% starch analog on 75 gsm copier, 90 gsm bond, and 100 gsm diary paper.**

Moreover, 8% starch analog was viscous enough to form an even coating onto the charred document that resulted in the formation of white precipitated flakes of starch, which hindered smooth application. None of the text got deciphered on 90 gsm, bond paper, and 100 gsm diary paper, and only a few texts were faintly seen through the naked eye on 75 gsm copier paper (Figure 4.11) that was not recognized by G-lens (Figure 4.12). After it got dried, cracks of coating developed on the surface and it got curled.

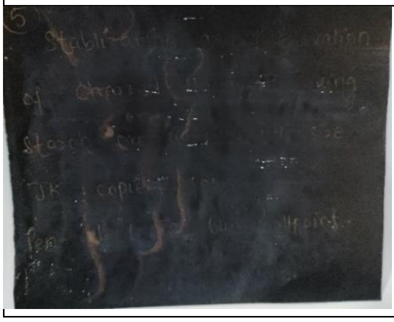
| **8% Starch Analog** | | |
|---|---|---|
| **75 gsm** | **90 gsm** | **100 gsm** |
|  |  |  |

**Figure 4.11: Coated and preserved charred samples with 8% starch analog on 75 gsm copier, 90 gsm bond, and 100 gsm diary paper.**

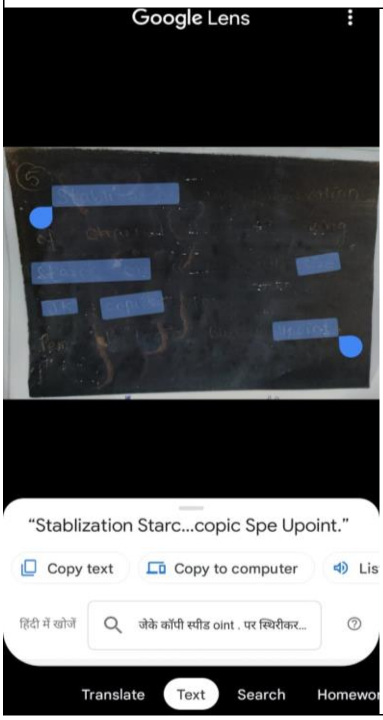
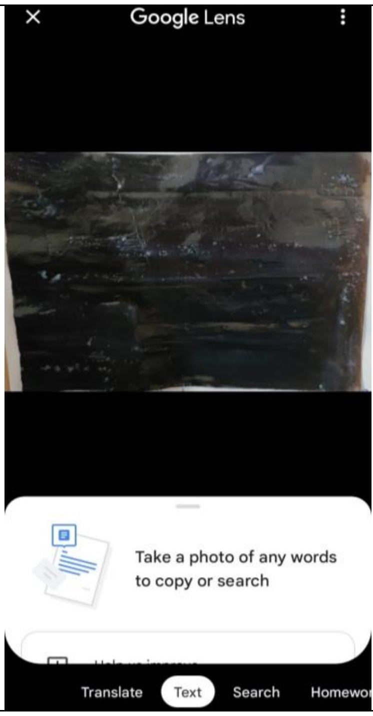
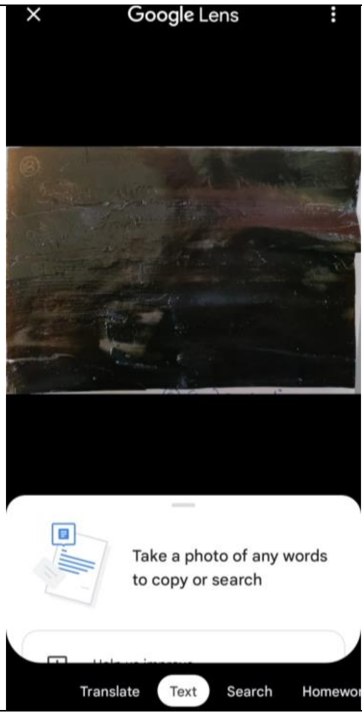
| **75 gsm** | **90 gsm** | **100 gsm** |
|---|---|---|
|  |  |  |

**Figure 4.12: G-lens read texts of coated charred samples with 8% starch analog on 75 gsm copier, 90 gsm bond, and 100 gsm diary paper.**

Based on the above results of varied concentrations of starch analog, the optimal concentration for the starch-based analog was found to be 6%. At this concentration, the analog exhibited the highest level of transparency, allowing for easy visualization of the coated documents. The viscosity of the 6% solution was also in the appropriate range i.e., 15 centipoise (cp), ensuring smooth and consistent application. Furthermore, the application on charred documents showed excellent adhesion and coverage with minimal smudging. After applying, it dried within 10-15 minutes at room temperature. The analog also demonstrated remarkable strength against external forces, indicating its ability to effectively protect and preserve charred documents for further analysis. Lastly, as soon as the analog was applied to the surface of charred documents, the illegible contents were deciphered, indicating that the 6% starch-based analog had the superior capability to unveil invisible vital information on non-coated charred documents. Therefore, the rest of the result shown in this chapter is the stabilization, preservation, and decipherment of charred documents using a 6% starch-based analog.

### 4.6. Stabilization and Decipherment of Documents made with Blue Ballpoint Pen Inks

This section shows the effect and results of stabilization and decipherment of charred documents made with three different brands of blue ballpoint pen (BBP) ink viz., Linc Pentonic, Elkos Better, and Unique EZY, on all three types of paper viz. 75 gsm copier paper, 90 gsm bond paper, and 100 gsm diary paper. The results of each combination are illustrated below.

#### 4.6.1. Linc Pentonic Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

The combination-1 consisting of a Linc pentonic blue ballpoint pen on 75 gsm copier paper exhibited the highest degree of charring when exposed to a temperature of 300 ºC, having invisible texts, as shown in Figure 4.13 (a). After the fragile charred documents were stabilized using 6% starch-based analog, it resulted in the decipherment of the invisible texts within seconds soon after the application over the charred documents in all three types of paper, and was clearly visible to the naked eye, as shown in Figure 4.13 (b)-4.14 (b). This can be due to the difference in polarity of starch analog consisting of glycerol and oils and fats in ink. The residual traces of oils and fats on the charred document act as a repellent to the synthesized analog. Hence, the starch analog gets absorbed by the charred paper except on the writing, leading to the differentiation due to colour contrast between the background and ink composition of Linc pentonic blue ballpoint ink, containing volatile solvents which facilitated the preservation of legible information even after exposure to high temperatures.

Furthermore, the optical character recognition (OCR) analysis through G-lens successfully recognized significant texts from the captured image of the deciphered charred document as shown in Figure 4.13 (c). In combination-1 and combination-2 (Figure 4.14), almost all the texts were recognized, whereas in combination-3 few texts were not recognized by G-lens, as shown in Figure 4.15 (c). The percentage of deciphered characters by G-lens is shown in Table 4.23. Subsequently, the deciphered document underwent further analysis using an advanced technique, Video Spectral Comparator (VSC) after almost a month. In all three combinations, the texts were clearly visible under flood light in the visible range, as shown in Figure 4.13 (d), which showed the efficiency of the current preservation and decipherment technique using starch-based analog.

The successful decipherment may be attributed to the combined effect of stabilization using the starch-based analog and the type of ink used to make a document, which likely enhanced the legibility of the texts.

**Table 4.23: Showing the Percentage of Correctly Recognized Characters of BBP Linc Pentonic pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **1.** | BBP Linc Pentonic+75 gsm | Stabilization and Presevation of Charred Document using Starch | 55/56 | 99 |
| **2.** | BBP Linc Pentonic+90 gsm | Stabilization and of Charred Document using Starch | 44/56 | 79 |
| **3.** | BBP Linc Pentonic+100 gsm | Stablization and Preservation of charred Documents sing Starch | 54/56 | 97 |

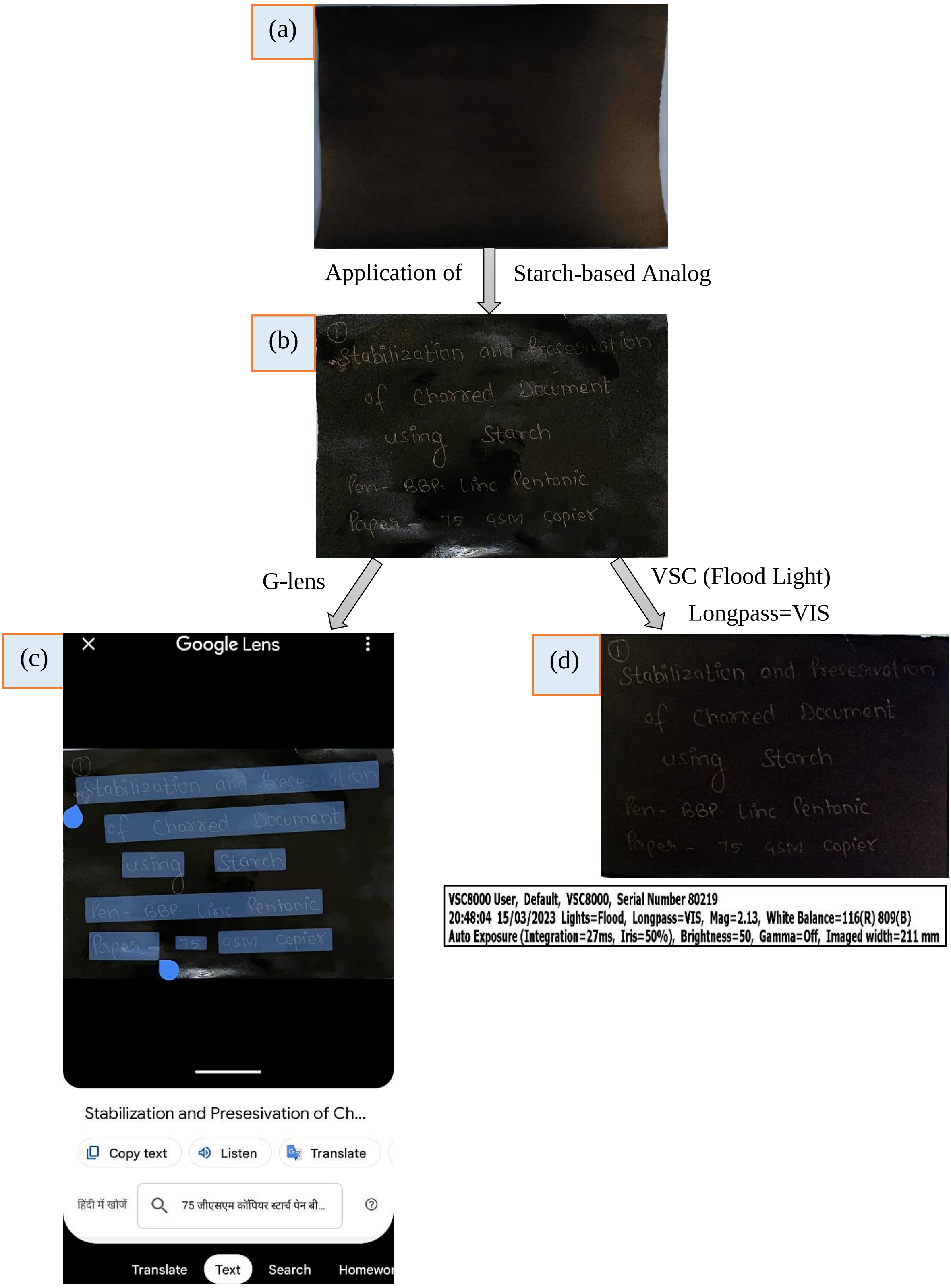



**Figure 4.13: Shows BBP Linc Pentonic on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

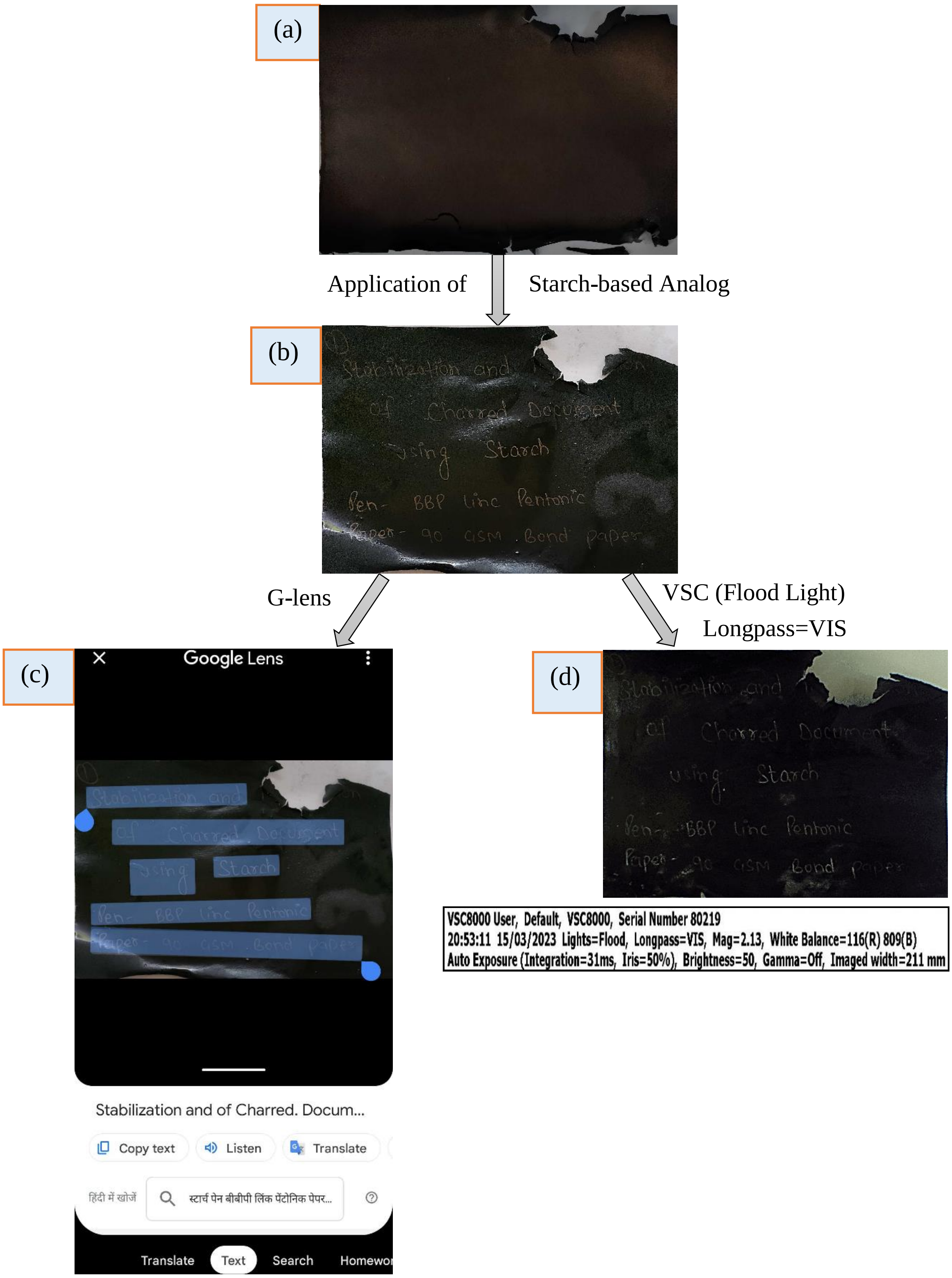



**Figure 4.14: Shows BBP Linc Pentonic on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

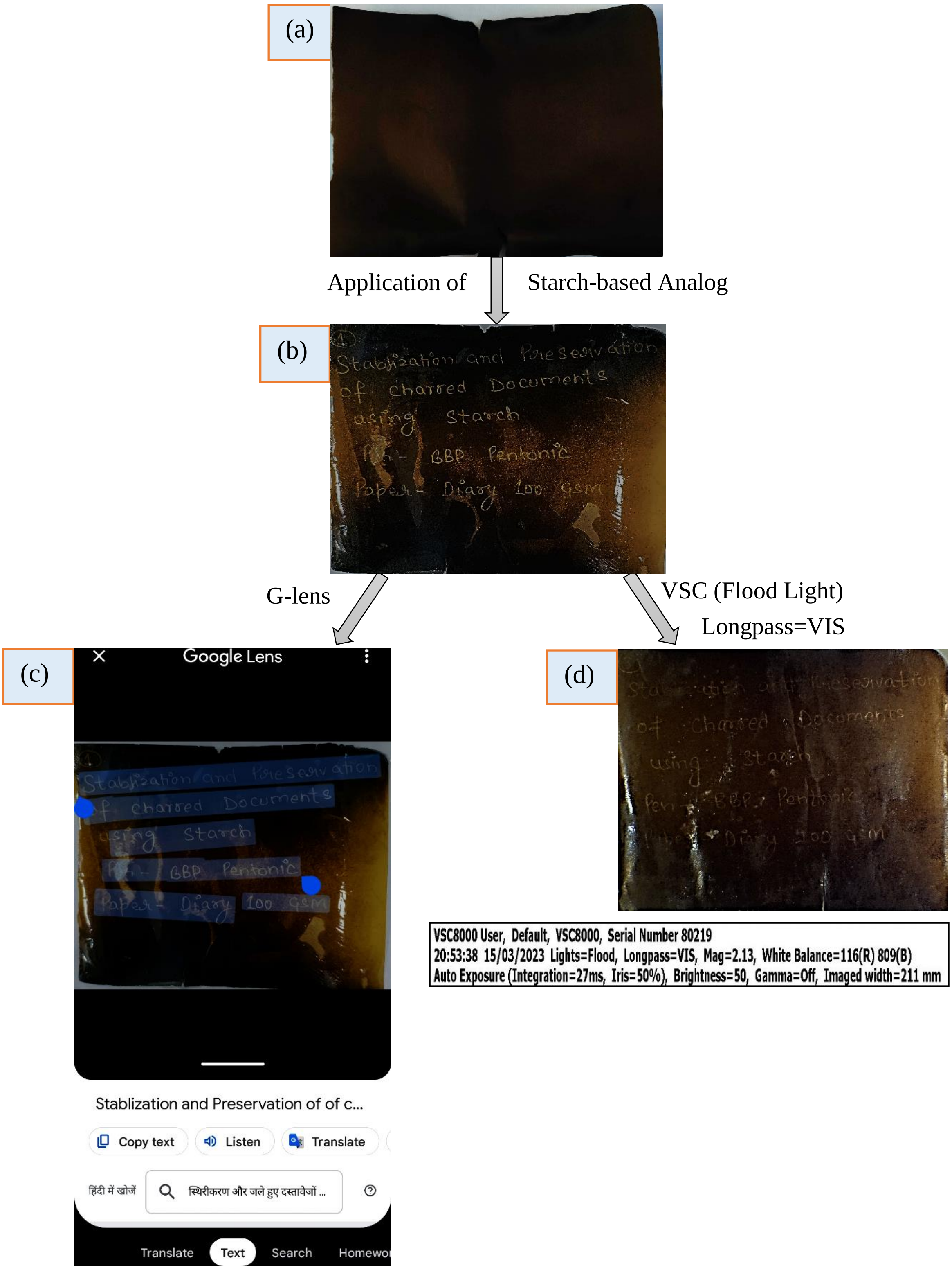



**Figure 4.15: Shows BBP Linc Pentonic on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.6.2. Elkos Better Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

Similarly, Figures 4.16-4.18 show the effect of BBP Elkos Better pen ink on 75 gsm copier paper, 90 gsm bond paper, and 100 gsm diary paper. The documents made with BBP Elkos better on 75 gsm paper at its maximum charring stage, 300 ºC, had invisible texts. Applying synthesized starch-based analog on the fragile charred documents made the invisible texts readable on nearly all three types of paper within seconds.

This may be due to the nature of ballpoint pen ink used in Elkos pen, which is likely to contain certain compounds that undergo a chemical change when exposed to high temperatures, such as 300 ºC and above. This change could cause the ink to become colourless or not visible on the paper with the naked eye due to the heat-induced alteration of the ink's chemical properties. However, when the charred document was coated with a starch-based analog, a chemical reaction between the analog and the remaining ink residues on the paper may have occurred. The starch analog might have acted as a solvent or reagent, reacting with the altered ink and restoring its visibility or colour, hence getting deciphered and visible to the naked eye.

Furthermore, the deciphered texts were also recognized by the G-lens, and it converted the image into readable and copiable text format. In combination-4 and combination-6, more than 90% of the texts were deciphered and recognized G-lens, as shown in Figures 4.16 (c) and 4.18 (c), whereas in combination-5, faintly visible texts were not recognized by G-lens, Figure 4.17 (c). This may be due to the thin layer of coating in combination-5 (90 gsm paper).

The percentage of the characters that the G-lens successfully recognized is shown in Table 4.24. In addition, the stabilized document was further subjected to VSC analysis, which also deciphered the texts under flood light in the VIS region, flood light at longpass 665, and flood light in VIS region, in 75 gsm, 90 gsm, and 100 gsm respectively, even after approximately a month, Figures 4.16-4.18 (d).

**Table 4.24: Showing the Percentage of Correctly Recognized Characters of BBP Elkos Better pen by G-lens.**

| **Combination** | | **G-lens Recognized Characters** | **No. of Recognized Characters** | **Character Deciphered (%)** |
|---|---|---|---|---|
| **4.** | BBP Elkos Better+75 gsm | alization and Presevation of Charred Documents using Starch | 51/56 | 91 |
| **5.** | BBP Elkos Better+90 gsm | Stabliz using Starch | 18/56 | 32 |
| **6.** | BBP Elkos Better+100 gsm | Stablization and Preservation of Charred Documents using Storch | 55/56 | 98 |

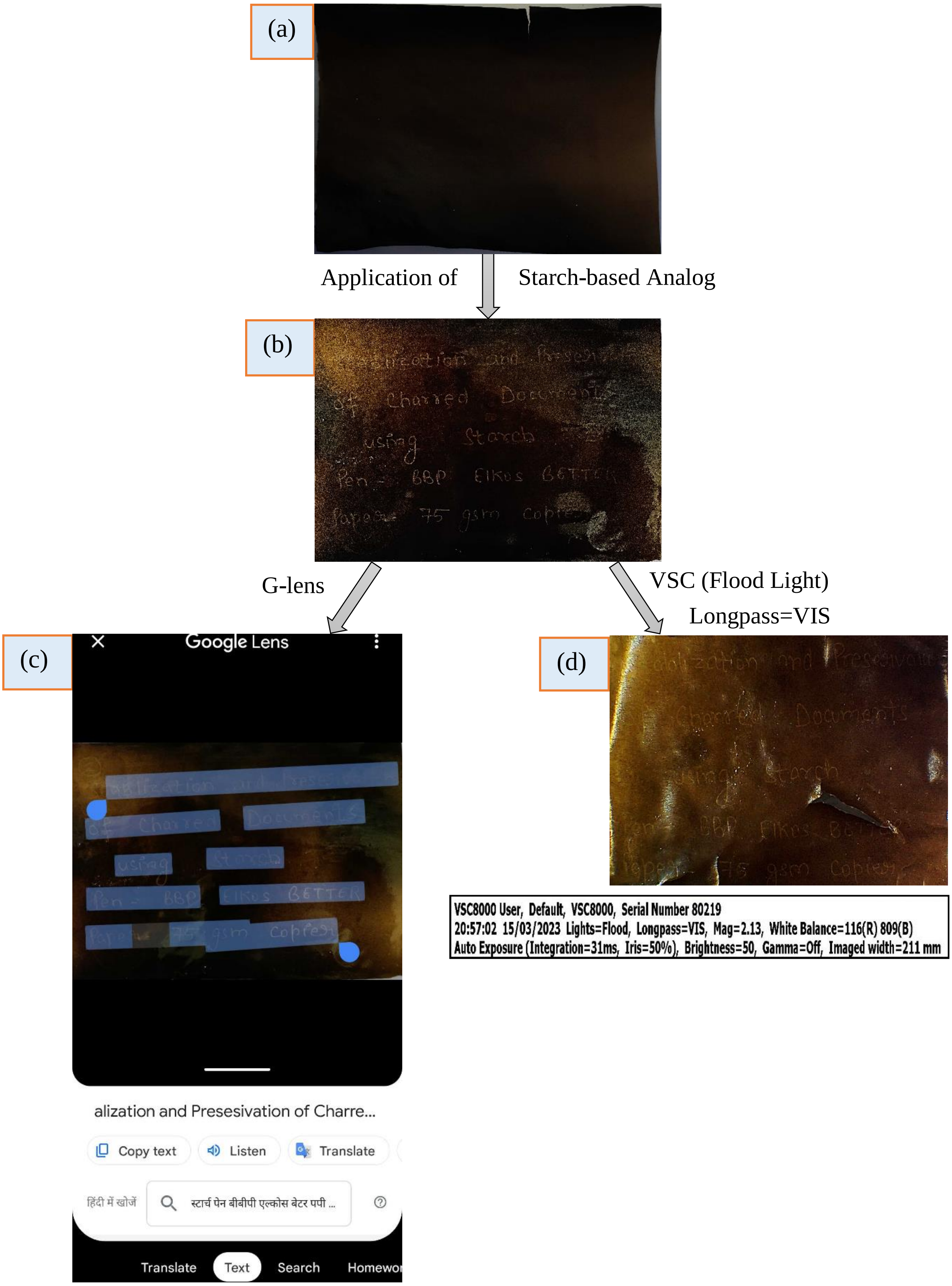



**Figure 4.16: Shows BBP Elkos Better on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

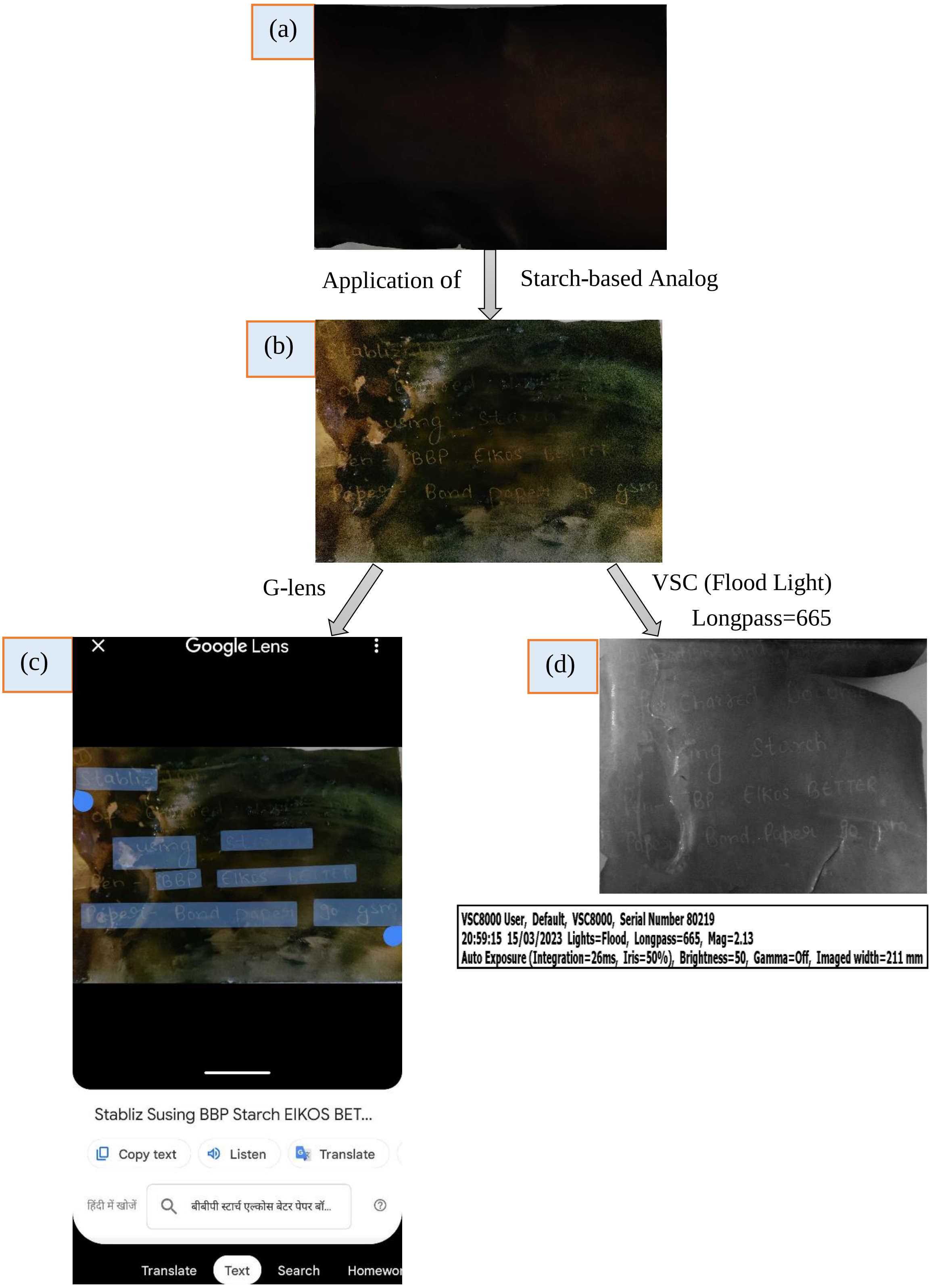



**Figure 4.17: Shows BBP Elkos Better on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

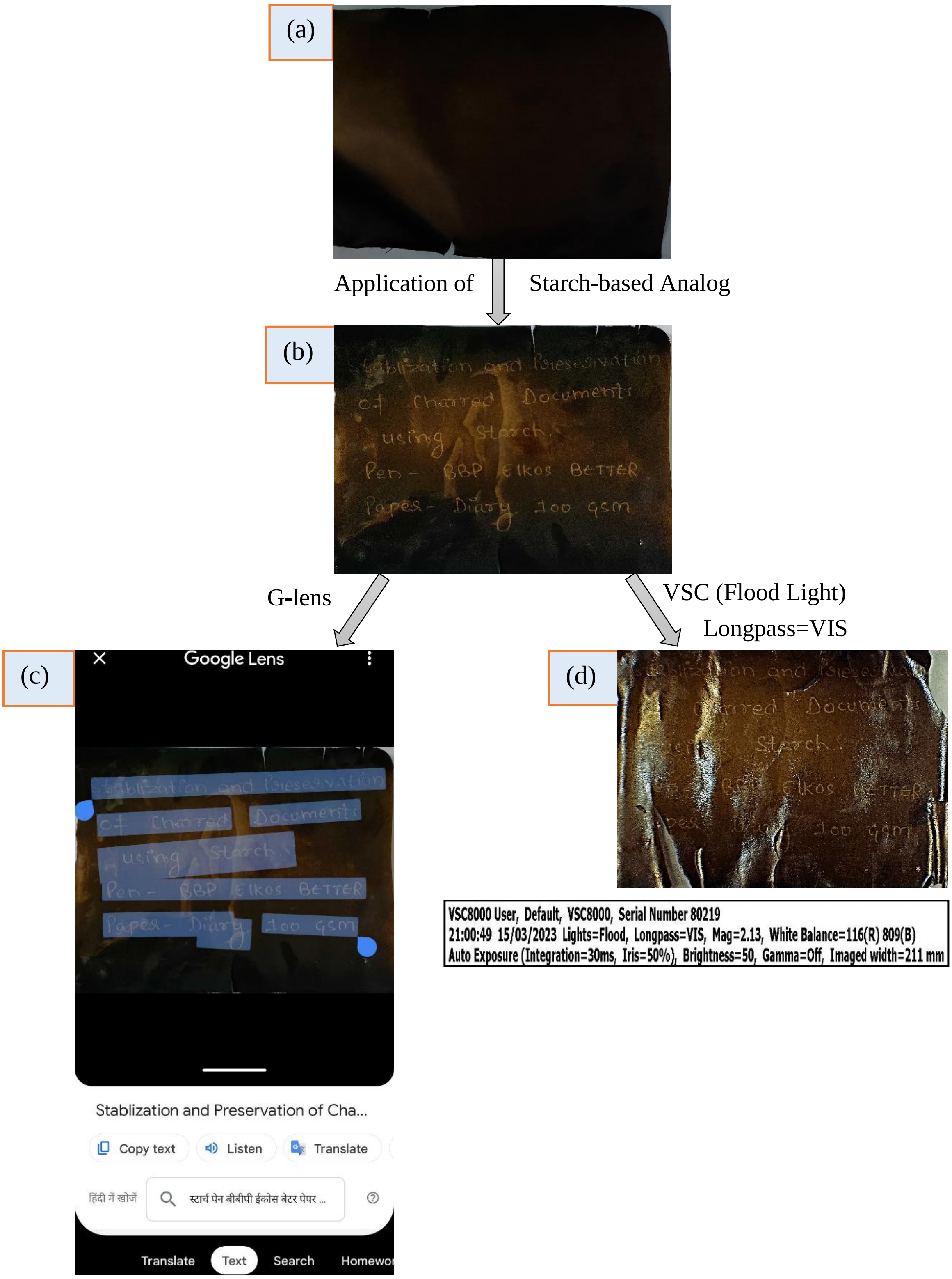



**Figure 4.18: Shows BBP Elkos Better on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, texts got deciphered, (c) G-lens recognized all deciphered texts, (d) VSC analysis of charred document.**

### 4.6.3. Unique EZY Grip Pen Inks 75 gsm, 90 gsm, and 100 gsm Paper

Figures 4.19-4.21 of combination-7, combination-8, and combination-9, made using BBP Unique EZY Grip pen on 75 gsm copier paper, 90 gsm bond paper, and 100 gsm diary paper, respectively, show that, after applying the starch-based analog, none of the written texts was visible to the naked eye in combination-7 (BBP Unique EZY+75 gsm) and combination-9 (BBP Unique EZY+100 gsm), whereas very few characters were faintly visible in combination-8 (BBP Unique EZY+90 gsm). This may be due to the nature and composition of Unique EZY blue ballpoint ink and the combined effect of ink type on paper substrate. The solvents present in ink may account for complete evaporation and disintegration due to the charring process, rendering the invisible texts irretrievable, which on coating with starch-based analog, did not adhered to it and thus did not produced a contrasting background.

The OCR analysis through G-lens also did not recognized any texts, as shown in Table 4.25. However, when the document was further subjected to VSC analysis, the invisible texts got deciphered in combination-7 under white spot light at longpass in the visible range, whereas only a few characters got faintly deciphered in combination-8 and combination-9 under flood light at longpass 695 and 780, respectively.

**Table 4.25: Showing the Percentage of Correctly Recognized Characters of BBP Unique EZY pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **7.** | BBP Unique EZY+75 gsm | No text visible | 0/56 | 0 |
| **8.** | BBP Unique EZY+90 gsm | No text visible | 0/56 | 0 |
| **9.** | BBP Unique EZY+100 gsm | No text visible | 0/56 | 0 |

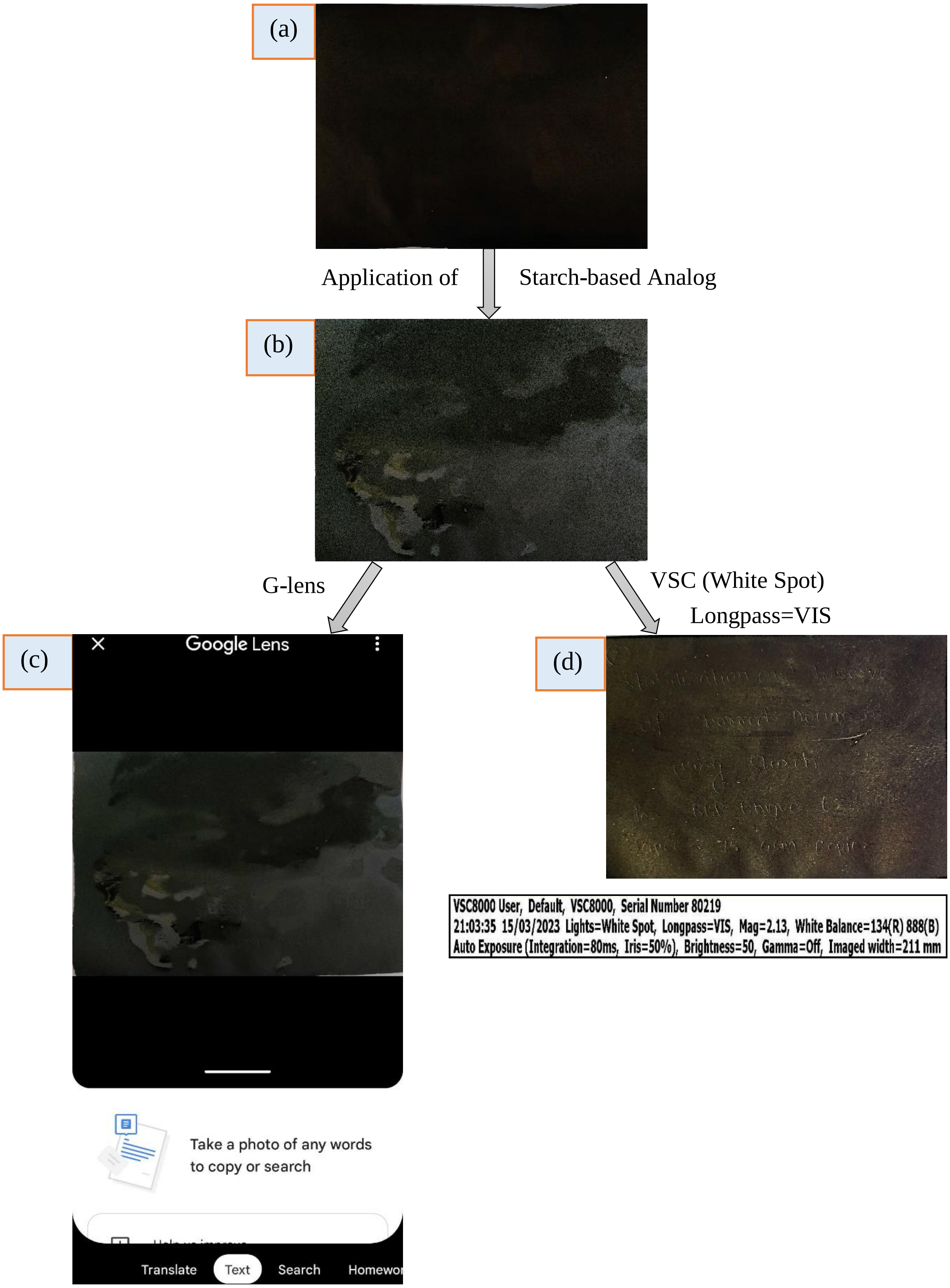



**Figure 4.19: Shows BBP Unique EZY on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

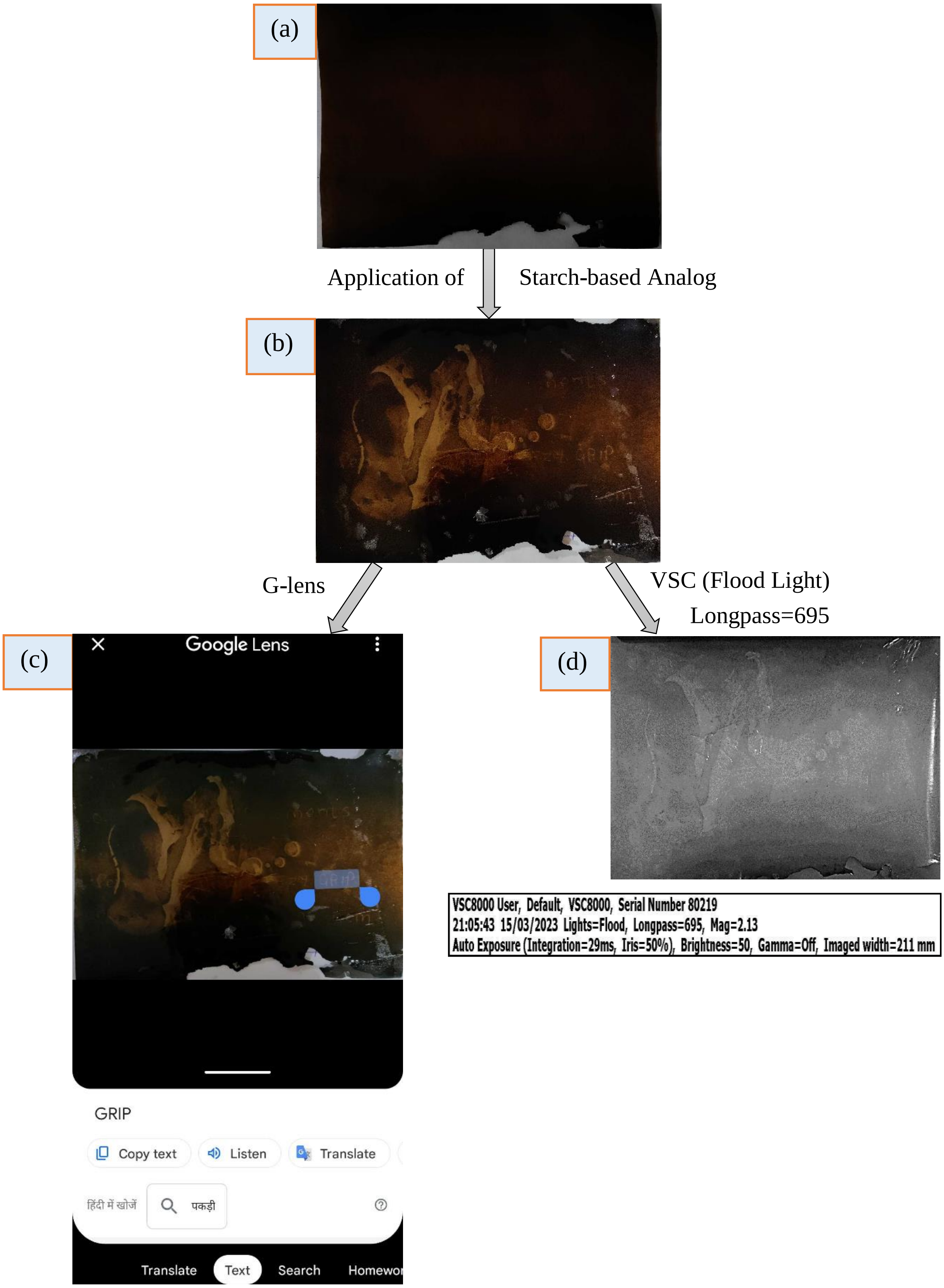



**Figure 4.20: Shows BBP Unique EZY on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

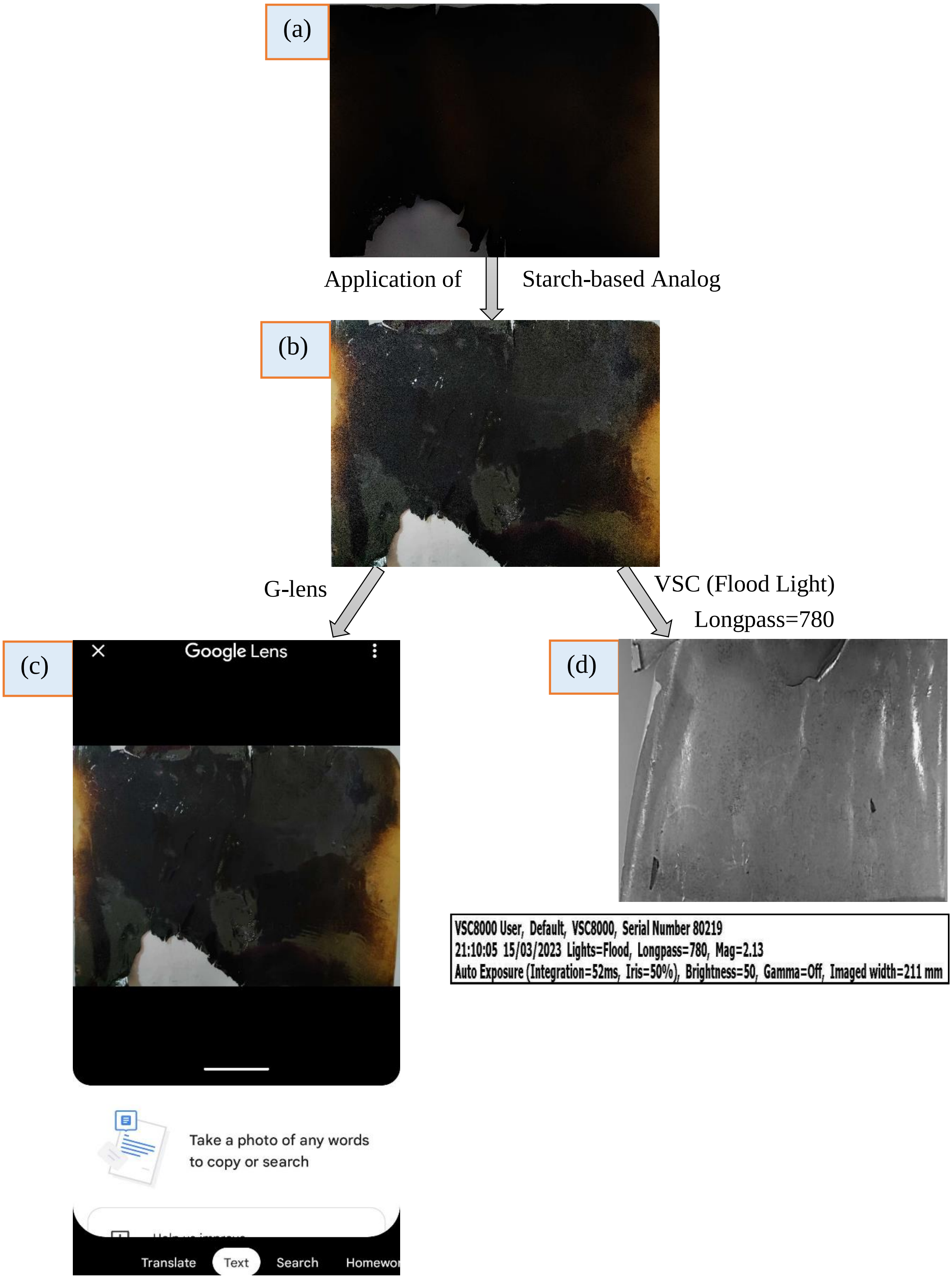



**Figure 4.21: Shows BBP Unique EZY on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

## 4.7. Stabilization and Decipherment of Documents made with Black Ballpoint Pen Inks

### 4.7.1. Linc Pentonic Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

The combination-10 of Linc pentonic Black ballpoint pen on 75 gsm paper demonstrated that 75 gsm paper charred at 300 ºC had invisible texts after undergoing excessive heat, thus turning documents into a fragile state, as shown in Figure 4.22 (a). Thereafter, applying starch-based analog revealed the invisible texts and became visible to the naked eye, as shown in Figure 4.22 (b). Similarly, combination-11 (BLBP Linc pentonic+90 gsm) and combination-12 (BLBP Linc pentonic+100 gsm) charred at their highest charring state, on application with starch-based analog got deciphered, as shown in Figure 4.23 and Figure 4.24. This can be due to the difference in polarity of starch analog consisting of glycerol; and oils and fats in ink. The residual traces of oils and fats on the burnt paper act as a repellent to the synthesized analog. Hence, the starch analog gets absorbed by the charred paper except on the writing, leading to the differentiation due to colour contrast between the background and ink composition, containing volatile solvents, which facilitated the preservation of legible information even after exposure to high temperatures. Furthermore, the deciphered texts from a captured image were also recognized by G-lens, as shown in Figure 4.22 (c), and the percentage of characters correctly recognized by G-lens is shown in Table 4.26. In addition, VSC also successfully deciphered the texts even after approximately a month, as shown in Figure 4.22 (d).

**Table 4.26: Showing the Percentage of Correctly Recognized Characters of BLBP Linc Pentonic pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **10** | BLBP Linc Pentonic+75 gsm | Stabilization and Reservation of Charred Document ising Starch | 54/56 | 97 |
| **11** | BLBP Linc Pentonic+90 gsm | Stabilization and Pesevation of Charred Document using Starch | 54/56 | 97 |
| **12** | BLBP Linc Pentonic+100 gsm | Stabilization and Pesevation of Charred Document using Sarch | 53/56 | 96 |

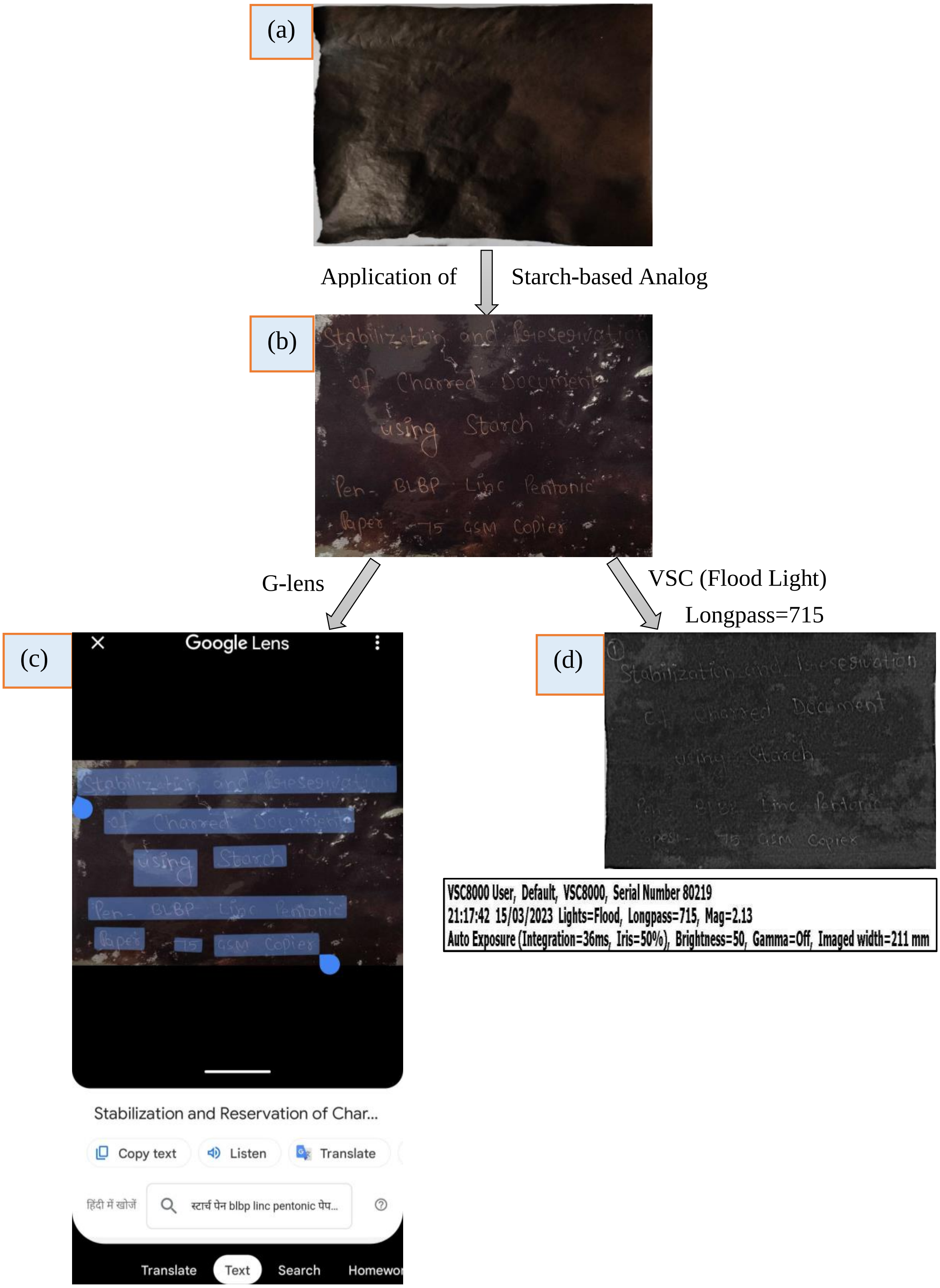



**Figure 4.22: Shows BLBP Linc Pentonic on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

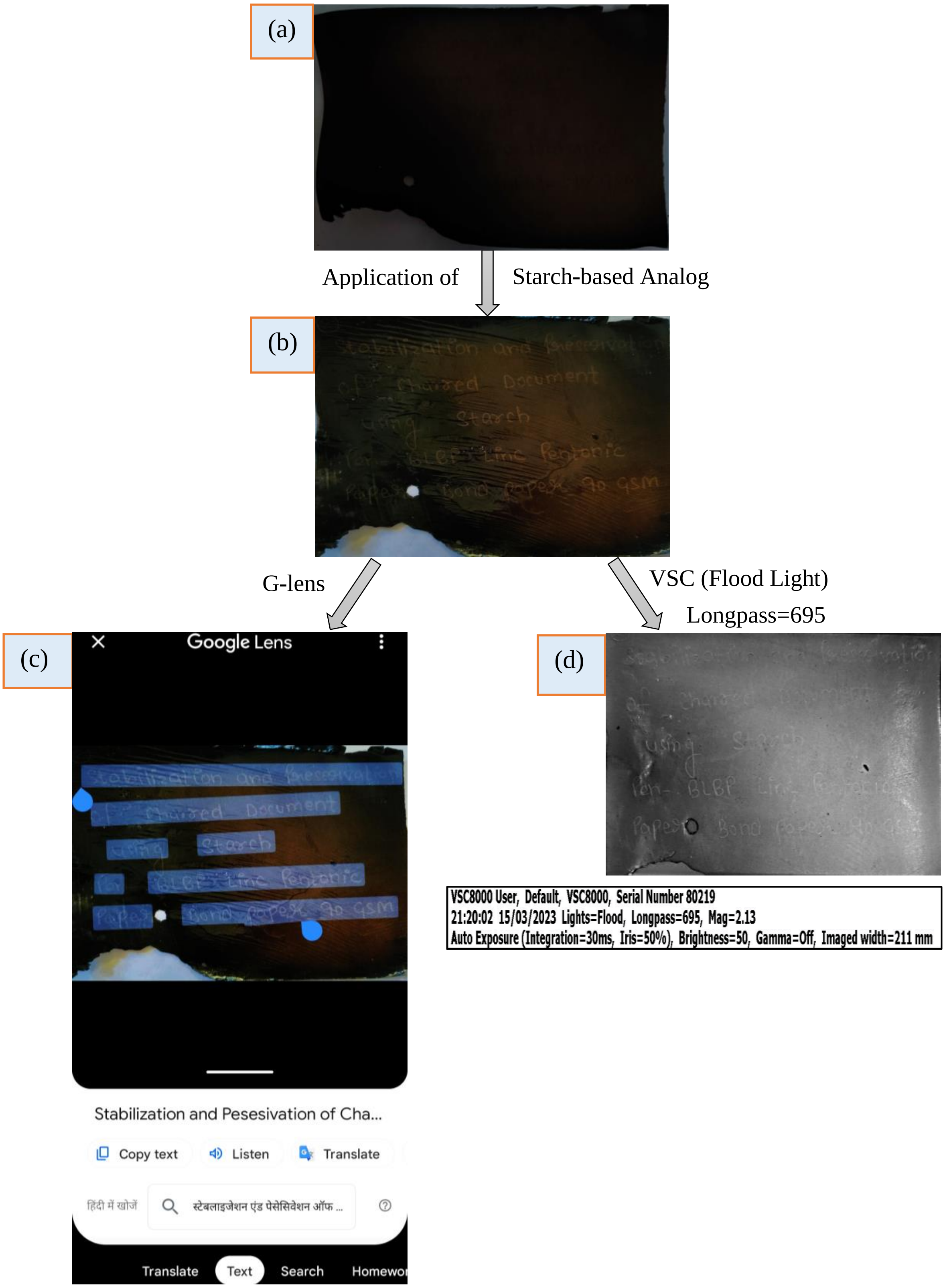



**Figure 4.23: Shows BLBP Linc Pentonic on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

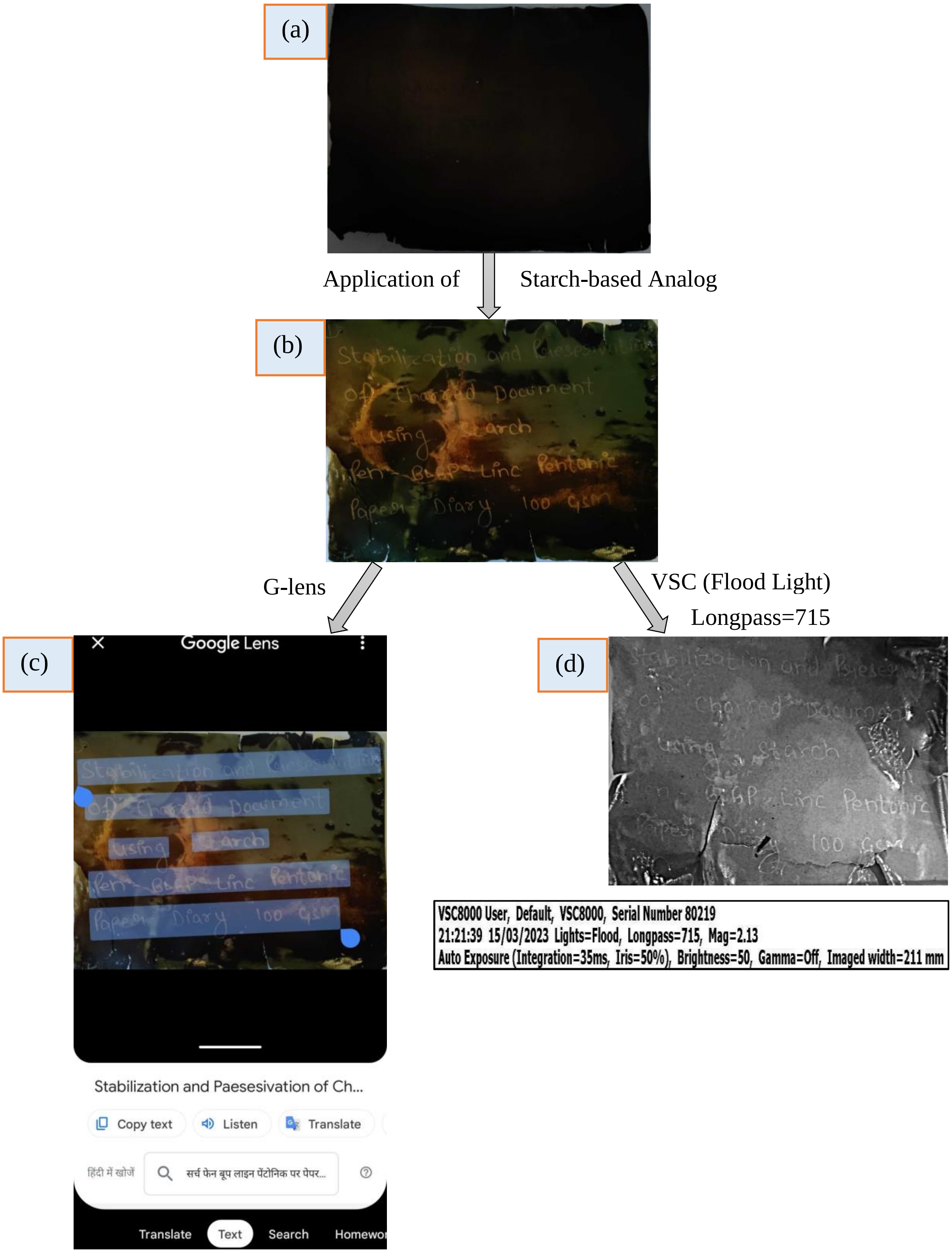



**Figure 4.24: Shows BLBP Linc Pentonic on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.7.2. Elkos Better Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

Figure 4.25-4.27 of combinations-13, 14, and 15 made using BLBP Elkos Better pen ink on 75 gsm copier paper, 90 gsm bond paper, and 100 gsm diary paper shows that, in 90 gsm and 100 gsm paper, more than 65% of invisible texts got deciphered after applying starch-based analog on fragile charred documents, which G-lens also recognized correctly. This can be due to the chemical reaction that might have occurred between the ink composition and the starch-based analog. The ink of Elkos Better contains certain compounds or dyes that are sensitive to specific chemicals. When the ink is exposed to heat, such as charring, the chemical composition of the ink may change or react with the paper, making the writing appear invisible to the naked eye. However, when the starch-based analog was applied over charred documents, a chemical reaction may occur between the composition of the starch-based analog and the compounds in the ink or paper. This reaction can lead to the restoration or decipherment of the original texts. In contrast, in 75 gsm paper, only a few texts faintly got deciphered that were visible to the naked eye, which, on further analysis using G-lens, only recognized a few characters. This may be due to the uneven coating and application of starch-based analog over the charred surface. The percentage of correctly deciphered characters through G-lens is shown in Table 4.27. Furthermore, the VSC analysis of all three combinations gave quite good results, as combination-13 (BLBP Elkos Better +75 gsm) and combination-14 (BLBP Elkos Better+90 gsm) got deciphered under spot light at 665 longpass (Figure 4.25 d and 4.27 d), whereas combination-15 (BLBP Elkos Better+100 gsm) under flood light at 715 longpass.

**Table 4.27: Showing the Percentage of Correctly Recognized Characters of BLBP Elkos Better pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **13** | BLBP Elkos Better+75 gsm | Bilzation an | 11/56 | 20 |
| **14** | BLBP Elkos Better+90 gsm | Stabilization Charred Document ing Starch | 37/56 | 66 |
| **15** | BLBP Elkos Better+100 gsm | Stabiliation and hrrd Document using Starch | 39/56 | 70 |

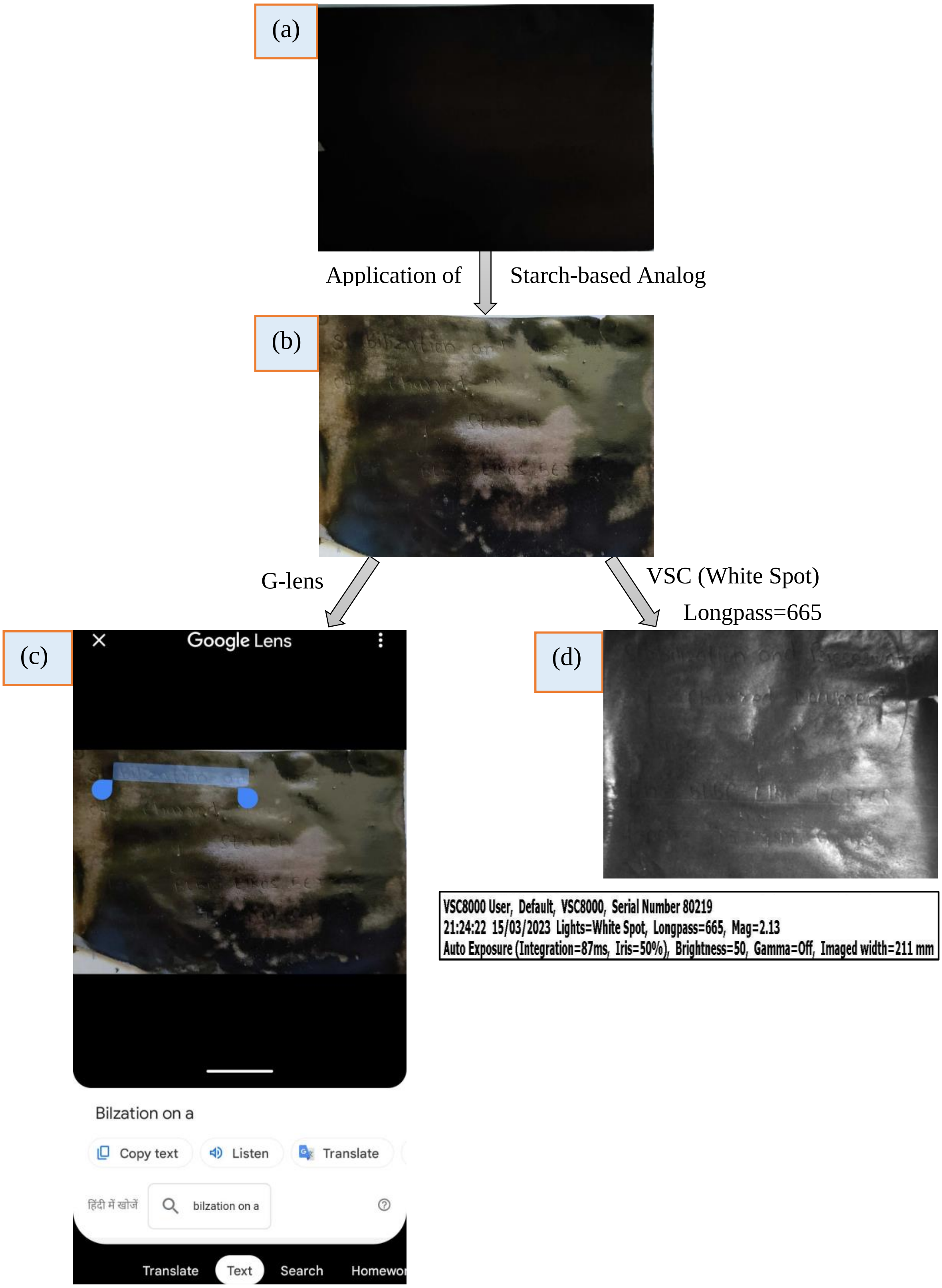



**Figure 4.25: Shows BLBP Elkos Better on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

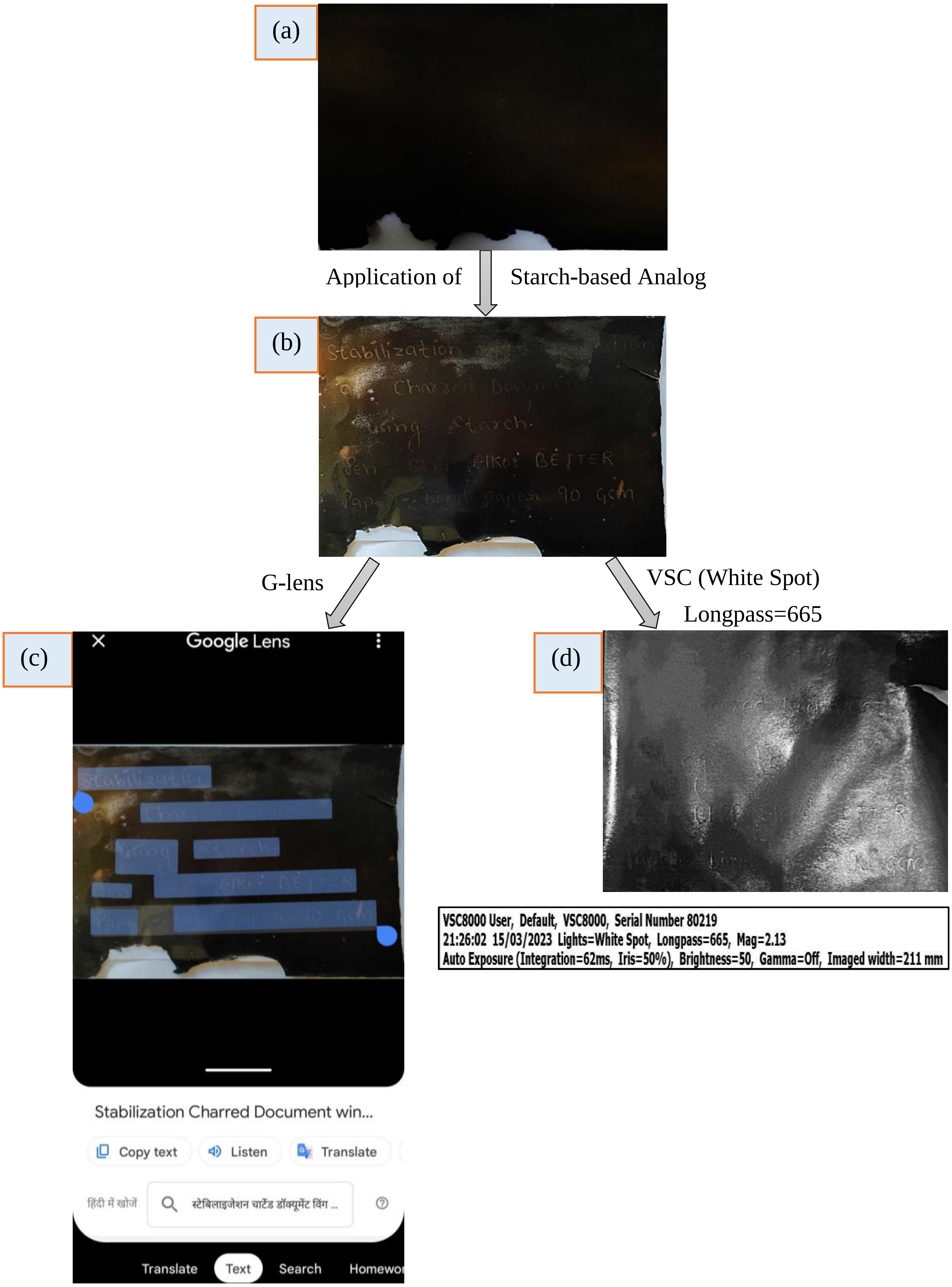



**Figure 4.26: Shows BLBP Elkos Better on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

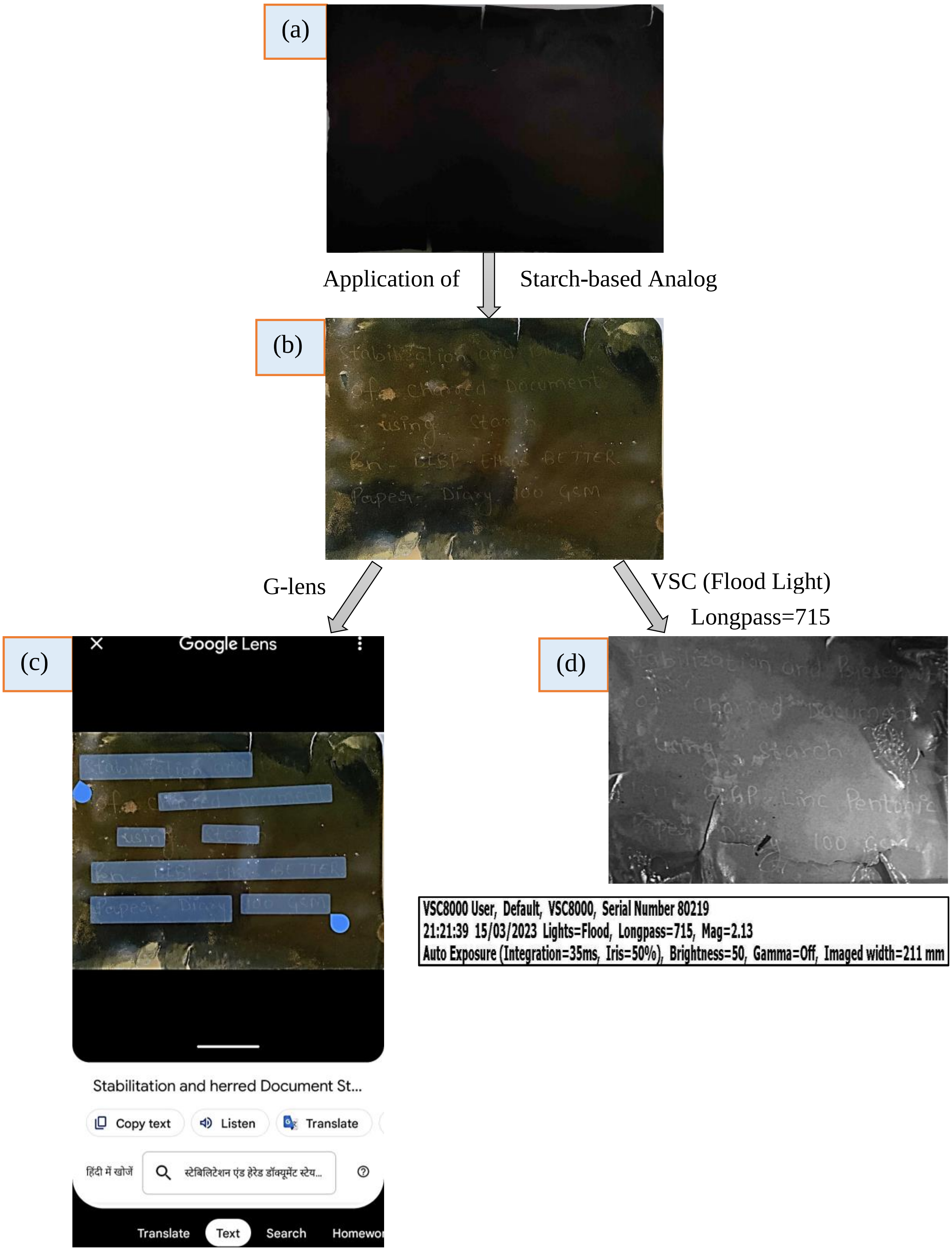



**Figure 4.27: Shows BLBP Elkos Better on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.7.3. Hauser Germany Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

Similarly, the writings made with BLBP Hauser Germany pen inks on 75 gsm, 90 gsm, and 100 gsm paper showed that the documents charred at their maximum state turned into a fragile state having invisible to hardly visible writing. Therefore, coating them with starch-based analog gave very promising results. In combination-16 (BLBP Hauser+75 gsm), the maximum texts were deciphered correctly, which G-lens also recognized. Moreover, in combination-17 (BLBP Hauser+90 gsm) and combination-18 (BLBP Hauser+100 gsm), all the texts got deciphered and were clearly visible to the naked eye, which G-lens also recognized efficiently, as shown in Figures 4.28-4.30. This may account due to the composition of Hauser Germany brand of black ballpoint ink. The ballpoint ink contains oil-based solvents that remain at the surface even after the documents underwent high temperature for charring, leaving the ink residues. Thereafter, on applying starch-based analog over the charred surface, the starch present in the synthesized analog may have bound to the ink particles and made them visible by producing contrast with the background. Moreover, the coatings may fill in the grooves of paper caused by pen pressure and in the gaps and cracks of the charred documents, thus enhancing contrast and visibility [190]. The percentage of correctly recognized characters is shown in Table 4.28. Furthermore, the documents analysis of documents under VSC also deciphered the texts even after a month under flood light in the visible range.

**Table 4.28: Showing the Percentage of Correctly Recognized Characters of BLBP Hauser Germany pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **16** | BLBP Hauser Germany+75 gsm | Stabilization Preservation of Charred Document using Starch | 53/56 | 95 |
| **17** | BLBP Hauser Germany+90 gsm | Stabilization and Preservation of Charred Document using Starch | 56/56 | 100 |
| **18** | BLBP Hauser Germany+100 gsm | Stabilization and Preservation of Charred Document using Starch | 56/56 | 100 |

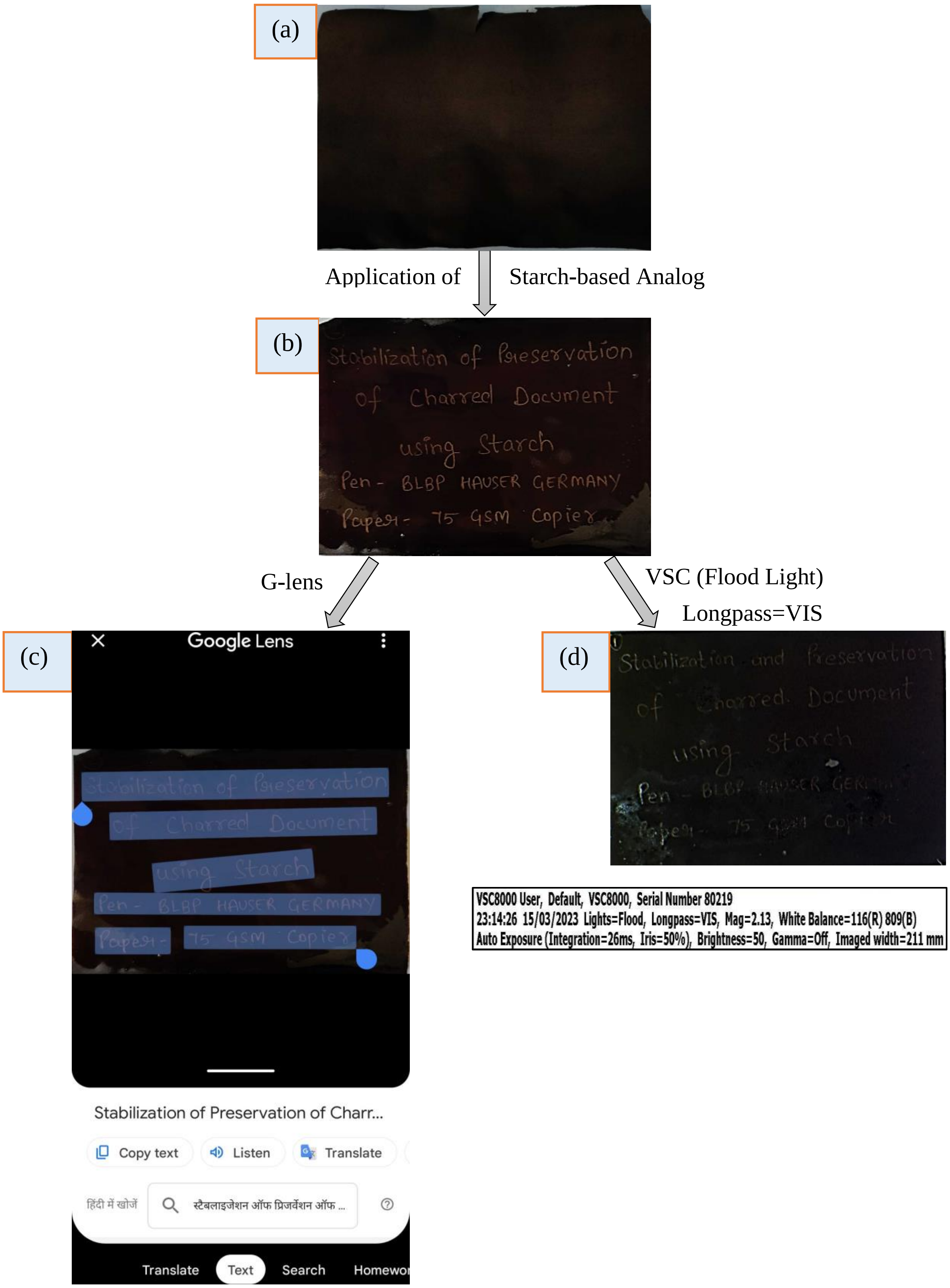



**Figure 4.28: Shows BLBP Hauser Germany on 75 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

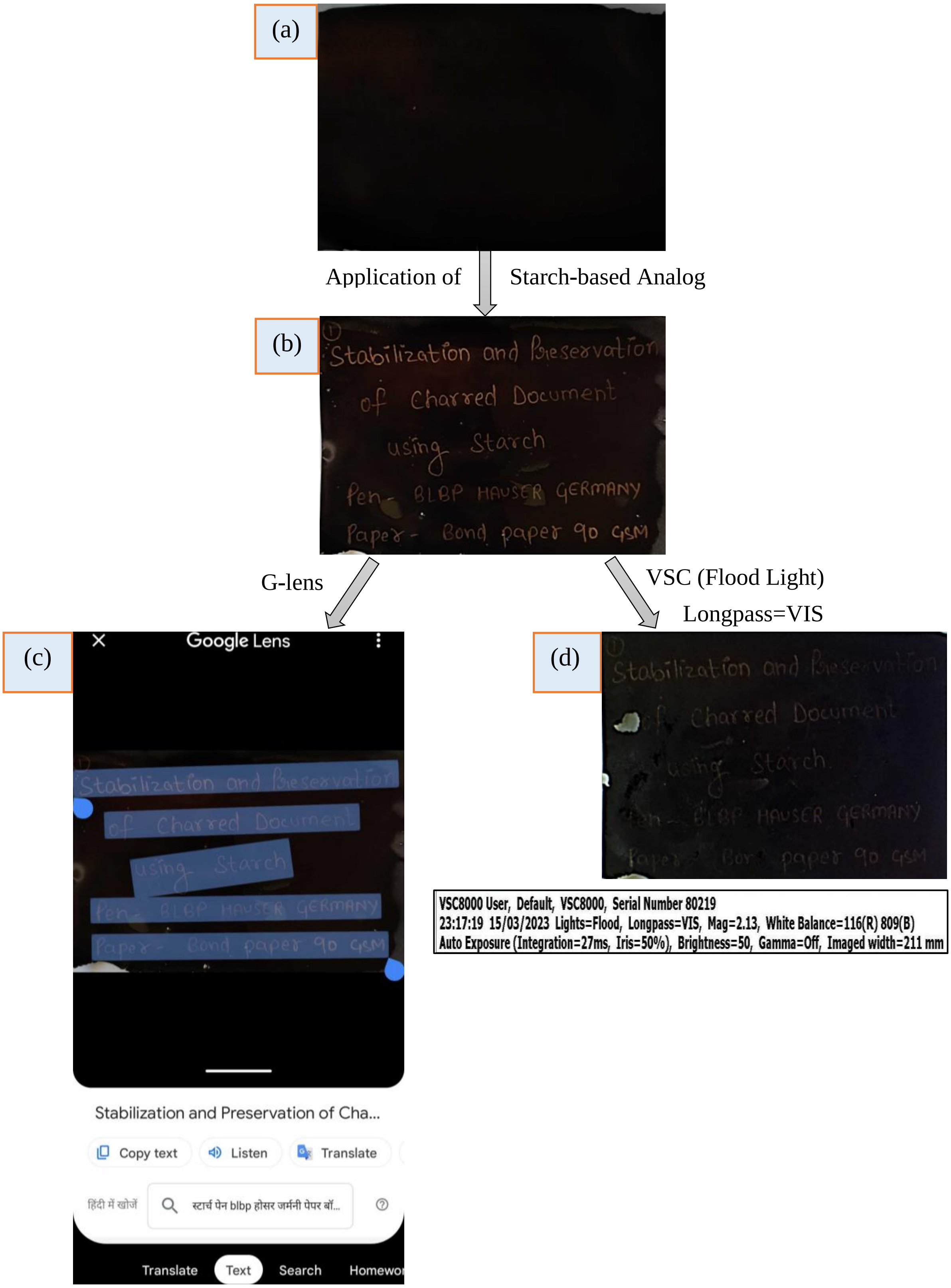



**Figure 4.29: Shows BLBP Hauser Germany on 90 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

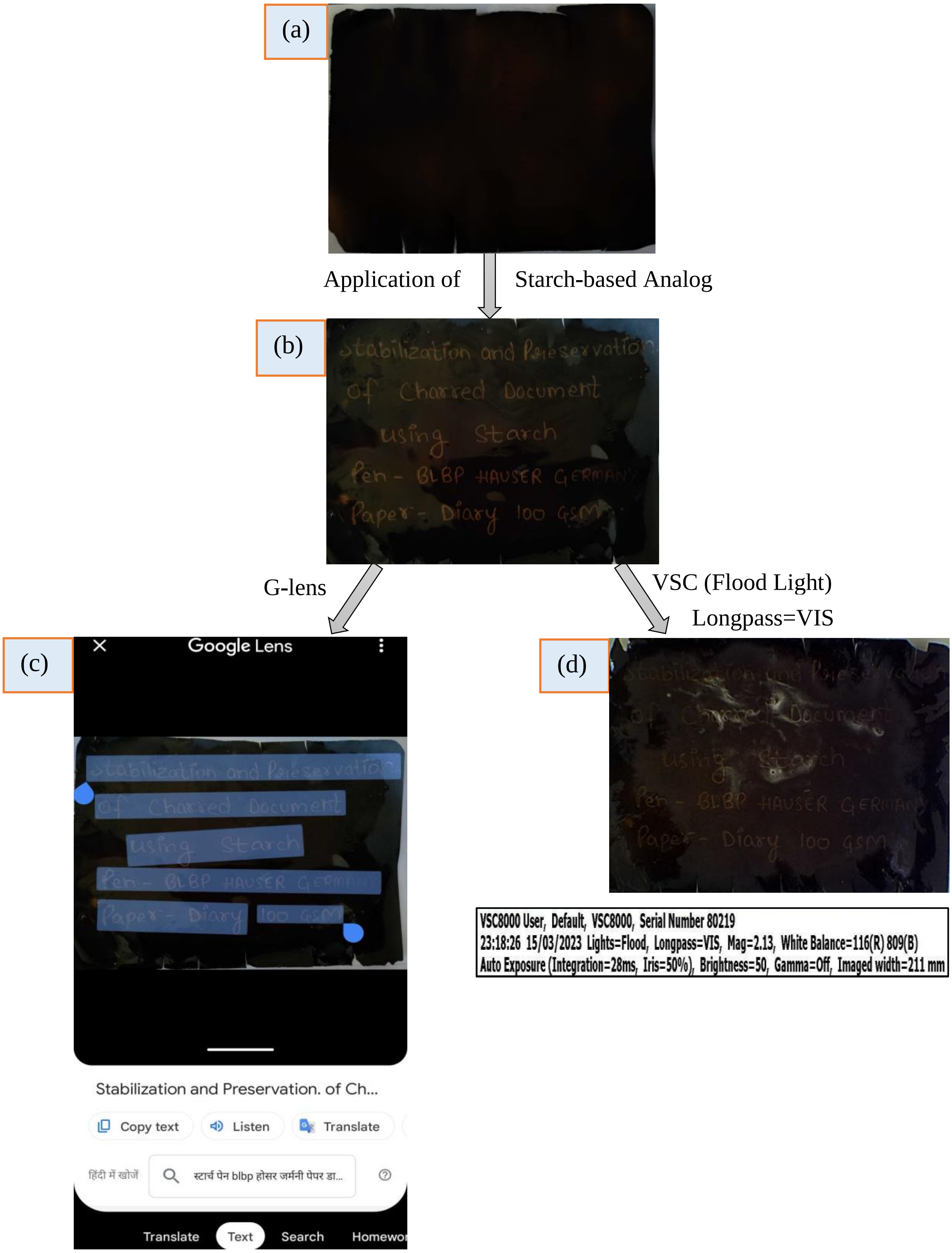



**Figure 4.30: Shows BLBP Hauser Germany on 100 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.8. Stabilization and Decipherment of Documents made with Red Ballpoint Pen Inks

This section shows the decipherment of texts written with three types of Red ballpoint pen (RBP), viz. Linc Pentonic, Elkos Better, and Hauser Germany pen on 75 gsm, 90 gsm, and 100 gsm papers.

#### 4.8.1. Linc Pentonic Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

The initial charring process of documents showed that the texts were invisible to the naked eye. However, applying the starch-based analog coating effectively deciphered the visibility of the hidden text. In all three combinations (Figures 4.31-4.33) made on 75 gsm paper, 90 gsm, and 100 gsm paper, the charred texts showed a high level of legibility after the stabilization process using starch-based analog. The starch-based analog provided a uniform and transparent layer, enabling clear visualization of the underlying text. Moreover, the starch-based analog significantly reduced the impact of charring, resulting in highly legible, easily interpretable text and easy handling of documents. This can be due to the colour contrast of red ballpoint ink and the dyes present in its composition, which reacted with the starch-based analog and produced a high contrast with the background, thus revealing the invisible texts to the naked eye. Furthermore, the G-lens also correctly recognized all the deciphered texts and gave 100% decipherment, as shown in Table 4.29. After a month, the VSC analysis of all three combinations also revealed all the texts successfully under flood light in the visible range.

**Table 4.29: Showing the Percentage of Correctly Recognized Characters of RBP Linc Pentonic pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **19** | RBP Linc Pentonic+75 gsm | Stabilization and Preservation of Charred Document using Starch | 56/56 | 100 |
| **20** | RBP Linc Pentonic+90 gsm | Stabilization and Preservation of Charred Document using Starch | 56/56 | 100 |
| **21** | RBP Linc Pentonic+100 gsm | Stabilization and Preservation of Charred Document using Starch | 56/56 | 100 |

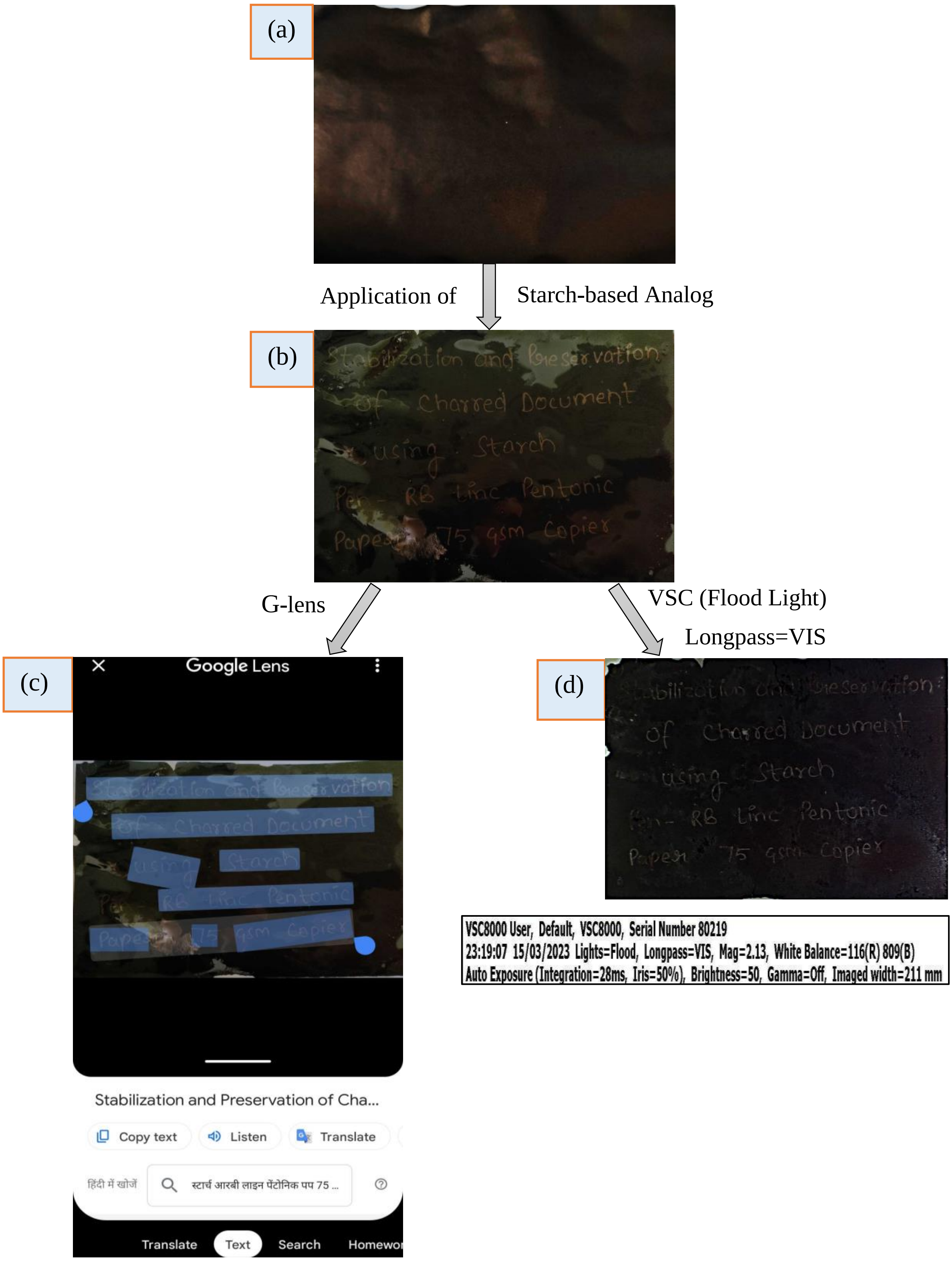



**Figure 4.31: Shows RBP Linc Pentonic on 75 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

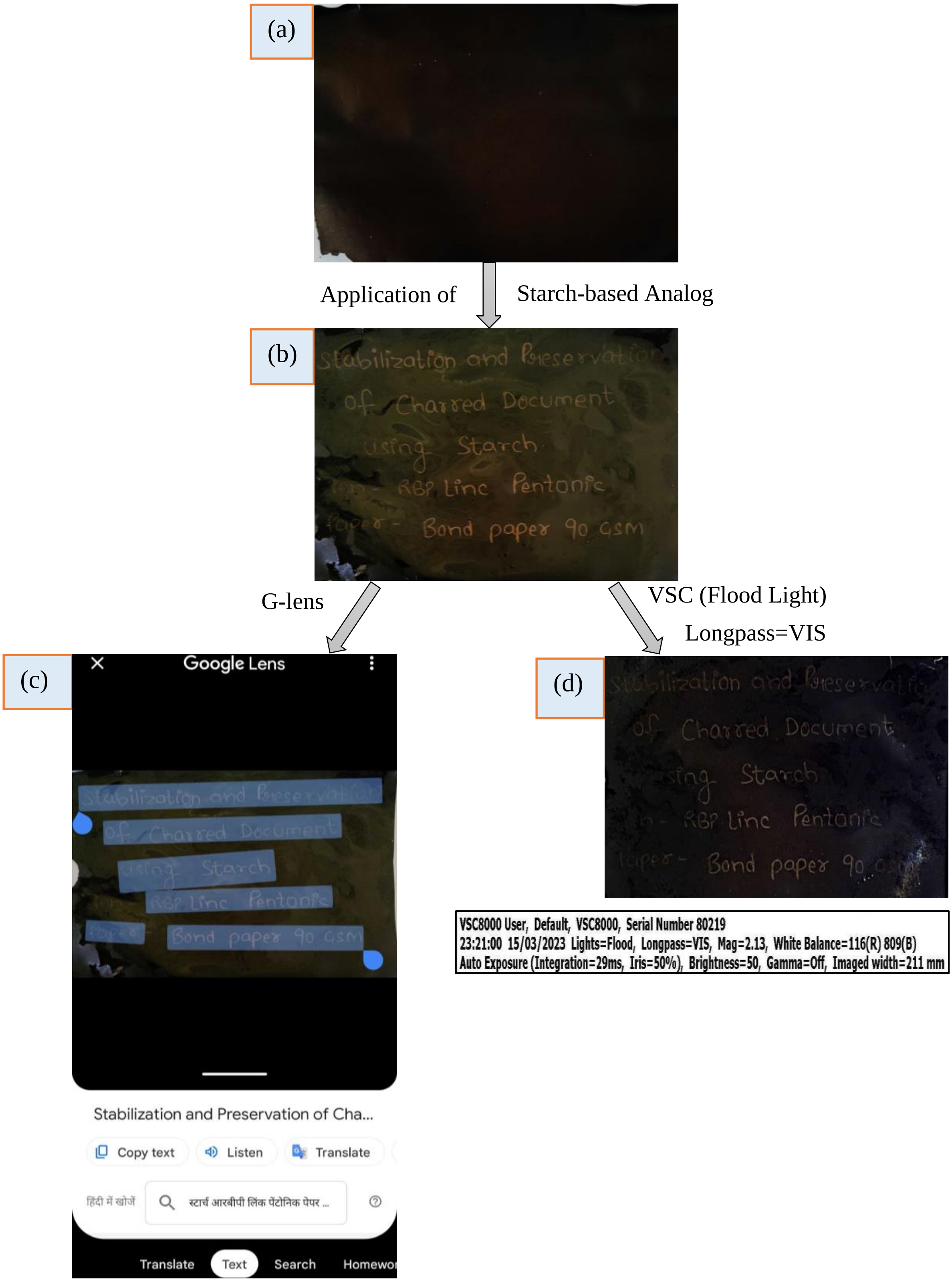



**Figure 4.32: Shows RBP Linc Pentonic on 90 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

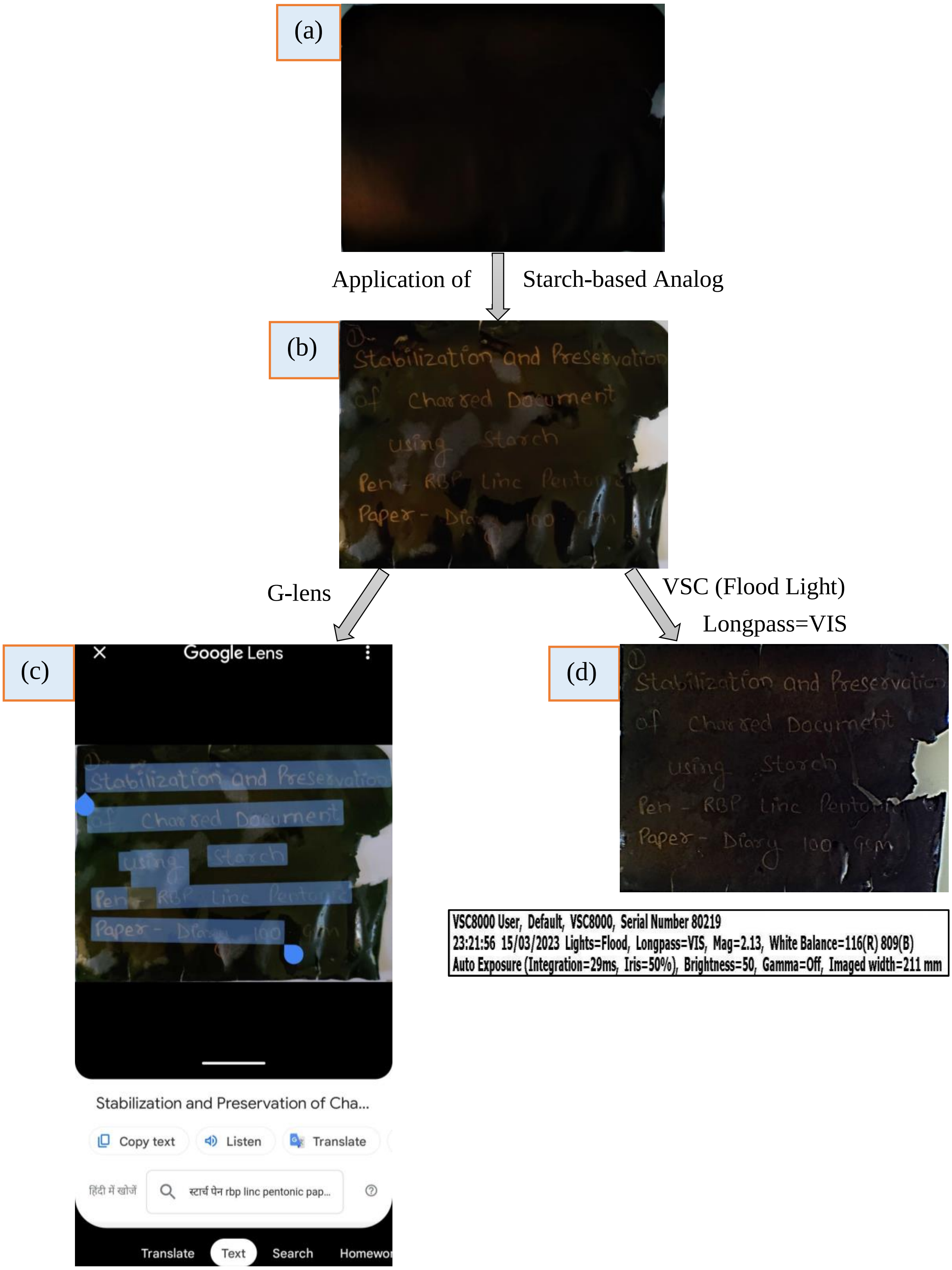



**Figure 4.33: Shows RBP Linc Pentonic on 100 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

#### 4.8.2. Elkos Better Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

The below combinations-22, 23, and 24, made with RBP Elkos Better pen inks on three paper types, show that, in 90 gsm bond paper and 100 gsm diary paper, after coating with starch-based analog for their stabilization, the majority of the texts got successfully deciphered and were visible to the naked eye (Figure 4.34-4.35). The G-lens also recognized more than 80% of the texts correctly. Whereas, in 75 gsm copier paper, texts got deciphered but were faintly visible to the naked eye (Figure 4.34 b), which on analyzing through G-lens, recognized more than 55% of the texts, as shown in Table 4.30. Furthermore, analyzing coated samples under VSC after approximately a month also successfully deciphered the texts under white spot and flood light, which fainted due to the passage of time.

The successful decipherment of the invisible texts after documents getting charred can be attributed to the combination of the charring process, paper type, i.e., gram per square meter, and the application of the starch-based analog coating. The charring process caused by different temperatures played a crucial role in rendering the text invisible, while the starch-based analog coating helped mitigate the damage caused by the charring process, thus deciphering the invisible texts.

**Table 4.30: Showing the Percentage of Correctly Recognized Characters of RBP Elkos Better pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **22** | RBP Elkos Better+75 gsm | stabilization and eservation Chared | 32/56 | 57 |
| **23** | RBP Elkos Better+90 gsm | Stabilization and reservation Charred Document Starch | 48/56 | 86 |
| **24** | RBP Elkos Better+100 gsm | Stabil and Preservation Charred Document using Starch | 46/56 | 82 |

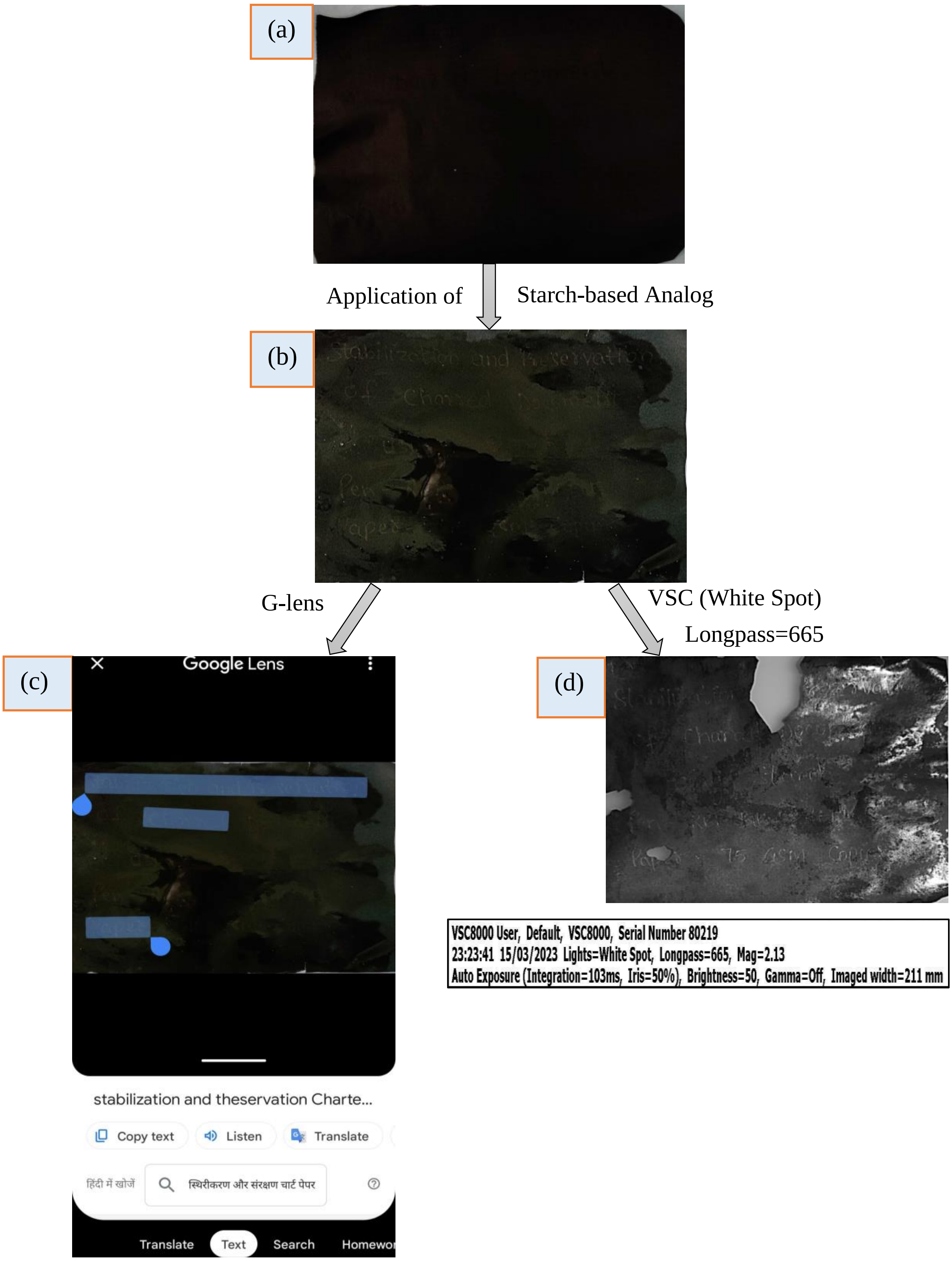



**Figure 4.34: Shows RBP Elkos Better on 75 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

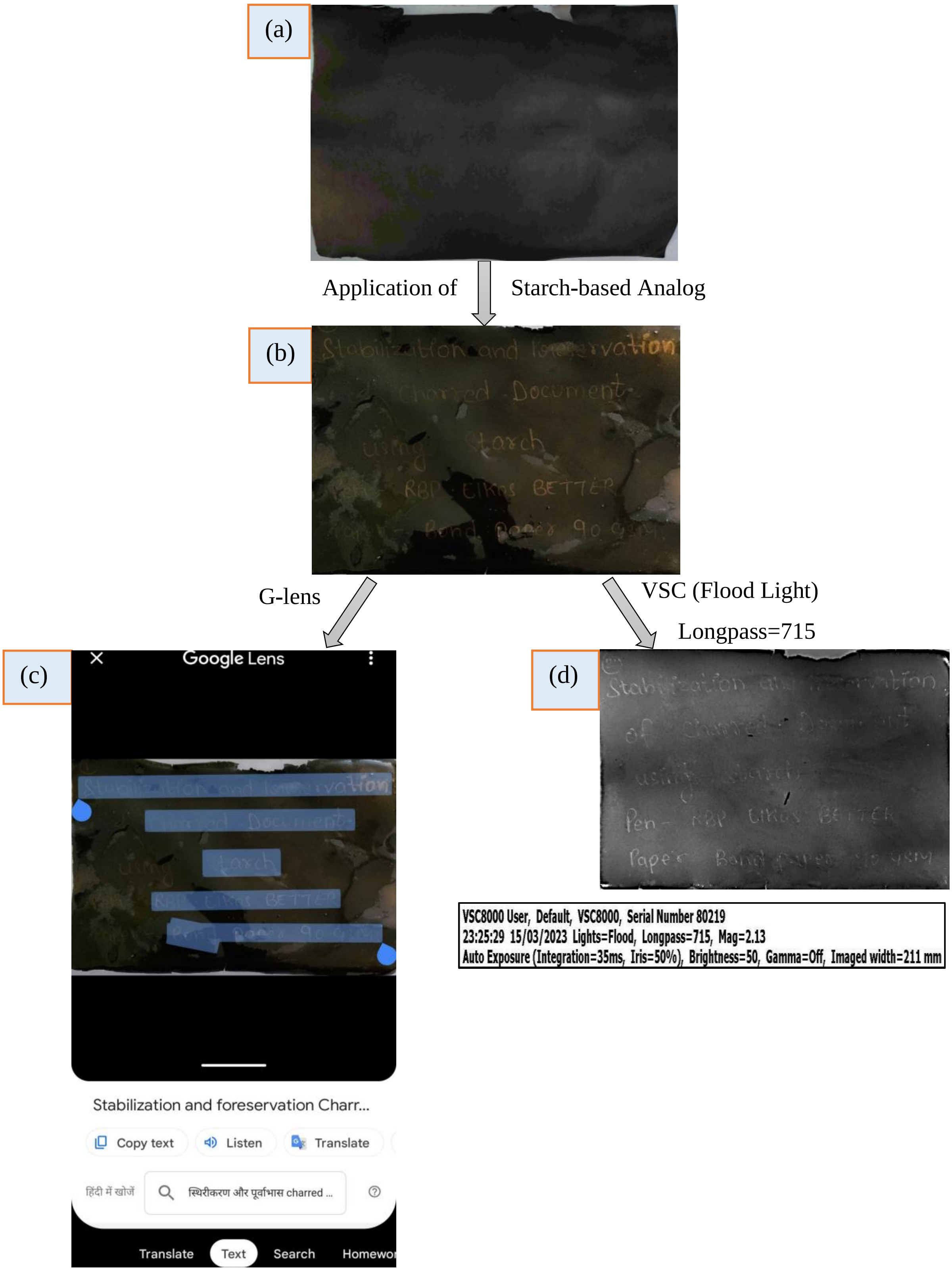



**Figure 4.35: Shows RBP Elkos Better on 90 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

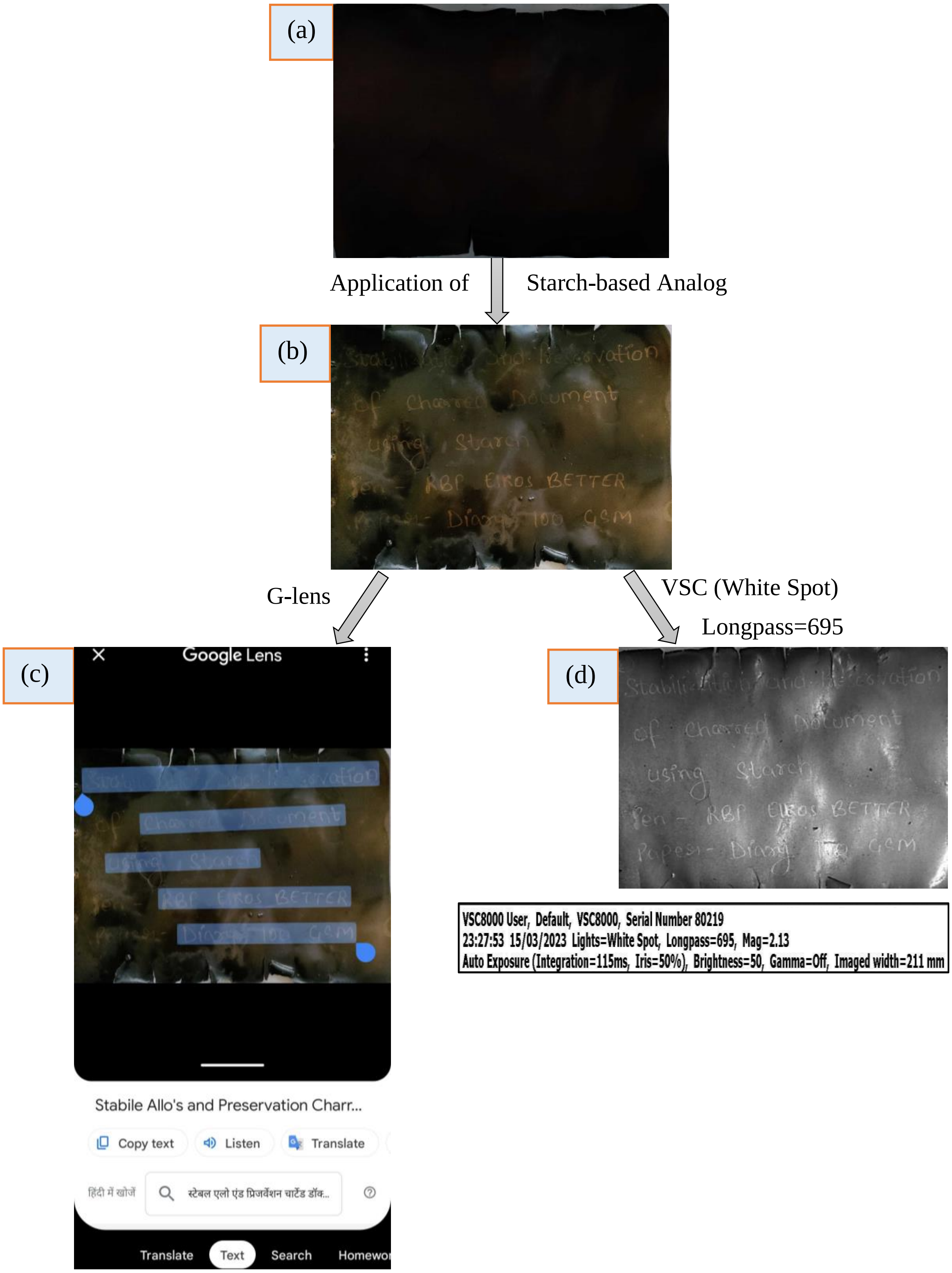



**Figure 4.36: Shows RBP Elkos Better on 100 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.8.3. Hauser Germany Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

Similarly, documents made with Red Hauser Germany on 75 gsm, 90 gsm, and 100 gsm paper showed that the documents at their maximum charring state were fragile and had invisible texts, which on stabilization with starch-based analog gave promising results. In all three combinations, the majority of the texts got successfully deciphered as soon after the starch-based analog was applied to the charred surface and were visible to the naked eye (Figures 4.37-4.39). However, further analysis through G-lens, in combination-25 (RBP Hauser+75 gsm) and combination-27 (RBP Hauser+100 gsm), all the characters got correctly recognized, whereas in combination-26 (RBP Hauser+90 gsm), few characters got incorrectly recognized, as shown in Table 4.31. This may be due to the way of writing the alphabet in a fast mode. The OCR algorithm in google lens searched and analyzed the captured images and converted them into readable and copiable texts format. This technique proved to be effective in deciphering legible characters, enhancing the visibility of the text, and generating digital transcriptions for further analysis. The successful decipherment in the case of RBP pen may account because of the composition of red inks and the dyes present in it. The red ballpoint ink residue contrasts with the background when coated with the starch-based analog, from which the starch bound, thus revealing the hidden or invisible texts on the charred documents. Further, on subsequent analysis under VSC after about a month, the texts were successfully deciphered in combination-25 under flood light at 715 longpass, and in combination-26 and 27 under white spot light at 715 longpass.

**Table 4.31: Showing the Percentage of Correctly Recognized Characters of RBP Hauser Germany pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **25** | RBP Hauser Gemany+75 gsm | Stabilization and Preservation of Charred Document using Starch | 56/56 | 100 |
| **26** | RBP Hauser Gemany+90 gsm | Stabilization and Psevation Charred Document using Starch | 51/56 | 92 |
| **27** | RBP Hauser Gemany+100 gsm | Stabilization and Preservation of Charred Document using Starch | 56/56 | 100 |

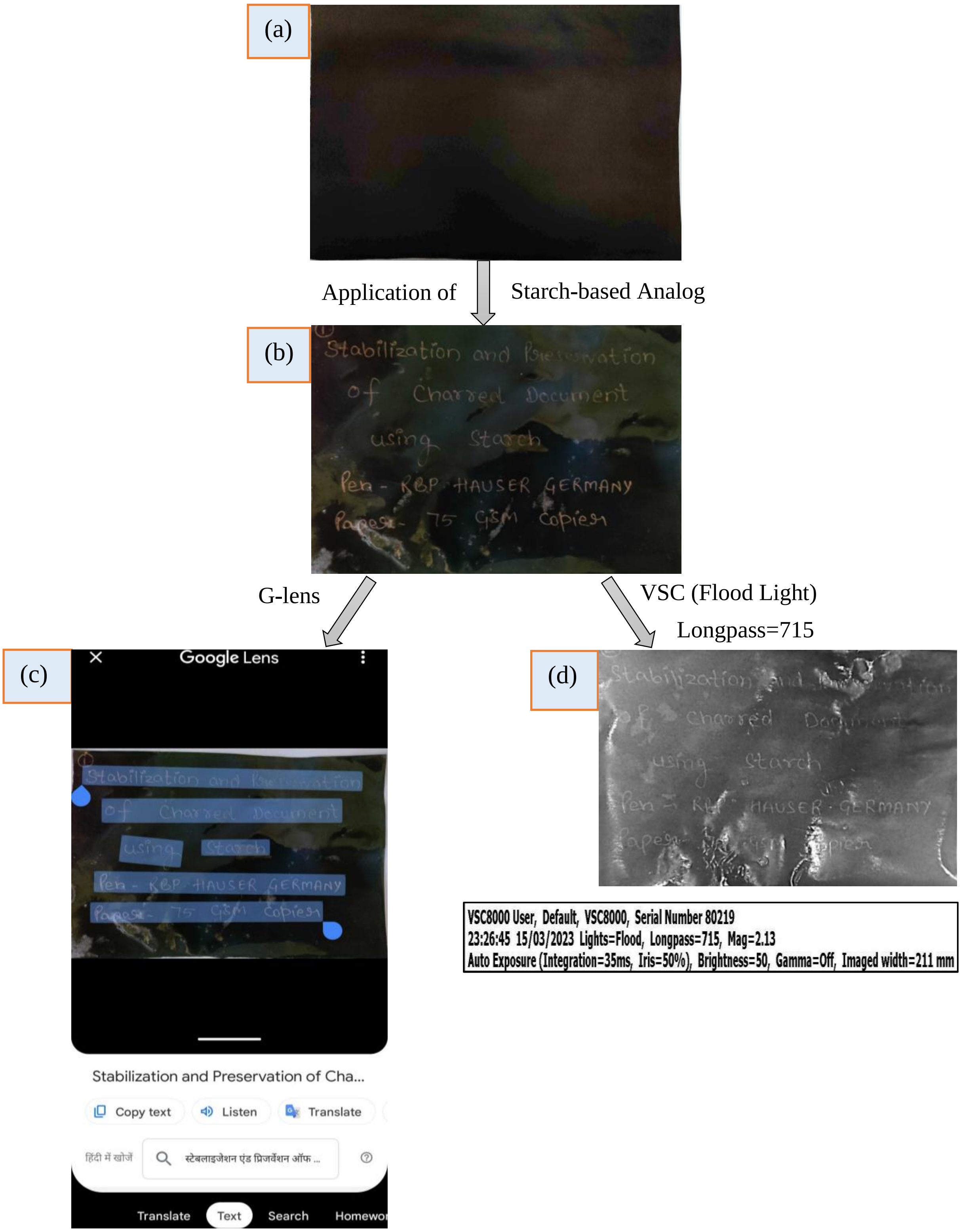



**Figure 4.37: Shows RBP Hauser Germany on 75 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

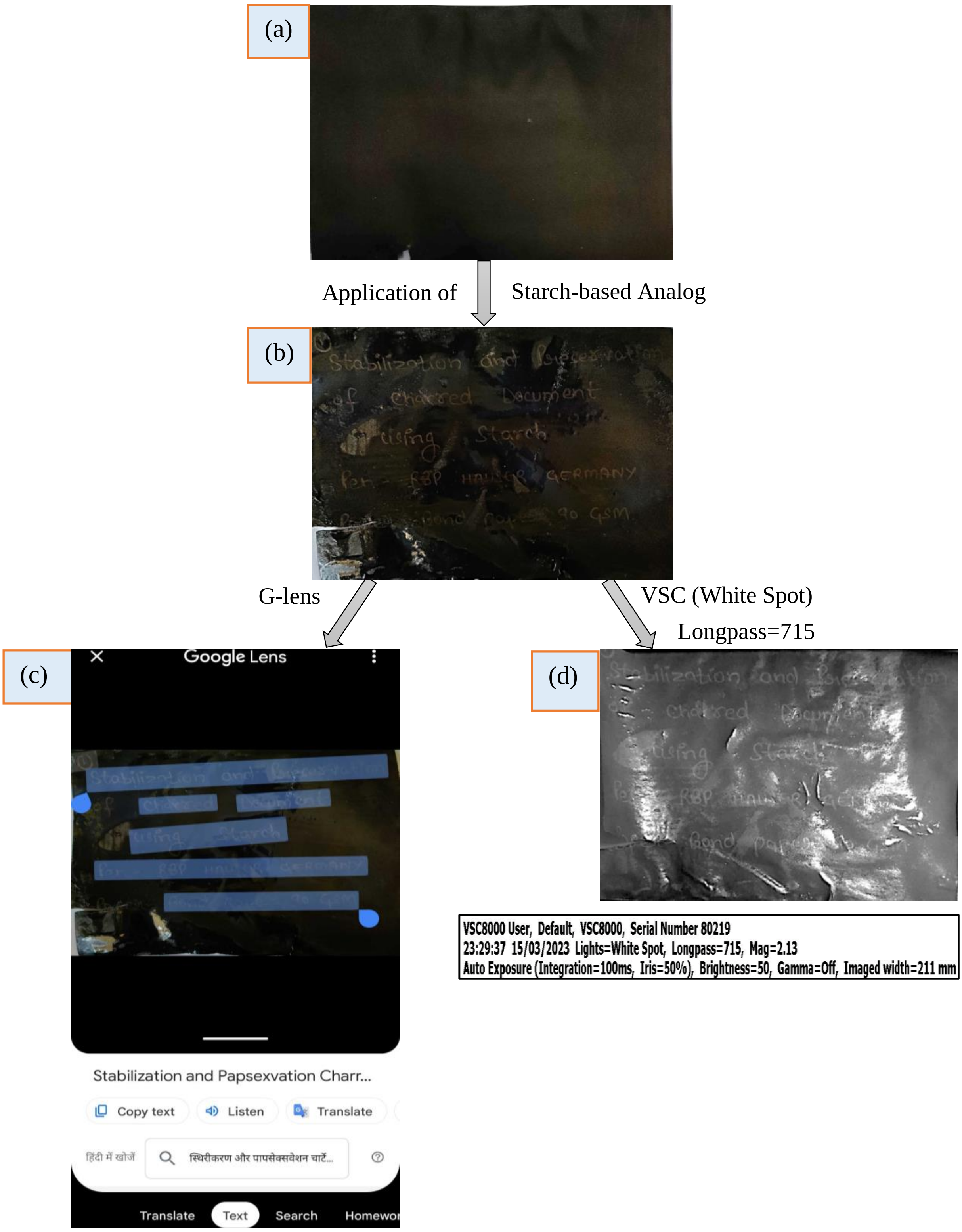



**Figure 4.38: Shows RBP Hauser Germany on 90 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

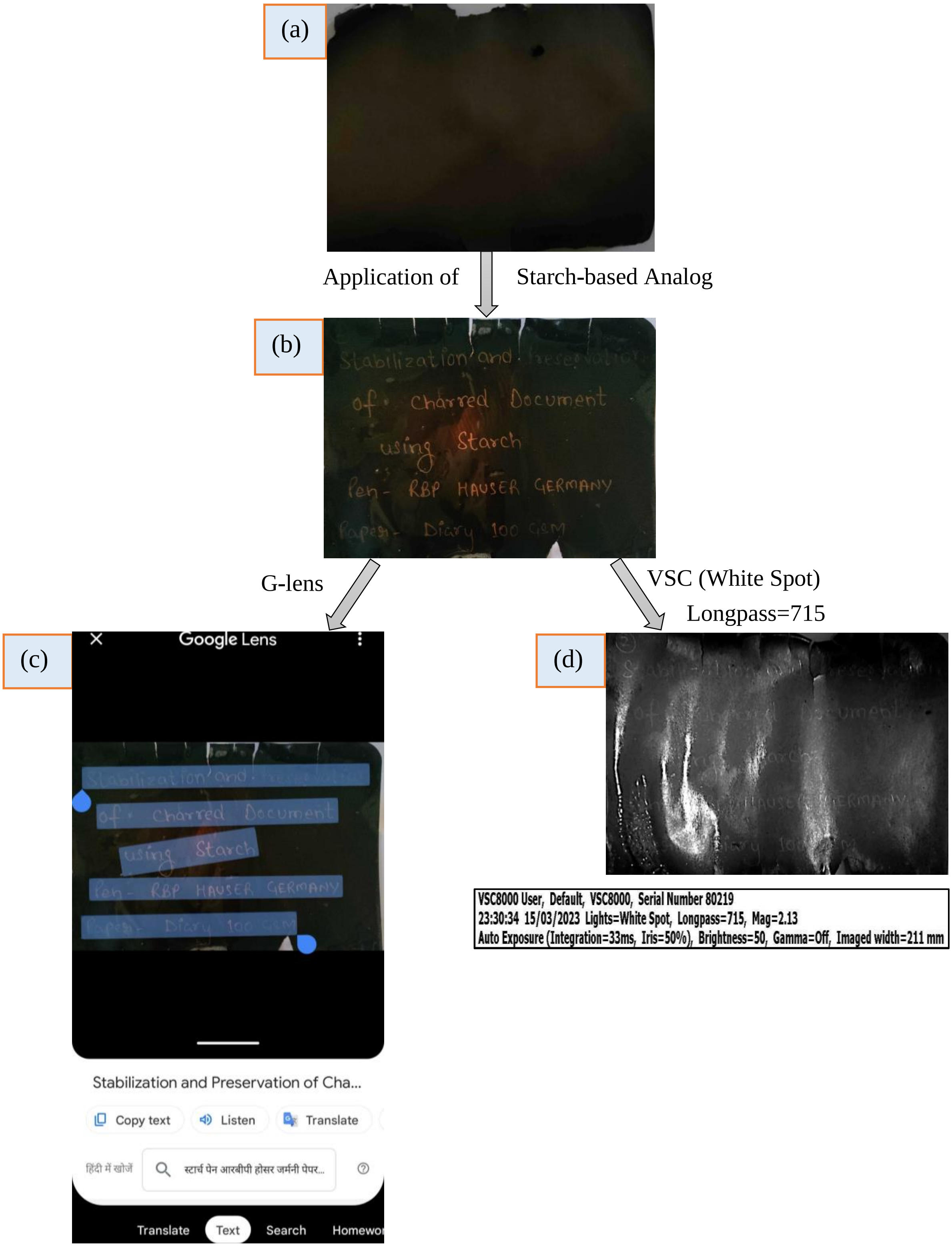



**Figure 4.39: Shows RBP Hauser Germany on 100 gsm, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.9. Stabilization and Decipherment of Documents made with Blue Gel Pen Inks

This section of the study shows the result and discussion of the charred documents made using Blue Gel pen inks of three different brands; Classmate octane, Flair glass, and Elkos magic on 75 gsm copier paper, 90 gsm bond paper, and 100 gsm diary paper.

#### 4.9.1. Classmate Octane Gel Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

The documents made with BG pen inks did not degrade text invisibility completely, even after charring at a high temperature of 300 ºC and above. This may be due to the formulation of water-based ink in a gel form that is resistant to elevated temperatures. Moreover, gel-based inks penetrate to absorb the paper substrate more effectively compared to ballpoint inks. Due to high temperatures, the document becomes fragile; therefore, after stabilization using starch-based analog, the faintly and incompletely visible texts became visible to the naked eye. The G-lens also correctly recognized most of the deciphered texts and converted them into a copiable text format. The percentage of correctly deciphered characters by G-lens is shown in Table 4.32. In the stabilized documents, the deciphered texts were becoming faded by losing their intensity with each passing day. Therefore, when analyzed under VSC after a month, the texts could not be completely deciphered in 75 gsm paper (combination-28) under white spot light at 780 longpass (Figure 4.40 d), whereas 90 gsm (combination-29) and 100 gsm paper (combination-30) showed faint decipherment (Figure 4.41-4.42). This may be because of the thickness of paper types, which facilitates ink absorption and disintegration due to charring.

**Table 4.32: Showing the Percentage of Correctly Recognized Characters of BG Classmate Octane pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **28** | BG Classmate Octane+75 gsm | Stabilization reservation of Charred Document Using | 46/56 | 82 |
| **29** | BG Classmate Octane+90 gsm | abilization and Preservation Charred Document us Starch | 49/56 | 88 |
| **30** | BG Classmate Octane+100 gsm | Stabilization and Reservation of Charred Document using Starch | 54/56 | 97 |

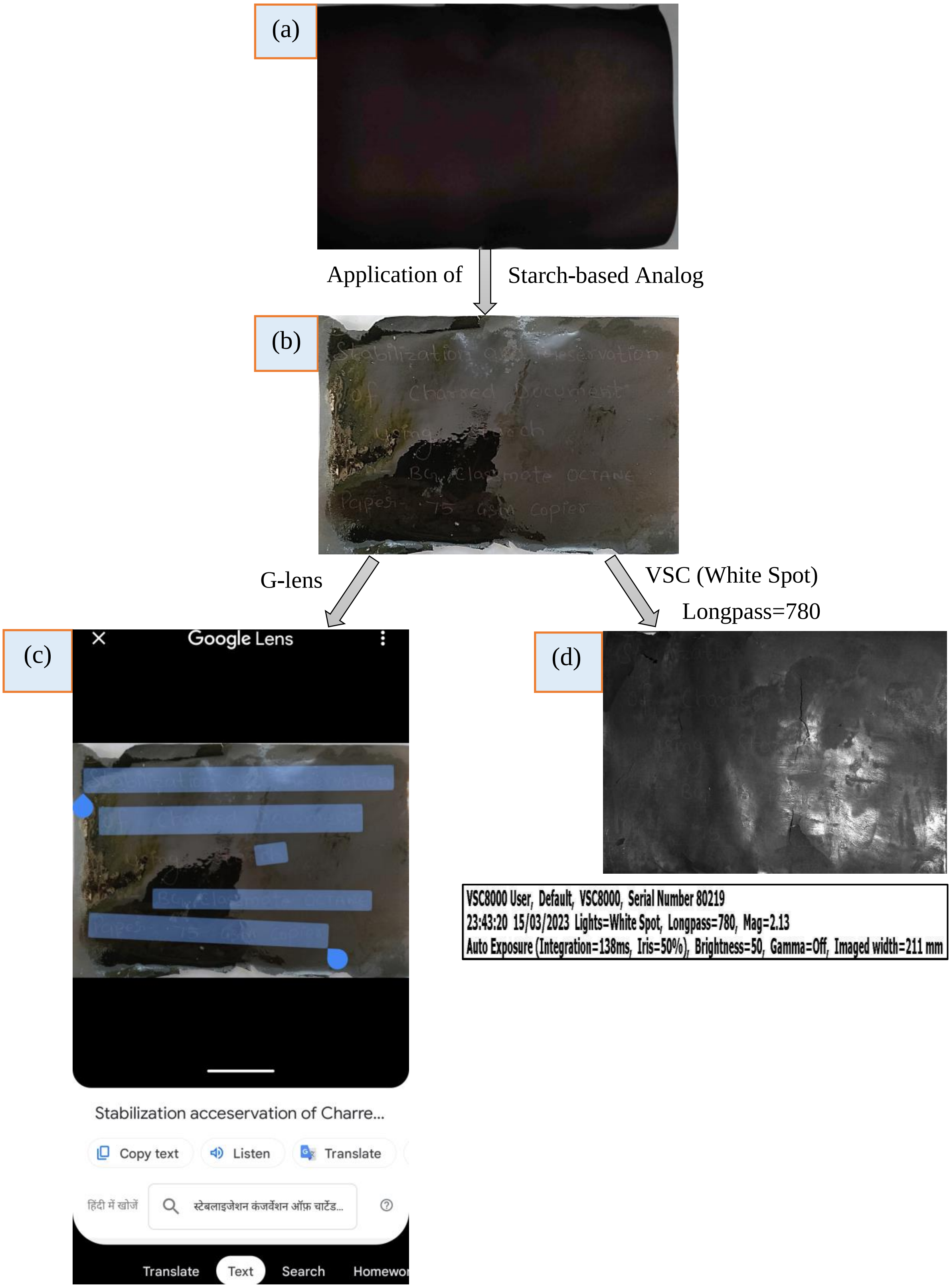



**Figure 4.40: Shows BG Classmate Octane on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

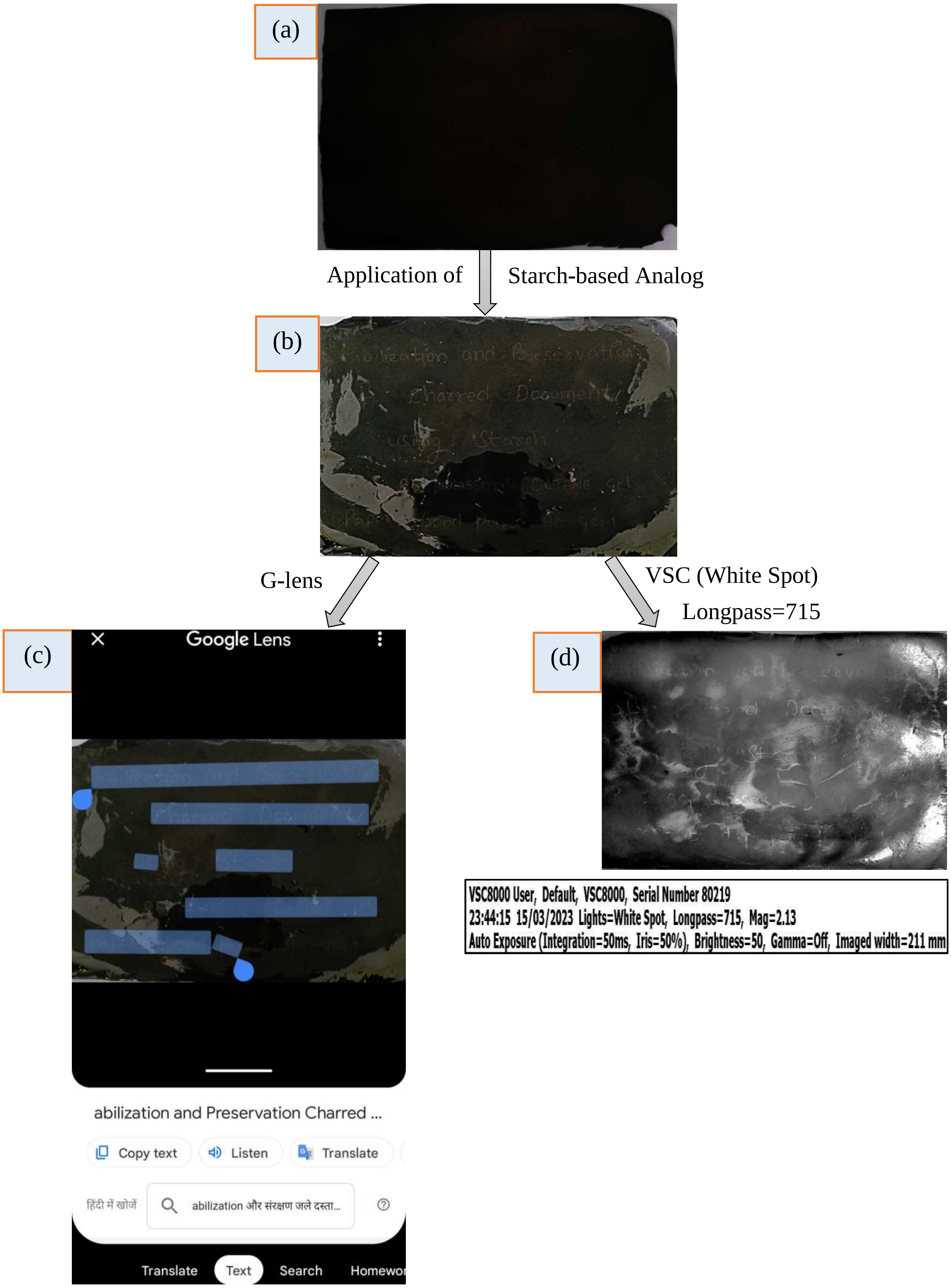



**Figure 4.41: Shows BG Classmate Octane on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

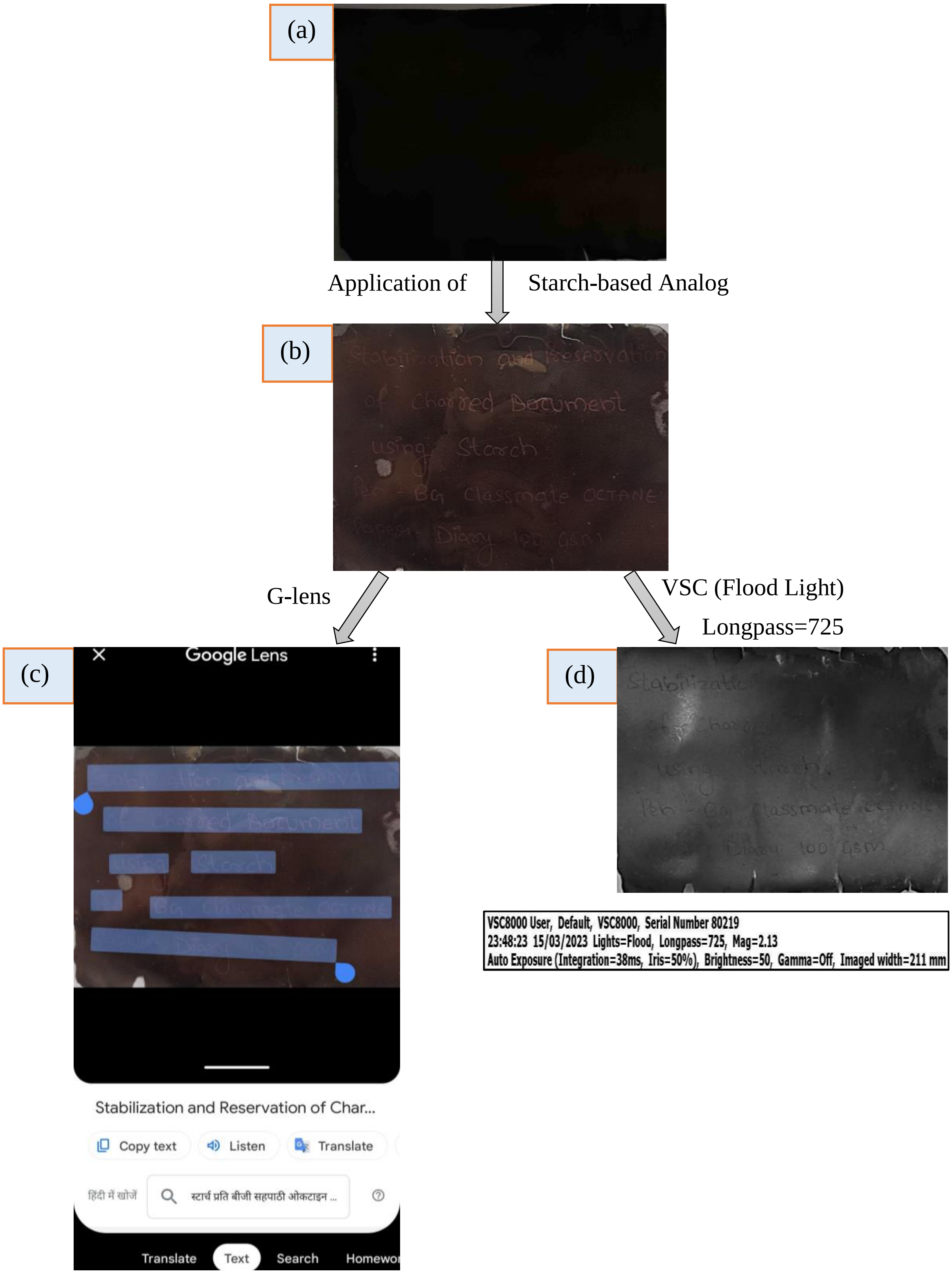



**Figure 4.42: Shows BG Classmate Octane on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.9.2. Flair Glass Gel Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

Similarly, the documents made with Flair Glass BG pen inks on 75 gsm, 90 gsm, and 100 gsm paper show that after charring the documents to their maximum charring state that can be handled with care, gel inks did not get completely disappear, instead it sustained at the surface at some areas. As discussed earlier, this is because of the ink formulation of gel pen inks. However, due to charring, the document became extremely fragile. Therefore, the documents were stabilized using a starch-based analog. Applying the analog over charred documents, the gel pen inks did not show appreciable decipherment; instead, the texts were faintly legible (Figures 4.43-4.45). Furthermore, when the captured image of the coated document was subjected to the OCR tool using G-lens, it only recognized a few correct characters, as shown in Table 4.33.

Furthermore, the VSC analysis was conducted to decipher the complete statement on the coated charred documents. The analysis revealed that the ink on 75 gsm paper (combination-31) was faintly deciphered under flood light at 725 longpass, as shown in Figure 4.43 (d), whereas in 90 gsm (combination-32) and 100 gsm paper (combination-33), the texts were deciphered to an appreciable level under white spot and flood light at 645 longpass, respectively, as shown in Figure 4.44 (d)-4.45 (d).

**Table 4.33: Showing the Percentage of Correctly Recognized Characters of BG Flair Glass pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **31** | BG Flair Glass+75 gsm | bilization and Starch | 19/56 | 34 |
| **32** | BG Flair Glass+90 gsm | stabilization and re Charred Documen | 33/56 | 59 |
| **33** | BG Flair Glass+100 gsm | Chaed Do | 7/56 | 13 |

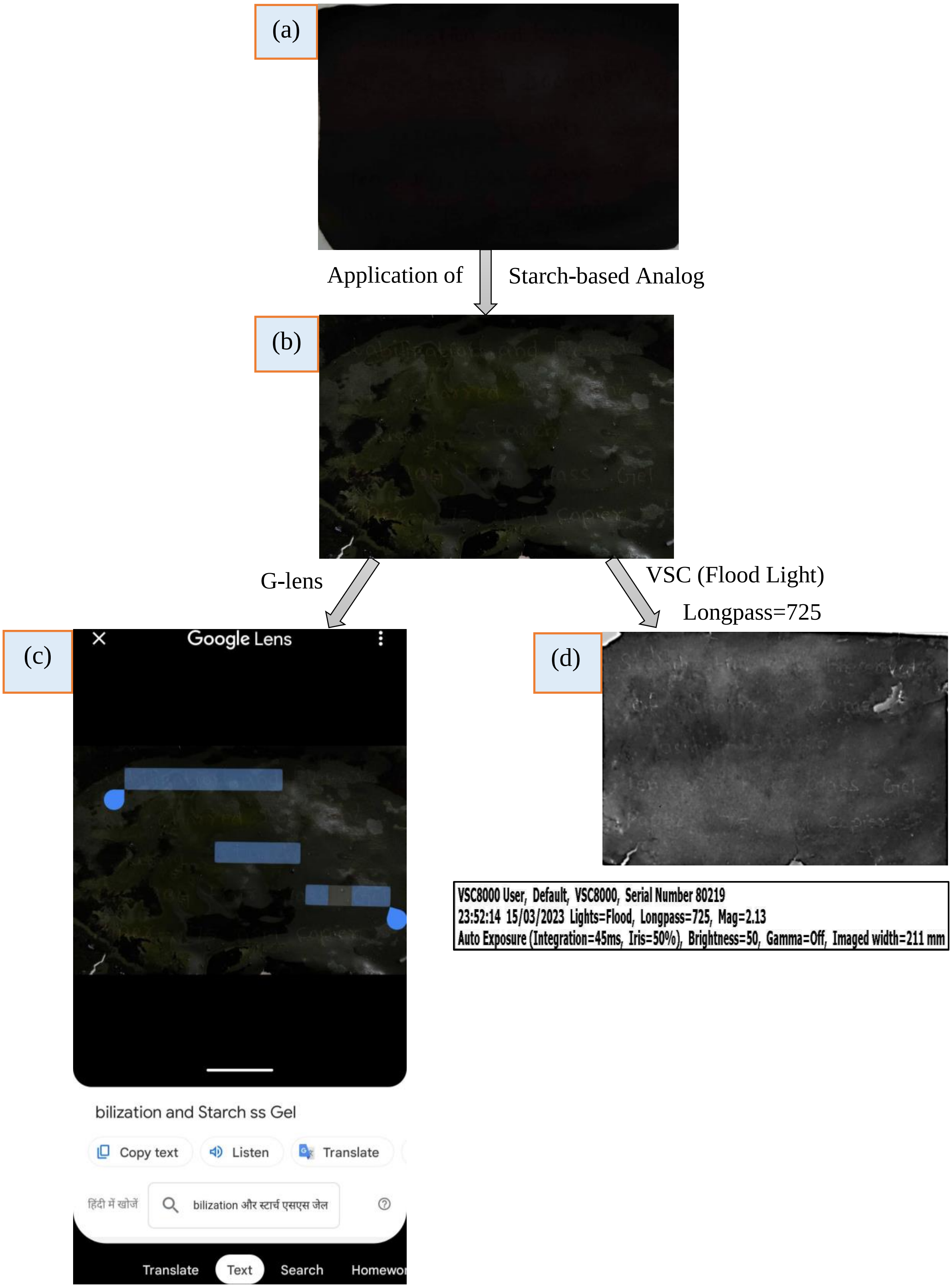



**Figure 4.43: Shows BG Flair Glass on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

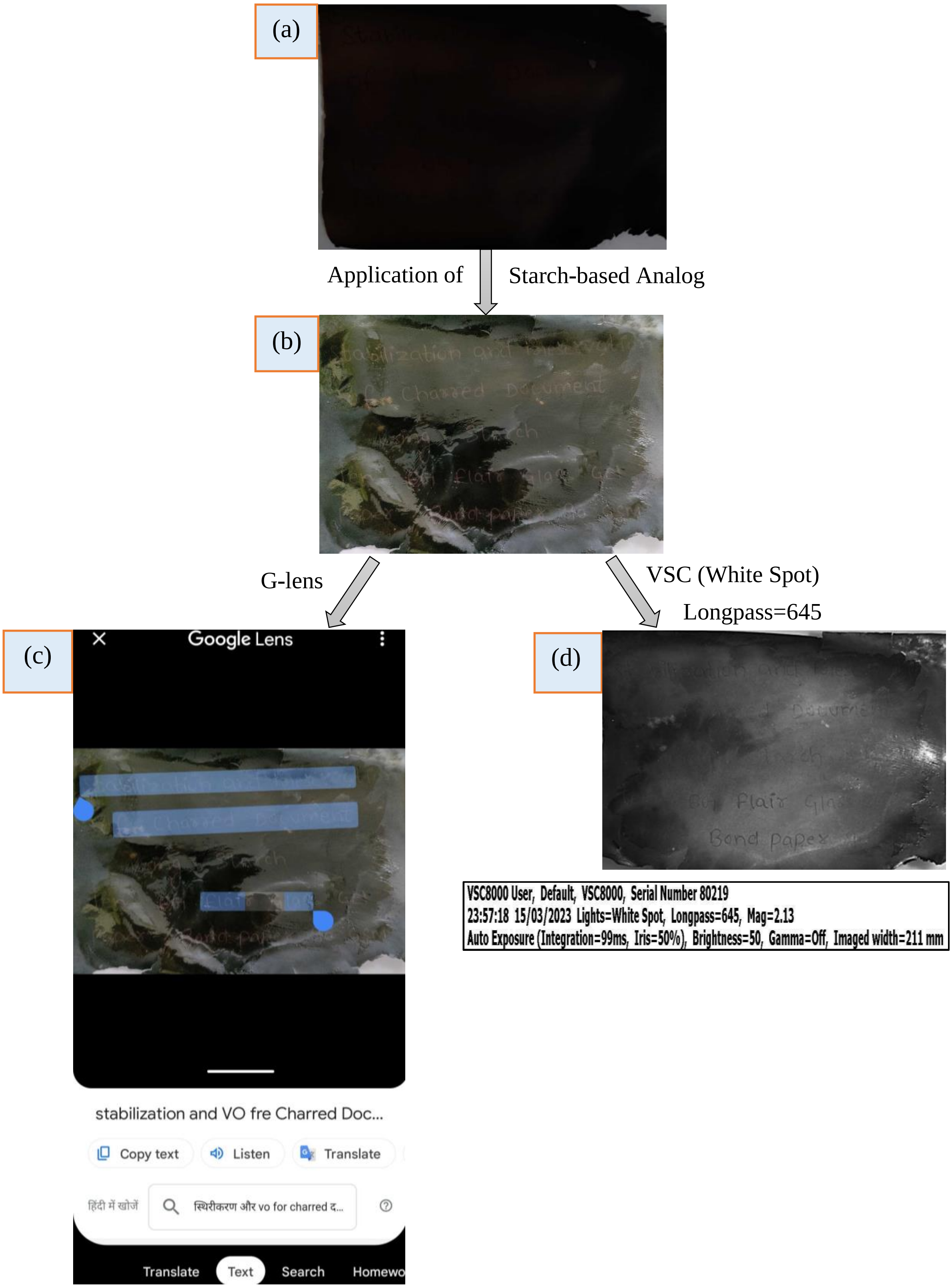



**Figure 4.44: Shows BG Flair Glass on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

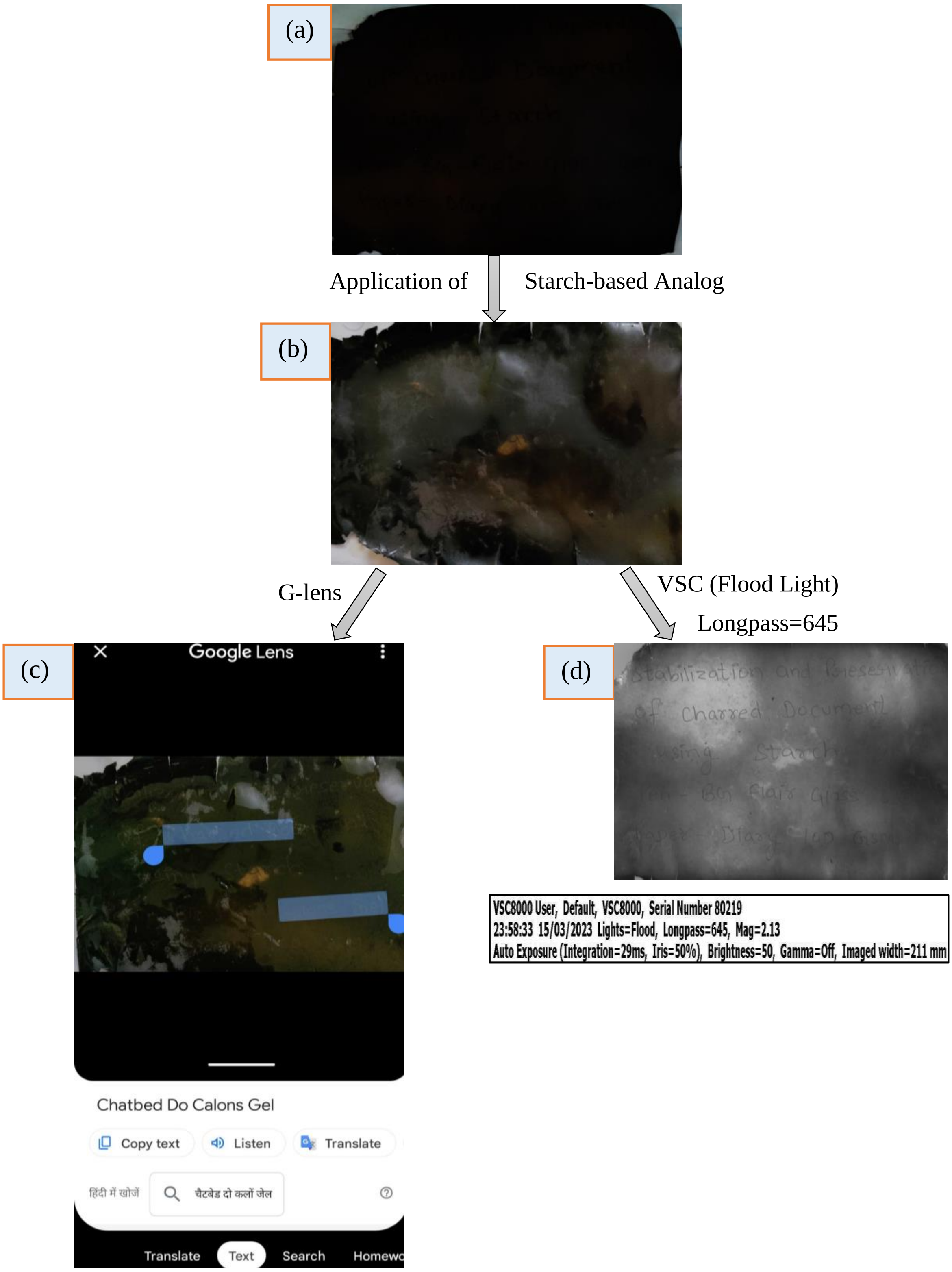



**Figure 4.45: Shows BG Flair Glass on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.9.3. Elkos Magic Gel Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

The documents made with Blue Elkos Magic gel pen inks on three types of paper showed that Elkos Magic pen ink, as the name suggests, actually works like that. Despite being a gel formulation, the ink disappeared or became invisible when the documents underwent a charring process at different temperatures according to the paper type and became fragile. So, after coating with starch-based analog, the documents became stabilized, and it was observed that no texts got revealed or deciphered in all three combinations made with BG Elkos Magic pen ink. This may be due to the ink formulations of Elkos Magic manufacturer. Gel inks often contain a combination of pigments, dyes, and gel-forming agents that may undergo chemical changes when exposed to high temperatures. These changes can result in irreversible damage to the ink, making it difficult or impossible to recover the original text that can be seen through the naked eye. Moreover, the OCR algorithm using G-lens also recognized no texts, as shown in Table 4.34.

Furthermore, the samples were visualized under VSC at varied light sources and wavelengths. In combination-34 (BG Elkos Magic+75 gsm) and combination-35 (BG Elkos Magic+90 gsm), very few texts were faintly visible under white spot light at 725 longpass and flood light at 725 longpass (Figures 4.46-4.47), whereas in combination-36 (BG Elkos Magic+100 gsm), the texts were clearly deciphered under flood light at 715 longpass (Figure 4.48). This may account for the paper thickness and the extent to which the ink disintegrated due to the charring process.

**Table 4.34: Showing the Percentage of Correctly Recognized Characters of BG Elkos Magic pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **34** | BG Elkos Magic+75 gsm | No text recognized | 0/56 | 0 |
| **35** | BG Elkos Magic+90 gsm | No text recognized | 0/56 | 0 |
| **36** | BG Elkos Magic+100 gsm | No text recognized | 0/56 | 0 |

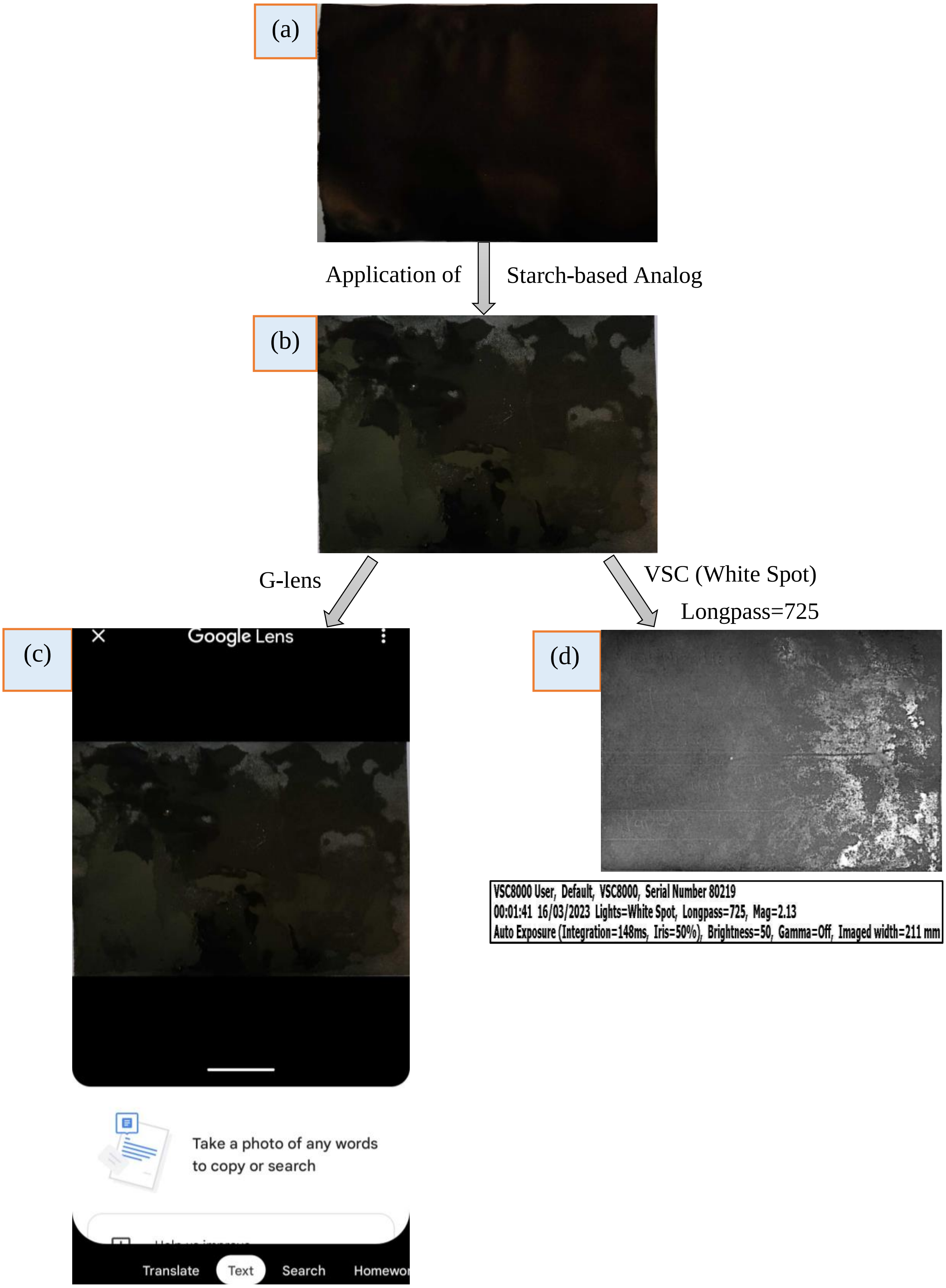



**Figure 4.46: Shows BG Elkos Magic on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

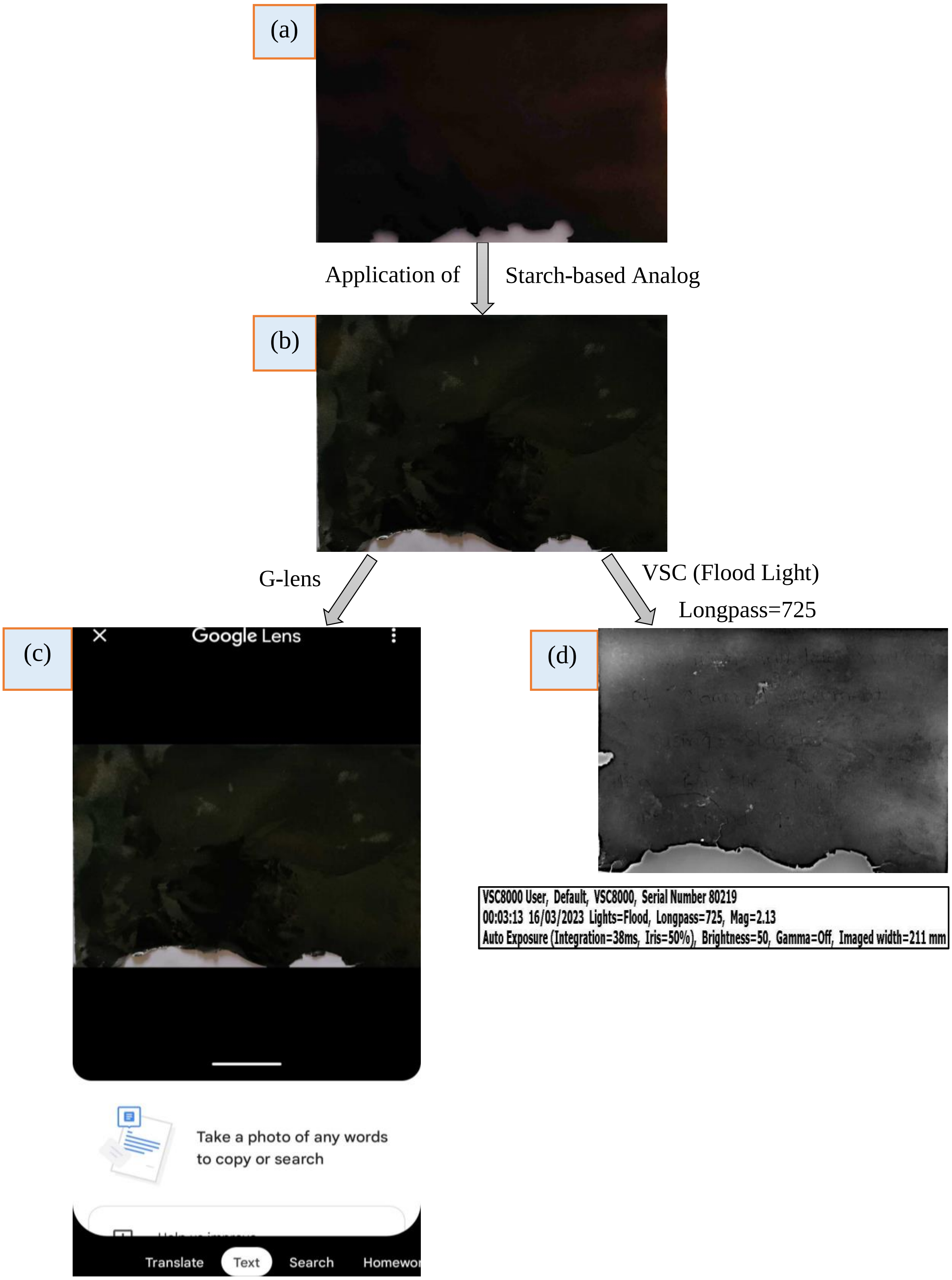



**Figure 4.47: Shows BG Elkos Magic on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

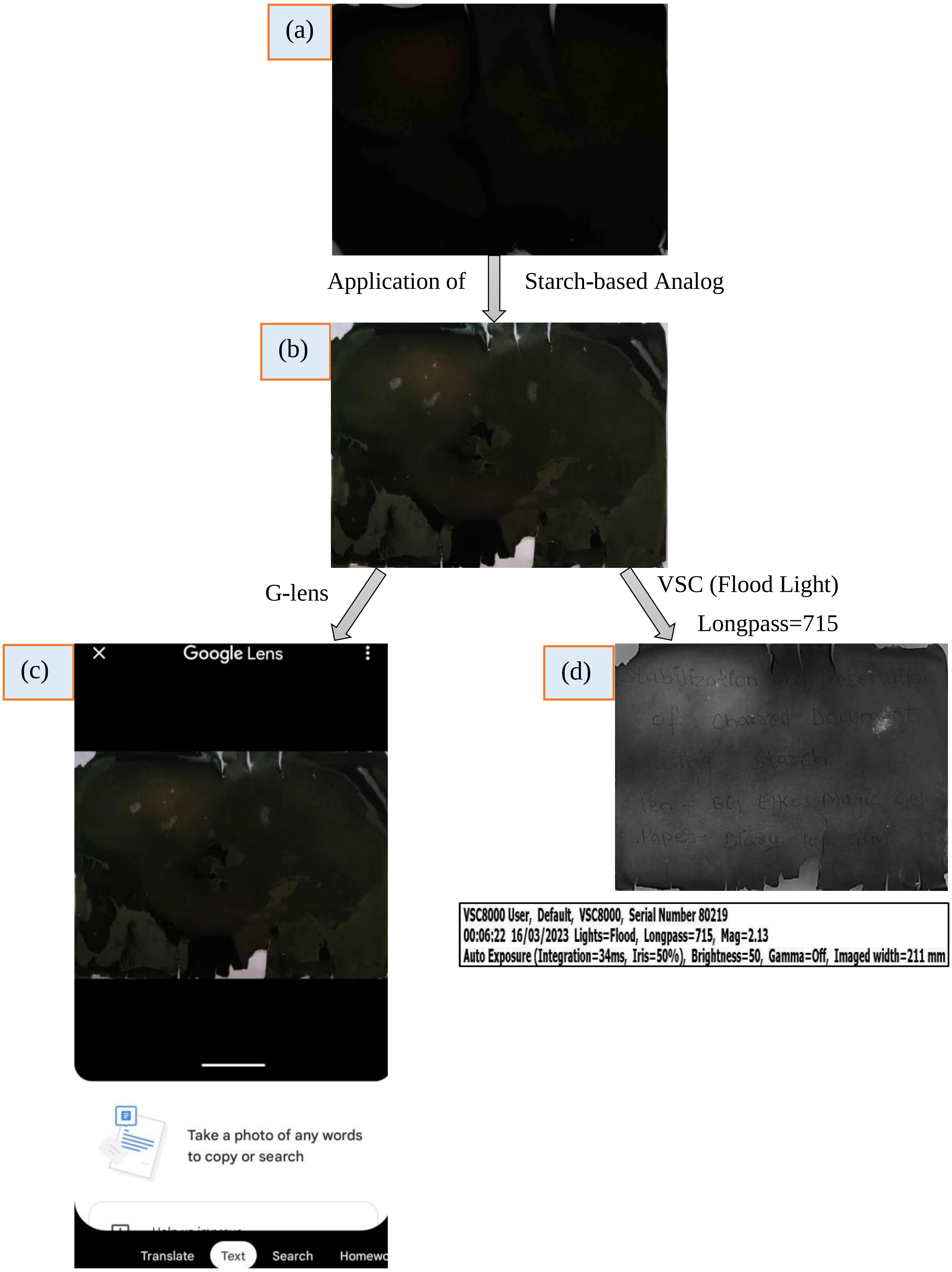



**Figure 4.48: Shows BG Elkos Magic on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.10. Stabilization and Decipherment of Documents made with Black Gel Pen Inks

This section shows the decipherment of charred documents made using Black gel pen ink of three different brands, viz., Classmate octane, Flair glass, and Elkos magic, on 75 gsm, 90 gsm, and 100 gsm paper.

#### 4.10.1. Classmate Octane Gel Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

After charring the documents made with BLG classmate pen ink, the texts became invisible in all three combinations and became fragile. Applying a starch-based analog for their stabilization and decipherment showed that the texts became visible to the naked eye as soon as the analog was applied over charred documents. The successful decipherment of texts can be due to the interaction of ink residue left even after charring of the documents with the starch-based analog. Starch acts as a binding agent, forming a temporary bond with the ink particles and enhancing their visibility. In addition, the OCR algorithm using G-lens also successfully recognized the deciphered texts to an appreciable extent. In combination-37 (BLG Classmate+75 gsm), the G-lens correctly recognized 98% of the deciphered characters of the statement, whereas, in combination-38 (BLG Classmate+90 gsm) and combination-39 (BLG Classmate+100 gsm), the tool recognized 91% and 88% of the characters correctly, as shown in Table 4.35. Furthermore, the VSC analysis of coated and stabilized charred documents was done after nearly 15 days to monitor the deciphered text sustainability, and it was observed that the texts were visible in combinations of 75 gsm under flood light at 645 longpass (Figure 4.49), whereas in 90 gsm and 100 gsm under flood light at 715 longpass (Figure 4.50-4.51).

**Table 4.35: Showing the Percentage of Correctly Recognized Characters of BLG Classmate Octane pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **37** | BLG Classmate Octane+75 gsm | Stabilization and Preservation of Charred Docment using Starch | 55/56 | 98 |
| **38** | BLG Classmate Octane+90 gsm | Stabilization and Preservatio of Ched Document sing Starch | 51/56 | 91 |
| **39** | BLG Classmate Octane+100 gsm | Stabilization and Preservation Charred Document Starch | 49/56 | 88 |

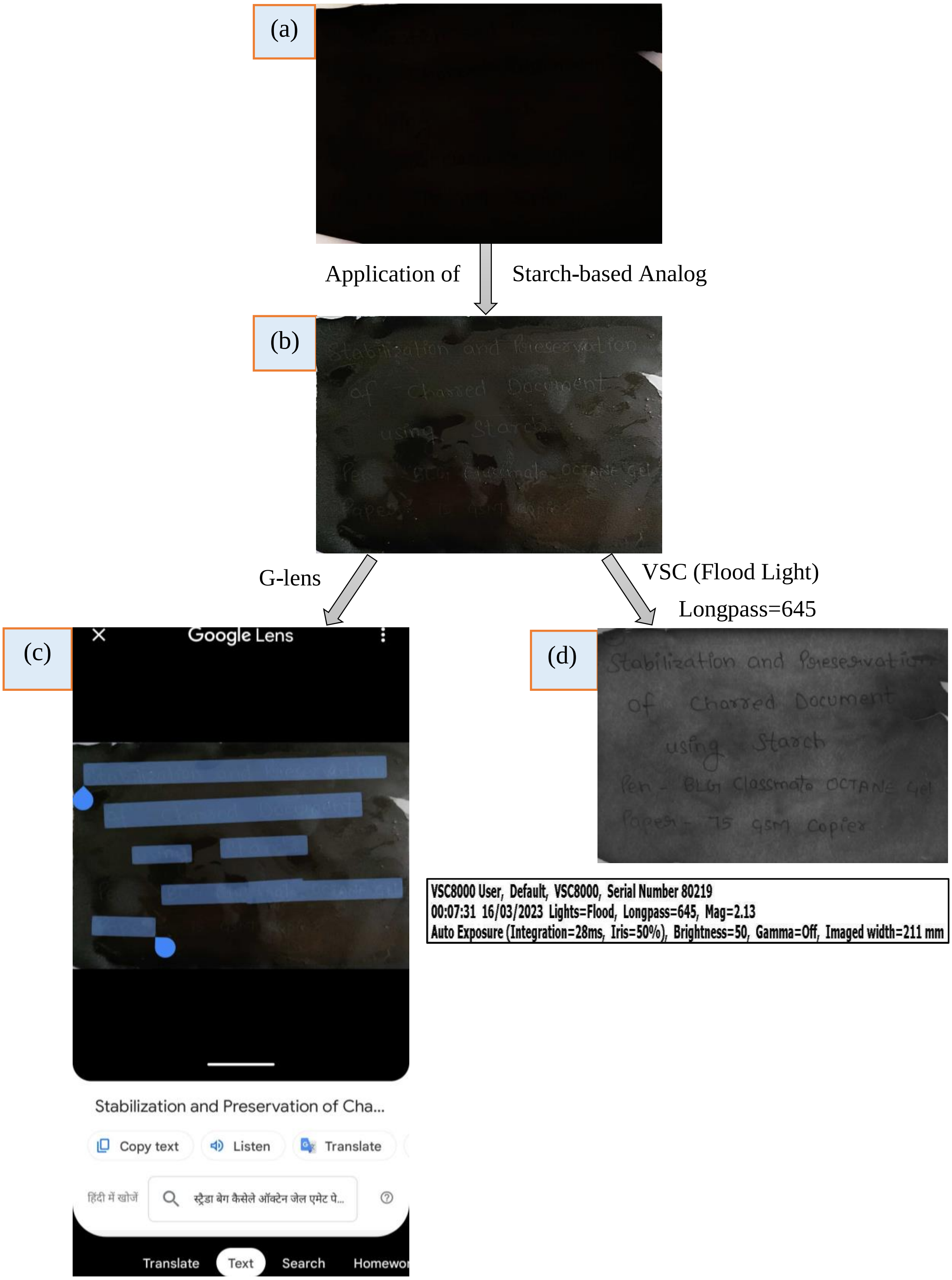



**Figure 4.49: Shows BLG Classmate Octane on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

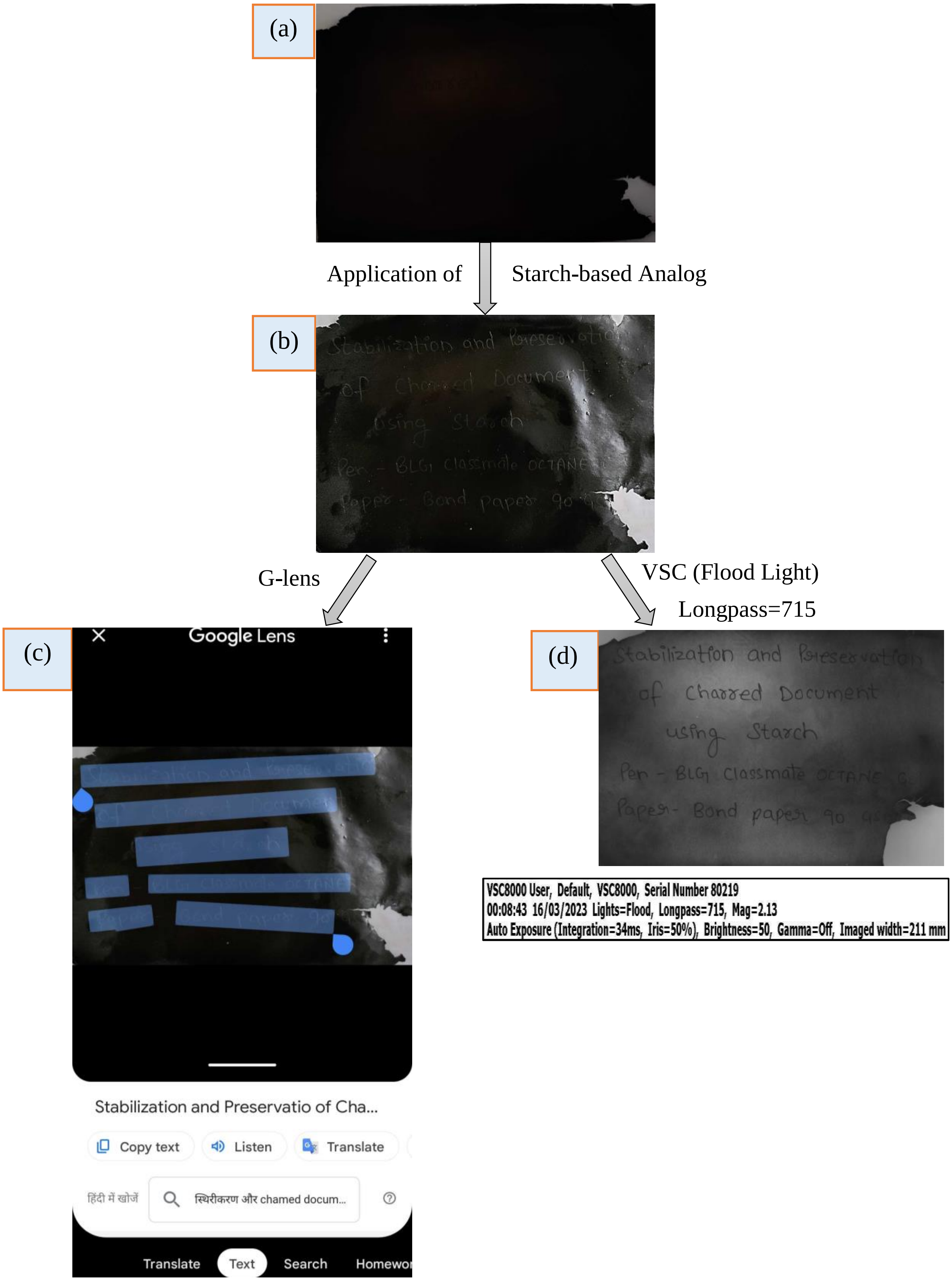



**Figure 4.50: Shows BLG Classmate Octane on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

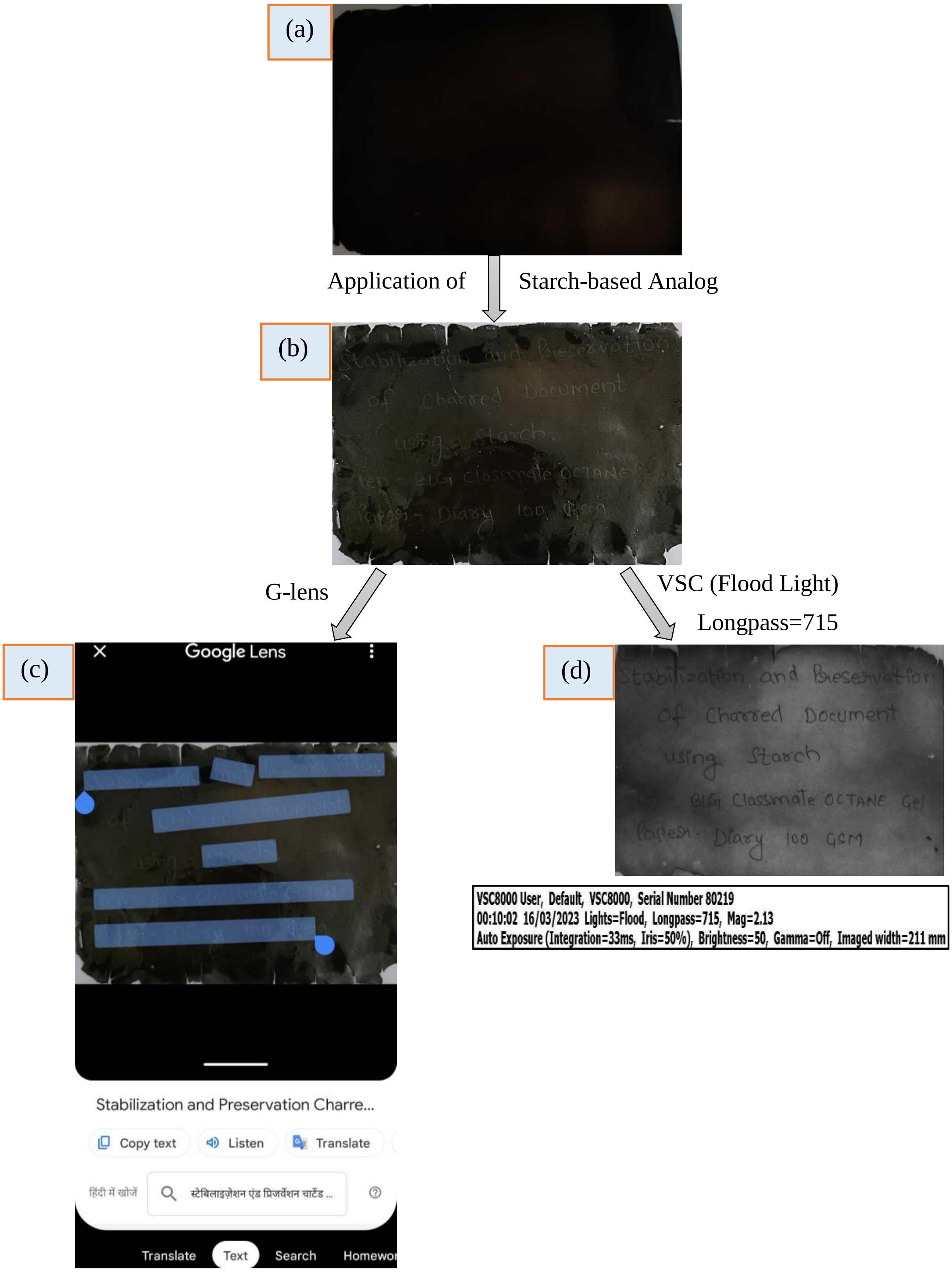



**Figure 4.51: Shows BLG Classmate Octane on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.10.2. Flair Glass Gel Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

Similarly, the documents made with BLG Flair glass pen inks on three different grades of paper showed that, after the charring process, the documents lost their text visibility to the naked eye. However, when the synthesized starch-based analog was applied over charred documents, the earlier illegible texts became legible. This may be due to the nature of ink solvents and the dyes present in their formulation. The black dyes and the gel inks are water in gel form-based, which does not get easily decomposed or disintegrated completely on even charring at high temperatures but becomes invisible to the naked eye. However, when it comes in contact with the starch-based analog, it interacts to form a bond and thus produces a contrast from the background, hence becoming visible. Furthermore, the deciphered texts were also recognized by the G-lens from the captured image, and it converted the image form into a copiable format. The percentage of characters that G-lens recognized correctly is shown in Table 4.36.

In addition, the VSC analysis of the coated charred documents also gave appreciable results, as the texts sustained and was successfully deciphered even after about a month in all three combinations. Combination-40 and combination-41 got deciphered under flood light at 715 longpass (Figure 4.52-4.53), whereas combination-42 under flood light at 645 longpass (Figure 4.54).

**Table 4.36: Showing the Percentage of Correctly Recognized Characters of BLG Flair Glass pen by G-lens.**

| **Combination** | | **G-lens Recognized Characters** | **No. of Recognized Characters** | **Character Deciphered (%)** |
|---|---|---|---|---|
| **40** | BLG Flair Glass+75 gsm | Stabilization and Preseatio of Charred Document using Starch | 53/56 | 95 |
| **41** | BLG Flair Glass+90 gsm | stabilization and Preservatio of Charred Document using Starch | 55/56 | 98 |
| **42** | BLG Flair Glass+100 gsm | Stabilization and Preservatio of Charred Document Starch | 50/56 | 89 |

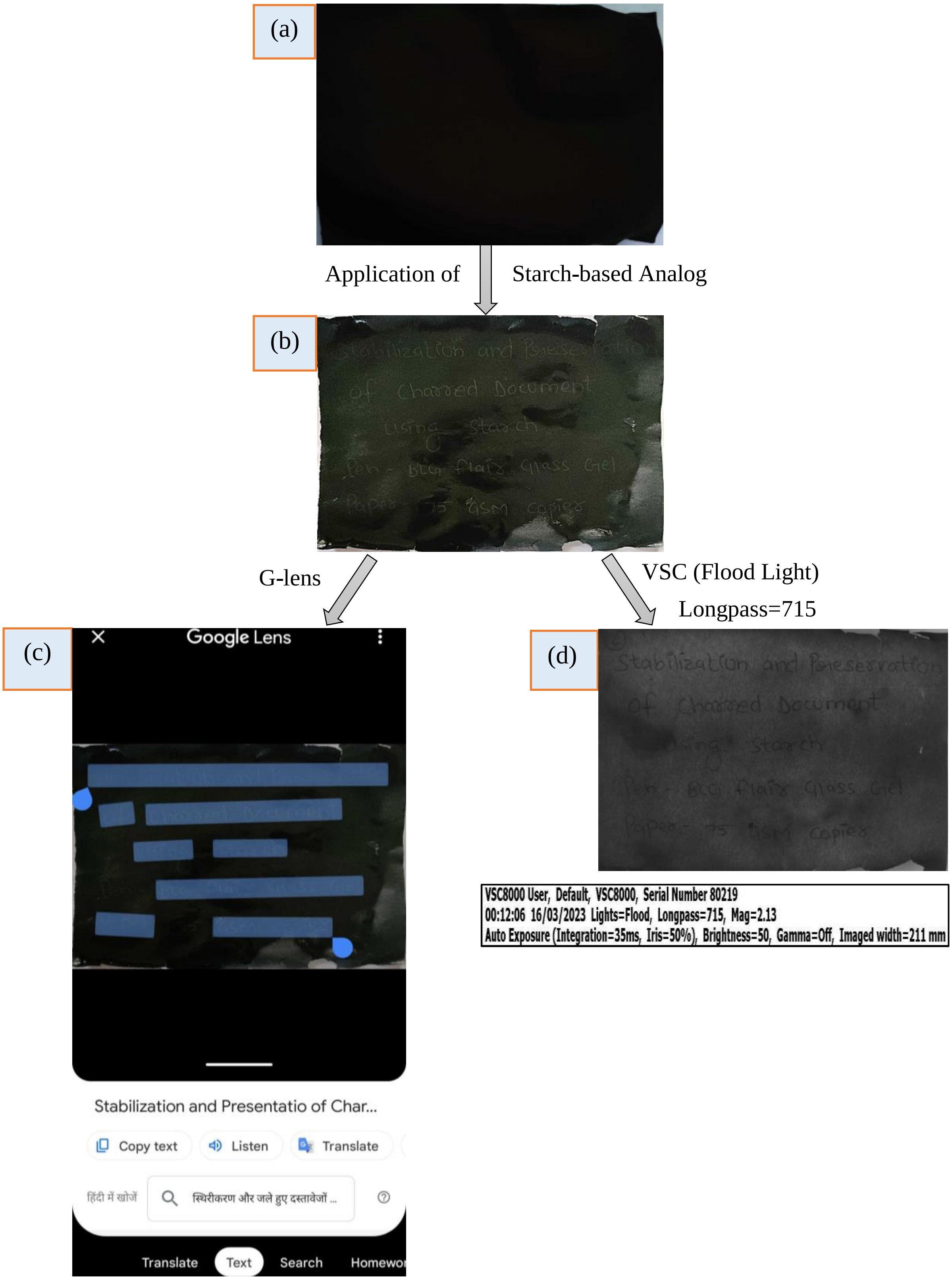



**Figure 4.52: Shows BLG Flair Glass on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

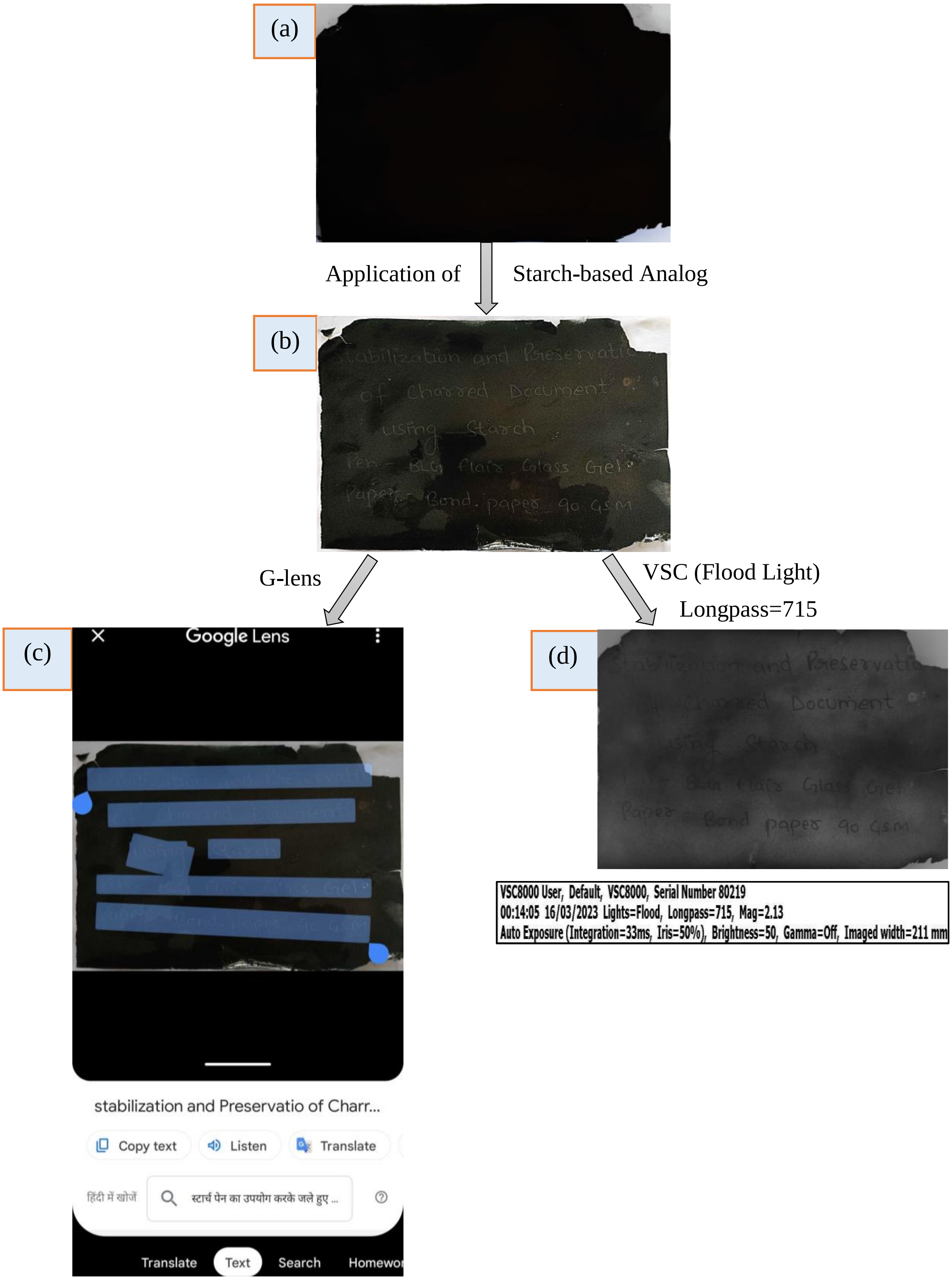



**Figure 4.53: Shows BLG Flair Glass on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

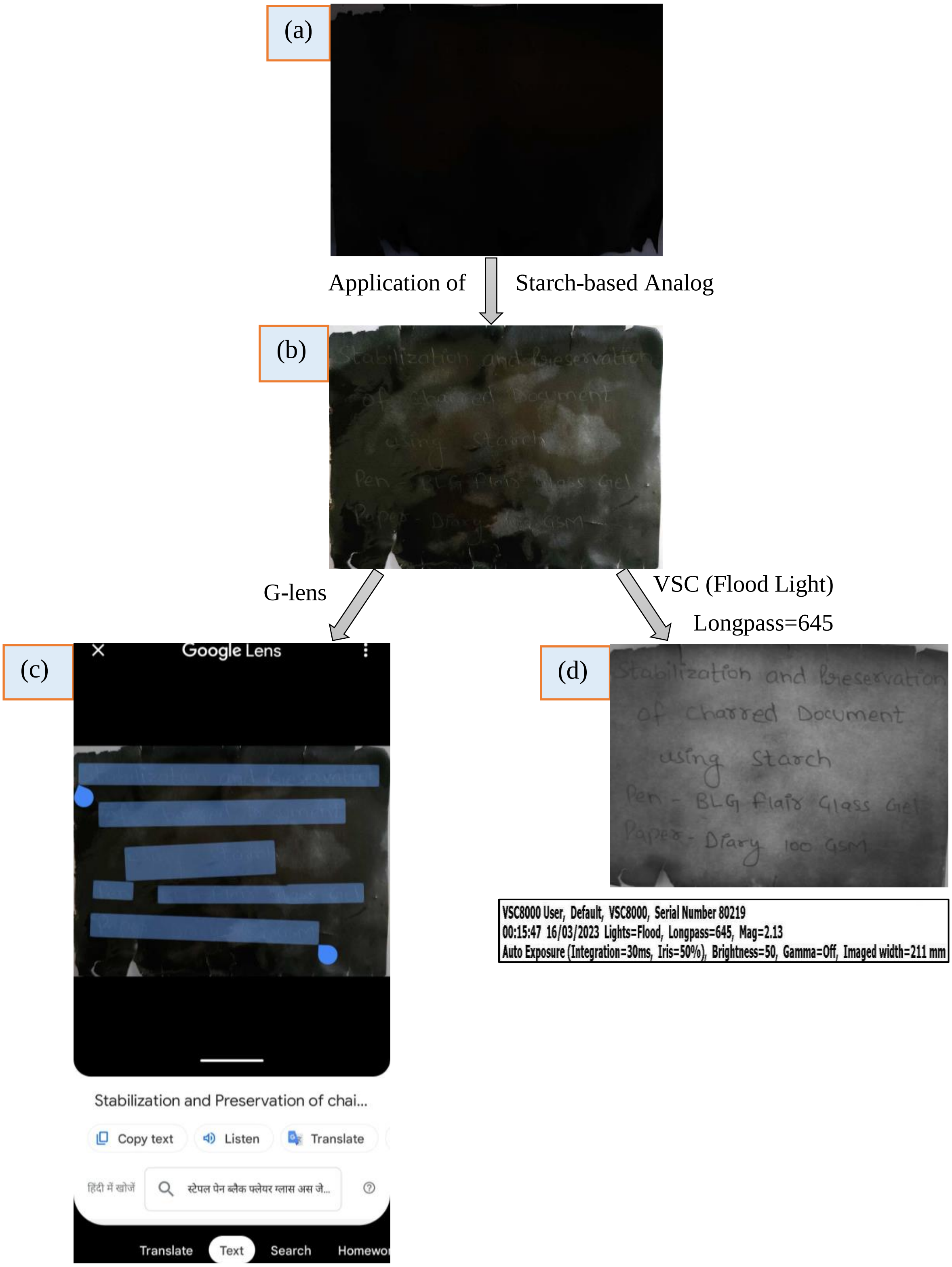



**Figure 4.54: Shows BLG Flair Glass on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.10.3. Elkos Magic Gel Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

The documents made with BLG Elkos Magic pen inks on three different grades of paper showed that, after the documents got charred to their maximum charring state, they became fragile, and the texts on them became invisible. However, as soon as the starch-based analog was applied to the surface of charred documents, the texts got deciphered and were visible to the naked eye in all three combinations, as shown in Figures 4.55-4.57.

As discussed earlier, this is due to the unique formulation of gel-based inks, which do not easily disintegrate and are absorbed on the paper surface, which on coating with starch-based analog, forms a temporary bond and thus becomes visible. Further, on subsequent analysis of the deciphered charred documents, the G-lens gave an appreciable result, as it successfully recognized 98% of the deciphered characters in all three combinations, as shown in Table 4.37.

Moreover, the coated charred documents were visualized under VSC after a month, and it was found that the texts were clearly visible under flood light at 715 longpass in all three combinations of Elkos Magic gel pen inks.

**Table 4.37: Showing the Percentage of Correctly Recognized Characters of BLG Elkos Magic pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **43** | BLG Elkos Magic+75 gsm | Stabilization and Preservatio of Charred Document using Starch | 55/56 | 98 |
| **44** | BLG Elkos Magic+90 gsm | Stabilization and Presevation of Charred Document using Starch | 55/56 | 98 |
| **45** | BLG Elkos Magic+100 gsm | Stabilization and Preservatio of Charred Document using Starch | 55/56 | 98 |

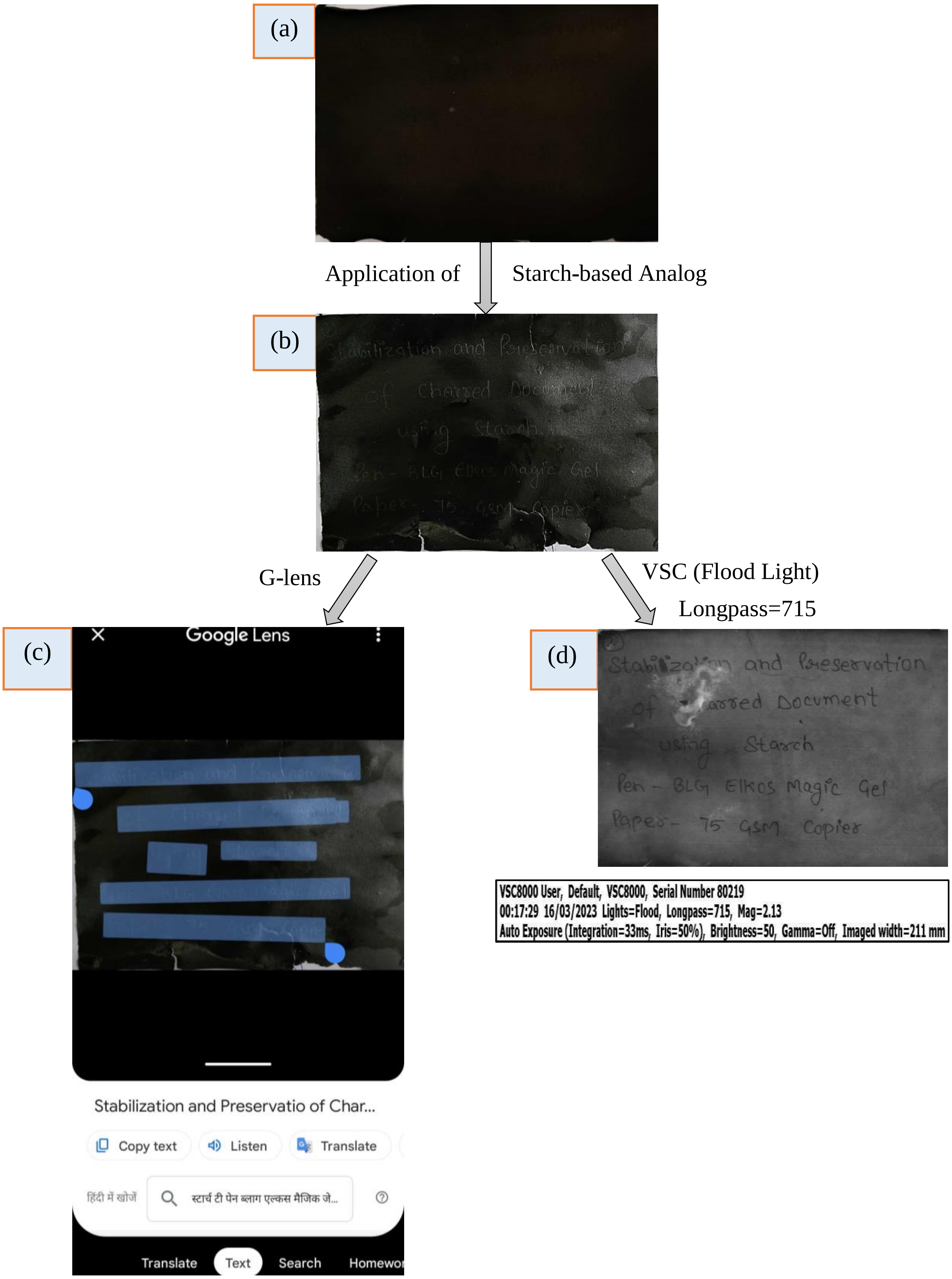



**Figure 4.55: Shows BLG Elkos Magic on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

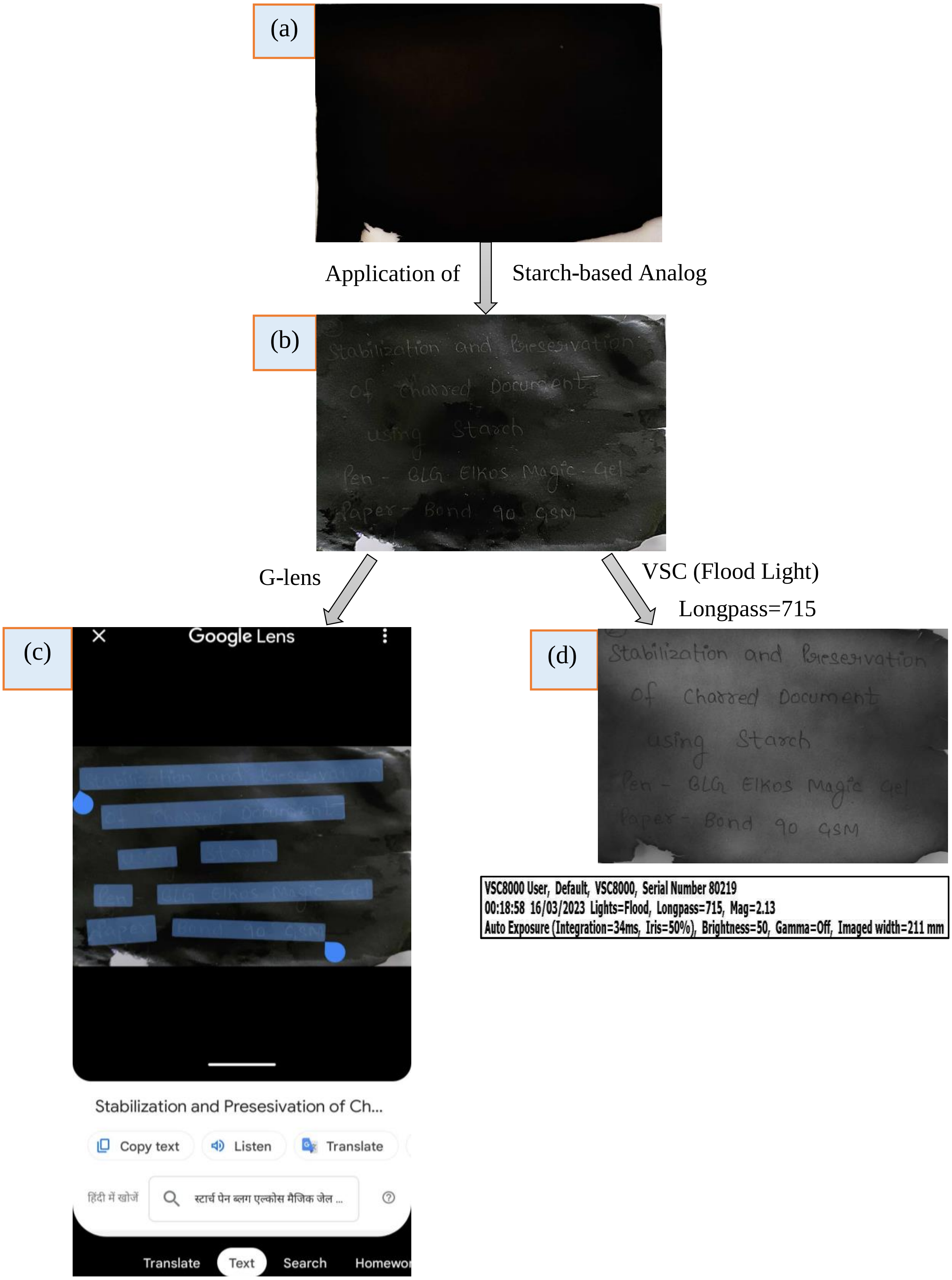



**Figure 4.56: Shows BLG Elkos Magic on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

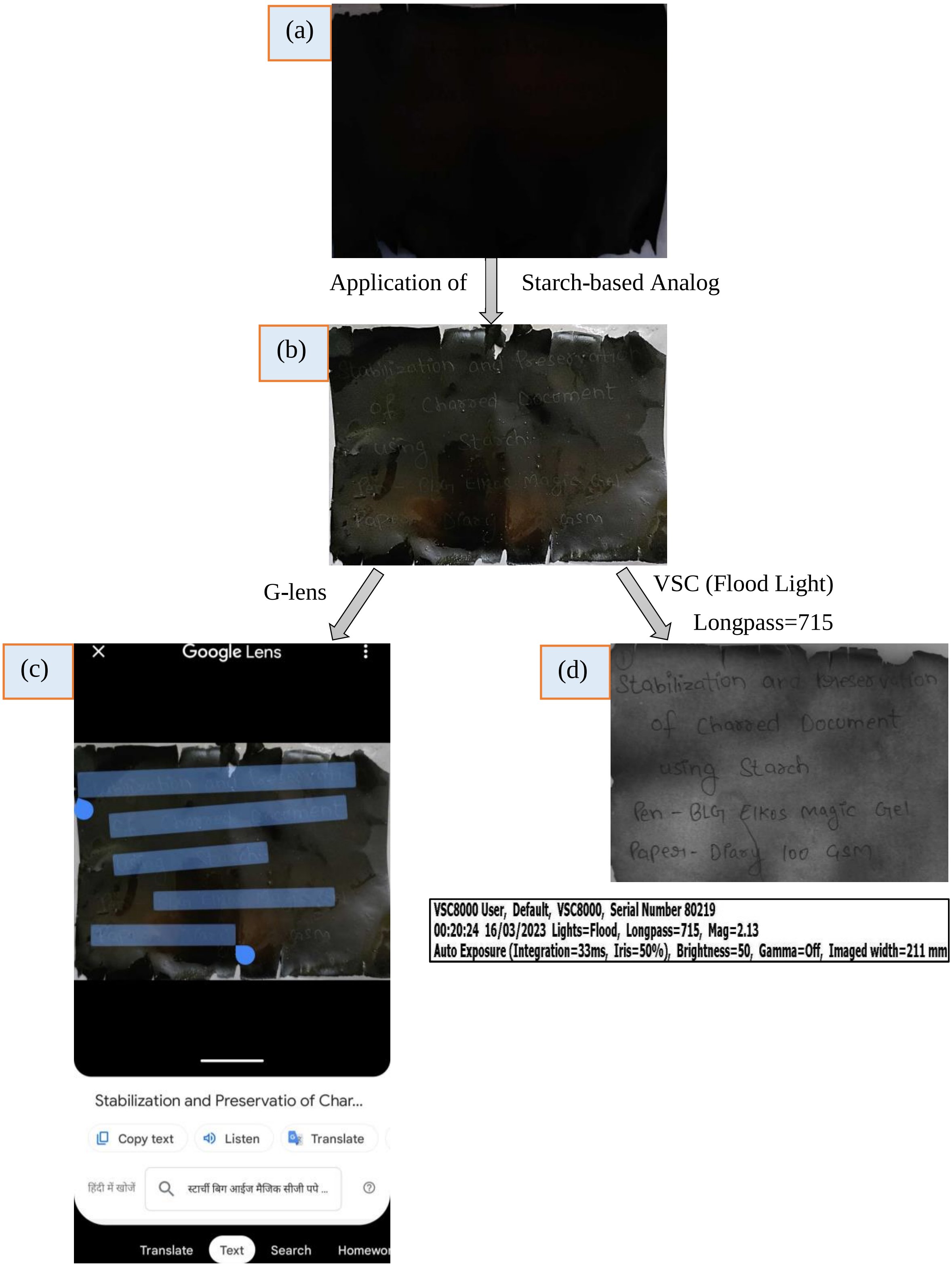



**Figure 4.57: Shows BLG Elkos Magic on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

## 4.11. Stabilization and Decipherment of Documents made with Red Gel Pen Inks

This section shows the results of stabilization and decipherment of charred documents made with three different brands of Red Gel pen, viz. Classmate octane, Elkos velo, and Reynolds jiffy on 75 gsm, 90 gsm, and 100 gsm paper.

### 4.11.1. Classmate Octane Gel Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

The charring of documents resulted in the invisibility of texts in all three combinations. This may be due to the volatile nature of the solvent present in gel ink formulation. Applying starch-based analog on the charred documents resulted in faintly visible texts on 75 gsm and 90 gsm paper (Figure 4.58-4.59), whereas no texts got deciphered in 100 gsm paper (Figure 4.60). The inability to decipher red gel pen inks on charred documents after coating with a starch-based analog can be attributed to several factors. Red gel ink compositions often differ from blue or black inks, utilizing different pigments and chemical formulations. These variations can result in a reduced affinity or compatibility between the red ink residues and the starch-based analog. Consequently, the analog may not effectively bind to the red ink particles, leading to minimal or no visibility enhancement. Moreover, the G-lens only recognized a few characters in combination-46, whereas no texts were recognized in the other two combinations, as shown in Table 4.38. Furthermore, the decipherment under VSC also not gave appreciable results as no to very faintly characters were visible under white spot light and flood light.

**Table 4.38: Showing the Percentage of Correctly Recognized Characters of RG Classmate Octane pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **46** | RG Classmate Octane+75 gsm | Documents | 9/56 | 16 |
| **47** | RG Classmate Octane+90 gsm | No text visible | 0/56 | 0 |
| **48** | RG Classmate Octane+100 gsm | No text visible | 0/56 | 0 |

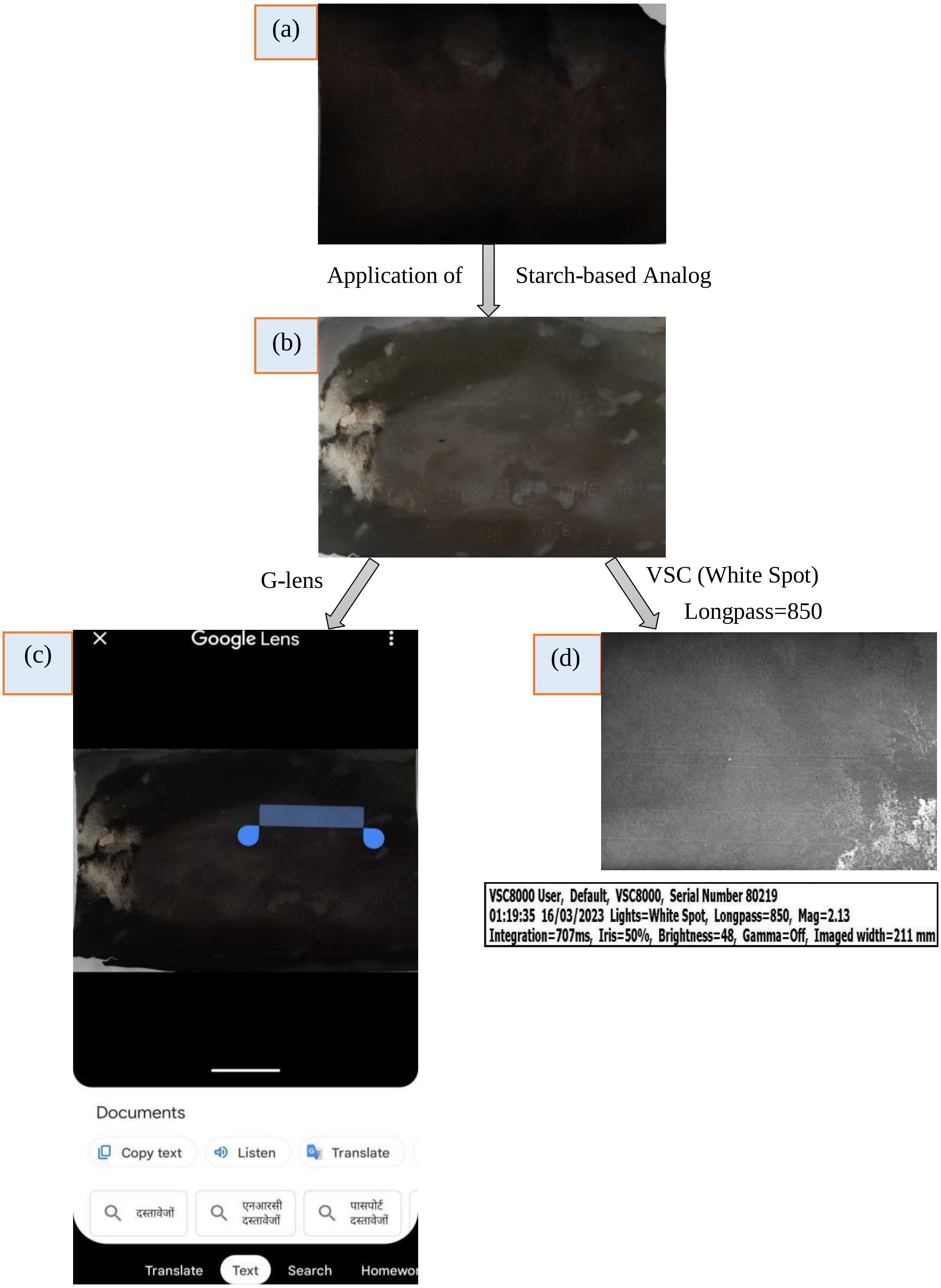



**Figure 4.58: Shows RG Classmate Octane on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

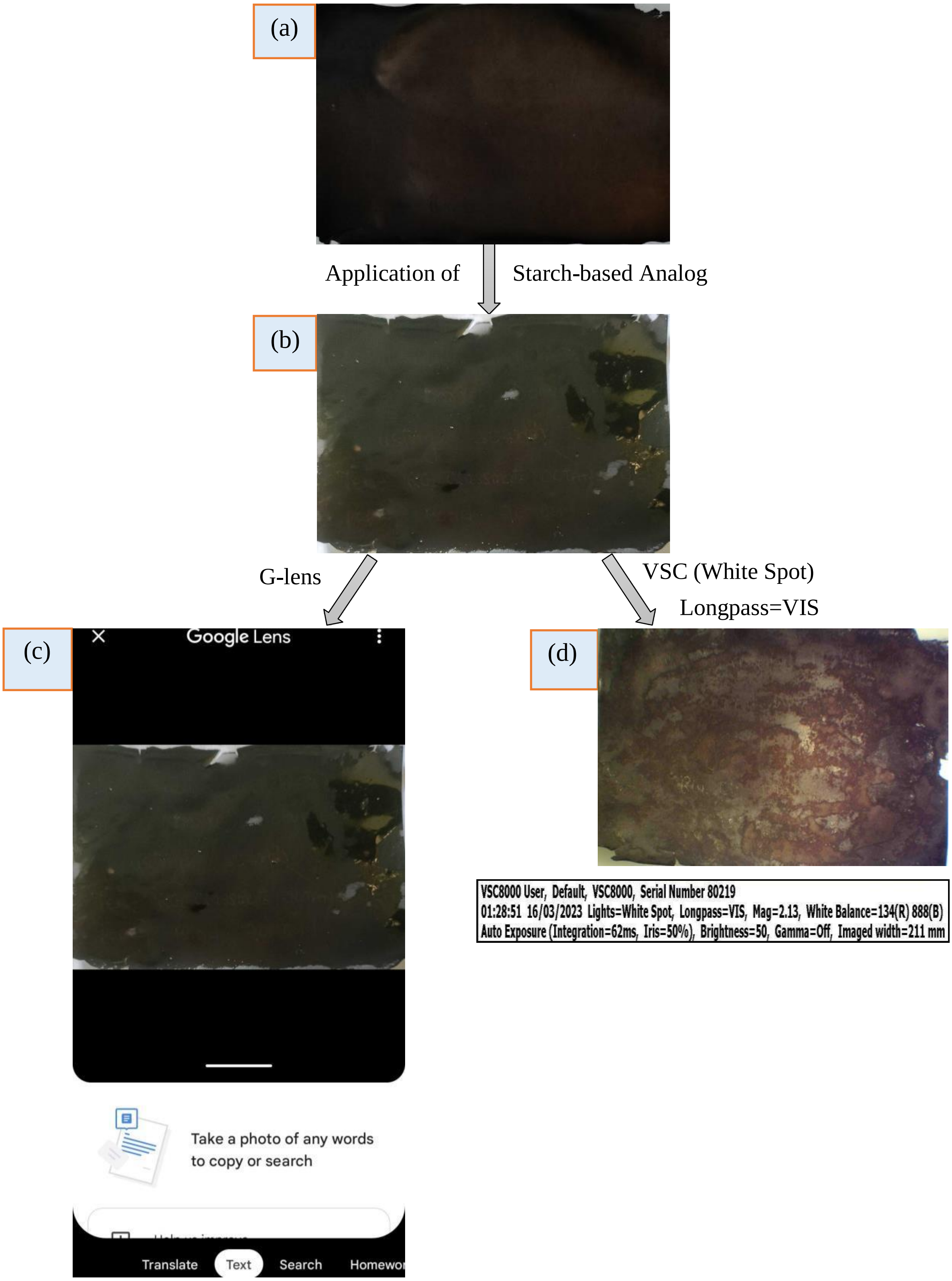



**Figure 4.59: Shows RG Classmate Octane on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

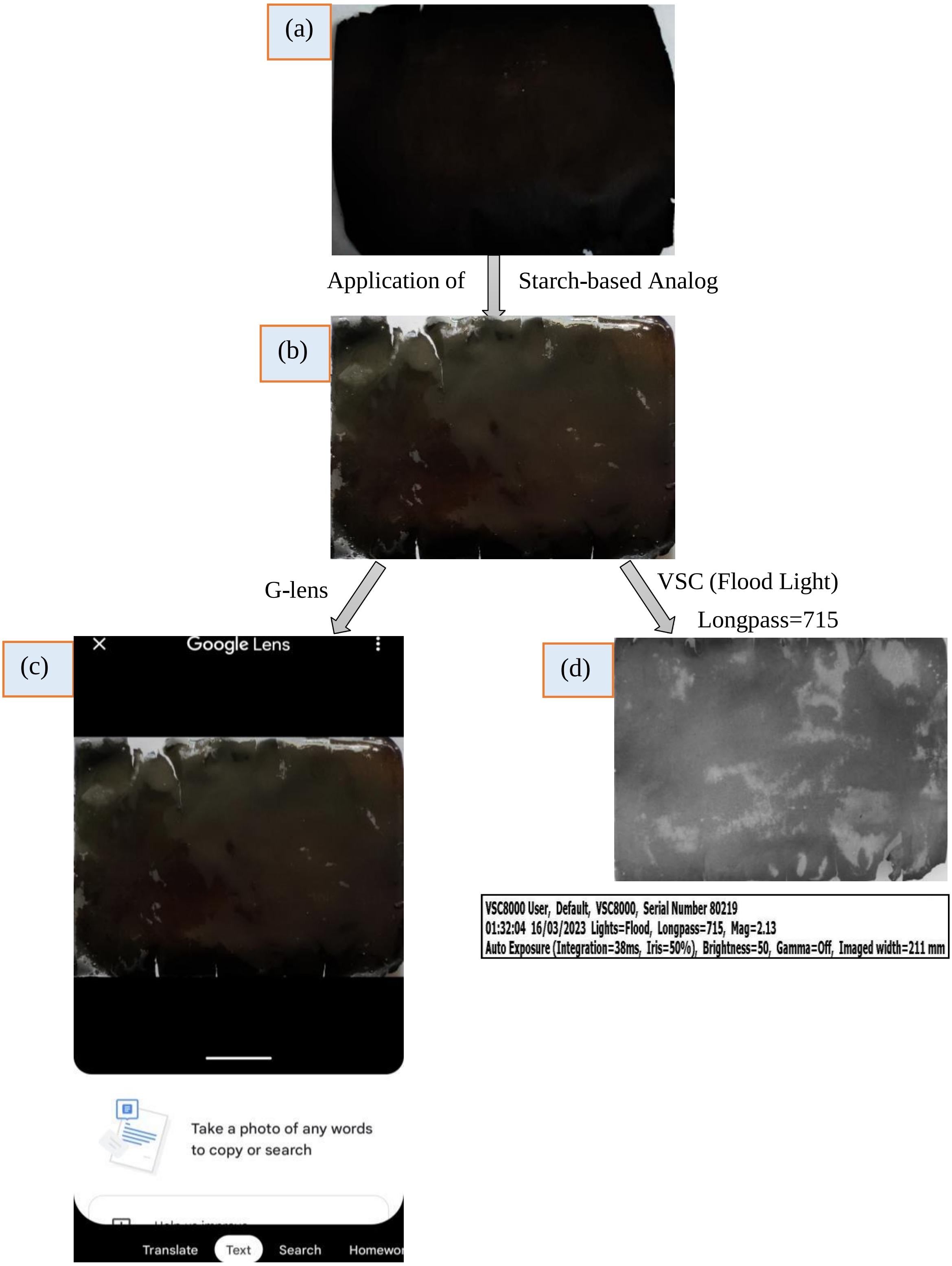



**Figure 4.60: Shows RG Classmate Octane on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.11.2. Elkos Velo Gel Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

The combinations made using RG Elkos Velo pen inks on three different grades of paper, viz. 75 gsm copier paper, 90 gsm bond paper, and 100 gsm diary paper, charred at their maximum charring state at 300 ºC, 304 ºC, and 304 ºC, respectively, resulted in the illegible and invisible written texts. Moreover, the documents became fragile due to excessive heat; hence applying and coating each combination with starch-based analog for stabilization and decipherment resulted in the non-decipherment of texts in all three combinations. This can be due to the ink formulation and the dye pigments present in the red gel inks. As mentioned earlier, unlike other colours of gel inks, red colour pigment exhibits higher intensity, which may make it challenging to distinguish any remaining residues on the charred document even after applying starch-based analog. Additionally, the starch-based analog may not effectively bind to the red ink particles, leading to no visible effect of decipherment, as shown in Figures 4.61-4.63. Thereafter, the captured image underwent OCR analysis using G-lens, which also not recognized any characters of the statement, as shown in Table 4.39.

Furthermore, the samples were analyzed under VSC at different light sources to effectively decipher the illegible texts, which resulted in the decipherment of very faintly visible texts in combination- 49 and combination-50 under white spot light at 695 longpass, and in combination-51, under white spot at longpass 830.

**Table 4.39: Showing the Percentage of Correctly Recognized Characters of RG Elkos Velo pen by G-lens.**

| Combination | | G-lens Recognized Characters | No. of Recognized Characters | Character Deciphered (%) |
|---|---|---|---|---|
| **49** | RG Elkos Velo+75 gsm | No text visible | 0/56 | 0 |
| **50** | RG Elkos Velo+90 gsm | No text visible | 0/56 | 0 |
| **51** | RG Elkos Velo+100 gsm | No text visible | 0/56 | 0 |

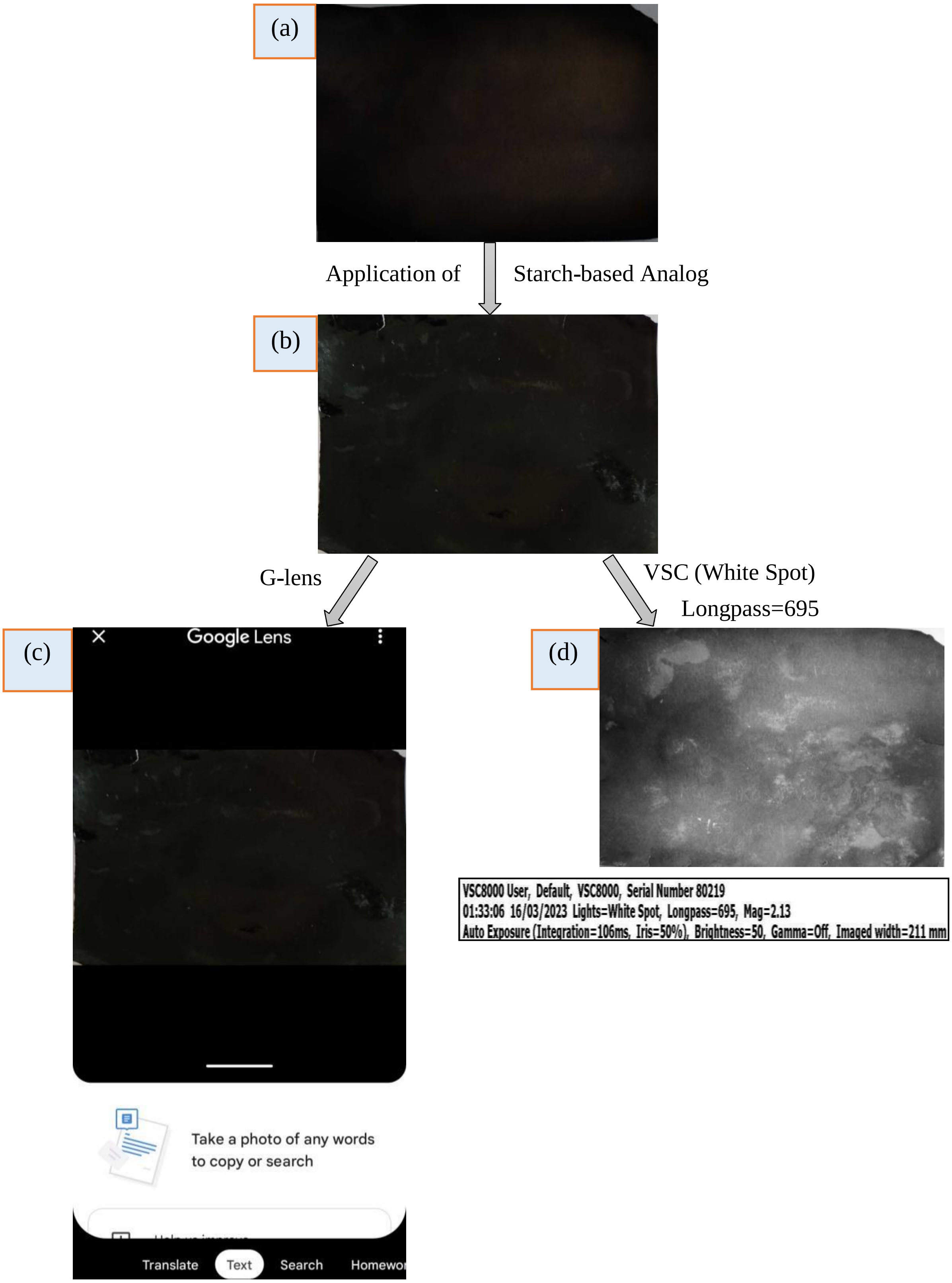



**Figure 4.61: Shows RG Elkos Velo on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

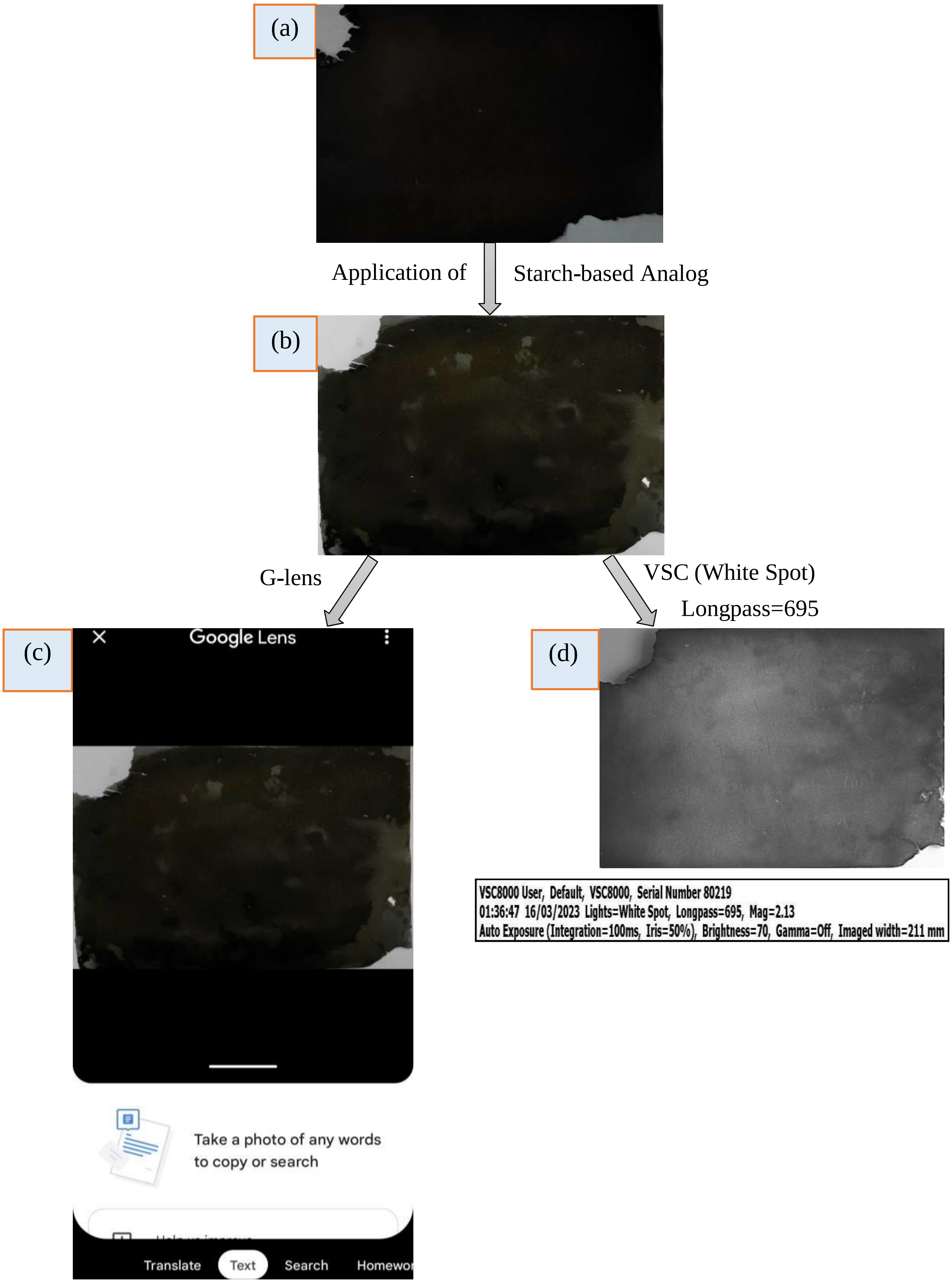



**Figure 4.62: Shows RG Elkos Velo on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

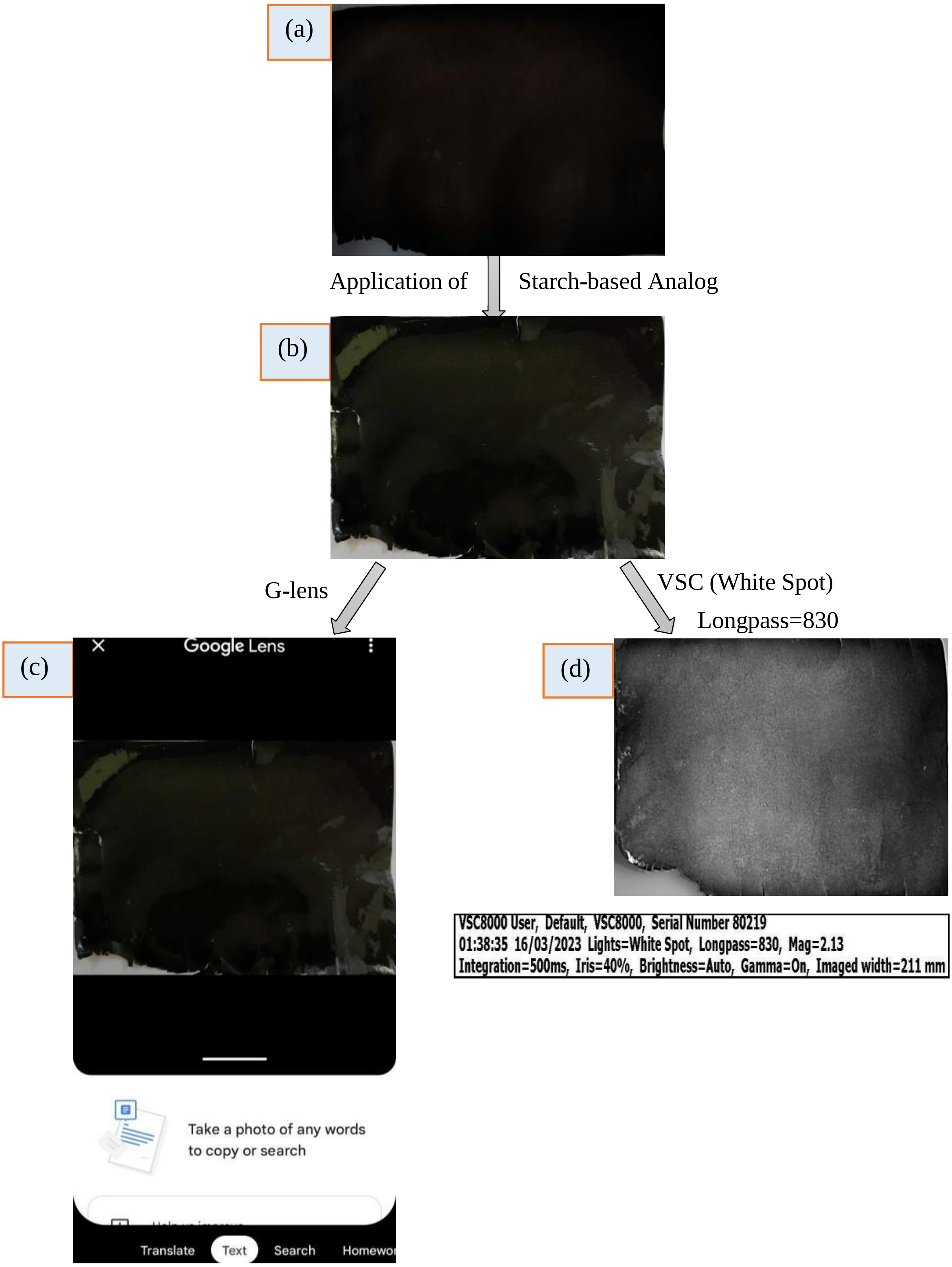



**Figure 4.63: Shows RG Elkos Velo on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

### 4.11.3. Reynolds Jiffy Gel Pen Inks on 75 gsm, 90 gsm, and 100 gsm Paper

Similarly, the documents made using RG Reynolds Jiffy pen inks on 75 gsm copier paper, 90 gsm bond paper, and 100 gsm diary paper also not resulted in the decipherment of any texts by treating and coating with synthesized starch-based analog. As mentioned earlier, this may be due to the ink formulation of red gel pen ink and the dyes present in it. Even if the texts might have been deciphered, they were not visible to the naked eye in the three combinations. Hence, the OCR tool also did not recognized any texts, as shown in Table 4.40.

Thereafter, when the coated charred documents were visualized under video spectral comparator (VSC), a few texts got very faintly deciphered in combination-52 (RG Reynolds+75 gsm) under left side light in visible range (Figure 4.64), whereas many texts got faintly visible in combination-53 (RG Reynolds+90 gsm) and combination-54 (RG Reynolds+100 gsm) under white spot at 725 longpass, as shown in Figures 4.65-4.66. The VSC gave a promising result of decipherment in case the texts were not visible to the naked eye after stabilizing charred documents.

**Table 4.40: Showing the Percentage of Correctly Recognized Characters of RG Reynolds Jiffy pen by G-lens.**

| **Combination** | | **G-lens Recognized Characters** | **No. of Recognized Characters** | **Character Deciphered (%)** |
|---|---|---|---|---|
| **52** | RG Reynolds Jiffy+75 gsm | No text visible | 0/56 | 0 |
| **53** | RG Reynolds Jiffy+90 gsm | No text visible | 0/56 | 0 |
| **54** | RG Reynolds Jiffy+100 gsm | No text visible | 0/56 | 0 |

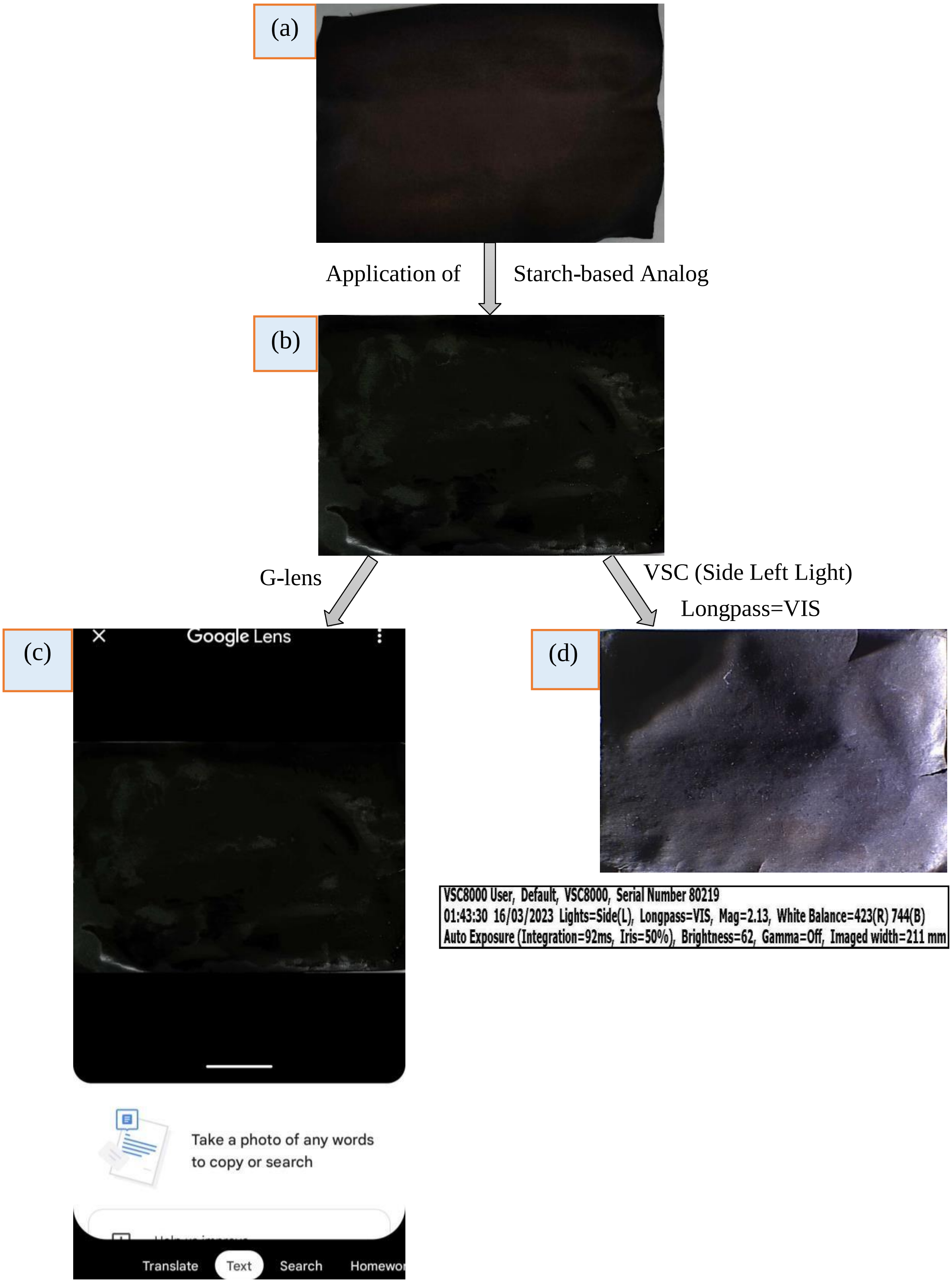



**Figure 4.64: Shows RG Reynolds Jiffy on 75 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

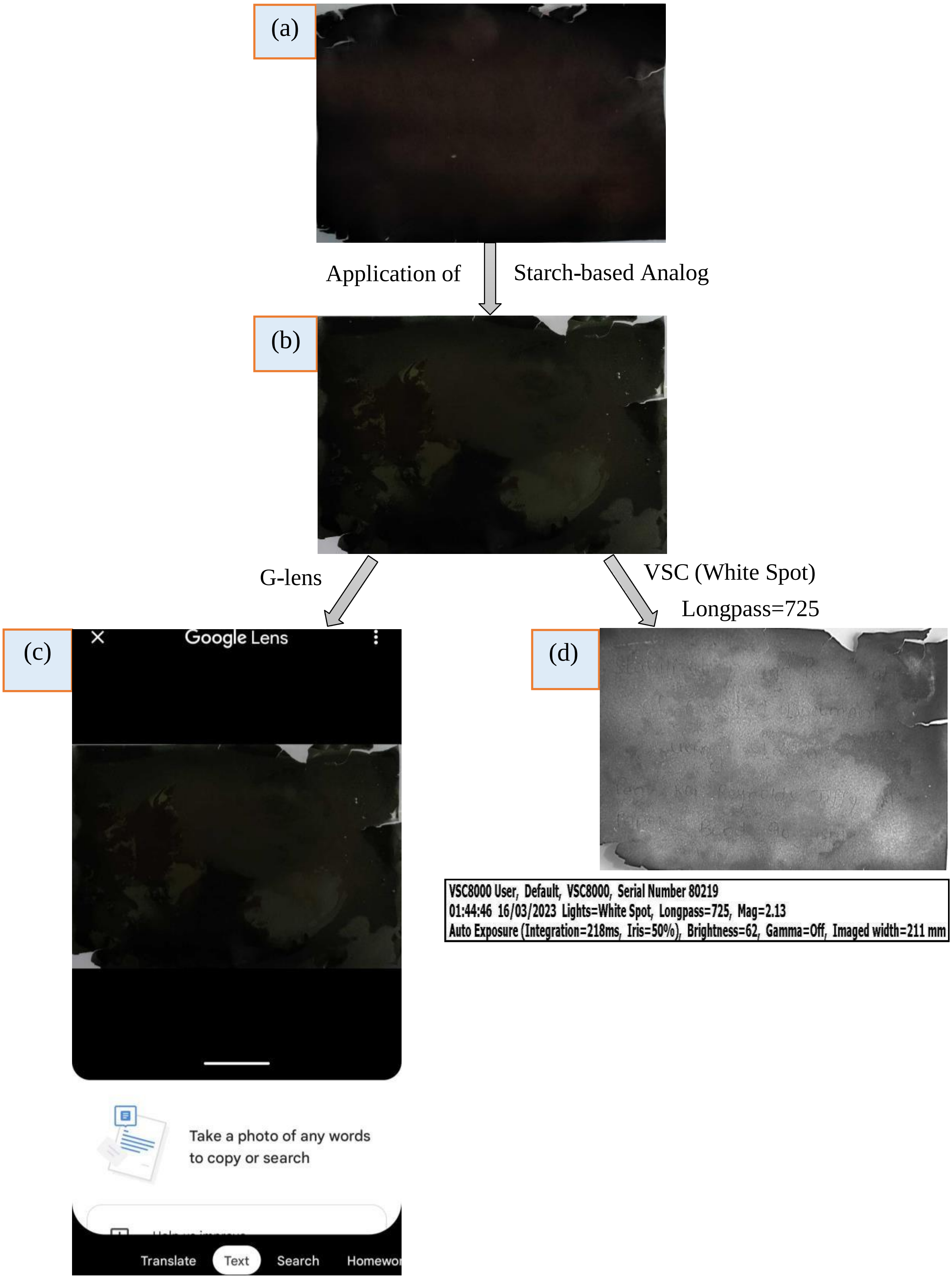



**Figure 4.65: Shows RG Reynolds Jiffy on 90 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

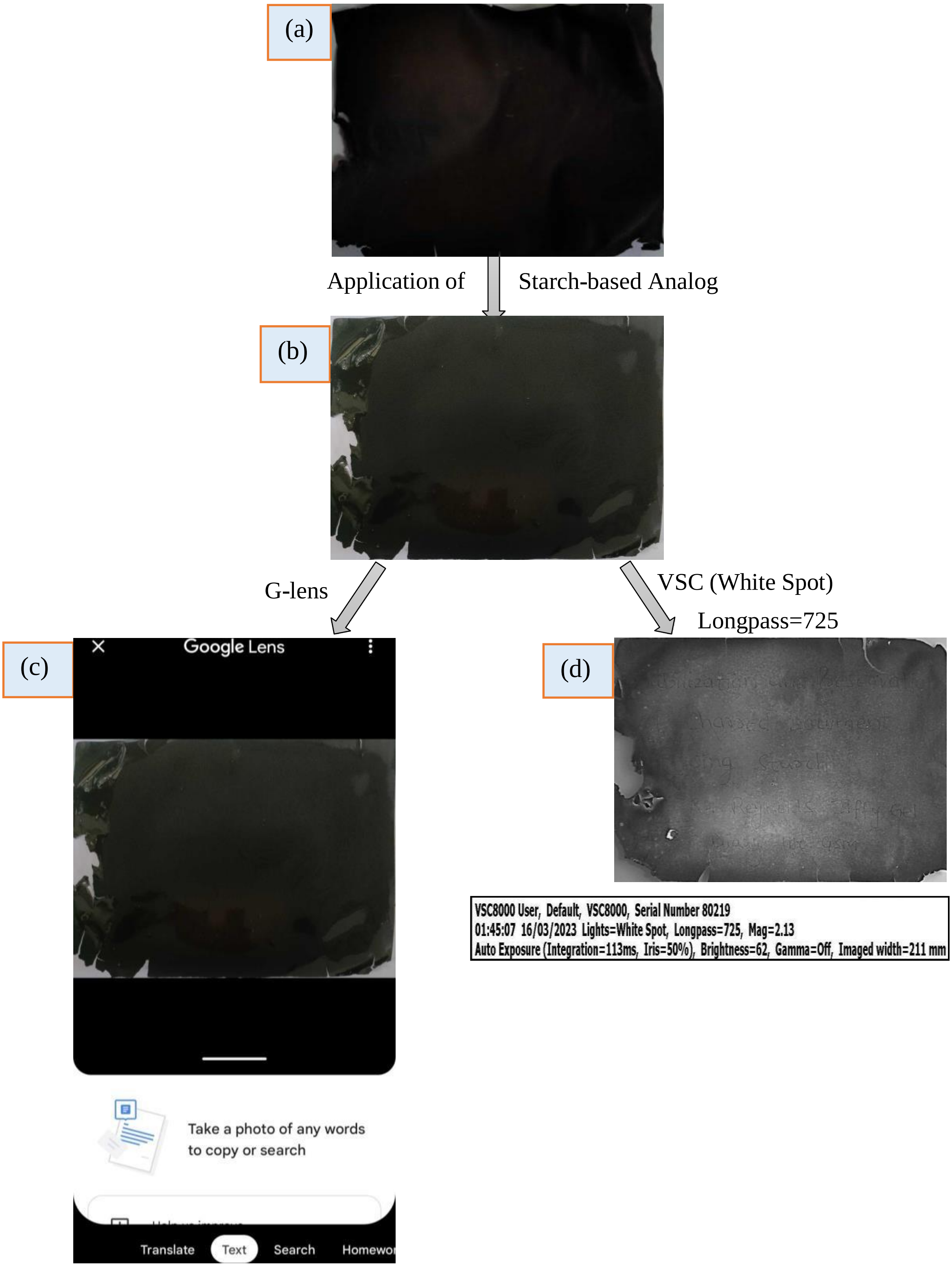



**Figure 4.66: Shows RG Reynolds Jiffy on 100 gsm paper, (a) charred document with invisible texts, (b) after application of starch-based analog, (c) G-lens recognized texts, (d) VSC analysis of charred document.**

The above findings of the research demonstrated that not all the documents made with any kind of ink on any type of paper, charred at any stage of charring, can be found fruitful for deciphering the contents made on it. This is because each paper type differs depending on its composition and thickness (gsm), and each pen variety, either ballpoint or gel, of different colours and manufacturers differ in their formulations, the solvents, dyes, and pigments present in it. Thus, as seen in the above sections, some combinations successfully got deciphered on stabilizing and coating with synthesized 6% starch-based analog, while some did not.

The decipherment of texts in combinations made with ballpoint pen inks gave better results than the gel pen inks. Three brands of ballpoint pen inks gave 100% decipherment (Table 4.41), while five brands showed more than 90% of decipherment in different paper types (Table 4.42). The results also showed that only one brand of ballpoint ink gave more than 80% (Table 4.43) and 0% decipherment, i.e., BBP Unique EZY (Table 4.44). This comparative study gave a clear view of the pen brands and colour, which were successfully deciphered using a novel synthesized starch-based analog.

**Table 4.41: Comparative Result of 100% decipherment in Ballpoint pen brands.**

| **100% Decipherment in Ballpoint Pens** | | | | |
|---|---|---|---|---|
| **S. No.** | **Pen Type** | **75 gsm** | **90 gsm** | **100 gsm** |
| **1.** | **BLBP Hauser Germany** | No | Yes | Yes |
| **2.** | **RBP Linc Pentonic** | Yes | Yes | Yes |
| **3.** | **RBP Hauser Germany** | Yes | No | Yes |

**Table 4.42: Comparative Result of Above 90% decipherment in Ballpoint pen brands.**

| Above 90% Decipherment in Ballpoint Pens | | | | |
|---|---|---|---|---|
| **S. No.** | **Pen Type** | **75 gsm** | **90 gsm** | **100 gsm** |
| **1.** | **BBP Linc Pentonic** | Yes | Yes | Yes |
| **2.** | **BBP Elkos Better** | Yes | No | Yes |
| **3.** | **BLBP Linc Pentonic** | Yes | Yes | Yes |
| **4.** | **BLBP Hauser Germany** | Yes | No | No |
| **5.** | **RBP Hauser Germany** | No | Yes | No |

**Table 4.43: Comparative Result of Above 80% decipherment in Ballpoint pen brands.**

| Above 80% Decipherment in Ballpoint Pens | | | | |
|---|---|---|---|---|
| **S. No.** | **Pen Type** | **75 gsm** | **90 gsm** | **100 gsm** |
| **1.** | **RBP Elkos Better** | No | Yes | Yes |

**Table 4.44: Comparative Result of 0% decipherment in Ballpoint pen brands.**

| 0% Decipherment in Ballpoint Pens | | | | |
|---|---|---|---|---|
| **S. No.** | **Pen Type** | **75 gsm** | **90 gsm** | **100 gsm** |
| **1.** | **BBP Unique EZY** | Yes | Yes | Yes |

Similarly, the comparative study of decipherment on the document made using Gel pen inks showed that none of the pen brand and colour gave 100% decipherment, possibly due to the gel-based ink formulations. However, three brands i.e., BG Classmate octane, BLG Classmate octane, and BLG Flair glass, gave more than 90% of deciphered characters in different paper types. Similarly, the same three brands showed more than 80% decipherment in papers other than 90% of decipherment, as shown in Tables 4.45-4.46. In addition, the least decipherment of 0% was observed in four different brands namely, BG Elkos velo, RG Classmate octane, RG Elkos velo, and RG Reynolds jiffy, in almost all three types of paper, as shown in Table 4.47. This shows that the ballpoint ink with only one brand showing 0% decipherment proved to be better in the successful decipherment of charred documents, and suggests that the crucial documents should be written using ballpoint pen rather than gel pen inks, which possibly may help in retrieval of vital information if lost in any fire damage.

**Table 4.45: Comparative Result of Above 90% decipherment in Gel pen brands.**

| Above 90% Decipherment in Gel Pens | | | | |
|---|---|---|---|---|
| **S. No.** | **Pen Type** | **75 gsm** | **90 gsm** | **100 gsm** |
| **1.** | **BG Classmate Octane** | No | No | Yes |
| **2.** | **BLG Classmate Octane** | Yes | Yes | No |
| **3.** | **BLG Flair Glass** | Yes | Yes | No |

**Table 4.46: Comparative Result of Above 80% decipherment in Gel pen brands.**

| Above 80% Decipherment in Gel Pens | | | | |
|---|---|---|---|---|
| **S. No.** | **Pen Type** | **75 gsm** | **90 gsm** | **100 gsm** |
| **1.** | **BG Classmate Octane** | Yes | Yes | No |
| **2.** | **BLG Classmate Octane** | No | No | Yes |
| **3.** | **BLG Flair Glass** | No | No | Yes |

**Table 4.47: Comparative Result of 0% decipherment in Gel pen brands.**

| 0% Decipherment in Gel Pens | | | | |
|---|---|---|---|---|
| **S. No.** | **Pen Type** | **75 gsm** | **90 gsm** | **100 gsm** |
| **1.** | **BG Elkos Magic** | Yes | Yes | Yes |
| **2.** | **RG Classmate Octane** | No | Yes | Yes |
| **3.** | **RG Elkos Velo** | Yes | Yes | Yes |
| **4.** | **RG Reynolds Jiffy** | Yes | Yes | Yes |

After coating and stabilizing charred documents using starch-based analog, the analog's adhesive, and consolidating properties allowed it to penetrate the charred layers, strengthening the fragile substrate and producing a contrast with the background that reveals the invisible writings on the charred documents. In addition, this coating prevents them from further deterioration.

Moreover, the level of strengthening that a starch-based analog provided when the charred documents were coated with it, compared to non-coated charred documents, also plays a significant role in their preservation. Therefore, the bursting strength of each combination of coated and non-coated charred documents was evaluated.

## 4.12. Bursting Strength Determination of Coated and Non-Coated Charred Documents

This section focuses on the effectiveness of synthesized starch-based analog for stabilizing brittle and fragile charred documents which underwent charring at high temperatures. The charred documents were stabilized by coating them with a synthesized green product, i.e., a starch-based analog, that aids in providing appreciable strength to the coated charred document with that of non-coated charred documents [178]. After the coated charred documents were dried at room temperature, a significant increase in strength was observed with that of non-coated charred documents by general observation. Further, determining and comparing the bursting strength of the coated and non-coated charred documents using a digital bursting strength tester also confirmed an appreciable increase in bursting strength in terms of force applied at the moment of sample rupture in $kg/cm^2$.

The result of the analysis for each combination made on 75 gsm copier paper, 90 gsm bond paper, and 100 gsm diary paper before the stabilization showed that the bursting strength of 75 gsm copier paper charred at 300 ºC was found to be 0.12 $kg/cm^2$, 90 gsm bond paper charred at 304 ºC was 0.15 $kg/cm^2$, and for 100 gsm diary paper charred at 308 ºC was found to be 0.25 $kg/cm^2$ ± standard deviation.

Furthermore, when another pair of these charred documents of the same combination was stabilized and coated with a starch-based analog, a noticeable increase in strength was observed. For example, the combination of Linc Pentonic blue ballpoint pen ink on 75 gsm paper had bursting strength of 0.12 kg/cm$^2$, which after getting stabilized, gained an adequate increase in strength to 0.21 kg/cm$^2$. This may be due to the penetration and absorbance of starch-based analog onto the charred layer of paper substrate that adhered to the surface, strengthening the charred layer, hence increasing the strength, as shown in Figure 4.67. A similar observation was seen in all the combinations made with different pen types on three different types of papers, as shown in Figures 4.68-4.69.

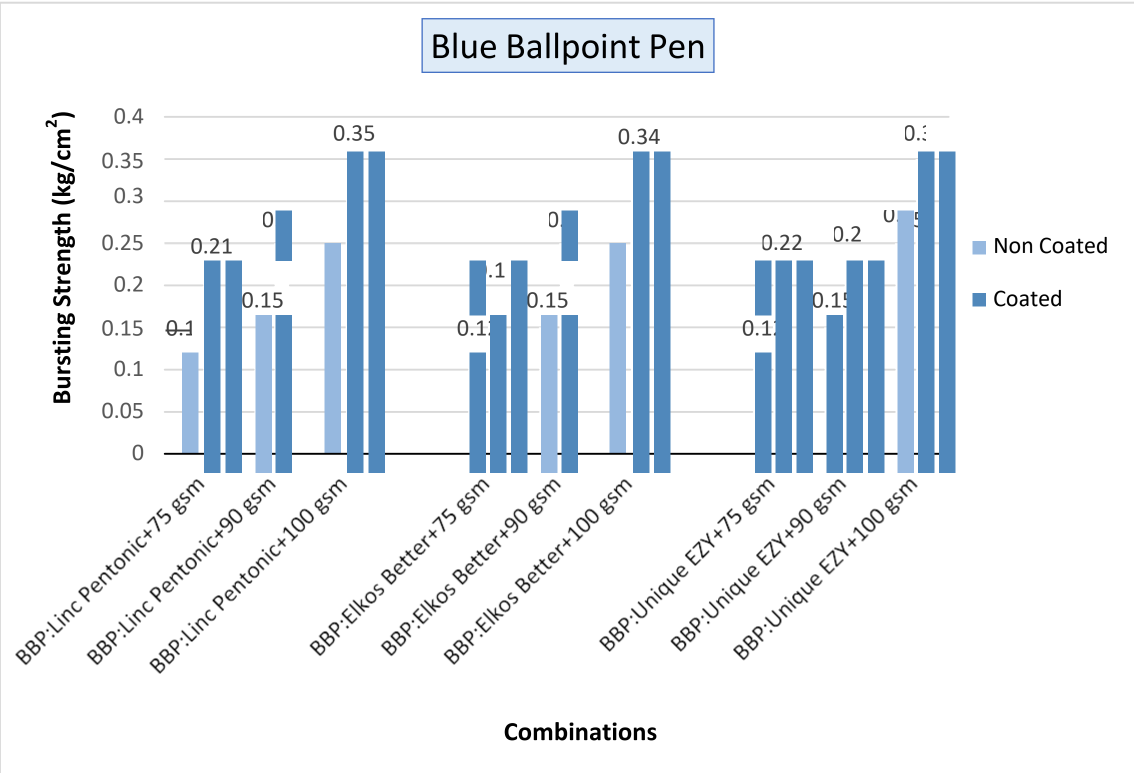



**Figure 4.67: Graphical representation of the increase in Bursting Strength between Non-Coated and Coated charred documents made using Blue Ballpoint Pens on 75 gsm, 90 gsm, and 100 gsm paper.**

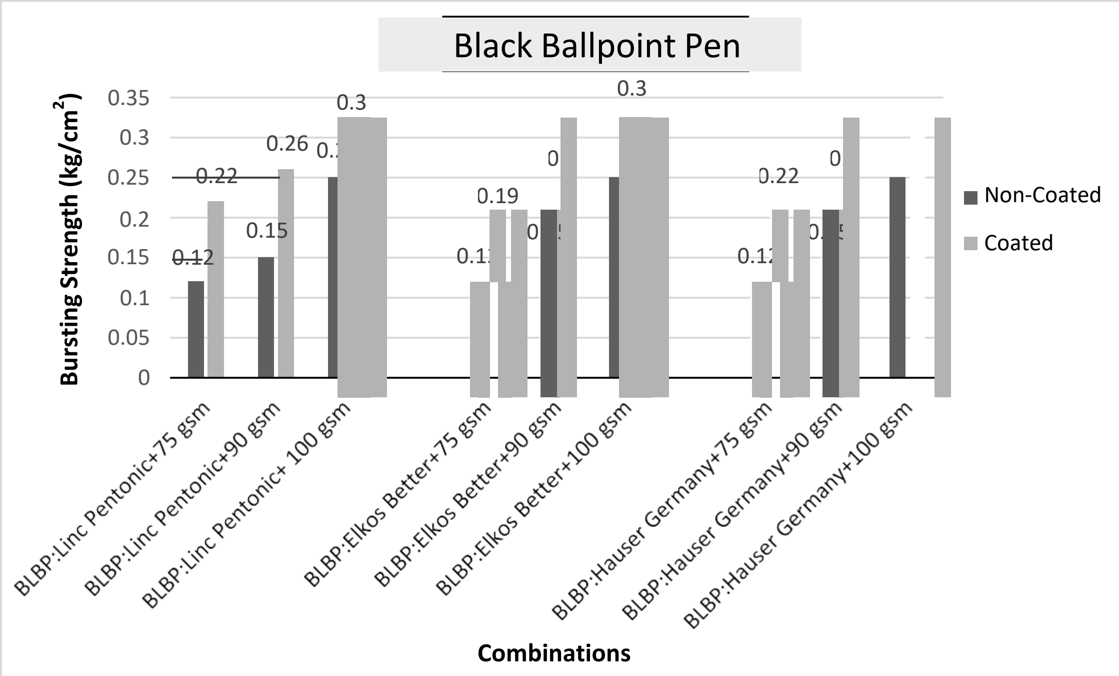



**Figure 4.68: Graphical representation of the increase in Bursting Strength between Non-Coated and Coated charred documents made using Black Ballpoint Pens on 75 gsm, 90 gsm, and 100 gsm paper.**

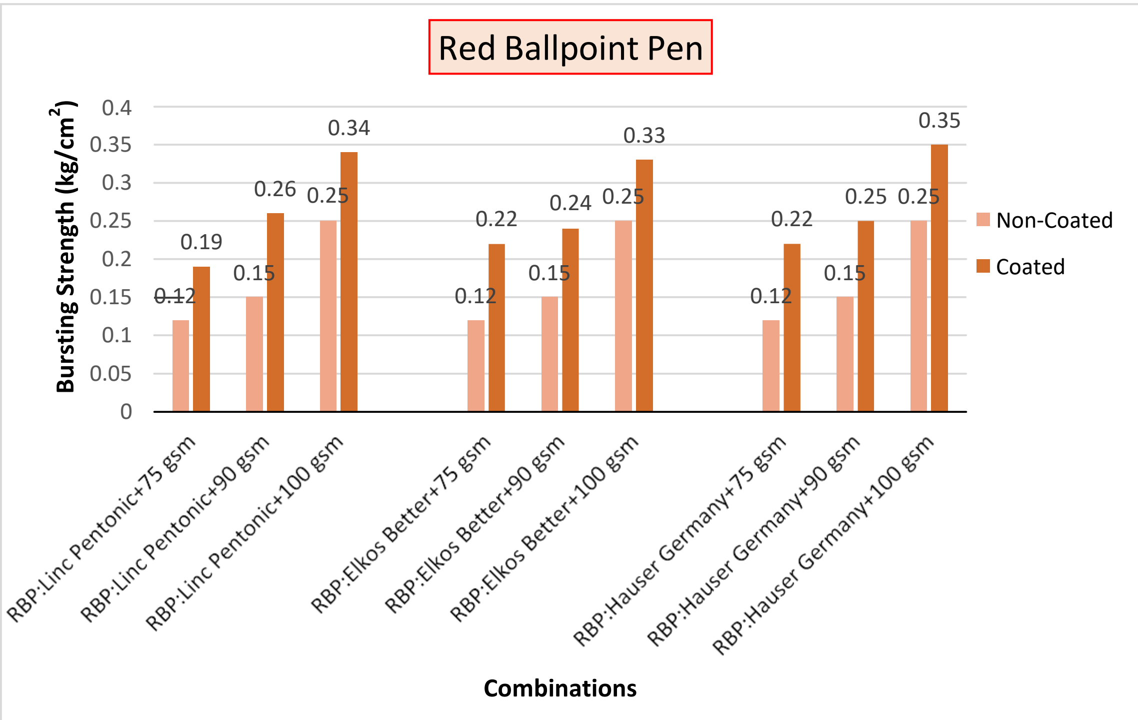



**Figure 4.69: Graphical representation of the increase in Bursting Strength between Non-Coated and Coated charred documents made using Red Ballpoint Pens on 75 gsm, 90 gsm, and 100 gsm paper.**

As observed in the above combinations of ballpoint pens with three different grades of paper, there is a significant increase in the bursting strength of the coated and non-coated charred documents in all the combinations. This signifies that the stabilization of charred documents has increased their stability, which can now be handled with little ease and can be kept for a little longer in a safe manner for producing them as evidence in a court of law or any future need.

Similarly, the bursting strength of combinations made with gel pens on three different grades of paper also showed a significant increase in their bursting strength after getting stabilized using a starch-based analog. For example, the bursting strength of a combination made with BG Classmate octane pen on 75 gsm paper increased from 0.12 $kg/cm^2$ to 0.23 $kg/cm^2$. Moreover, 95 gsm bond paper increased from 0.15 $kg/cm^2$ to 0.23 $kg/cm^2$, whereas 100 gsm diary paper increased from 0.25 $kg/cm^2$ to 0.32 $kg/cm^2$. Likewise, the bursting strength of other gel pen and paper combinations also gave promising results, as shown in Figures 4.70-4.72.

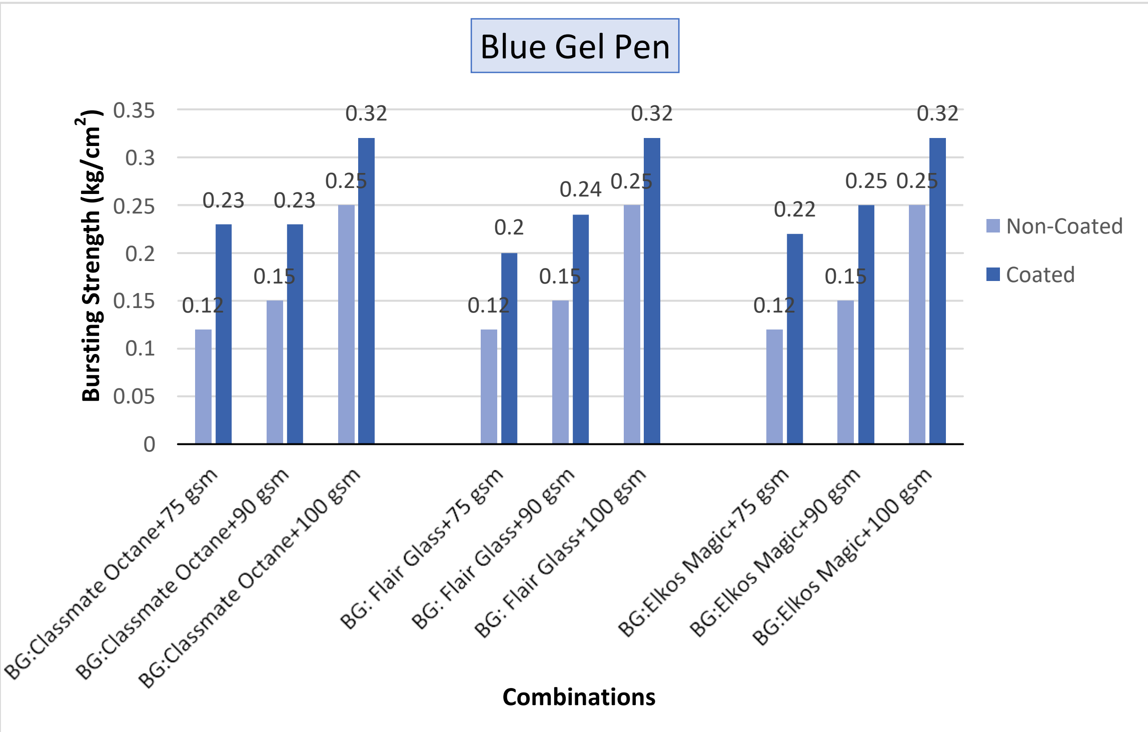



**Figure 4.70: Graphical representation of the increase in Bursting Strength between Non-Coated and Coated charred documents made using Blue Gel Pens on 75 gsm, 90 gsm, and 100 gsm paper.**

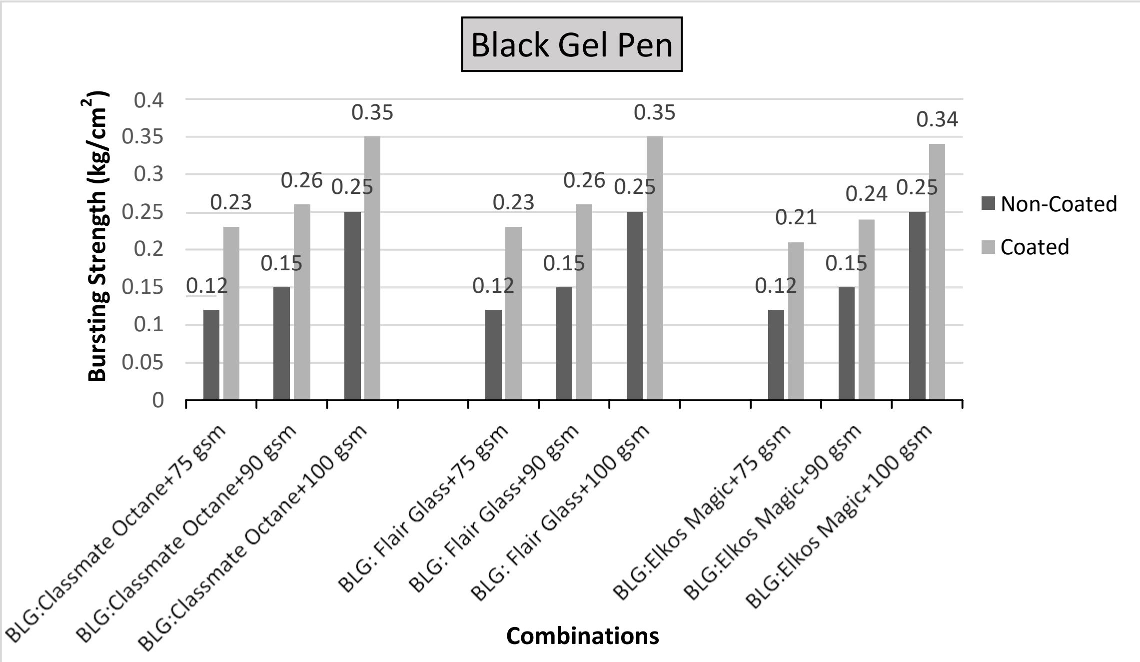



**Figure 4.71: Graphical representation of the increase in Bursting Strength between Non-Coated and Coated charred documents made using Black Gel Pens on 75 gsm, 90 gsm, and 100 gsm paper.**

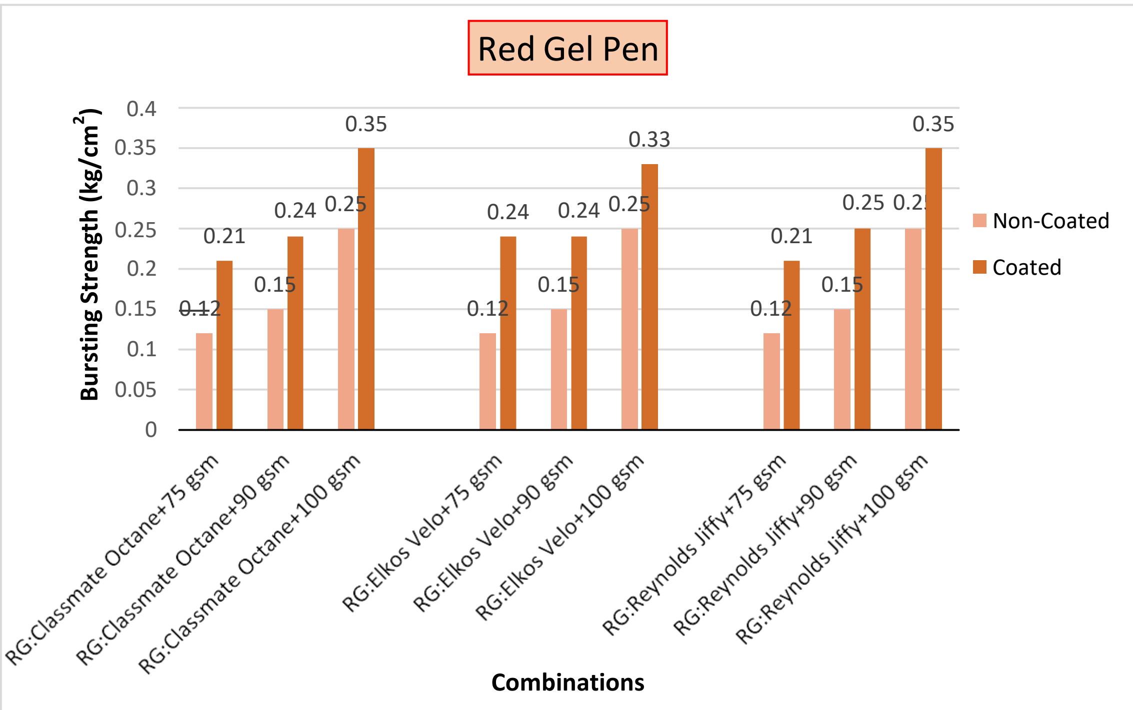



**Figure 4.72: Graphical representation of the increase in Bursting Strength between Non-Coated and Coated charred documents made using Red Gel Pens on 75 gsm, 90 gsm, and 100 gsm paper.**

It is evident from the above figures that the bursting strength was significantly increased in comparison to the non-coated charred documents by treating and coating the charred documents of each paper type and combination with starch-based analog. This may be because the starch-based analog can fill in between the fibers of charred paper and enhance the adhesion of the fibers, thus hindering their sliding and stretching. Therefore, the integrity of the document is sustained now since the increase in the strength of coated fragile charred documents helps maintain their integrity during handling and examination. Fragile documents are prone to damage or fragment loss, compromising the content and making analysis challenging. Thus, strengthening the documents ensures their physical stability and prevents further deterioration [191].

# CHAPTER-5

# CONCLUSIONS

Charred documents are basically such documents that either intentionally or accidentally met with a fire incident. Stabilization and decipherment can be done only to those fragile charred documents, charred to such a state, sturdy enough to handle until they do not catch fire, which turns them into ash. In addition, the conventional methods used in the stabilization and decipherment of charred documents are associated with many issues, like their chemical nature, toxic effect, and non-sustainability. In contrast, the use of starch as an alternative to a problem associated with charred documents examination was proposed since starch, being a non-toxic, sustainable resource, biodegradable with many other properties as a coating material, was found appropriate to bring into the picture in the field of forensic document examination. Problems associated with starch as a stabilizing agent, such as opacity and brittleness, can be overcome by substituting that with their analog, which was found transparent, easy to apply, and the formation of the smooth coating layer on the documents.

Current research entitled **"Stabilization and Preservation of Charred Documents Using Natural Polysaccharide and their Decipherment"** involved the synthesis of starch-based analog in preserving and deciphering the charred document, which was found very effective and can be claimed as a potential candidate for preserving the documents obtained at arson cases as well as to decode the content written on the charred documents that got partially or completely invisible after charring. Furthermore, the use of starch as a green material, along with glycerol to synthesize the coating material and the use of microwave irradiation made this study completely green and sustainable. No use of harmful solvents made this work safer and more eco-friendly.

The significance of employing starch-based analog as an effective material in stabilizing and preserving charred documents and facilitating the decipherment of invisible texts gave promising results. Also, for non-deciphered content, some of the combinations were facilitated by applying an advanced decipherment technique that incorporated algorithms in optical character recognition tools via G-lens and sophisticated optical instruments VSC. Therefore, synthesizing a novel stabilizing and decipherment material has yielded a cost-effective, easy, sustainable, and environment-friendly method. Moreover, the analog's adhesive and consolidating properties strengthened the fragile substrate and reveal invisible writings, ultimately ensuring their integrity during handling, examination, and analysis.

Moreover, the starch-based analog acted as a protective barrier, shielding the charred material from environmental factors that could accelerate degradation. The application of the starch-based analog demonstrated promising results, as it effectively stabilized the charred samples by providing a coating over the charred surface that increased their strength, minimizing their susceptibility to crumbling and loss of information. This was evaluated based on the bursting strength of the coated and non-coated charred documents to assess their preservation, and it was found that the analog provided an increase in strength of stabilized and coated charred documents compared to non-stabilized charred documents.

Hence, based on these findings, it was concluded that this application of starch-based analog holds great potential for the preservation and restoration of charred documents, enabling future decipherment and the retrieval of valuable content. The study can contribute to forensic document analysis and provide valuable insights for professionals involved in the preservation and deciphering of charred documents. In addition, the findings can contribute to the potential use of charred documents as evidence, as they can be stabilized and deciphered even after exposure to high temperatures using a starch-based analog.

## FUTURE SCOPE

**1.** The study suggests exploring more pronounced techniques for deciphering charred documents made with inks consisting of gel-based solvents.

**2.** The study suggests to explore the results based on more combinations of pens, like fountain pens, markers, etc., on different grades and colours of paper.

**3.** The study suggests to explore the use of starch-based analog for more forensic significance; for example, it may be used as secret writing as invisible writing ink.

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