

**Recreating van der Wielen and de Groot's (2019) thermocasted
Paraloid™ B-72, with a twist.**

by

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Submitted for the partial fulfilment of the degree
MSocSci Cultural Heritage Studies: Heritage Conservation

in the

SCHOOL OF THE ARTS
FACULTY OF HUMANITIES
UNIVERSITY OF PRETORIA

NOVEMBER 2024

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ABSTRACT AND KEY TERMS

Conserving stained glass is very challenging – when a replacement glass piece is inserted, the lead can become distorted due to the inflexibility of the glass, resulting in more pieces dislodging. Van der Wielen and de Groot (2019) devised a method to use thermocast resin for replacement parts because of resins' greater flexibility and colour-matching capabilities. This dissertation attempts to recreate van der Wielen and de Groot's (2019) proposed new method of thermocasting Paraloid™ B-72 for use in glass conservation. The primary objective is to successfully recreate thermocasted Paraloid™ B-72 and test this new method's reproducibility. The experiments found that although this method is reproducible, a significant amount of further research must be completed to create a standard procedure for thermocasting. The results of this study will aid in furthering glass and stained-glass conservation, particularly in arid and hot climates. The reproduction of this article was not entirely successful, and it emphasises the need for more detailed research and documentation to create a standard procedure for thermocasting.

Keywords:

Paraloid™ B-72, Paraloid™ B-48N, glass conservation, thermocasting, thermocasted, adhesive, conservation

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DECLARATION OF ORIGINALITY

1. I understand what plagiarism entails and am aware of the University of Pretoria's policy in this regard.
2. I declare that this mini-dissertation is my own, original work. Where someone else's work was used (Whether from a printed source, the internet, or any other source) due acknowledgement was given and reference was made according to department requirements.
3. I did not make use of another student's previous work and submitted it as my own.
4. I did not allow and will not allow anyone to copy my work with the intention of presenting it as their own work.

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ACKNOWLEDGEMENTS

First and foremost, I would like to thank the Andrew W. Mellon Foundation for granting me the Andrew W. Mellon Scholarship, allowing me to fund and complete my master's degree.

Secondly, I want to thank my supervisors for helping me throughout this journey. Without their help, guidance, and patience, I would not have had a dissertation to submit. They never gave up on me through all the stress and doubts; they stuck with me.

To all my loved ones, friends, and family, thank you. To everyone who has helped me through this process, thank you for your unending encouragement, patience, and understanding. Without your support, I would not have come this far in my studies, and there would be no dissertation. Words cannot describe how thankful I am for this support.

CHAPTER ONE:

1.1. Background and identification of the research issue

The origin of glassmaking is believed to extend back beyond 4,000 years, originating in ancient Mesopotamia, current day Iraq (Davison, 2003:16). This craft has played a crucial role in the technological advancements and innovations of humanity. Glass artefacts, ranging from beads that attest to trade among ancient civilisations, to equipment utilised in scientific and medical advancements,¹ have been integral to human society. In recognition of glass's significant impact on societal development, the United Nations and ICOM-Glass proclaimed 2022 the International Year of Glass (International Year of Glass, 2021).

Given its importance in advancing knowledge, glass is also an element of our cultural heritage that necessitates preservation. Many heritage or cultural objects are composed of glass; however, their maintenance poses challenges due to the material's inherent fragility. Various factors contribute to the deterioration of glass objects within collecting institution environments, including physical damage, moisture, light, ultraviolet radiation, and environmental pollutants (Al-Azzam, 2011:32-40). When glass artefacts deteriorate specifically due to physical forces and damage, the glass objects can be remedied by re-adhering broken fragments and cracks through suitable conservation adhesives.²

Paraloid™ B-72³ (or Acryloid® B-72) is an acrylic copolymer resin widely used by conservators due to its long-term chemical stability and resistance to degradation from oxidation, light, and hydrolysis (Davison, 2009:110; Koob, 1986:7). This resin does not yellow over time, and is reversible, allowing for future interventions and removal if necessary (Koob, 1986:7). Paraloid™ B-72 is purchased in solid, dry, pellet form which can then be dissolved in a range of solvents, in concentrations ranging from 5%

¹ This equipment can range from multiple glass objects such as glass beakers, distillation columns, desiccators, extraction systems, and reaction tubes (Corning, 2024).

² An adhesive can be defined as a substance that is capable of joining materials through surface attachment (Down, 2015:1).

³ Paraloid™ B-72 is a trademarked solid grade thermoplastic acrylic resin by company Rohm and Haas (Rohm and Haas, 2007).

solutions used to consolidate, to 50% solutions for adhesion, which makes it adaptable for a variety of applications (Koob, 2015:189-190). Paraloid™ B-72 dries transparent and has a similar refractive index,⁴ 1.49, to that of glass (Davison, 2003:217).⁵ Due to the previously mentioned factors, Paraloid™ B-72 is often the preferred choice of adhesives during conservation treatments.

In a recent study by conservators in the Netherlands, Roy van der Wielen and Suzan de Groot (2019) introduced a novel technique for casting Paraloid™ B-72 using heat, termed 'thermocasting'. This approach eliminates the necessity for solvents and produces a resin that exhibits high resistance to yellowing, bubble formation, and physical damage (van der Wielen & de Groot, 2019).⁶ While 'thermocasted' Paraloid™ B-72 is a relatively recent development in the field of conservation, it holds significant potential, warranting further exploration and research for its application in glass conservation. The primary objective of this master's mini-dissertation was to advance knowledge regarding 'thermocasted' Paraloid™ B-72. The steps to achieve this, as well as the related objectives and aims, will be expanded in section 1.3 of this chapter.

1.2. Significance of the study

Conservation is still an ever-expanding field with new and innovative ways of conserving cultural and tangible heritage. These developments can set the standard for future conservation and preservation practices globally. To achieve this standard practice, these new developments must be tested repeatedly to ensure that they are easily reproducible and do not cause any damage to the object on which they are used. This mini-dissertation is testing these things on this new thermocasting process to see if the original research is reproducible in a different, particularly warmer, environment.⁷ Traditional methods of solvent-cast Paraloid™ B-72 often include toxic

⁴ The refractive index (RI) is a measure of how much light is bent or changed in speed as it passes through various transparent materials (Down, 2015b:24).

⁵ The refractive index of a transparent object is important when choosing an adhesive for conservation. If the adhesive's refractive index is very different from that of the object, distortion will happen, making the glue line of the fix very visible. If the adhesive's and object's refractive indexes are near identical, the glue line will be almost invisible (Down, 2015b:24).

⁶ Solvent-cast Paraloid™ B-72 is notorious for bubble formation during its creation. To prevent this, the solvent evaporation procedure must be strictly followed. The entire process may require several days to a week to cure completely (van der Wielen & de Groot, 2019:112).

⁷ South Africa has a much warmer climate than many European countries, particularly during heat waves that frequent the country.

solvents such as xylene and toluene, posing a risk to the conservator and the environment (Koob, 2015:189). As stated earlier, solvent-cast Paraloid™ B-72 has a noted behaviour of bubble formation, which can impact the stability of the adhesion (van der Wielen & de Groot, 2019:112). In addition, Paraloid™ B-72 is unsuitable for warmer regions and climates as it has a glass transition temperature of 40°C, making it unsuitable for objects placed outdoors or objects exposed to direct sunlight (Koob, 2009:117). Eliminating these challenges associated with solvent-cast Paraloid™ B-72 through the thermocasting process can potentially be the future of glass conservation by creating an improved adhesive and filler for glass conservation practices.

1.3. Aim and objectives of the study

This mini-dissertation aims to use Paraloid™ B-72 to re-create van der Wielen and de Groot's (2019) thermocasting process and test if it is reproducible for Southern African conservation practises. Their research and proposed method only use the thermocasting process for Paraloid™ B-72. However, for this study, Paraloid™ B-48N was also tested using this method. Using a combination of these specific adhesives is due to the literature supporting that a mixture of these adhesives works well in warmer climates. This is further discussed in chapter two, section 2.6.

After the primary aim of this mini-dissertation was established, the subsequent objectives (in chronological order) to recreate van der Wielen and de Groot's (2019) thermocasting process using Paraloid™ B-72 and Paraloid™ B-48N are as follows:

1. Recreate the thermocasting process according to the process outlined in van der Wielen & de Groot (2019) using Paraloid™ B-72.
2. Recreate the thermocasting process according to the process outlined in van der Wielen & de Groot (2019) using Paraloid™ B-48N.
3. Recreate the thermocasting process according to the process outlined in van der Wielen & de Groot (2019) using a mixture of Paraloid™ B-72 and Paraloid™ B-48N in the following concentrations:
 - a. 25% Paraloid™ B-72 : 75% Paraloid™ B-48N
 - b. 50% Paraloid™ B-72 : 50% Paraloid™ B-48N
 - c. 75% Paraloid™ B-72 : 25% Paraloid™ B-48N

4. Compile the findings of the various thermocasting experiments and compare results to the original paper (van der Wielen & de Groot, 2019).

1.4. Research methodologies

This mini-dissertation used a combination of theoretical and empirical research methodologies to achieve the objectives set above. Van der Wielen and de Groot's (2019) research on Paraloid™ B-72 and their proposed method for thermocasting was consulted to create a methodology to recreate the process. Once this was achieved, the reproducibility of this new method was tested through various sample creation experiments.

1.5. Overview of chapters

This mini dissertation is divided into five chapters and comprises the following:

Chapter One discusses the study's background, identifies the research issues explored, and explains why this study is significant to the conservation field in Southern Africa. The study's aim and objectives, as well as the research methodology, are explained in detail.

Chapter Two explores the gap in the literature surrounding the topic of thermocasting Paraloid™ B-72. Afterwards, the most relevant resources and literature to this study are discussed, why each source is relevant and valuable, and the downfalls of the literary sources. The third chapter reviews the sourcing of the different equipment, tools, and materials for reproducing the experiment. This section also details the characteristics of both Paraloid™ B-72 and Paraloid™ B-48N.

The fourth chapter of the mini-dissertation documents the process of creating the samples. It describes how each sample was made, reviews how each resin behaved during the process, and describes how the samples were set. The fifth chapter concludes this mini-dissertation by briefly reviewing the different chapters, the experiments' findings, and further studies that should be conducted.

CHAPTER TWO:

2.1. Introduction

For this mini-dissertation, it was essential to establish what has already been written on Paraloid™ B-72 and B-48N. This chapter is focused on reviewing literature that has already been written on the topics explored and used as a theoretical basis for this dissertation. The purpose of this literature review is to provide a comprehensive analysis of existing research on both Paraloid™ B-72 and B-48N. This includes critically analysing the core sources and discussing how each contributes to understanding the research topic.

The following chapter and literature are divided into five themes that were the focus of this research. The first theme deals with the history of early restoration and the adhesives used to conserve ceramic and glass objects.⁸ After discussing the history of restoration and conservation, selecting an appropriate adhesive for a treatment plan is discussed, focusing on the preferable criteria for choosing an adhesive for the desired treatment plan.

The third section provides an in-depth evaluation of the primary source used. As this study examined the reproducibility of van der Wielen and de Groot's (2019) thermocasting technique, their paper must be evaluated to derive a clear plan to recreate the process. This includes any gaps within the paper and factors that need further research. This literature review's fourth and fifth sections examine the core sources of Paraloid™ B-72 and B-48N. These sections review the source's contents, identify gaps within those literary pieces, and explain why it is a core source for this paper.

It is important to note that this literature review differs slightly from other academic works. This is because van der Wielen and de Groot's (2019) paper documents a

⁸ As ceramic and glass are similar in terms of conservation methods and techniques, they are often grouped together.

process that is the first of its kind, so there are no other sources about the thermocasting process of Paraloid™ B-72.

2.2. Use of Resin Through History

Throughout the ages, humans have been craftsmen. Humans create tools to ease workloads or make visually aesthetic objects. As with all things, these objects age and degrade to a degree where intervention is needed before the object is completely lost. This need to fix objects to prevent loss has been instilled in humans since an early age.

2.2.1. Early history of restoration

During the Neolithic Era, evidence shows that humans repaired their broken vessels (Dooijes & Nieuwenhuyse, 2009:7-10).⁹ The technique involved using a flint or obsidian tool to drill holes along the break and adhere the sherds with an organic material such as leather or rope. During this same period, in other areas of the Near East, bitumen was used instead of cords made of organic materials. These two techniques were often used together, and the bitumen could have been used to waterproof these breakages (Dooijes & Nieuwenhuyse, 2009:7-8). After ceramics were introduced,¹⁰ these same techniques were implemented with ceramic vessels. These Neolithic repairs were not applied to every vessel, only those that were associated with high-quality vessels used for serving (Dooijes & Nieuwenhuyse, 2009:8). Various excavation sites across Europe and Asia that date from approximately 7000 B.C.E. have held earthenware objects that show signs of repairs using natural adhesives such as metal rivets, wire, plaster, and animal glues (Garachon, 2010:36). Later, during the Uruk period,¹¹ a different approach to vessel repair emerged, using bitumen in various methods (Dooijes & Nieuwenhuyse, 2009:9-10) primarily.

⁹ The Neolithic Era is a period that lasted from 8000 B.C.E. to 5000 B.C.E. (Dooijes & Nieuwenhuyse, 2009:8).

¹⁰ Dooijes and Nieuwenhuyse (2009:8) suggests that ceramics were introduced approximately 7000 B.C.E.

¹¹ The Uruk period was approximately from 3200 to 3000 B.C.E. (Dooijes & Nieuwenhuyse, 2009:9-10).

During an excavation of a Late Bronze Age Middle Assyrian settlement, multiple pottery workshops and repaired vessels were found.¹² These repaired vessels displayed the techniques of previous periods, except that gypsum or lime paste was used instead of bitumen to fill holes or cracks. Occasionally, these repaired vessels were fired again after a clay cover was applied (Dooijes & Nieuwenhuyse, 2009:10). Due to the manner of these repairs, the argument was made that aesthetics was not a concern, but instead, the function of the vessel was prioritised (Dooijes & Nieuwenhuyse, 2009:10-11).

Unlike ceramics, cases of adhered archaeological glass are slim;¹³ natural glues could have deteriorated during burial or were washed away during the excavation process (Eggert & Straub, 2009:3). Two standard techniques of mechanical adhesion were employed at archaeological sites. In one method, broken glass fragments were reassembled using molten glass as an adhesive. In a similar approach, metal was used for mechanical adhesion, where precise holes were drilled along the fractures, and the fragments were subsequently repaired with metal rivets or silver wire. These drilled holes were sealed with molten mastic to ensure a watertight seal (Eggert & Straub, 2009:3).

2.2.2. Natural Adhesives

People used various methods to join or adhere to broken glass and ceramic objects when repairing objects,¹⁴ such as cellulose nitrate, iron clamps or shellac.¹⁵ However, these joining and adhesion methods were subpar and would separate from the glass and ceramic objects within 20 years (Koob, 2003:158). Additionally, naturally occurring materials were used for adhesion: gypsum, waxes, and plant and animal resins. These adhesives were unappealing due to their colour and were prone to dry out, leading to embrittlement and shrinkage over a period (Davison, 2009:108). Before synthetic

¹² The Late Bronze Age was a time from approximately 1200 B.C.E. (Dooijes & Nieuwenhuyse, 2009:10).

¹³ This is due to the degradation of the adhered glass.

¹⁴ As noted, glass and ceramics are often grouped together, however, there are considerable differences between the two mediums. Regarding adhesion, ceramics in nature have a degree of porosity, while glass is essentially non-porous (Davison, 2009:107). Due to the non-porous nature of glass, adhesives will not be absorbed into the exposed surface.

¹⁵ Shellac is an adhesive, soluble in alcohol, deposited by the *Tacchardia lacca* insect onto the surface of trees, after which it is harvested and refined for use. Shellac polymerises into a thick, dark brown substance that is virtually insoluble and very difficult to remove (Davidson, 2009:108; Derry, 2012:20).

adhesives were developed, natural adhesives were used to repair objects. From the eighteenth century onwards, recipes for natural glues often included egg whites, natural resins, waxes, and oils (Garachon, 2010:40).

There are two broad categories of natural resins: those that are derived from plants and those derived from animals (Williams, 1995:[sp]). The most common animal-based resin is shellac, while there are dozens of popular plant-derived resins (Williams, 1995:[sp]). Only from the 17th century were solvents used for dissolving and applying resins in conservation efforts (Horie, 2013:9). These techniques were later developed, and from the late 19th century, materials such as natural rubbers and paraffin wax were applied to objects for conservation purposes (Horie, 2013:9).

Specifically for glass conservation, various animal glues derived from fish, bone, horn, and hide were manufactured as an adhesive. They were applied on the edges of a broken object as a warm liquid and left to cool down into a gel state between two sherds. As this gel state cooled down further, it shrank through water loss, creating enough tension to lose adhesive force and come loose from the glass surface (Davidson, 2009:108).

2.3. Selecting an Appropriate Adhesive

Resins are used for many different purposes in conservation, such as consolidants,¹⁶ adhesives, coatings, moulding, casting, support stands, and for the display and storage of materials (Horie, 2013:3). Stephen Koob (2006:47) describes several requirements adhesives must meet to be successful in glass conservation.¹⁷ First, the adhesive should not harm or damage the glass object during the application, curing, or ageing. Secondly, adhesives need to bond well with the glass surface to succeed. Thirdly, the adhesive should be reversible and not threaten the stability or overall 'health' of the glass object during the reversal process. Fourth, when adhering to glass objects, the chosen adhesive should be transparent for a more cohesive and

¹⁶ A consolidant is a product that is introduced to a deteriorated material to compensate for the loss of material (Down, 2015:1).

¹⁷ These requirements are based on global conservation ethics that guide the assessment of suitable adhesives. They are: 1) the treatment must not adversely affect the object; 2) the adhesive must be compatible with the treatment process and should not prevent future treatments; 3) the adhesive should be weaker than the material that is treated; 4) adhesives should be reversible; 5) using adhesives should not be an invasive treatment; 6) the adhesive should have good aging properties, and must be chemically and physically stable over time; and 7) the adhesive should be inexpensive (Down, 2015a:1; Dignard, 2015:117).

aesthetically pleasing appearance. Fifth, the adhesive should remain stable within a museum environment for at least 100 years. Lastly, the adhesive should be easy to use, and the process should be reproducible. Koob (2006:47) recommends two adhesives for glass conservation that meet the previously mentioned requirements: Paraloid™ B-72 and epoxy resins.

Besides the requirements identified by Koob (2006:47), which directly apply to glass conservation, Carole Dignard (2015:118) lists five adhesive properties that should be considered before selecting an appropriate adhesive:

- 1) Strength: The strength needed in a repair must be assessed, including whether the bond will be load-bearing and which present and future stresses are predicted. The adhered repairs will need to overcome these stresses exerted during handling and display, as well as changes in relative humidity and temperature (Dignard, 2015:118).
- 2) Flexibility: The flexibility of an adhesive is related to its glass transition temperature (T_g).¹⁸ Polymers with a lower T_g are more flexible, while polymers with a higher T_g are more brittle. Adhesives with a T_g around or below the room temperature of their environment can remain tacky, attracting dust or sticking to other materials. The flexibility of the area after repair will depend on the flexibility of the chosen adhesive, how deep it penetrates the object's surface, and the thickness of the adhesive (Dignard, 2015:118).
- 3) Viscosity and Penetration: An adhesive with the desirable viscosity for a specific treatment plan is often desirable.¹⁹ In addition, the porosity of an object is also an essential factor when choosing an adhesive, as the viscosity of the adhesive will determine how deep into the object's surface it

¹⁸ The glass transition temperature of a material is the lowest temperature where the material will start changing from a solid, into a more liquid state (Conservation Unit Museums and Galleries Commission, 2013:42).

¹⁹ Viscosity is the resistance a liquid offers to flowing; the larger the molecules in a substance, the greater the viscosity and its resistance to flow. The lower the viscosity of a liquid, the more easily it will flow (Conservation Unit Museums and Galleries Commission, 2013:19).

will penetrate.²⁰ The acquired penetration depth will depend on the porosity of the object's surface (Dignard, 2015:118).²¹

- 4) Adhesive surface deposits and gloss: Surface appearance and its characteristics, such as refractive index, should not be altered by an adhesive or accompanied solvent (Dignard, 2015:118).
- 5) Drying time: Adhesives characterised by rapid drying times are favoured in straightforward treatment plans. However, adhesives that exhibit prolonged drying periods are advantageous in treatment plans that need intricate planning and strategic execution, particularly when adhering pieces into precise positions (Dignard, 2015:118).

2.3.1. Glass and Epoxy Resins

Epoxy resins are considered thermosetting resins and consist of a two-part system: a resin and a hardener.²² When these two parts are combined, their atoms crosslink over time to create a solid and insoluble polymer (Koob, 2015:191). According to Koob (2003:158), epoxy resins are excellent to use for the repair of clear, colourless glass, high-fired ceramics, and plaster objects for aesthetic reasons, as epoxy resins are clear when cast (Schuck, Fischer & Schwahn, 2019:131; van Beeman *et al*, 2013:79). Another advantage of epoxy resin is that they have different refractive indexes and can be matched by a conservator to the glass object in order to blend the adhered area into the surrounding glass (Koob, 2003:158). However, one major drawback of epoxy resins is their tendency to yellow and lose mechanical properties over time (Coutinho *et al*, 2009:127; Down, 1986:159). An additional disadvantage to epoxy resin is its extremely high strength and is difficult to reverse (Koob, 2015:192). For this reason, using epoxy resin for glass conservation is often not advised, as the cured epoxy can be harder than the glass itself.

²⁰ Porosity can be defined as the pore space in the total volume of a material, the space that is not occupied by any solid matter (Conservation Unit Museums and Galleries Commission, 2013:126).

²¹ This adhesive property would not be relevant to glass conservation as glass is non-porous and the adhesive would not penetrate the material.

²² A thermosetting resin undergoes a chemical process that leads to an insoluble product that cannot be undone by heat or dissolved in a solvent (Down, 2015a:4).

2.4. Evaluation of Primary Source: van der Wielen & de Groot (2019)

The primary source of this study was presented at the Interim Meeting of the ICOM-CC Working Group in 2019 in London, England. It presents the preliminary findings of a new method of using Paraloid™ B-72 without solvent evaporation. Instead, the method uses heat to melt pure Paraloid™ B-72 in silicone moulds to create flat samples for lost glass fragments (van der Wielen & de Groot, 2019:111).

2.4.1. Introduction

Van der Wielen & de Groot (2019:111) start their paper with a good introduction, stating the primary concern in resin infills in glass conservation and the risks associated with using resins, both to the object and the conservator. The paper then introduces Paraloid™ B-72 and states that they propose an alternative method of using this resin in indoor stained-glass conservation (van der Wielen & de Groot, 2019:112).

2.4.2. Thermocasting Paraloid B-72: heating Paraloid B-72

This section of the paper discusses the heating of Paraloid™ B-72 and the varying temperature (180°C) at which the optimal viscosity of the resin is met and at which temperature (200°C), due to too much heat the resin will yellow and form bubbles (van der Wielen & de Groot, 2019:112).

The next part speaks about preparing the Paraloid™ B-72 for the heating process. This includes details such as the measurement of the sieve that the processed resin pellets need to pass through (500µm) and the oven settings used in thermocasting (van der Wielen & de Groot, 2019:113). It also mentions that thermocasting Paraloid™ B-72 makes it less sensitive to moisture than using it with solvents.

2.4.3. Thermocasting Paraloid B-72: *thermocasting in silicone rubber*

This section briefly mentions using a silicone mould and then jumps straight to the thermocasting process; little information is given on the moulding process or the mould itself (van der Wielen & de Groot, 2019:114). The process of the thermocasting is explained; however, there is no mention of the cooling process of the samples, which can influence their outcome. The lack of information and guidance on the cooling process made reproducing the method more difficult. Nevertheless, this is expanded on in Chapter Four.

2.4.4. Thermocasting Paraloid B-72: light-aging of thermocast Paraloid B-72

As stated by Down (1986:159), resins tend to yellow over time, and so van der Wielen and de Groot (2019:114-115) have age-tested their thermocasted Paraloid™ B-72 to determine if the sample would yellow when exposed to UV radiation.

2.4.5. Colouring Thermocast Paraloid B-72: dyes and pigments

The colouring section of the van der Wielen and de Groot (2019:115) article describes the colouring of resins using dyes and pigments and explains why this same process cannot be used for thermocasted samples. The process used for colouring the thermocasted samples involves heating the resin on a hot plate; however, this process is not explained clearly and should be studied further.

2.4.6. Colouring Thermocast Paraloid B-72: Heat-Fused Surface Colour

Van der Wielen and de Groot (2019:115-118) have provided two different methods to colour thermocasted Paraloid™ B-72, using dyes and pigments mentioned above and heat-fusing the colour to the surface of the thermocasted sample. This process is explained, but details are omitted, which can lead to confusion when recreating this method. This section ends by stating that the long-term stability of both colouring processes has yet to be studied.

2.4.7. Limitations and further research: Silicone rubber mould material

The next part of the article is dedicated to the study's limitations and further research that should be conducted in the thermocasting process. The article states that the relationship between silicone rubber moulds, both in material and shape, should be further researched, as thermocasting is still a new technique being developed.

2.4.8. Limitations and further research: Mechanical properties

Van der Wielen and de Groot (2019:118) mention that due to solvent-cast Paraloid™ B-72 films retaining some degree of flexibility, the mechanical properties should still be studied further. There are no mentions of specific mechanical properties that should be tested, nor of how this further research is related to thermocasted Paraloid™ B-72. Additional research should be conducted on the mechanical properties of thermocasted Paraloid™ B-72, but this was beyond the scope of this study.

2.4.9. Limitations and further research: Solvent vapour release

As heating the Paraloid B-72 is a new technique, little is known about its safety aspects and whether it harms the conservator using the thermocasting process. Van der Wielen and de Groot (2019:118) mention possible risks when heating Paraloid B-72, such as solvent and other vapours that could be released.

2.5. Paraloid™ B-72

As this mini-dissertation works with Paraloid™ B-72, it is crucial to research and read the literature that is already written about the subject. Paraloid™ B-72 has been used and researched for decades and is well-covered in the academic and conservation fields. Two core sources were used when researching and referencing Paraloid™ B-72; they are as follows:

- *Paraloid B-72®: 25 years of use as a consolidant and adhesive for ceramics and glass* (2009), by S Koob, is a chapter in the book *Holding it all Together* (2009) edited by J Ambers, C Higgitt, C Harrison & D. Saunders, detailing the use of Paraloid™ B-72 in the conservation field. This chapter on Paraloid™ B-72 speaks to the adhesive's history, advantages, use, and preparation. This chapter is a brief but impactful overview of Paraloid™ B-72 for use in ceramic and glass conservation and aided this study with the abovementioned topics.
- *New developments for casting Paraloid™ B-72 for filling losses in glass* (2013), by N.A.R Van Giffen, S.P Koob and R O'Hern, is a conference paper in *Recent Advances in Glass, Stained-glass, and Ceramic Conservation 2013*. This source details what characteristics in a resin or adhesive are necessary for a successful cast for glass infilling, and why Paraloid™ B-72 is a suitable resin. This source provides a rough guideline for the characteristics that must be considered and searched for in an adhesive for conservation treatment.

2.6. Paraloid™ B-48N

Paraloid™ B-48N is not as well studied and explored as Paraloid™ B-72. This could be because it is not as versatile in conservation treatments as it is primarily used when working with metals (CAMEO, 2022a). As such, the following core sources were used for more of a theoretical background to Paraloid™ B-48N than any practical use.

- *Paraloid® B-72/B-48N 1:1 as an adhesive for Use in Hot Climates: Literature Review, Laboratory Testing, and Observational Field Study* (2021) by S.L Davis, C Roberts, and A Poli is a conservation paper focusing on a hybrid adhesive. This paper focuses on an experiment mixing Paraloid B-72 and B-48N as a hybrid adhesive, especially in hot climates.²³ This is a core source as it explores creating a mixed adhesive from these two adhesives, documenting whether and how the combined adhesives work. Although the paper discusses solvent evaporated Paraloid™, this research benefitted from this source because it led to combining the two adhesives. Of course, neither the processes nor the results are the same, but this study provided insight into mixed adhesives.
- *Analytical Observations Regarding Butvar B-98 and Paraloid B-72 Blends as a Suitable Adhesive in Hot Climates* (2017), by P.L Schmidt, A Shugar, and R Ploegar is a conservation paper also exploring hybrid adhesives. This conservation article also discusses creating a hybrid adhesive for specific use in hot climates. However, this research included the adhesive Butvar B-98. This mini-dissertation did not use this adhesive, but rather the article's use of the hybrid adhesives; it goes into quite detailed descriptions of creating the hybrid adhesives in terms of the physical process of it but also the ratios used and the results of each ratio. This is an essential source in understanding hybrid adhesives, especially between Paraloid™ B-72 and Paraloid™ B-48N, and how they turned out even a month after casting. As mentioned, these hybrid adhesives are solvent-evaporated and not thermocasted, but they still provide relevant information.

2.7. Adhesives sources

This literature review section covers the sources used regarding adhesives in general. They clarified the fundamentals of adhesives, the relevant properties of adhesives, and how they function and make adhesives successful or not. The following two sources were used to gain a better understanding of adhesives.

²³ Due to Paraloid™ B-72 T_g being 40°C (CAMEO, 2022b), it is often difficult to use in areas where the average temperature is equal or exceeding this temperature (Davis, Roberts, & Poli, 2021:358).

- *Adhesives Compendium for Conservation* (2015), compiled by J.L. Down, is a collection of chapters by various authors. This book entails the basics and intricacies of adhesives in an easily understandable manner: how adhesives work, the properties of adhesives, testing, and choosing the correct one for conservation purposes. This book provided insight into the fundamentals of adhesives and aided in the theoretical and practical understanding of adhesives.
- *Science for Conservators, Volume 3: Adhesives and Coatings* (2013), published by the Conservation Unit Museums and Galleries Commission, is a guide to various adhesives and coatings for conservation. This was another core source for understanding adhesives, their properties, and how they work. How this book is formatted provides detailed definitions and explanations. A downside of this book is that some topics are very vaguely covered, which can lead to misunderstandings.

2.8. Conclusion

Reviewing the literature surrounding thermocasted Paraloid™ B-72 presented specific challenges, as only one source specifically addresses this application. This limitation in available research highlights a gap in the current body of knowledge, particularly in understanding the nuances and practical implications of thermocasting with this material. However, the extensive literature on Paraloid™ B-72 significantly compensates for this shortcoming, offering valuable insights into its chemical properties, versatility, and established uses in conservation and materials science. Despite the scarcity of specific studies on its thermocasting properties, the general understanding of Paraloid™ B-72 provides a solid foundation for experimentation. As I approach the experimental phase, I am confident in my understanding of the material's fundamental characteristics, which will guide addressing the challenges and uncertainties that may arise. Further research into the thermocasting of Paraloid™ B-72 is essential to fill the existing gap and refine its application in various conservation practices. By building upon the existing literature and conducting targeted studies, future work can enhance our understanding of its performance and potential as a conservation material in different contexts.

CHAPTER THREE:

3.1. Introduction

This chapter is divided into five sections. The first three sections explain the sourcing process of the equipment, tools, and adhesives used to create the samples. The last two parts explore primarily the properties of both Paraloid™ B-72 and Paraloid™ B-48N.

3.2. Sourcing materials

As this study aims to test the reproducibility of thermocasting in a Southern African context, the materials sourced for the experiments should be easily accessible. The following tables document the materials used for recreating the thermocasting process. Firstly, the various equipment and tools used to create the samples in the thermocasting process, and secondly, the adhesives.

3.2.1. Sourcing Equipment

The following table documents the equipment used for the thermocasting processes:



Figure 1: Amber 21I Mini Kitchen Countertop Oven and Double Plate Stove.
Photograph by author.



Figure 2: Ibili Kitchen Aids Magnetic Digital Thermometer with probe. Photograph by author.



Figure 3: Bosch Coffee Grinder. Photograph by author.



Figure 4: USB Digital microscope. Photograph by author.

Table 1: Equipment used for the thermocasting process.

3.2.2. Sourcing Tools

The following table documents the tools used for the thermocasting processes:



Figure 5: Microfibre cloth. Photograph by author.



Figure 6: 500-micron nylon mesh from Dawning Filters in embroidery hoop. Photograph by author.



Figure 7: Stainless-steel sharp-nosed tweezers and spatula. Photograph by author.



Figure 8: Silicone casting moulds. Photograph by author.



Figure 9: Silicone baking mould. Photograph by author.



Figure 10: Personal Protective Equipment (PPE). Photograph by author.

Table 2: Tools used in the thermocasting process.

3.2.3. Sourcing Adhesives

The following table documents the adhesives used for the thermocasting processes:



Figure 11: Paraloid™ B-72 pellets. (ZOIC Palaeotech, 2024).



Figure 12: Paraloid™ B-48N pellets. (TALAS, 2024).

Table 3: Adhesives used in the thermocasting processes.

3.3. Paraloid™ B-72

Paraloid B-72 is trademarked and produced by the North American company Rohm and Haas (Rohm and Haas, 2007:1-2). As mentioned in Chapter One, Paraloid™ B-72 is an acrylic copolymer composed of ethyl methacrylate ($C_6H_{10}O_2$) and methyl

acrylate (C₄H₆O₂) (Schmidt, Shugar & Ploeger, 2017:1928; Baglioni *et al.*, 2014:6799). Conservators use it because it has long-term chemical stability and is resistant to degradation through oxygen, light, and hydrolysis (Koob, 2015:191). This resin also dries transparent and is reversible for future conservation (Koob, 1986:7). Additionally, Paraloid™ B-72 has a high T_g at 40°C and is safe to use as it can be activated using non-toxic solvents (Koob, 2015:189). Paraloid™ B-72 is a thermoplastic acrylic resin, so the bonds within the resin can be reversed using heat; this is considered an advantage as treatment is reversible (Koob, 2015:191).²⁴

3.3.1. Properties

The following are the physical properties of Paraloid™ B-72 (CAMEO, 2022b):

Soluble in	Toluene, xylene, acetone, ethanol, and carbon tetrachloride
Molecular weight	105 000 g.mol ⁻¹
T _g	40°C
Refractive Index	1.479-1.489
Melting point	150°C

Table 4: The physical properties of Paraloid™ B-72.

As the T_g of Paraloid™ B-72 is 40°C, archaeological conservators have noted this as a severe drawback when working in areas where the average temperatures regularly approach or exceed 40°C (Davis, Roberts & Poli, 2021:357).

3.4. Paraloid™ B-48N

Paraloid™ B-48N is also trademarked and produced by the North American company Rohm and Haas. Paraloid™ B-48N is a copolymer formed from the polymers methyl methacrylate (C₅H₈O₂) and butyl acrylate (CH₂=CHCOO(CH₂)₃CH₃) (Schmidt, Shugar & Ploeger, 2017:1928). It is primarily used as a clear coating for metals such as copper, brass, bronze, and zinc (CAMEO, 2022a).

²⁴ A thermoplastic polymer is characterised by its molecular structure where the polymer chains are not chemically bonded with one another. This arrangement enables the molecules to move freely past one another when the material is in a molten state or dissolved in a solvent. As such, thermoplastic polymers can undergo multiple cycles of melting and solidification through cooling (Down, 2015a:3-4).

3.4.1. Properties

The following are the physical properties of Paraloid™ B-48N (CAMEO, 2022a):

Soluble in:	Toluene, xylene, cellosolve acetate, methyl ethyl ketone, and acetone
Density	1.15 g.cm ³
Molecular weight	250 000 g.mol ⁻¹
T _g	50°C
Refractive Index	1.89
Melting Point	Not available

Table 5: The physical properties of Paraloid™ B-48N.

3.5. Conclusion

With all the equipment, tools, and adhesives acquired for this experiment, the next phase of the study, which involves the practical aspects of the research, can now proceed. This phase is arguably the more engaging component of the investigation. However, this chapter also includes essential information regarding the physical and chemical properties of the substances used, as understanding these characteristics is crucial for ensuring a safe laboratory environment.

CHAPTER FOUR:

4.1. Introduction

This mini-dissertation chapter is dedicated to the thermocasting processes and sample preparation. The experimenting processes did not go as expected when van der Wielen and de Groot's (2019) article was used as a guide. This chapter documents the challenges encountered and the steps before the sample preparation. The intended methodology of the sample preparation and the challenges faced thereof are documented and expanded on in this chapter. Each set of samples in the thermocasting process is recorded, accompanied by photographs of the created samples and the results of that particular set.

4.2. Challenges Encountered

At almost every stage of this experimental process, obstacles and challenges were encountered. Three significant challenges were encountered during this process. The first challenge was the lack of a fume cupboard. As a safety precaution, the experiments were conducted outside on the back patio of the UP Heritage Conservation Laboratory. Working outside did aid in escaping the fumes that were released in the thermocasting process. As a result of conducting the experiments outside, some foreign particles landed in the samples during the creation process. This can be seen in the samples' photographs throughout this chapter.

The methodology was the second major. A set methodology was planned out for conducting the thermocasting processes according to van der Wielen and de Groot (2019); however, during the first set of sample preparation, many of the results found were not in line with van der Wielen and de Groot's (2019) findings. These are discussed in the sections of this chapter below. After the process and results of the first set of samples were recorded, it was decided that the methodology would follow a more fluid approach. After a set of samples are created and the results recorded, the methodology for the next set of samples is adjusted slightly to observe any change in the samples. This resulted in fascinating results and is discussed further in each

section of the sample sets below. Any changes in methodology are recorded in each relevant section.

The third major challenge encountered was the various unknown elements within van der Wielen and de Groot's (2019) article. Many actions and procedures were not specified within their paper and required certain aspects to be slightly adapted. It was decided not to contact the article's authors, as the ease of reproduction of the thermocasting process is to be explored and recorded. The challenges mentioned earlier were the larger ones that affected each set of samples; any smaller or specific challenges or obstacles encountered are documented in the relevant section in which they were experienced.

4.3. Prebaking the mould before thermocasting

As per van der Wielen and de Groot (2019:114), before the resins can be cast, the moulds need to be prebaked; the process is as follows: the Amber Oven was preheated to 140°C, using the Ibili digital thermometer to ensure a more accurate temperature within the oven, this took approximately 5 minutes to reach the correct temperature. The Amber oven has a dial to set the temperature within the oven, and it was challenging to set the correct temperature as there are only LOW, 65, 150, 200, and 250°C settings on the oven. This challenge was overcome using the Ibili digital thermometer and multiple micro-adjustments to the dial.

While the Amber oven was preheating, the moulds were washed with dish soap and warm water, allowing them to air dry. Once the Amber oven was at the correct temperature, 140°C, the moulds were placed into the oven.²⁵ Opening the oven door allowed cool air to enter the oven and dropped the temperature. As soon as the temperature once again reached 140°C, a timer was set for two hours as per van der Wielen and de Groot (2019:114). After two hours, the silicone moulds underwent a visible change from milky-white to a brown/yellow colour. This was the first challenge encountered in the experimentation, as it was later deduced that the incorrect moulds

²⁵ As per van der Wielen and de Groot's (2019:114) article, they prepared their silicone moulds by baking them for two hours at 140°C.

were obtained. However, due to scientific curiosity, these moulds were still used for thermocasting to see the resulting outcome.

As the moulds were prebaked for the casting process, the Bosch coffee grinder was cleaned using a damp microfibre cloth and allowed to air dry, and the other elements for the casting process were prepared. After the Bosch coffee grinder was cleaned and dried, the Paraloid™ B-72 pellets were placed in the coffee grinder and ground with short pulses. It took multiple rounds of blitzing in the coffee grinder to allow the Paraloid™ B-72 powder to pass through a 500µm sieve encased within an embroidery hoop. The next challenge arose in this step of the preparations, as the Bosch coffee grinder has a small motor, which tended to overheat very quickly during the preparations of Paraloid™ B-72; the motor heated up to such an extent that the Paraloid™ B-72 powder started to melt and proceeded to get stuck in the motor. This was not easy to clean as spatulas and tweezers were used to pick the melted Paraloid™ B-72 out from beneath the blades of the coffee grinder. Afterwards, a mixture of ethanol and water (70:30) was used to eradicate the last of the Paraloid™ B-72 powder from under the blades and any heated powder residue from the bottom and sides of the coffee grinder bowl.

It should be noted that the powdered Paraloid™ B-72 acted unexpectedly; it was statically attracted to both the equipment and tools used to interact with it. This static attraction was not witnessed with the Paraloid™ B-48N under the same conditions. This is something that should be researched further for future studies. Below is a magnified image of the powdered Paraloid™ B-72. The red line indicated on the image represents 1 millimetre.

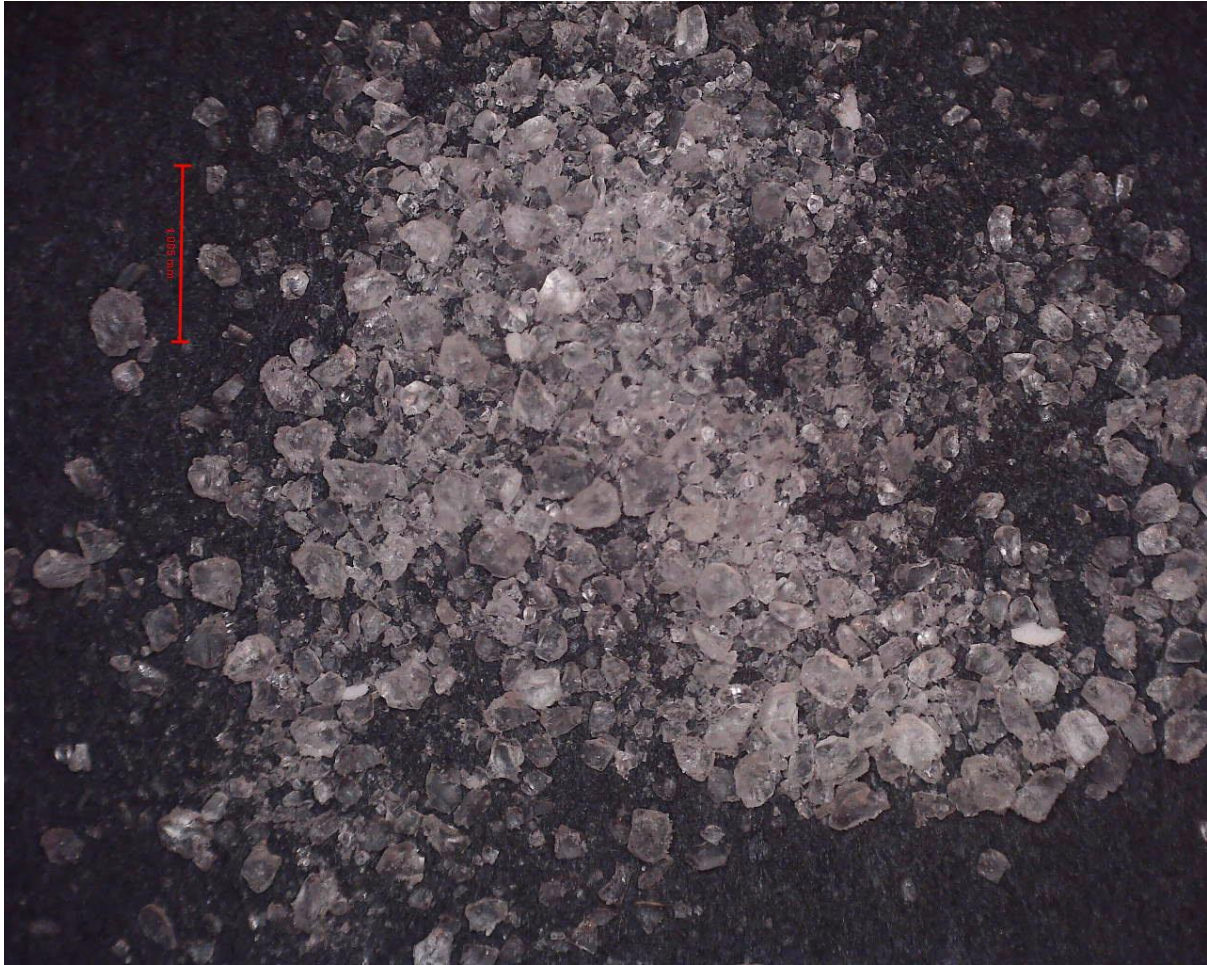


Figure 13: Microscopic image of powdered Paraloid™ B-72, taken using the USB Digital Microscope. The red line represents 1 millimetre. Photograph by author.

The Paraloid™ B-48N underwent a similar preparation before the thermocasting. The pellets were placed in the Bosch coffee grinder after it was cleaned and dried. The pellets were then ground with short pulses multiple times until the pellets were a fine powder. Grinding the Paraloid™ B-48N pellets went significantly quicker than the Paraloid™ B-72 pellets. The powdered Paraloid™ B-48N was then passed through the same 500µm sieve to ensure its suitability for thermocasting. The powdered Paraloid™ B-48N did not show the same static attraction displayed by the powdered Paraloid™ B-72. Below is a magnified image of the powdered Paraloid™ B-48N. The red line on the image represents 1 millimetre.

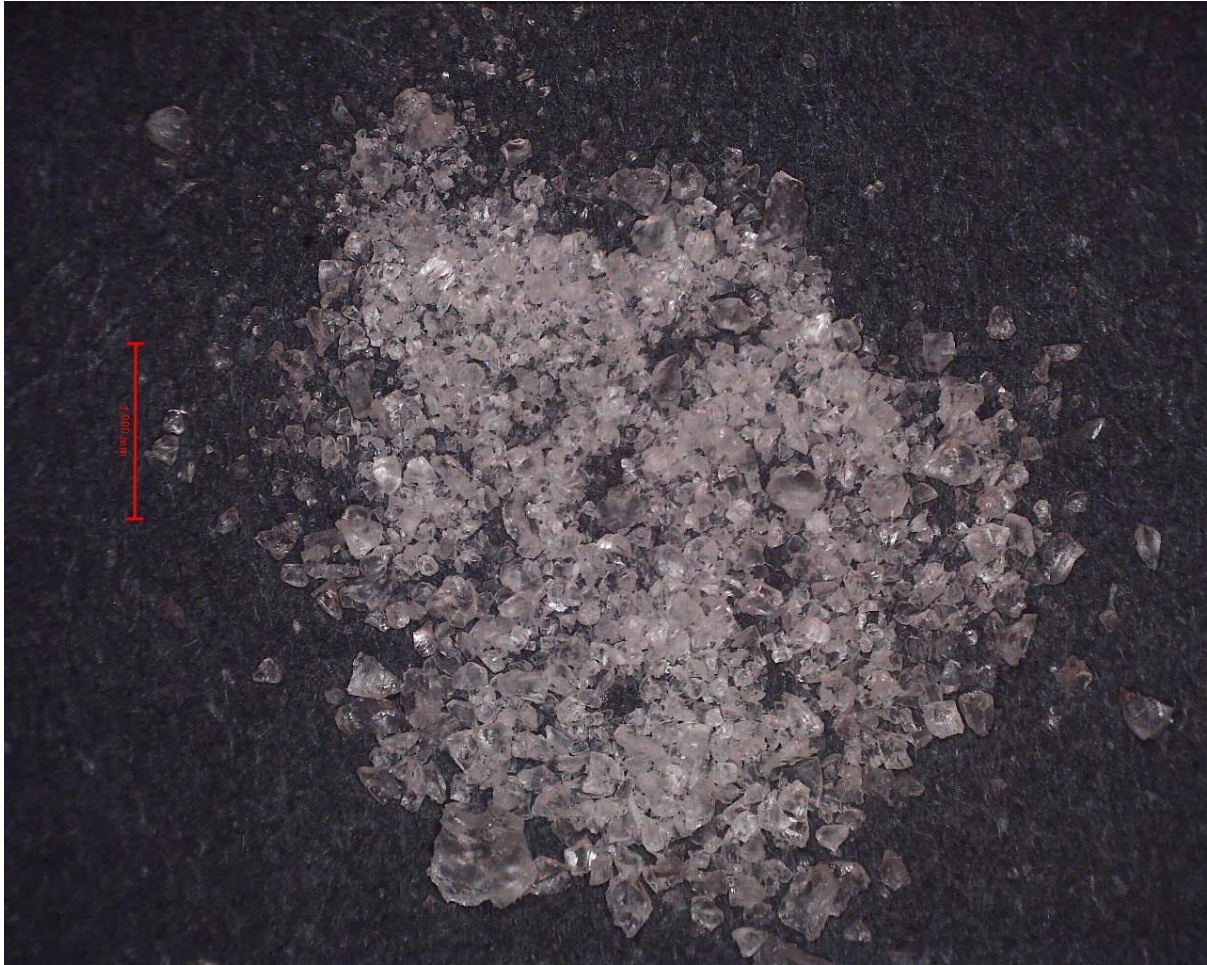


Figure 14: Microscopic image of powdered Paraloid™ B-48N, taken using the USB Digital Microscope. The red line represents 1 millimetre. Photograph by author.

4.4. Methodology

This section expands on the methodological approach of the experimentation process. Below, documented in Table 6, is the original methodology used, heavily influenced by van der Wielen and de Groot (2019).

Step 1:	Ground the Paraloid™ B-72 into a fine powder that can pass through a 500µm sieve.
Step 2:	Preheat the oven to 180°C on a function with both top and bottom heating elements and no air circulation function.
Step 3:	Place the silicone mould in the oven to preheat with the oven.
Step 4:	Evenly distribute the Paraloid™ B-72 powder into the mould, creating a less than 2mm layer. ²⁶
Step 5:	Once the first layer is melted into a transparent film, Step 4 is repeated.

²⁶ This 2mm layer would be measured using a ruler to ensure accuracy.

Step 6:	Repeat Steps 4 and 5 until a sample of 5mm is achieved.
Step 7:	Once a 5 mm sample is achieved, the mould will be removed to cool to room temperature.

Table 6: The initial methodology for thermocasting Paraloid™ B-72.

The results obtained using this methodology for the first set of samples deviated significantly from the expected outcomes, as van der Wielen and de Groot (2019) reported. As a result, it became necessary to modify the methodology. Again, as mentioned in the challenges section of this chapter, the above methodology was adapted to be more fluid. Each methodology adjustment is noted in the corresponding section of the set.

4.5. Thermocasting Paraloid™ B-72

The next section of the chapter is dedicated to thermocasting Paraloid™ B-72. The first few sets of samples were made by following the proposed methodology. When a change in methodology is applied, it is noted in the description of the process in the relevant set. The concentrations and techniques of thermocasting the Paraloid™ B-72 are listed below in Table 7.

Set Number	Concentration of Paraloid™	Techniques	Temp.	Mould
Set 01	100% Paraloid™ B-72	Multiple thin layers	180	Silicone, preheated
Set 02	100% Paraloid™ B-72	Multiple thin layers	180	Silicone, preheated
Set 03	100% Paraloid™ B-72	Multiple thin layers	180	Baking parchment, Not preheated
Set 04	100% Paraloid™ B-72	Multiple thin layers	80	Silicone, preheated
Set 05	100% Paraloid™ B-72	Multiple thin layers	100	Baking silicone, Not preheated
Set 06	100% Paraloid™ B-72	One thick layer	180	Baking silicone, Both preheated and not
		One thin layer	180	Baking silicone, Both preheated and not

Table 7: Concentrations and techniques of Sets 01 through 06.

The sample preparation process, images, and results of each set are documented below.

4.5.1. Creating the samples – Set 01

As per van der Wielen and de Groot (2019), the Amber oven was preheated to 180°C with the silicone moulds inside. Using the Ibili temperature gauge, once the Amber oven was at the desired temperature, a millimetre of ground Paraloid™ B-72 powder was added to the preheated silicone mould using a pre-measured out amount of the Paraloid™ B-72.²⁷ The powder immediately melted once it interacted with the silicone mould, creating a combination of melted and unmelted Paraloid™ B-72. A stainless-steel spatula was used to even out the top layer of Paraloid™ B-72 powder.²⁸ After 10 minutes in the Amber oven, the first millimetre of Paraloid™ B-72 was completely transparent. This contradicts van der Wielen and de Groot (2019:113) as their paper states that the Paraloid™ B-72 only flowed into a transparent film after approximately 30 minutes.

After the first millimetre of Paraloid™ B-72 powder was melted into a transparent film, the second millimetre was added. It reacted like the first millimetre, melting immediately when it came into contact with the warm surface. Once the second millimetre was placed, it only took approximately one minute to become transparent. However, it still appeared to have a granular texture. It again took approximately 10 minutes for the Paraloid™ B-72 to flow into a transparent film with a visually smooth appearance.

The third millimetre of Paraloid™ B-72 was added to the silicone mould, and as the previous layers, had immediately melted and became transparent. A spatula was again used to ensure homogeneity, but the un-melted Paraloid™ B-72 powder, white in colour, turned into a tacky, viscous lump. This lump of Paraloid™ B-72 slowly began to melt, and after approximately 10 minutes, the resin flowed into a transparent film. The sample of thermocasted Paraloid™ B-72 was given an additional 15 minutes to combine thoroughly. Since van der Wielen and de Groot (2019) do not mention the cooling-off process, it was decided that the samples would be left in the Amber oven

²⁷ Van der Wielen and de Groot's (2019) article does not mention how exactly the powdered Paraloid™ B-72 is added to the silicone mould in the oven.

²⁸ There is no mention in van der Wielen and de Groot's (2019) paper on how they ensured that the layer of powder was even, so I used the stainless-steel spatula to do this.

once switched off to decrease in temperature gradually. This was motivated by a process similar to heated glass - annealing.²⁹

The Amber oven and sample within it were left for 24 hours. Afterwards, the sample was demoulded and inspected, see Figure 15.



Figure 15: Two samples of thermocasted Paraloid™ B-72 from Set 01. Photograph by author.

The samples from Set 01 easily came out of the moulds. Both samples are noticeably yellow with foreign particles, with one sample (right) appearing more discoloured than the other (left). The reason for the difference in colour between the two samples is unknown, as they were thermocasted simultaneously. A positive note from these samples is that there is no noticeable bubble formation in either of the samples.

4.5.2. Creating the samples – Set 02

The second set of samples created was similar to the first; the Amber oven was preheated to 180°C and confirmed using the Ibili digital thermometer. As with the first batch, the silicone moulds were placed in the oven to preheat. Once the Amber oven and silicone moulds were preheated to the correct temperature, a measured amount of the powdered Paraloid™ B-72 was added to the silicone mould, filled to one millimetre.

The second layer was added to the mould and immediately started to melt. This process was repeated for the third layer, with the same results as the first batch. This

²⁹ Annealing is the process where heated glass is put into a box called an annealer to very slowly decrease in temperature as not to crack the glass.

batch of samples, however, had an added fourth layer of powdered Paraloid™ B-72, following the same 15 minutes as the previous layers in this batch. As such, there were two distinct differences between the first and second sets: the number of layers of powdered Paraloid™ B-72 and the period between when the layers were added to the silicone moulds. Fifteen minutes after the fourth layer was added, the Amber oven was turned off, and the samples were allowed to cool off with the oven, like the previous batch. The Amber oven and samples within it were left for 24 hours. Afterwards, the samples were demoulded and inspected, see Figure 16.



Figure 16: Samples from Set 02 of thermocasting Paraloid™ B-72. Photograph by author.

The samples from Set 02 are similar to those of Set 01 in terms of having foreign objects embedded in the sample, one sample (right) being visually more yellow than the other sample (left), and both samples showing no visible bubble formation. Both Sets 01 and 02 have one sample (right in both Figures 15 and 16) with visible foreign objects, and both samples also show more yellowing in colour. This can be due to the foreign object causing an increase in the yellowing of the sample. This would have to be evaluated and studied further.

4.5.3. Creating the samples – Set 03

After witnessing the discolouration of the samples in Sets 01 and 02, the possibility of the incorrect moulds causing the discolouration was explored. To test this theory, the thermocasting process of Paraloid™ B-72 would be done without using the previously mentioned silicone moulds. This was done by creating a vessel with baking parchment to place the powdered Paraloid™ B-72 in, see Figure 17.

As before, the Amber oven was preheated to 180°C without adding the baking parchment vessel or Paraloid™ B-72.³⁰ Once the oven was preheated and checked with the Ibili digital thermometer, a small amount of powdered Paraloid™ B-72 was added to the baking parchment vessel. The baking parchment vessel was then added to a large silicone mould to hold its shape better and was placed in the Amber oven.



Figure 17: Baking parchment vessel used in Set 03. Photograph by author.

After 10 minutes, the layer of Paraloid™ B-72 was completely melted and formed a circular-shaped film. At this point, the second layer was sprinkled over the first layer using a stainless-steel spatula. This layer acted similarly to previous batches, whereas the powdered Paraloid™ B-72 at first remained white but was tacky and viscous before becoming transparent in colour and blending with the layer underneath. As this was just a test to confirm if the silicone moulds were causing the discolouration in the previous samples, two layers were deemed efficient. After 10 minutes, the sample was taken out of the Amber oven with a kitchen spatula and allowed to cool off on top of the oven. The decision to take the sample out of the oven instead of letting it gradually cool off was also to determine if this was a factor in discolouration.

³⁰ The decision to not preheat any elements while preheating the oven stems from the fact that baking parchment becomes brittle and discolours when exposed to heat, this discolouration could have impacted the results of the experiment and so, was not preheated.



Figure 18: A sample of thermocasted Paraloid™ B-72 made within a baking parchment vessel. Photograph by author.

The above sample was made to determine if the discoloured moulds were the reason behind the samples' yellowing. The sample came out without any yellowing; the cloudy ring around the clear centre in Figure 18 is due to the baking parchment adhering to the melted Paraloid™ B-72 and is not a colour change. Therefore, baking parchment would not be a plausible solution when thermocasting as it would adhere to any sample. It is important to note that bubbles are seen in the centre of this sample.

4.5.4. Creating the samples – Set 04

The fourth set of thermocasting powdered Paraloid™ B-72 is different from the previous sets as the temperature at which this set of samples was created was 100°C. A temperature of 80°C was decided on because it is double the T_g of Paraloid™ B-72, which is 40°C (Koob, 2015:189). As with previous sets, the Amber oven was preheated with the silicone moulds inside to 80°C, ensuring the correct temperature with the Ibili digital thermometer.³¹ Once the correct temperature was reached, the first layer of powdered Paraloid™ B-72 was added. After 15 minutes, there was no change to the Paraloid™ B-72. Only an hour and a half into the experiment did the particles adhere to each other into a hard layer, with some powder particles still loose. It was not viscous or tacky, only hard. The following change to the powdered Paraloid™ B-72 was observed two hours and 15 minutes into the experiment; the Paraloid™ B-72 had become tacky and viscous.

³¹ The same silicone moulds were used as the temperature difference was tested with this set.

30 minutes later, a total of two hours and 45 minutes after the start of the experiment, the Paraloid™ B-72 had become more melted but not completely. After another 30 minutes, three hours and 15 minutes into the experiment, the Paraloid™ B-72 was approximately ninety per cent clear, with only a few particles of powdered Paraloid™ B-72 left. After an additional 30 minutes and a total of three hours and 45 minutes into the experiment, the Paraloid™ B-72 was melted entirely and had started to homogenise. The second layer of powdered Paraloid™ B-72 was added four hours and 15 minutes into the experiment, which also started to melt immediately when it came into contact with the melted Paraloid™ B-72. The sample was then left for an additional 30 minutes to combine better. Again, the Amber oven was turned off, and the samples were left to cool inside the oven gradually.



Figure 19: Set 04 of samples using the thermocasting technique at 80°C. Photograph by author.

As with the previous samples made with the rectangular silicone moulds, these also discoloured even though the temperature was decreased significantly. It was then concluded that the silicone moulds were the reason for these samples' extreme yellowing, which would be changed for future sets.

4.5.5. Creating the samples – Set 05

As the previous batch of samples still showed slight discolouration despite the temperature change, the following experiment would be creating samples with two considerable changes to the methodology, namely, the moulds would be changed to a silicone baking tray used to make muffins for example, and the silicone mould would not be preheated along with the Amber oven, but instead inserted cold with the first layer of powdered Paraloid™ B-72 already placed in the mould.

The Amber oven was preheated to 100°C without the mould being placed inside, and the correct temperature was confirmed using the Ibili digital thermometer. Once the Amber oven was at the correct temperature, the room temperature mould with the first layer of powdered Paraloid™ B-72 was placed in the oven. After 15 minutes, the Paraloid™ B-72 was approximately ninety per cent melted. 30 minutes into the experiment, the Paraloid™ B-72 powder melted approximately ninety-five per cent. 15 minutes after the previous step, a total of 45 minutes into the experiment, the powdered Paraloid™ B-72 was one hundred per cent melted; however, the sample's surface was uneven. After two hours into the experiment, the unevenness was still noted. The Amber oven was turned off, and the samples were allowed to cool gradually within the oven.



Figure 20: First sample from Set 05.
Photograph by author.



Figure 21: Second sample from Set 05.
Photograph by author.

Both samples from this set cracked when demoulded; this can be due to them only having a thin layer of powdered Paraloid™ B-72 instead of previous samples with multiple layers. The samples show no sign of yellowing or discolouration; however, they had significant bubble formation throughout the samples. This bubble formation can be due to the temperature of the silicone mould, which was not preheated. Van der Wielen and de Groot (2019:112) state that lower temperatures, noted in their paper as 150°C and below, show signs of increased bubble formation.³²

³² Since there were discrepancies between van der Wielen and de Groot's (2019) thermocasting and my own finding, I continued with testing creating samples at 150°C to confirm that bubble formation did happen at that temperature.

4.5.6. Creating the samples – Set 06

As the previous set of samples was filled with bubbles, the strategy of the experiment changed once again to previous versions where there was considerably less bubble formation. This batch had various changes to the previous set, Set 05, namely the thicknesses of the samples and the samples placed in either preheated or room temperature moulds. The different samples were labelled as follows: A) a thick layer of powdered Paraloid™ B-72 that was added to an already preheated silicone mould, B) a thin layer of powdered Paraloid™ B-72 that was added to an already preheated silicone mould, C) a thick layer of powdered Paraloid™ B-72 that was preheated along with the silicone mould in the Amber oven, and D) a thin layer of powdered Paraloid™ B-72 that was preheated along with the silicone mould in the Amber oven.

Samples C and D were placed in the silicone mould in the Amber oven, and the oven was turned up to 180°C and monitored with the Ibili digital thermometer. After 10 minutes, the oven reached the desired temperature, and both samples C and D were fully melted, but bubbles were produced within the sample. Samples A and B were added to the already heated silicone mould and melted immediately. After 10 minutes, samples A and B were added. A total of 20 minutes into the experiment, the powdered Paraloid™ B-72 in sample B was completely melted but had an uneven surface. Sample A had entirely melted by this point; however, bubble formation was noticed. A total of 30 minutes into the experiment, sample B's surface was still noticeably uneven, and additional bubbles were noticed in sample A. After 15 minutes, a total of 45 minutes into the experiment, a second layer to sample B was added and completely melted within the next 10 minutes.

The samples were left in the Amber oven for two and a half hours to become homogeneous. Three hours and 15 minutes after the experiment started, the Amber oven was turned off, and the samples were allowed to cool off inside the oven.



Figure 22: Sample A of Set 06, one thick layer of Paraloid™ B-72 in the preheated silicone mould. Photograph by author.

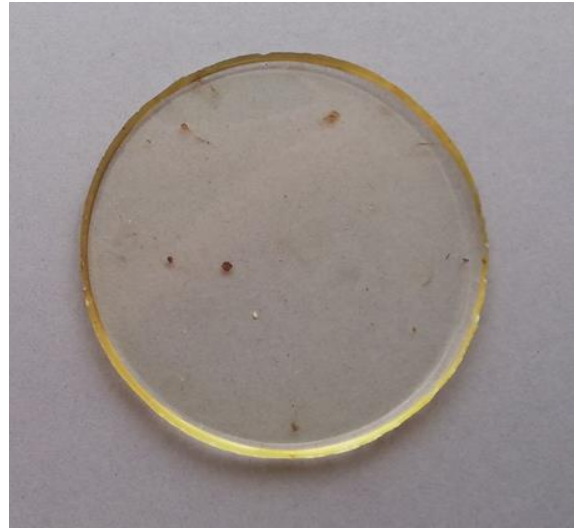


Figure 23: Sample B of Set 06, one thin layer of Paraloid™ B-72 in the preheated silicone mould. Photograph by author.

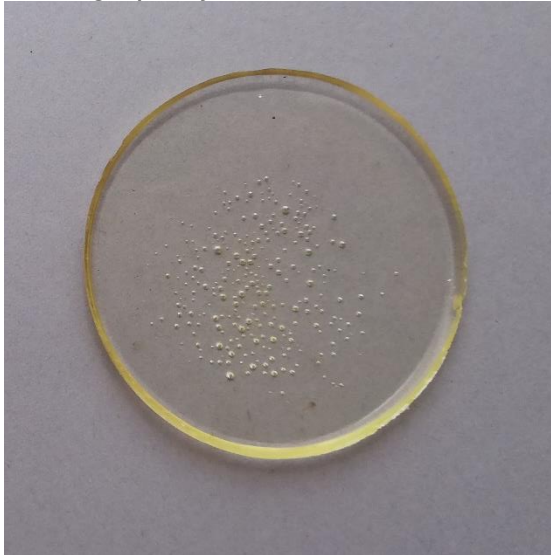


Figure 24: Sample C of Set 06, one thick layer of Paraloid™ B-72 in the room temperature silicone mould. Photograph by author.



Figure 25: Sample D of Set 06, one thin layer of Paraloid™ B-72 in the room temperature silicone mould. Photograph by author.

The samples of this set share one similarity: they all show various degrees of yellowing. There are also quite a few differences between the samples. The samples made from one thin layer, B and D (Figures 23 and 25), were fragile and challenging to demould. While the two samples, made with one thick layer of Paraloid™ B-72, felt very solid. This confirms van der Wielen and de Groot's (2019) advice to create a sample with multiple layers. Both samples made using the preheated silicone mould have the same degree of yellowing. However, Sample B shows minor bubble

formation, whereas Sample A does not. Sample C (Figure 24) shows a significant degree of bubble formation; this can be due to the room temperature mould, as seen in set 05.

4.6. Thermocasting Paraloid™ B-48N

Reviewing the results of the Paraloid™ B-72 samples, the degree of yellowing is concerning for the long-term stability of the samples. After looking into the use of Paraloid™ B-72 in warmer climates, the two articles on combining the two Paraloids™ initiated the following four sets of samples. The Paraloid™ B-48N was prepared using the same steps as the Paraloid™ B-72. Based on the observations from the first six sets of samples, it was noted that an unheated mould led to bubble formation and that the temperature of 180°C caused yellowing in the samples. Thus, Set 07 was created using a preheated mould at 165°C.

The 150°C temperature caused excessive bubbling, which van der Wielen and de Groot (2019:112) noted to occur at the same temperature. 180°C was again too high in temperature, and a notable yellowing was observed in the samples. The temperature for the following sample creation process was the difference between the two temperatures, so the following tests were carried out at 165°C. The silicone mould was also preheated along with the Amber oven, as previous thermocasting attempts showed that excessive bubbling occurred if the temperature of the silicone mould was too low. Below, in Table 8, the concentration and techniques for the Paraloid™ B-48N are listed.

Set Number	Concentration of Paraloid™	Techniques
Set 07	100% Paraloid™ B-48N	One thick layer
		Multiple thin layers

Table 8: The concentration and techniques used in Set 07.

4.6.1. Creating the samples – Set 07

Once the oven and silicone mould were at the correct temperature, the powdered Paraloid™ B-48N was placed in the moulds. Sample A was a single, thick layer of the powdered Paraloid™ B-48N, and sample B was multiple thin layers of the powered Paraloid™ B-48N. Ten minutes after the samples were placed in the preheated

silicone mould and Amber oven, they were approximately 70% melted and had the visual appearance of melted sugar.

After 20 minutes, sample A was fully melted; however, it had an uneven consistency towards the top of the layer. Sample B had also fully melted and, similarly to sample A, had an uneven surface layer, but sample B had pockets of bubbles within the sample. 40min after the start of the experiment, the samples were still the same as at 20 minutes. A visible change was only noted after 50 minutes for sample A, where the surface was more even in texture and consistency. At this stage, sample B was still unchanged. One hour into the experiment, samples A and B had a more even and consistent surface texture, but they were still not completely melted.

One hour and 20 minutes into the experiment, samples A and B were more even than before. At this experiment stage, the second layer was added to Sample B. After 10 minutes, the second layer in Sample B was melted entirely; however, it still had an uneven surface. After ten minutes, the third layer was added to sample B; it was approximately 95% melted but had already started to show signs of yellowing with the sample. Two hours after the start of the experiment, the samples had even layers where the top was fully melted and had flowed into itself. At this point, the Amber oven was turned off, and the samples were allowed to cool off inside the oven.



Figure 26: Sample A in Set 07, one thick layer of Paraloid™ B-48N. Photograph by author.



Figure 27: Sample B in Set 07, multiple thin layers of Paraloid™ B-48N. Photograph by author.

The results of this set are interesting; sample A (Figure 26) displays significant yellowing, while sample B (Figure 27) is transparent with small circular areas of yellowing in different areas of the sample. Both samples show significant amounts of bubble formation.

4.7. Thermocasting mixed samples of Paraloid™ B-72 and Paraloid™ B-48N

It was decided to create a mixed sample by mixing Paraloid™ B-72 and Paraloid™ B-48N in different concentrations. This has been attempted before by Davis, Roberts, and Poli (2021); however, these were done with solvent evaporated Paraloid™ B-72 and Paraloid™ B-48N, and not thermocasting the process. The hybrid thermocasted samples were done in three different concentrations using two different techniques. These are listed in the table below:

Set Number	Concentration of Paraloid™	Techniques
Set 08	25% : 75%	One thick layer
	Paraloid™ B-72 : Paraloid™ B-48N	Multiple thin layers
Set 09	50% : 50%	One thick layer
	Paraloid™ B-72 : Paraloid™ B-48N	Multiple thin layers
Set 10	75% : 25%	One thick layer
	Paraloid™ B-72 : Paraloid™ B-48N	Multiple thin layers

Table 9: Concentrations and techniques for the hybrid Paraloid™ samples.

4.7.1. Creating the samples – Set 08

The Amber oven was preheated to 165°C, ensured using the Ibili digital thermometer, and the silicone baking tray was preheated along with the oven. Once the desired temperature was reached, the powdered mix of 25% Paraloid™ B-72 and 75% Paraloid™ B-48N was thoroughly mixed and placed in the silicone mould. Sample A is a thick layer of the powder mix, and Sample B is the sample with multiple layers of the powdered mix.

After 10 minutes, both samples were approximately 70% melted. After an additional 10 minutes, both samples were melted entirely; samples A and B had uneven surfaces, and sample A had visible bubbles. Only after an hour did sample A have a slightly more visually even surface, and sample B remained unchanged. After 10

minutes, sample A remained unchanged while sample B's surface became even. After an additional 10 minutes, sample B's second layer was added.

An hour and a half later, sample B's second layer was melted entirely and clear but had an uneven surface as the first and second layers had not yet fully flowed into each other. At this point, sample A remained unchanged. An hour and 40 minutes into the experiment, sample A showed signs of yellowing, while sample B's second layer was even. The third layer was now added to sample B. After 10 minutes, sample B's third layer melted entirely but had an uneven surface layer. At this point, sample B also started showing signs of yellowing. Two hours after the start of the experiment, both samples had an even surface. The Amber oven was turned off, and the samples were allowed to cool gradually.



Figure 28: Sample A of Set 08, one thick layer of the hybrid mix. Photograph by author.



Figure 29: Sample B of Set 08, multiple thick layers of the hybrid mix. Photograph by author.

Both samples (Figures 28 & 29) show degrees of yellowing in areas of the samples instead of throughout the sample. Sample A reacted differently than set 08's sample A, as the surface cured unevenly. There are also areas of bubbles in the samples, rather than throughout the sample, as seen in sample B and multiple previous sets of samples.

4.7.2. Creating the samples – Set 09

This set's preparation was precisely the same as Set 08's; the Amber oven and silicone mould were heated to 165°C, and the temperature was confirmed with the Ibili digital

thermometer. However, this set was made using the powdered mix with a 1:1 ratio between Paraloid™ B-72 and Paraloid™ B-48N. Two samples were made: sample A, a thick layer of the powdered mix, and sample B, with multiple thin layers of the powdered mix.

After 10 minutes, both samples melted approximately 75%. After 10 minutes, both samples showed a substantial amount of bubble formation. This bubble formation increased over the next 10 minutes. The following change occurred after approximately 50 minutes when the surface of Sample A was even, but the bubbles were still visible beneath the surface. The surface layer of the samples became more even after 30 minutes, which was when the second layer was added to sample B. As with previous samples, this second layer immediately started to melt and flow into the first layer. The samples started to change within the next 10 minutes. Sample A started showing signs of yellowing, sample B's surface was even, and the second layer entirely flowed into the first layer. The third and final layer to sample B was added due to the even surface. After 10 minutes, this third layer was approximately 95% melted, with only a few remaining unmelted areas in the sample.

After an additional 10 minutes, sample B also showed signs of yellowing. The third layer was melted entirely, but the sample's surface was uneven. After two hours, both samples had an even surface. The Amber oven was then turned off, and the samples were allowed to cool in the oven gradually.



Figure 30: Sample A of Set 09, one thick layer of the hybrid mix. Photograph by author.

Figure 31: Sample B of Set 09, multiple thin layers of the hybrid mix. Photograph by author.

The samples in this set show approximately the same amount of yellowing throughout the sample, not in areas as in the previous sets'. Sample A (Figure 30), the single thick layer, shows a large amount of bubble formation, while sample B (Figure 31), the multiple thin layers, shows little bubble formation. This is in direct contrast to the previous sets' bubble formation patterns.

4.7.3. Creating the samples – Set 10

This sample set had the same conditions as the previous sets regarding temperature and used the preheated silicone mould. This set created two hybrid Paraloid™ samples using a 25% Paraloid™ B-48N : 75% Paraloid™ B-72 mix. Sample A was one thick layer of the powdered Paraloid™ mix, and sample B was multiple thin layers of the powdered Paraloid™ mix. Once the Amber oven and silicone mould reached 165°C, the samples were poured into the silicone mould. After 10 minutes, both samples were approximately 90% melted. Next, 10 minutes later, both samples were completely melted with an uneven surface consistency. Sample A showed signs of bubble formation, while sample B showed no signs of bubbles. In the next 30 minutes of the experiment, the surfaces of both samples evened out into a more uniform surface.

At the one-hour mark, both samples had a completely even surface layer, and the second layer of powdered mix was added to sample B. After 10 minutes, the second layer of Sample B was completely melted but looked very granular and uneven, and sample A remained unchanged. Sample B's second layer continued to melt into a more even and smooth layer over the next 20 minutes. An hour and a half later, sample B's surface layer was completely smooth, and the third layer of the powdered mix was added, which immediately started melting and became transparent on contact with the second layer. Sample A's surface was very smooth at this point, with the visual appearance and shine of glass. After 10 minutes, there were signs of bubble formation in Sample B. Both samples' surfaces continued to smooth and became even more so over the next 20 minutes of the experiment. Two hours later, both samples had smooth

and even surface layers. Thus, the Amber oven was turned off, and the samples were allowed to cool along with the Amber oven.



Figure 32: Sample A of Set 10, one thick layer of the hybrid mix. Photograph by author.



Figure 33: Sample B of Set 10, multiple thin layers of the hybrid mix. Photograph by author.

These samples show a slight degree of yellowing, but less so than previous sets'. The bubble formations of these samples are similar to that of Set 09 and in contrast to that seen in Set 08.

4.8. Conclusion

This chapter detailed the thermocasting experiments conducted using Paraloid™ B-72, Paraloid™ B-48N, and a hybrid mixture of the two conservation adhesives. Throughout the experiments, multiple samples exhibited issues such as bubble formation, yellowing, or a combination of both. Specifically, Sets 01, 02, and 04 did not show signs of bubbling, yet they exhibited the most significant discolouration among all the samples. This discolouration suggests that the type of silicone mould used in the process could have contributed to the yellowing, potentially interfering with the final aesthetic quality of the samples. In contrast, despite yellowing, the best results were achieved using Paraloid™ B-72, following the method outlined in this study. These results indicate that, while Paraloid™ B-72 showed promising outcomes, the mould material may have played a role in the observed discolouration, underscoring the importance of selecting appropriate materials for such experiments.

It is also worth noting that factors such as temperature control and the size of the moulds could have influenced the results. Better regulation of these parameters, including experimenting with different mould sizes, may yield more consistent and optimal outcomes in future experiments. This highlights the need for further refinement of the process to minimise unwanted side effects such as bubble formation and yellowing while enhancing the overall quality and consistency of the thermocasted samples. While this study provides valuable insights into the thermocasting process of Paraloid™ B-72 and its hybrid forms, it also reveals several areas where improvements can be made. Future research should explore the role of mould materials more thoroughly and investigate the impact of temperature and mould size on the final results. Such investigations will contribute to a more comprehensive understanding of the thermocasting process, enabling more effective and reliable use of Paraloid™ B-72 and similar adhesives in conservation applications.

CHAPTER FIVE:

5.1. Summary of Chapters

The research and experimentation documented in this mini-dissertation aimed to reproduce the thermocasting method for Paraloid™ B-72 developed by van der Wielen and de Groot (2019). Chapter 1 outlines the critical properties of this research: namely, the background and identifying the research issue, the significance of the study, a breakdown of the aims and objectives for the experimentation, as well as the research methodologies that were implemented to achieve the identified goals.

The second chapter investigated the literature surrounding thermocasted Paraloid B-72. Multiple sources document the advantages and disadvantages of solvent-evaporated Paraloid B-72. However, due to the newly developed thermocasting method, only one literary source could be referenced. This article by van der Wielen and de Groot (2019) was then discussed section by section to discover the gaps within that source and create a literary foundation for the experimentation procedures. This literature review also included other critical sources to build this foundation, such as two case studies of creating a hybrid adhesive using various ratios of Paraloid™ B-72 and Paraloid™ B-48N.

Chapter 3 noted the equipment, tools, and adhesives used in this mini-dissertation's experimentation section. It also included the technical properties of both adhesives, Paraloid™ B-72 and Paraloid™ B-48N. The fourth chapter contains the experiment procedures and results. It documents the significant challenges encountered, the preparation before thermocasting, the thermocasting processes, images, and results of the 10 Sets of thermocasted samples. These samples are composed of Paraloid™ B-72, Paraloid™ B-48N, and hybrid samples with different ratios of the two adhesives.

5.2. Contribution of Study

This study contributed to the field of conservation by highlighting gaps within the knowledge of thermocasted Paraloid™ B-72 and areas in the method that should be studied further. In addition to this, the study reproduced the experiment in a different climate using cost-effective and easily accessible equipment. As this is a relatively

new technique of working with a well-known conservation adhesive, little is known about it besides what is in van der Wielen and de Groot's (2019) paper. Thermocasted Paraloid™ B-72 could be the future of glass and stained-glass conservation; any information that can be added to the little there is on the topic is an abundance of knowledge for the betterment of the conservation field.

5.3. Limitations of Study

Within the thermocasting process, this study has three primary limitations. The first limitation is the lack of literature; thermocasting is a new technique, so there is a single source. This limits the theoretical foundation that the experiment started with. In addition, there were multiple gaps within the source regarding smaller practical implementations during the thermocasting process, such as the cooling process.

The second limitation was the equipment that was available to be used to create the thermocasted samples. The Amber oven's temperature fluctuated frequently, and using the dial on the oven to achieve the desired temperature was difficult. Even with the digital thermometer, achieving and recording the correct temperature was still challenging. The oven had to be used outside as a safety precaution. Being outside allowed foreign objects, such as dust and dirt, to be caught within the samples, possibly altering the results.

The third limitation is time. I would have preferred to carry on experimenting with the thermocasting method to discover more. To test and perfect the method using easily obtainable materials so that any conservation practitioners, regardless of their socio-economic background, can use this method to preserve glass objects and contribute towards the conservation field. There are still so many factors to thermocasting that are unknown and could be perfected; these factors are noted in the section below.

5.4. Suggestions for Further Study

As mentioned, many factors are unknown since the new thermocasting method needs further research. They are divided below into six different sections according to theme:

5.4.1. Temperature

- The temperature at which bubbling occurs for both Paraloid™ B-72 and Paraloid™ B-48N can be helpful when creating samples with each Paraloid™ on their own and when used in a hybrid mix.
- The temperature at which yellowing occurs.³³ As yellowing is a significant concern when it comes to the appearance of glass, knowing the temperature range of when Paraloid™ B-72, Paraloid™ B-48N, and the mix of the two in thermocasted samples occurs can then be avoided to create a crystal-clear sample void of any yellowing.

5.4.2. Time

- There were time discrepancies, mentioned in Chapter 4, between the times it took the powdered Paraloid™ B-72 to melt and what was documented by van der Wielen and de Groot (2019:113). They stated it takes approximately half an hour for one 2-millimetre layer of powdered Paraloid B-72 to melt entirely. I, however, achieved this in under 10 minutes under the same conditions.³⁴ This should be investigated further to establish an average time frame for this to occur. This will help to standardise thermocasting and make it more reproducible.
- The period that the samples should set (i.e. cool off) after the thermocasting process should be explored, as different periods of setting could lead to different results for the samples.

5.4.3. Process

- The best method to place the powdered Paraloid™ into the silicone moulds was unclear, and this would ensure consistency throughout various samples and within the layers themselves. It will also aid repeatability.
- The thermocasting process should be explored more so that it can be divided into clear steps so that anyone can easily reproduce it.

³³ This was unable to be determined due to the Amber oven not having a light inside, this caused all samples to appear clear until they were removed from their moulds.

³⁴ This could be due to the use of larger moulds than what this study utilised and can be tested for further research.

- The thermocasting process is used only to create flat or straight samples. Investigating the process to see whether or not thermocasting can be used to create curved or shaped samples should be considered.

5.4.4. Silicone Moulds

- Which type of silicone moulds are the best to use, and which would affect the samples themselves in terms of bubble formation, yellowing, and the colouring process of coloured thermocasted samples.

5.4.5. Sample Testing

- The created thermocasted samples should be tested for a variety of factors. Accelerated age testing to document if samples yellow when exposed to ultraviolet (UV) light over long periods. How colourants used within the thermocasted sample react over extended periods. Strength testing to see how strong the end product is can also be linked to testing the scratch resistance of the surface of the thermocasted sample.

5.4.6. Recurring Phenomenon

- Once a sample of Paraloid™ B-72, B-48N, or a mix of the two is completely melted, the surface of the melted sample is often visually uneven. This occurred in multiple sample sets, and the reason for this is that it is an avenue for further research.
- In samples with multiple thin layers, the second or third layer of the powdered Paraloid would immediately start to melt and incorporate within the previous layer. This occurred in every sample that used multiple layers and should be studied further.

5.5. Final Remarks

The primary objective of this study was to replicate the thermocasting process outlined by van der Wielen and de Groot (2019) using Paraloid™ B-72, Paraloid™ B-48N, and a hybrid mixture of the two adhesives. The findings underscore the need for extensive further research into various aspects of the thermocasting process in terms of the broader methodology and the specific factors influencing the outcomes. This study

makes a valuable contribution to thermocasting research, particularly by demonstrating the feasibility of replicating the process in a different climate and using cost-effective, readily available equipment.

Despite several limitations inherent to this study, these challenges have highlighted the existing gaps in knowledge surrounding thermocasting, which is still an under-researched area. In conclusion, while the study provides significant insights into the thermocasting process, it also lays the groundwork for further investigation into refining and expanding understanding of the subject. Ultimately, the findings of this research have the potential to enhance conservation practices by offering more reliable and accessible methods for preserving artefacts, thus contributing to the advancement of the field.

REFERENCES

- Al-Azzam, M. 2011. A Study of Glass Deterioration: Mechanism, Aspects, and Recent techniques for treatment. MA Thesis, Yarmouk University, Irbid.
- Baglioni, M., Raudino, M., Berti, D., Keiderling, U., Bordes, R., Holmberg, K. & Baglioni, P. 2014. Nanostructured fluids from degradable nonionic surfactants for the cleaning of works of art from polymer contaminants. *Soft Matter* 35(10):6798-6809. DOI: 10.1039/c4sm01084a.
- CAMEO. 2022a. *Paraloid B-48N*. [O]. Available: https://cameo.mfa.org/wiki/Paraloid_B-48N Accessed 6 October 2024.
- CAMEO. 2022b. *Paraloid B-72*. [O]. Available: https://cameo.mfa.org/wiki/Paraloid_B-72 Accessed 6 October 2024.
- Conservation Unit Museums and Galleries Commission. 2013. *Science for Conservators, Volume 3: Adhesives and Coatings*. United Kingdom: Taylor & Francis.
- Corning. 2024. Science of Glass: Glass Continues its Role in New Medicines. [O]. Available: <https://www.corning.com/worldwide/en/innovation/the-glass-age/science-of-glass/glass-continues-its-role-in-the-world-of-new-medicines.html> Accessed 26 November 2024.
- Coutinho, I., Ramos, A. M., Lima, A. M. & Fernandes, F. B. 2009. Studies of the degradation of epoxy resins used for the conservation of glass, in *Holding it All Together: Ancient and Modern Approaches to Joining, Repair and Consolidation*, edited by J. Ambers, C. Higgitt, L. Harrison & D. Saunders. London: Archetype Publications Ltd.:127-133.
- Davis, S. L., Roberts, C., & Poli, A. 2021. Paraloid® B-72/B-48N 1:1 as an Adhesive for Use in Hot Climates: Literature Review, Laboratory Testing, and Observational Field Study. *Studies in Conservation* 67(6):357-365.
- Davison, S. 2003. *Conservation and Restoration of Glass*, Second Edition. Oxfordshire: Routledge.
- Davison, S. 2009. A history of joining glass fragments, in *Holding it All Together: Ancient and Modern Approaches to Joining, Repair and Consolidation*, edited by J. Ambers, C. Higgitt, L. Harrison & D. Saunders. London: Archetype Publications Ltd.:107-112.
- Derry, J. 2012. Investigating Shellac: Documenting the Process, Defining the Product. A study on the processing methods of Shellac, and the analysis of

- selected physical and chemical characteristics. MA Dissertation, University of Oslo, Oslo.
- Dignard, C. 2015. Choosing Adhesives and/or Consolidants for Conservation Treatments, in *Adhesives Compendium for Conservation*, edited by J. L. Down. Ottawa: Canadian Conservation Institute:117-121.
- Dooijes, R. & Nieuwenhuyse, O. P. 2009. Ancient repairs in archaeological research: a Near Eastern perspective, in *Holding it All Together: Ancient and Modern Approaches to Joining, Repair and Consolidation*, edited by J. Ambers, C. Higgitt, L. Harrison & D. Saunders. London: Archetype Publications Ltd.:8-12.
- Down, J. L. 1986. The Yellowing of Epoxy Resin Adhesives: Report on High-Intensity Light Aging. *Studies in Conservation* 31(4):159-170.
- Down, J. L. 2015a. Introduction, in *Adhesives Compendium for Conservation*, edited by J. L. Down. Ottawa: Canadian Conservation Institute:1-4.
- Down, J. L. 2015b. Solid Adhesive Properties, in *Adhesives Compendium for Conservation*, edited by J. L. Down. Ottawa: Canadian Conservation Institute:21-29.
- Eggert, G. & Straub, D. S. 2009. Ancient glass gluing recipes, in *Holding it All Together: Ancient and Modern Approaches to Joining, Repair and Consolidation*, edited by J. Ambers, C. Higgitt, L. Harrison & D. Saunders. London: Archetype Publications Ltd.:3-7.
- Garachon, I. 2010. Old Repairs of China and Glass. *The Rijksmuseum Bulletin*. 58(1):34-55.
- Horie, C. V. 2013. *Materials for conservation: organic consolidants, adhesives and coatings*. London: Elsevier Science.
- International Year of Glass. 2021. 2022: the UN International Year of Glass. [O]. Available: <https://www.iyog2022.org/>
Accessed 11 November 2022.
- Koob, S. P. 1986. The Use of Paraloid B-72 as an Adhesive: Its Application for Archaeological Ceramics and Other Materials. *Studies in Conservation* 31:7-14. DOI: 10.1179/sic.1986.31.1.7.
- Koob, S. P. 2003. Tips and tricks with epoxy and other casting and molding materials. *Objects Specialty Group Postprints*, 10:158-172.
- Koob, S. P. 2006. *Conservation and Care of Glass Objects*. London: Archetype Publications.
- Koob, S. P. 2009. Paraloid B-72®: 25 years of use as a consolidants and adhesive for ceramics and glass, in *Holding it All Together: Ancient and Modern*

- Approaches to Joining, Repair and Consolidation*, edited by J. Ambers, C. Higgitt, L. Harrison & D. Saunders. London: Archetype Publications Ltd.:113-119.
- Koob, S. P. 2015. Ceramics and Glass, in *Adhesives Compendium for Conservation*, edited by J. L. Down. Ottawa: Canadian Conservation Institute:188-194.
- Rohm and Haas. 2007. *Paraloid™ B-72*. [O]. Available:
https://www-eng.lbl.gov/~shuman/NEXT/MATERIALS%26COMPONENTS/WLS_materials/paraloid_b-72_data.pdf
Accessed 22 September 2024.
- Schmidt, P. L., Shugar, A. & Ploeger, R. 2017. Analytical Observations Regarding Butvar B-98 and Paraloid B-72 Blends as a Suitable Adhesive in Hot Climates. *MRS Advances* 2:1927-1941. DOI: 10.1557/adv.2017.229
- Schuck, T., Fischer, A. & Schwahn, B. 2019. Acrylic Barrier Surface Coatings for Epoxy Resin Adhesive Bonds in Glass Conservation: Evaluation of Bond Strength and Reversibility. Paper presented at the Recent Advances in Glass and Ceramics Conservation 2019 Conference. 5-7 September, London.
- TALAS. 2024. *Paraloid B-48N*. [O]. Available:
https://www.talasonline.com/Paraloid-B-48?srsId=AfmBOoqmiKRCUv5LgJ9dNPfLeHdGvISK7PvWhnZC4yMdEuz_0k-urYyK
Accessed 17 November 2024.
- Van Beemen, R. M. C., Joosten, I., Megens, L. & van Lookeren Campagne, K. Suitable Bonding Methods for the Conservation of Large Broken Plaster Casts of Ancient Sculptures, in *Recent Advances in Glass, Stained-glass, and Ceramics Conservation 2013*, edited by H Roemich & K van Lookeren Campagne. Zwolle: SPA Uitgevers: 77-85.
- Van der Wielen, R. & de Groot, S. 2019. Thermocasting of PARALOID B-72: Solvent-Free Production of Acrylic Flat-Glass Restoration Casts. In: Mandrus, J. & Schussler, V. (eds.). *Recent Advances in Glass and Ceramics Conservation 2019: Interim Meeting of the ICOM-CC Glass and Ceramics Working Group and Icon Ceramics and Glass Group Conference, 5-7 September 2019, London, United Kingdom*. United Kingdom: ICOM, 2019.
- Van Giffen, N. A. R., Koob, S. P. & O'Hern, R. New Developments for Casting Paraloid™ B-72 for Filling Losses in Glass, in *Recent Advances in Glass, Stained-glass, and Ceramic Conservation 2013*, edited by H Roemich & K van Lookeren Campagne. Zwolle: SPA Uitgevers: 53-60.
- Williams, D. C. 1995. The past and future history of natural resins as coating materials in conservation. *Scottish Society for Conservation & Restoration*, 1995.

ZOIC Palaeotech. 2024. *Paraloid B-72*. [O]. Available:
https://www.zoicpalaeotech.co.uk/products/paraloid-b-72?srsId=AfmBOorTIVY_IUN8W1as8V0HFGgcfUNPaisAWzTjB3oJ_pwhxnERnHI
Accessed 17 November 2024.