Experimental Investigation of the Candelabra Tree's Milky Latex Thermal and Mechanical Performance for Adhesive Application

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***Abstract*—The growing demand for natural organic adhesives has attracted the attention of many researchers worldwide. This is due to their advantages over inorganic adhesives in terms of environmental impacts over a long period. This work is based on the investigation of the thermal and mechanical properties of the organic adhesive produced from the milky latex of the candelabra tree. The adhesive was produced according to the traditional African technique of heating/boiling at 180 ℃, 215 ℃, and 250 ℃ to polymerize milky latex until it became sticky. The sticky latex produced at various temperatures was analyzed for thermal stability and bonding strength through Thermogravimetric Analysis (TGA) and lap shear test respectively. The thermogravimetric results exhibit a 36% weight loss as the temperature increased from 28 ℃ to 110 ℃ at a rate of 10 ℃/min for raw latex. The thermal stability of the latex was achieved at temperatures between 110 ℃ and roughly 260 ℃ before decomposing at above 300 ℃ due to roughly 85% weight loss. The same behavior was displayed by the latex processed at 180 ℃, 215 ℃, and 250 ℃. The lap shear results show that a bonding force of 147 N, 58 N, and 196 N are achieved in the latex polymerized at 180 ℃, 215 ℃, and 250 ℃ respectively. Overall, the bonding strength of the produced adhesive improves with an increase in polymerizing temperature, however, limited to 300 ℃.**

***Keywords*—bonding strength, candelabra tree, milky latex, organic adhesive, polymerization**

I. Introduction

The Euphorbia candelabrum tree is native to semi-Savannas and dry lands of the Southern African regions where the climate conditions are sunny with little rain [1]. This plant is also known as Euphorbia ingens or naboom, its branches contain a milky latex that is extremely poisonous and can be dangerous when exposed to humans or other animals and insects although it is known to be consumable to black rhinoceros [2–4]. It uses this milky latex as a defensive mechanism against other animals and insects [5]. The milky latex of the candelabra tree can cause severe skin irritation when in direct contact with human skin, can cause blindness when spiled directly into human eyes or other animals, and can also be poisonous when ingested in humans and other animals [1, 5, 6]. However, the candelabra plant has been used in South Africa, Zimbabwe, Botswana, Mozambique, Malawi, and other Southern African countries as a medicine against cancer, and toothache, and as a laxative remedy for stomach cleaning [5, 7]. In the Northern part of South Africa and the Southern parts of Zimbabwe, the Candelabra tree stems are used to poison fish when fishing and its milky latex harvested from the stems and branches can be processed by boiling to produce a sticky wax used to catch birds [1, 5]. Based on the mentioned applications of the Euphorbia candelabrum tree's milky latex by the Southern African people, there is one fascinating application that has attracted the interest of the research work presented in this paper. The boiling/heating of the candelabra tree's milky latex to produce a sticky wax (adhesive) that is used to catch birds is one of the traditional ways of bird trapping in the Southern African region. The technique of producing the sticky wax (adhesive) from the candelabra milky latex is common to local people of Southern Africa. However, the mechanical, thermal, chemical, and other properties of the processed latex have not yet been studied and documented in detail. Hence this work focuses on the experimental investigation of the thermal stability, mechanical performance (bonding strength), and the failure mode of the candelabra tree's milky latex that can be used as an adhesive for general engineering applications not just for catching birds. The work covered in this paper is the ground-breaking integration of traditional African technology of producing adhesives with modern scientific knowledge aiming to expand and popularise this technique. Moreover, the work documents and preserves African science and technology for coming generations.

Adhesives are mechanisms that are used to join materials using chemical reactions to achieve bonding. Compared to other bonding mechanisms, adhesives are a much more practical joining method due to their ability to distribute stress uniformly and a large stress-bearing area [8]. They use Van der Waals forces to form bonds between the adherend surfaces and the adhesive [8]. Adhesives can also be classified by the type of applications they are used for, whether they are structural or non-structural applications [9]. Structural adhesives have a higher resistance to stresses and can be used in high-load applications while non-structural applications have low strength and can be used in light-load applications [10]. Apart from the distinguished applications of the adhesives, there are different types of adhesives such as inorganic and organic adhesives [11]. Bio adhesives have been around for centuries, and they have better benefits in their health and environmental properties. The increased awareness of global sustainability and changes in governmental regulations are increasing the popularity of bioadhesives [12]. Most organic adhesives are classified under non-structural adhesives owing to their low bonding strength [13]. Whereas structural adhesives possess relatively good shear strengths averaging around 7 MPa [14]. The advantage of organic adhesives is that they are abundantly available in nature. However, their disadvantage is that they possess lower bonding strengths when not chemically enhanced [15]. This opened new research areas where organic adhesives are targeted and investigated for improvement in terms of mechanical, thermal, and chemical properties. The mechanical performance of various adhesives has been widely studied and documented for decades. Budzik *et al.* [16] reviewed the various methods that are standardized to conduct the experimental investigation of the mechanical performance of adhesively bonded composite joints in various engineering applications. The standards of testing adhesives have laid significant research guidelines that are mostly used to obtain relevant results during scientific experiments. Deng *et al.* [17] investigated the performance of natural adhesives made from snail mucus for biological application (wound repair). The investigated adhesive was found to have good mechanical properties and was remarkable for rat wound repair compared to other wound repair adhesives. This study proves that the application of natural or organic adhesives can be extended beyond engineering applications. Hence, the present study adds to the existing knowledge of organic adhesives by introducing candelabra latex adhesive for wood-to-wood bonding performance.

II. Materials and Methods

A. Materials

The euphorbia candelabrum latex was harvested from the tree through the natural method of pocking a small hole/dent on the stem or the branch of the plant ensuring that the white milky latex drops out and then collected by a container. This method is lengthy and sometimes one hole is not enough depending on the size of the tree, however, proven to be effective. Fig. 1(a) shows the candelabra tree and Fig. 1(b) shows the stem of the candelabra tree with milky latex dropping through the hole created. The alternative method of harvesting the milky latex is to cut the branch of the tree cross-sectional as presented in Fig. 1(c) then squeeze the outer port to allow the latex to come out.

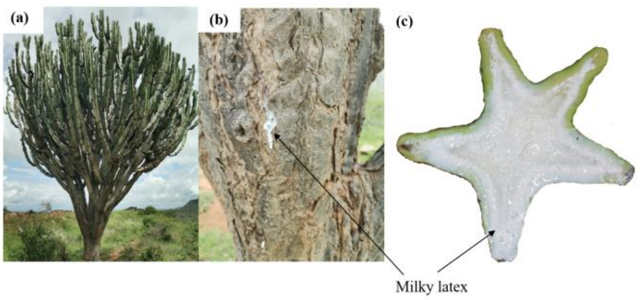

Fig. 1. (a) The Euphorbia candelabrum tree known as (Naboom of Euphorbia ingens), (b) the stem of the candelabra tree with milky latex dropping through a created dent, (c) the inner part of a branch of the candelabra tree.

The harvested milky latex was then stored in the cooler box and transported to the lab where it was stored in the refrigerator at temperatures between −3 ℃ and 10 ℃. For the primary examination of the candelabra latex, the branch of the plant was cross-sectionally dissected as presented in Fig. 1(c), and then analysed. The inner part of the candelabra tree presented in Fig. 1(c) shows that the milky latex of the plant is concentrated between the outer green part of the branch and the inner white part. This clearly shows that the better way of harvesting the milky latex of the plant is to target the inner part of the branch where the latex is highly concentrated. This observation has broadened up new techniques of harvesting milky latex other than the natural way. Harvesting methods such as squeezing the dissected candelabra tree branches with the hydraulic press have been adopted and they have shown to be quick and effective.

B. Material Processing

The candelabra plant’s milky latex was processed according to the flow diagram in Fig. 2. First, the raw latex was analysed for thermal stability using Thermogravimetric Analysis (TGA) to obtain the best-boiling temperature range. The obtained thermal stability results were then used to select the optimal heating temperatures. Secondly, the latex was poured into a boiling source and then boiled at a temperature of 180 ℃ while steering till it became sticky after roughly 18 minutes. The process was repeated at 215 ℃ and 250 ℃. The three groups of sticky polymerized latex were then applied to the wooden lap shear samples and left to dry for 24 hours.

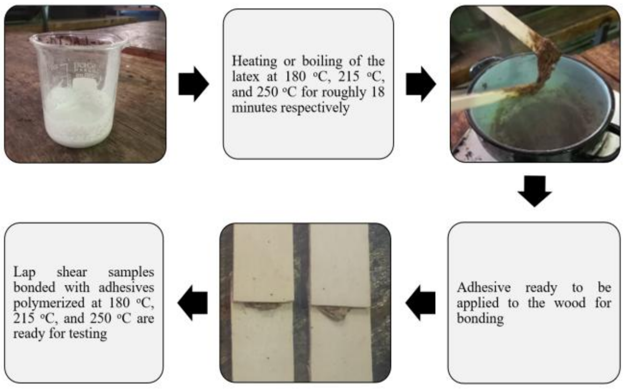

Fig. 2. The processing of latex for adhesive.

The wood test samples were cut conforming to ISO 4587 standards with the following dimensions; a total length of 101 mm, a width of 25 mm, and a thickness of 3 mm. The adhesive was applied on an overlap area of 12 by 25 mm which was standard for all prepared specimens. The analysis and the lap shear tests were then conducted, and the obtained results are presented and discussed in the next section.

III. Results and Discussion

A. Thermal Stability Analysis

The thermal stability for raw and processed latex was examined using the Thermogravimetric Analysis (TGA) machine model TGA5500. The heat rate on the machine was set to 10 ℃/min from 27 ℃ to 700 ℃. The Thermogravimetric (TG) results for the raw and processed latex are presented in Figs. 3 and 4 respectively. The TG curve in Fig. 3 represents the weight percentage loss of the raw latex against time. The trend shows a weight loss of 33% from 27 ℃ to roughly 115 ℃ due to the evaporation of moisture content within the latex. As the temperature increases, the thermal stability of the latex is achieved at roughly 115 ℃ to approximately

210 ℃. Further temperature increase causes the degradation between 210 ℃ to 250 ℃, and the major weight loss of 49% occurs between 250 ℃ towards 340 ℃ due to the decomposition of the latex. The complete decomposition of the combustion of latex took place from roughly 340 ℃ to 600 ℃ then the ash content remained at 700 ℃. These observations showed that the latex forms an adhesive at temperatures between 115 ℃ and 210 ℃ due to thermal stability.

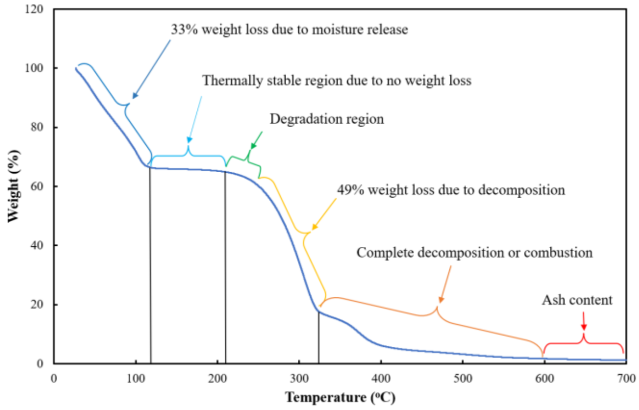

Fig. 3. The Thermogravimetric (TG) curve of the raw latex.

Further thermal stability analysis was conducted on the three types of sticky wax (adhesives) produced from the latex polymerized at 180 ℃, 215 ℃, and 250 ℃ as shown in Fig. 4. The TG trends of the three polymerized adhesives in Fig. 4 are similar from 27 ℃ to 700 ℃ and do not have a moisture loss region compared to raw latex, due to the polymerization process that occurred before analysis. The reason for not having evaporation or resulting in a very low moisture loss between 27 ℃ and roughly 140 ℃ is that the latex was boiled first to produce the adhesives. In short, the moisture loss occurred during the boiling or cooking process. The analyzed adhesives had less or no moisture content. However, three types of the examined adhesives were shown to be thermally stable from approximately 140 ℃ to 210 ℃. The is a similar thermal stability range to that of raw latex. As the temperature increases, from 210 ℃ to 700 ℃, the strand in Fig. 4 resembles the behavior of the trend in Fig. 3.

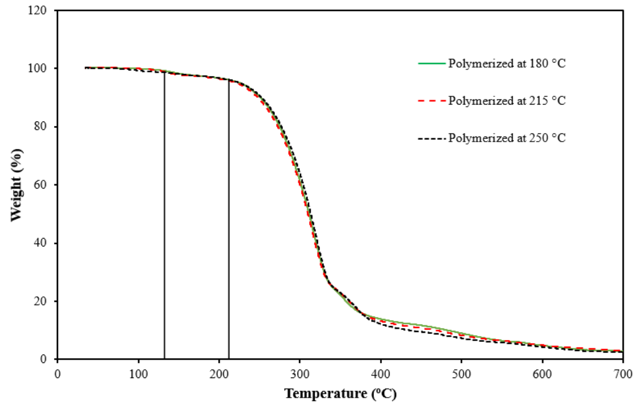

Fig. 4. The Thermogravimetric (TG) curves of the latex polymerised at 180℃, 215℃, and 250℃.

Overall, the thermal stability of the latex is reached at temperatures between 115 ℃ and 210 ℃, which provides the optimal heating temperatures for the processing of the candelabra milky latex to produce the adhesive. Temperatures above 210 ℃ to roughly 250 ℃ are acceptable for polymerization. However, accurate and assessed measures should be considered to ensure that the degradation to the decomposition of the adhesive does not occur. Further analysis was conducted through a lap shear test to examine the effect of boiling temperature on the bonding strength of the produced adhesive.

B. Lap Shear Analysis

The lap shear test was conducted using a Zwick/Roell Z250 tensile testing machine. The testing machine was set to a preload of 5 N and a pulling rate of 1.3 mm/min. The resulting stress-strain response of the adhesive prepared at the different temperatures of 180 ℃, 215 ℃, and 250 ℃ are presented in Fig. 5. It can be observed that an increase in polymerization temperature is directly proportional to an increase in the maximum shear strength. The average maximum ultimate shear strength obtained was 0.652 MPa for the adhesive processed at 250 ℃. However, the average maximum yielding shear strength of 0.402 MPa was achieved for adhesive prepared at 215 ℃. The summary of the stress-strain relationship of the three processed adhesives is presented in Table 1.

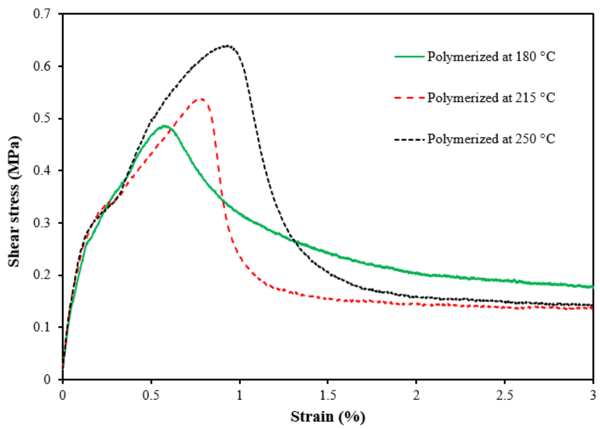

Fig. 5. The stress-strain relationship for the adhesives polymerized at 180 ℃, 215 ℃, and 250 ℃.

The second column of Table 1 presents the average maximum force recorded for each set of adhesives. It shows that the average maximum force recorded of 195.572 N is achieved from the adhesive polymerized at 250 ℃. This means adhesives processed at 250 ℃ are stronger than those processed at 215 ℃ and 180 ℃ respectively. However, the yield strength of the adhesive polymerized at 215 ℃ is slightly higher than those processed at 250 ℃. This might be due to the intermolecular forces between the adhesive atomic bonds that need to be investigated further for detailed understanding. In general, the polymerization temperature proved to influence the bonding strength of the produced adhesives.

Table 1. The summary of the lap shear results for the adhesives polymerized at 180 ℃, 215 ℃, and 250 ℃

Temperature [℃]	Maximum force [N]	Ultimate shea [MPa]	Yield Strength [MPa]
180 ℃	147.070	0.490	0.263
215 ℃	157.622	0.526	0.402
250 ℃	195.572	0.652	0.398

Further analysis was performed to assess the failure mode of the adhesives by examining the surfaces of the bonded lap shear specimens after the lap shear test through a microscope. The obtained results are analyzed in the next section.

C. Microscopic Analysis

The failed surfaces of the overlap joint for adhesives produced at 180 ℃, 215 ℃, and 250 ℃ are presented in Fig. 6.

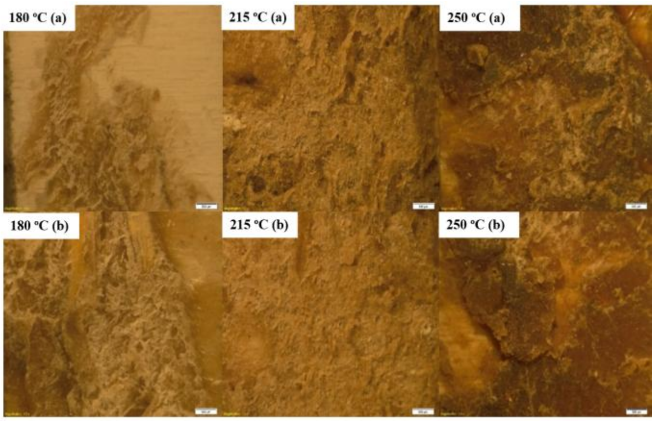

Fig. 6. The magnified images of the fractured lap shear surfaces of the specimen processed at 180 ℃, 215 ℃, and 250 ℃.

Fig. 6 180 ℃ (a) and 180 ℃ (b) present the failed surfaces of the adhesives polymerized at 180 ℃ applied to the lap shear samples (a) and (b) respectively. The two images of the surfaces were taken at a magnification of x 1.6 and show that the adhesive elongated before the complete fracture due to ductile properties. They also demonstrate a cohesive failure where a layer of adhesive remains on both surfaces after the lap shear test. The same mode of failure (cohesive) is also shown by Fig. 6. 215 ℃ (a), 215 ℃ (b) 250 ℃ (a), and 250 ℃ (b). Although all the samples were shown to fail similarly, the 215 ℃ (a) and 215 ℃ (b) appeared to be more rigid compared to 180 ℃ (a), and 180 ℃ (b). As the temperature increases to 250 ℃, the 250 ℃ (a), and 250 ℃ (b) surfaces appear to be more solid and darker compared to the surfaces of the adhesives polymerized at 180 ℃ and 215 ℃. This is influenced by the polymerization temperature as illustrated by the TGA results. As the temperature increases from above 210 ℃, the degradation of the adhesive begins, and the moisture content decreases drastically toward 400 ℃.

D. Other Recommendations

Investigation of chemically treated candelabra latex on metal-to-metal aluminum lap joints considering mechanical tests, and microscopic assessments.

Investigating metal-to-metal adhesive behaviour of chemically treated candelabra latex in mixed tension-shear loading.

IV. Conclusion

This work investigated the thermal stability, bonding strength, and failure mode of the adhesive made of Euphorbia candelabrum plant's milky latex. The milky latex was polymerized at 180 ℃, 215 ℃, and 250 ℃, then examined for thermal stability through Thermogravimetric Analysis (TGA). The bonding strength of the adhesives was analyzed using a lap shear test then further examinations were conducted to examine their failure mode and the following conclusions were made:

- The thermal stability of raw and the latex polymerized at 180 ℃, 215 ℃, and 250 ℃, was achieved at temperatures ranging from roughly 115 ℃ to 210 ℃, with the degradation of the adhesive starting from 210 ℃ to approximately 250 ℃ due to the temperature increase.
- The maximum average bonding force of 195.572 N and the average shear strength of 0.652 MPa were achieved for adhesive processing at 250 ℃.
- The microscopic analysis demonstrated a cohesive failure for adhesives polymerized at 180 ℃, 215 ℃, and 250 ℃ after lap shear tests.

Conflict of Interest

The authors declare no conflict of interest.

Author Contribution

All authors contributed to the study's conception and design. Siphesihle S. Xulu and Ronny T. Tebeta performed material preparation and data collection; Siphesihle S. Xulu, Ronny T. Tebeta, and Daniel D. Madyira performed data analysis; Siphesihle S. Xulu and Ronny T. Tebeta wrote the first draft of the manuscript; Daniel M. Madyira. Ronny T. Tebeta, Daniel M. Madyira provided resources and financial support; Harry M. Ngwangwa revised the original manuscript to the current version; all authors had approved the final version.

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