

## EXPERIMENTS INTO THE MECHANICAL AND CHEMICAL CHARACTERISTICS OF HYBRID MATERIALS MADE FROM EPOXY RESIN WITH NATURAL RESIN DAMMAR

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**Abstract:** The significance of utilizing environmentally friendly materials has increased recently. Natural resins derived from vegetal, animal, or mineral sources are being utilized with growing frequency. This article examines the characteristics of hybrid composites created by combining natural resin Dammar with epoxy resin. The Dammar volume proportions were 60%, 70%, and 80%, respectively. The article is divided into two parts. The chemical composition of the natural resin Dammar is analysed in the first part. The substance underwent purification through chromatography. The structure and purity of the isolated substances were analysed using [1] H-NMR, [13] C-NMR, and mass spectrometry. The second part focuses on the structural characterization and certain mechanical properties of the three distinct hybrid composites. To achieve this, the characteristic curves, modulus of elasticity, tensile strength, and the elongation at break were assessed.

**Keywords:** Dammar resin, Terpenoids, Material science, Natural products

### 1. Introduction:

Bio-composite materials have gained prominence in recent decades; however, they utilize a synthetic resin matrix, which presents challenges in processing due to high viscosity when melted, resulting in difficulties in recycling the final product. These deficiencies can be compensated for by utilizing natural resins, which may be fossil (Colophony), plant-based (Sandarac, Copal, Dammar), or animal-derived (Shellac). Natural resins are insoluble in water. They are soluble in petrol, alcohol, and oil. Consequently, they can be combined with organic solvents to produce solutions suitable for use as covering lacquers. Turpentine, colophony, and mastic are products of the distillation of specific coniferous resins. The properties of these resins are detailed in the study by Prati et al. [1]. Suprakas and Mosto [2] discuss various applications of these resins.

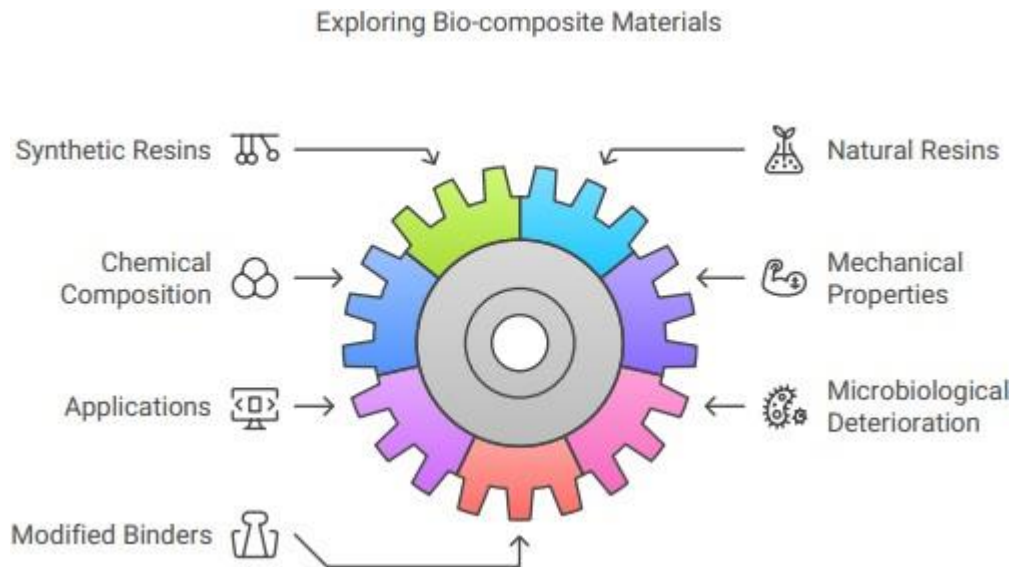


Figure:1(a) Bio-composite Materials

Research on these resins has primarily concentrated on their chemical composition and properties, with less emphasis on their mechanical properties. Romero Nagueram et al. [3] focus on enhancing the understanding of the microbiological bio-deterioration of Dammar-based lacquers in artworks subjected to inadequate protection conditions, especially those exposed for extended periods to elevated relative humidity levels. Zakaria and Ahmad [4] introduce a modified binder composed of silicon and Dammar, which minimizes the reliance on synthetic binders while exhibiting enhanced ecological properties. The study evaluates the optimal composition that guarantees superior properties for impact, hardness, tensile strength, and adhesion stresses. Additionally, Zakaria and Ahmad [5] examine in a separate study how Dammar addition can enhance the rigidity, elastic modulus, and hardness of modified silicon. The study examined the use of dammar gum as an additive to enhance thermal conductivity and performance in the preparation of composite phase change materials [6]. Hamadani et al. [7] examined the potential application of beeswax, tallow, and Dammar as phase change materials (PCM) in concrete structures. The influence of polymethyl methacrylate (PMMA) on the physical properties of Dammar for use in covering lacquers was analyzed [8]. The significance of polymer composites utilizing epoxy resins is extensively detailed in the research conducted by Hsissou et al. [9, 10].

Epoxy resins provide numerous advantageous properties and are easy to handle, making them suitable for coating materials for protection [11]. Consequently, the mechanical characteristics of composite materials surpass those of the constituent materials [12, 13].

However, there is a limited number of studies examining the mechanical behavior of natural resins. Pethe and Joshi [14] investigated the mechanical properties (tensile strength, percentage elongation, and Young's modulus), water vapor transmission characteristics, and moisture absorption properties of Dammar films, both with and without a softening agent. Additionally, there is a limited number of studies focusing on composite materials that utilize both natural materials for their matrix and reinforcing agents. The mechanical behavior of specific composite materials utilizing a Dammar-based bio-resin matrix, reinforced with cotton, flax, silk, and hemp, has been previously investigated [15].

## 2.0 Hypothesis

### 2.1 General

Every single reagent was obtained from commercial suppliers (Sigma-Aldrich or Acros) and utilized without additional purification. Solvents utilized were of analytical grade. Proton ( $^1\text{H}$ ) and carbon ( $^{13}\text{C}$ ) NMR spectra were obtained at room temperature using a Bruker Avance 300 operating at 400 MHz for  $^1\text{H}$ -NMR and 100 MHz for  $^{13}\text{C}$ -NMR. Chemical shifts ( $\delta$ ) are expressed in relation to the tetramethylsilane peak ( $\delta = 0.00$  ppm). Mass spectra were obtained using a Finnigan MAT 8400-MSS and a Finnigan MAT 4515. Purifications were monitored using thin-layer chromatography (TLC) on silica gel plates measuring  $40 \times 80$  mm, specifically Polygram Sil G UV254 (Macherey–Nagel).

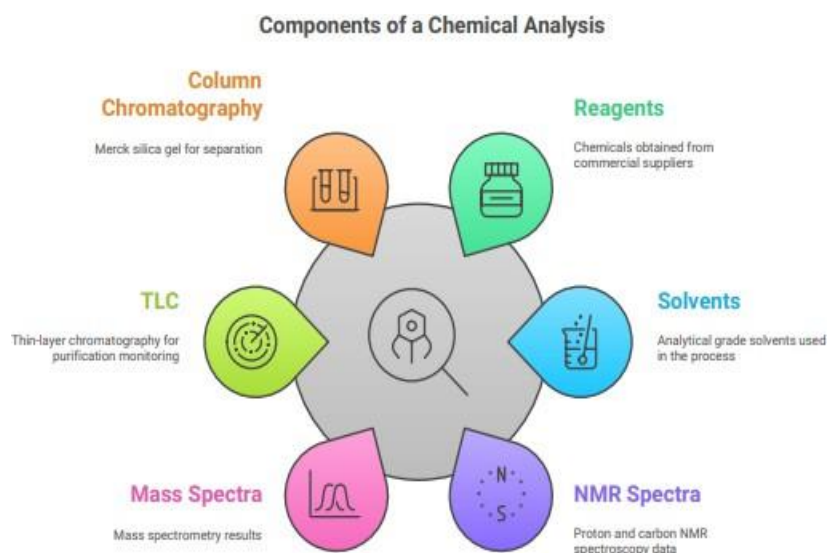


Figure: 1 (b) Components of a Chemical Analysis

Visualization on thin-layer chromatography was accomplished using ultraviolet light. Column chromatography utilized Merck silica gel 60 (70–200 mesh).

### 2.2 Extraction of specific compounds from Dammar resin

Fifteen grams of Dammar resin were dissolved in 100 milliliters of dichloromethane (DCM), also known as methylene dichloride. Fifty grams of silica gel were added to this solution. The solvent was removed, and the substance adhered to silica was loaded onto a silica gel column (200 g) and subjected to chromatography using an elution system of n-Hexane–Acetone with a gradient of (20:1–5:1), resulting in seven fractions (Fr.1-Fr.7). Amounts: Fr1: 1.3 g colorless oil; Fr2: 0.98 g white solid; Fr3: 1.6 g white solid; Fr4: 0.7 g white solid; Fr5: 0.83 g white solid; Fr6: 1.03 g white solid; Fr7: 1.12 g white solid.

### Compound 1

<sup>13</sup>C-NMR (CDCl<sub>3</sub>, 100 MHz) δ 131.55 (Cq), 124.71 (CH), 78.95 (CH), 75.44 (Cq), 55.85 (CH), 50.63 (CH), 50.27 (Cq), 49.82 (CH), 42.26 (CH), 40.48 (CH<sub>2</sub>), 40.35 (Cq), 39.03 (CH<sub>2</sub>), 38.95 (Cq), 35.22 (CH<sub>2</sub>), 31.16 (CH<sub>2</sub>), 27.98 (CH<sub>3</sub>), 27.51 (CH<sub>2</sub>), 27.37 (CH<sub>2</sub>), 25.72 (CH<sub>3</sub>), 25.31 (CH<sub>3</sub>), 24.79 (CH<sub>2</sub>), 23.60 (CH), 22.53 (CH<sub>2</sub>), 21.52 (CH<sub>2</sub>), 18.26 (CH<sub>2</sub>), 17.69 (CH<sub>3</sub>), 16.43 (CH<sub>3</sub>), 16.19 (CH<sub>3</sub>), 15.49 (CH<sub>3</sub>), 15.34 (CH<sub>3</sub>). <sup>1</sup>H-NMR (CDCl<sub>3</sub>, 400 MHz) δ 5.16–5.08 (m, 1 H); 3.20 (dd, J = 11.15 Hz, J = 5.07 Hz, 1 H); 2.30–2.15 (m, 1 H); 2.13–2.1.78 (m, 4 H); 1.78–1.57 (m, 3 H); 1.69 (s, 3 H); 1.62 (s, 3 H); 1.57–1.38 (m, 6 H); 1.38–1.17 (m, 4 H); 1.16–0.75 (m, 8 H); 1.14 (s, 3 H); 0.97 (s, 3 H); 0.96 (s, 3 H); 0.88 (s, 3 H); 0.84 (s, 3 H); 0.77 (s, 3 H). H,H-Cosy, HSQC and HMBC were made. MS(EI) 428 [6], 411 [17], 410 [20], 394 [100]. HRMS(ESI): m/z calcd. for C<sub>30</sub>H<sub>53</sub>O<sub>1</sub> + (M +H<sup>+</sup>) 429.4091, found 429.4096.

### Compound 2

M.p.: 140–142 °C. Elem. Anal. Calcd for C<sub>30</sub>H<sub>50</sub>O<sub>3</sub> (%): C, 78.55; H, 10.99. found (%): C, 78.23; H, 10.87. <sup>13</sup>C-NMR(CDCl<sub>3</sub>, 100 MHz) δ 179.86 (Cq), 147.42 (Cq), 131.59 (Cq), 124.61 (CH), 113.43 (CH<sub>2</sub>), 75.60 (Cq), 50.76 (CH), 50.64 (Cq), 49.44 (CH), 42.30 (CH), 40.99 (CH), 40.56 (CH<sub>2</sub>), 40.00 (Cq), 39.01 (Cq), 34.24 (CH<sub>2</sub>), 33.80 (CH<sub>2</sub>), 31.18 (CH<sub>2</sub>), 28.32 (CH<sub>2</sub>), 37.40 (CH<sub>2</sub>), 25.71 (CH<sub>3</sub>), 25.29 (CH<sub>3</sub>), 24.74 (CH<sub>2</sub>), 24.58 (CH<sub>2</sub>), 23.19 (CH<sub>3</sub>), 22.52 (CH<sub>2</sub>), 22.03 (CH<sub>2</sub>), 20.12 (CH<sub>3</sub>), 17.69 (CH<sub>3</sub>), 16.34 (CH<sub>3</sub>), 15.30 (CH<sub>3</sub>). <sup>1</sup>H-NMR(CDCl<sub>3</sub>, 400 MHz) δ 5.12 (t, J = 1.28 Hz, 1 H); 4.85 (s, 1 H); 4.66 (s, 1 H); 2.45–2.31 (m, 1 H); 2.25–2.13 (m, 1 H); 2.10–1.92 (m, 3 H); 1.90–1.57 (m, 6 H); 1.73 (s, 3 H); 1.69 (s, 3 H); 1.63 (s, 3 H); 1.57–1.36 (m, 7 H); 1.36–1.19 (m, 3 H); 1.18–1.03 (m, 2 H); 1.15 (s, 3 H); 1.00 (s, 3 H); 0.98–0.82 (m, 1 H); 0.89 (s, 3 H); 0.85 (s, 3 H). H,H-Cosy, HSQC and HMBC were made. MS(EI) 458 [3], 440 [25], 424 [100]. HRMS (ESI): m/z calcd. for C<sub>30</sub>H<sub>50</sub>Na<sub>1</sub>O<sub>3</sub> (M +Na<sup>+</sup>) 481.3652, found 481.3658.

### Compound 3

Elem. Anal. Calcd for C<sub>30</sub>H<sub>46</sub>O<sub>3</sub> (%): C, 79.25; H, 10.20. found (%): C, 79.13; H, 10.05. <sup>13</sup>C-NMR(CDCl<sub>3</sub>, 100 MHz) δ 217.74 (Cq), 207.27 (CH), 137.93 (Cq), 125.91 (CH), 55.23 (CH),

52.63 (CH), 50.17 (Cq), 47.37 (Cq), 46.76 (CH), 45.53 (CH<sub>2</sub>), 42.27 (Cq), 39.77 (Cq), 39.35 (CH<sub>2</sub>), 38.81 (CH), 36.62 (Cq), 34.14 (CH<sub>2</sub>), 32.62 (CH<sub>2</sub>), 31.80 (CH<sub>2</sub>), 30.14 (CH<sub>2</sub>), 26.84 (CH<sub>2</sub>), 26.58 (CH), 26.44 (CH<sub>3</sub>), 23.45 (CH<sub>2</sub>), 23.16 (CH<sub>2</sub>), 23.12 (CH<sub>3</sub>), 21.46 (CH), 21.03 (CH<sub>3</sub>), 19.54 (CH<sub>2</sub>), 16.95 (CH<sub>3</sub>), 15.29 (CH<sub>3</sub>). <sup>1</sup>H-NMR(CDCl<sub>3</sub>, 400 MHz) δ 9.33 (s, 1 H); 5.48–5.42 (m, 1 H); 5.36–5.32 (m, 1 H); 2.60–2.47 (m, 2 H); 2.44–2.31 (m, 2 H); 2.25–1.80 (m, 4 H); 1.79–1.20 (m, 8 H); 1.20–1.072 (m, 10 H); 1.10 (s, 3 H); 1.04 (s, 3 H); 0.97 (s, 3 H); 0.95 (s, 3 H); 0.94 (s, 3 H); 0.92 (s, 3 H). H,H-Cosy, HSQC and HMBC were made. MS(EI) 456 [3], 438 [29], 409 [100]. HRMS (ESI): m/z calcd. for C<sub>30</sub>H<sub>46</sub>Na<sub>1</sub>O<sub>3</sub> (M + Na<sup>+</sup>) 477.3339, found 477.3331.

#### Compound 4

Elem. Anal. Calcd for C<sub>30</sub>H<sub>44</sub>O<sub>3</sub> (%): C, 79.60; H, 9.80. found (%): C, 79.42; H, 9.65. <sup>13</sup>C-NMR (CDCl<sub>3</sub>, 100 MHz) δ 217.69 (Cq), 207.34 (CH), 143.04 (Cq), 122.98 (CH), 55.29 (CH), 49.10 (Cq), 47.41 (Cq), 46.78 (CH), 41.81 (Cq), 40.43 (CH), 39.53 (Cq), 39.16 (CH<sub>2</sub>), 38.96 (CH), 36.70 (Cq), 34.12 (CH<sub>2</sub>), 33.13 (CH<sub>2</sub>), 33.03 (CH), 31.26 (CH<sub>2</sub>), 30.62 (Cq), 27.68 (CH<sub>2</sub>), 26.71 (CH<sub>2</sub>), 25.40 (CH<sub>3</sub>), 23.50 (CH<sub>2</sub>), 23.39 (CH<sub>3</sub>), 22.04 (CH<sub>2</sub>), 21.44 (CH<sub>3</sub>), 19.54 (CH<sub>2</sub>), 17.18 (CH<sub>3</sub>), 15.64 (CH<sub>3</sub>), 15.04 (CH<sub>3</sub>). <sup>1</sup>H-NMR(CDCl<sub>3</sub>, 400 MHz) δ 9.40 (s, 1 H); 5.52–5.48 (m, 1 H); 5.39–5.35 (m, 1 H); 2.69–2.61 (m, 1 H); 2.60–2.47 (m, 1 H); 2.44–2.31 (m, 2 H); 2.25–1.80 (m, 4 H); 1.79–1.20 (m, 7 H); 1.20–1.072 (m, 8 H); 1.15 (s, 3 H); 1.09 (s, 3 H); 0.99 (s, 3 H); 0.96 (s, 3 H); 0.91 (s, 3 H); 0.88 (s, 3 H). H,H-Cosy, HSQC and HMBC were made. MS(EI) 454 [3], 436 [23], 407 [100]. HRMS (ESI): m/z calcd. for C<sub>30</sub>H<sub>44</sub>Na<sub>1</sub>O<sub>3</sub> + (M + Na<sup>+</sup>) 475.3183, found 475.3179.

#### 2.3 Infrared spectroscopy

The Bruker™ Fourier converted infrared spectrometer is utilized for recording infrared spectra. The light beam transmits through the sample. The sample thickness measures 2 μm. The analysis occurs within the range of 4000 to 600 cm<sup>-1</sup>.

#### 2.4 Hybrid material combinations

The naturally occurring resin Dammar, when diluted with turpentine, solidifies over time if applied in thin layers. When stored in containers, it retains its liquid state. The composite products solely utilizing this resin have an extended curing duration. To rectify this deficiency, It is adequate for this resin to be amalgamated with synthetic resins.

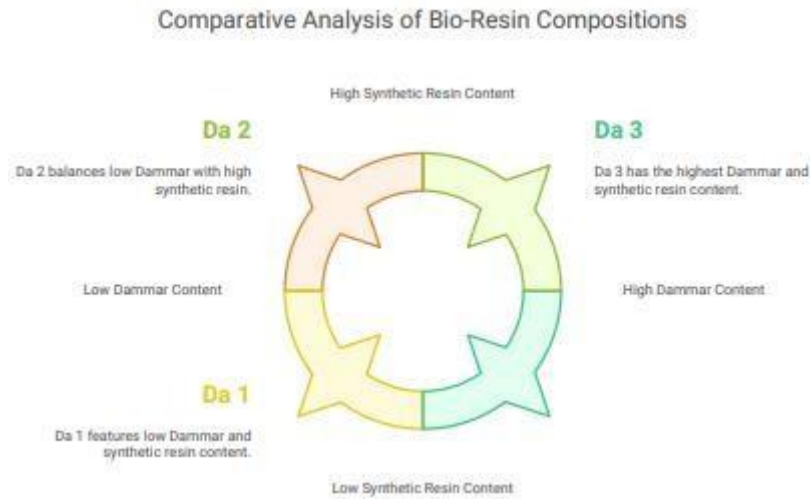


Figure:1(c) Highly synthetics Resin Content

We produced three bio-resin plates utilizing Dammar in volume proportions of 60% (Da 1), 70% (Da 2), and 80% (Da 3). The variation up to 100% comprised Resoltech 1050 epoxy resin and its corresponding reinforcing agent, Resoltech 1055. The synthetic component (epoxy resin and reinforcing agent) was essential for establishing rapid activation spots in the polymerization process. The temperature fluctuated between 21 and 23 °C. We adhered to the producer's instructions to formulate the combination of Resoltech 1050 and the reinforcing agent Resoltech 1055. We employed a combination in a 7:3 volume ratio. We combined the acquired epoxy resin with Dammar resin. All specimens of the three varieties of hybrid composite were excised after a duration of 10 days.

We extracted three sets of ten samples from the cast plates, designated Da 1.1–10, Da 2.1–10, and Da 3.1–10. The dimensions of the samples were 250 mm in length and 25 mm in width, in accordance with ASTM D3039. The thickness measured 6.1 mm for the Da 1.X and Da 2.X sample sets, and 6.0 mm for the Da 3.X sample set. The material's density varied from 1.04 to 1.06 g/cm<sup>3</sup>.

### 3.0 Findings and Analysis

#### 3.1 Characterization of individual chemicals in Dammar resin

A Dammar resin was purified using column chromatography, and the recovered compounds were analyzed by NMR spectroscopy and mass spectrometry. Previously, Hidayat et al. [16] examined the Dammar resin derived from *Aglaia elliptica*. They identified six chemicals that were extracted for the first time from this plant (Fig. 1). Additional findings are presented in [17].

Through chromatographic purification, we isolated seven fractions, of which four contained a



singular chemical. These were the fractions three, four, six, and seven. The remaining samples comprised mixes. The structure was determined primarily using  $^1\text{H-NMR}$  and  $^{13}\text{C-NMR}$  analyses, together with mass and elemental examination of the substances that are pure.

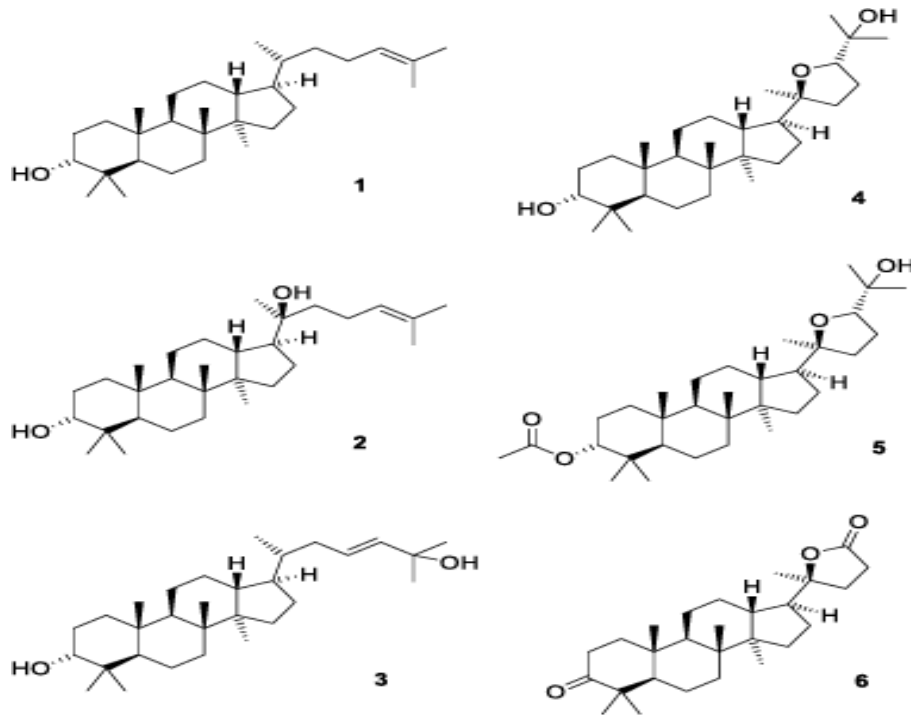


Figure: 1 For comparison: identified chemicals from Hidayat et al. [16].

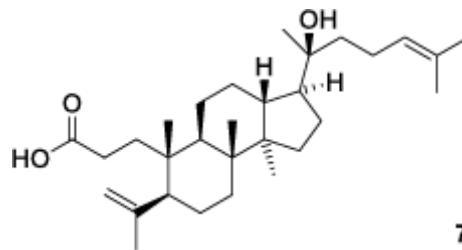


Figure: 2 illustrates the structure of Dammare nolic acid 7 from fraction 7.

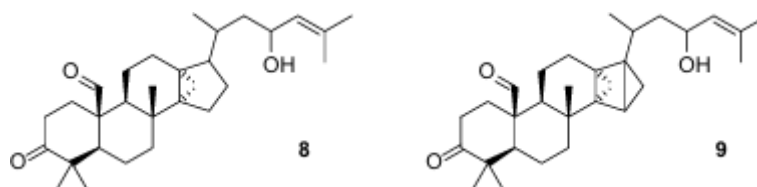


Figure: 3 Structures of compound 8 from fraction 3 and compound 9 from fraction 4  
The compound (5R,8R,9R,10R,13R,14R,17R)-4,4,8,10,14-pentamethyl is also known as 17-((R)-6-methylhept-5-en-2-yl).Hexadecahydro-1H-cyclo-penta[a]phenanthren-3-ol (1) was found in fraction six of the Dammar resin mixture under investigation. This is not surprising

given that the substance in question is the fundamental structure of the Dammar material class. Several groups, including Hidayat [16], have described it.

The component in fraction 7 was identified as 3-((3S,3aR,5aR,5aR,5aR,6S,7S,9aR,9bR).-3-((S)-2-hydroxy-6-methylhept-5-en-2-yl)-6,9a,9b-trimethyl-7-(prop-1-en-2-yl)Dodecahydro-1H-cyclo-penta[a]naphtha(lin-6-yl)propionic acid (7). This secondary metabolite opens ring A from the Dammar skeleton, resulting in carboxylic acid functionality through secondary alcohol oxidation at C-3 during C-C-bond breakage (Fig. 2). Compound 7 is sometimes called Dammarenolic acid [18].

Figure 3 shows the identification of two interesting chemicals in fractions 3 and 4: (5R, 8R, 9S, 10S, 13R, 14R).-17-(4-hydroxy-6-methylhept-5-en-2-yl)-4,4,8-trimethyl-3-oxododecahydro-15H-13,14-methanocyclopenta[a] phenanthrene-10(1H)-carbaldehyde (8) and (4aS,4bS,6aR,7bS,7cR,9aR).-6b-(4-hydroxy-6-methylhept-5-en-2-yl)-1,1,7c-trimethyl-2-oxo-dodeca-hydro-7H-6a,7b-methanocyclopropa[3,4], cyclobuta[1,2-a]phenanthrene-4a(2H)-carb-aldehyde (9). Both exhibit similar modifications. The hydroxy group at position three was oxidized to ketone as expected. Secondly, a methyl group was transformed into an aldehyde function. This aldehyde-ketone combination is unique to Dammar's substance class. Although these compounds are heavily oxidized in ring A, the prenyl group in the side chain remains intact.

The formation of a cyclopropyl ring is very intriguing. This work lacks clarity on how functionality is produced. Aldehydes 8 and 9 exhibit unique structural modifications when compared to compound 1, which represents the Dammar strain system.

### 3.2 IR spectral analysis: structural characterisation

Following the synthesis of the composite materials, we conducted structural identification using Fourier transform infrared spectroscopy. The IR spectra of the hybrid composite material Da 2.5 is presented in Fig. 4. The distribution of various bands of the substance is as follows. The band at  $3341\text{ cm}^{-1}$  signifies the various types of hydroxy groups. The elongation of aliphatic methylene bonds is indicated by the two bands at  $2922\text{ cm}^{-1}$  and  $2852\text{ cm}^{-1}$ . Finally, it is important to note the band at  $1032\text{ cm}^{-1}$ , which arises from the change in binding valence of aliphatic ethers (CH<sub>2</sub>-O). The IR spectra of compounds derived from Dammar resin predominantly exhibit bands associated with aliphatic methylene groups, resulting in minimal variances across the IR spectra of various hybrid composite materials.

### 3.4 Mechanical characteristics



The bio-resin specimens were subjected to a tensile test conducted in accordance with ASTM D3039 standards [19]. We utilized the LRX Plus testing apparatus from LLOYD Instruments, featuring the subsequent specifications: Force range: 2.5 kN; Travel: 1–735 mm; Crosshead speed: 0.1–500 mm/min; Analysis software: NEXYGEN.

The results derived from this experiment included the characteristic curve, tensile strength  $R_m$  (MPa), percentage elongation post-fracture  $A$  (%), and elasticity modulus  $E$  (N/mm<sup>2</sup>).

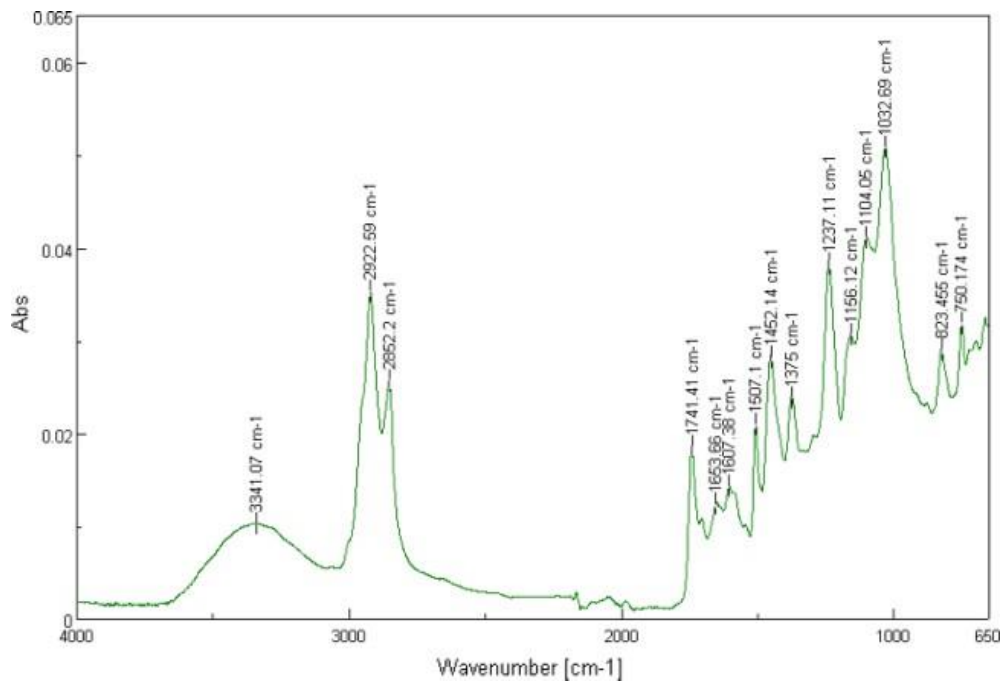


Figure 4 illustrates the infrared spectrum of a composite material comprising 30% epoxy resin and 70% Dammar (DA 2.5).

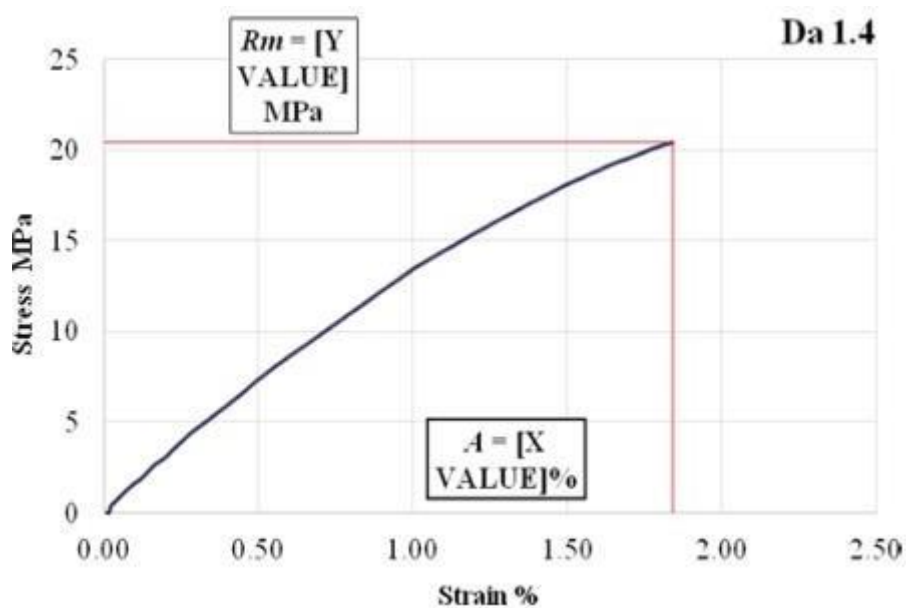


Figure:5 shows the characteristic curve of a Da 1.X set representative specimen.

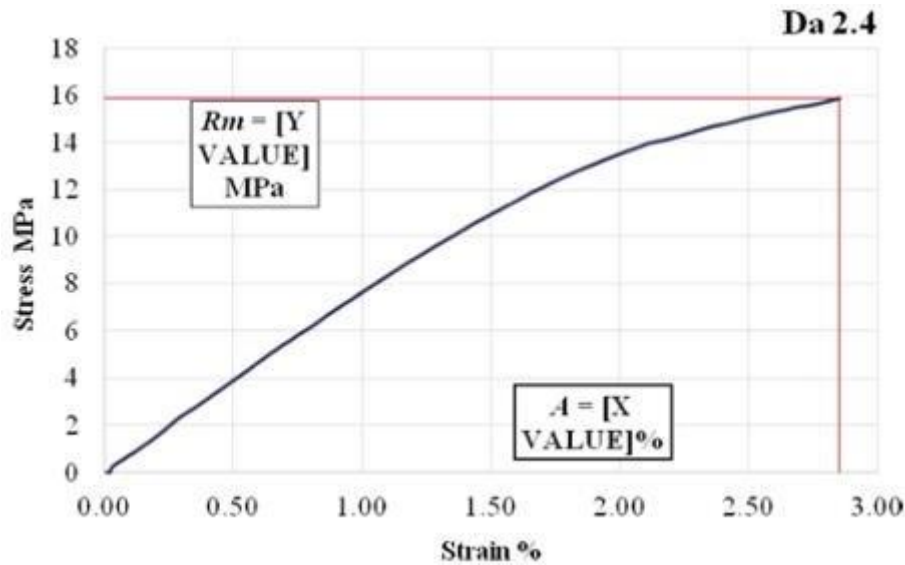


Figure: 5 shows the characteristic curve of a Da 1.X set representative specimen. Consequently, a representative sample refers to the sample possessing the average values of the examined mechanical parameters. The characteristic curves of the representative samples from the three sets of hybrid composites are illustrated in Figs. 5 and 6. and seven. Table 1 presents the value thresholds for tensile strength, modulus of elasticity, and extension at break for the three examined types of composites with hybrid properties.

### 5.0 Conclusion

The utilization of natural resins in the production of composite materials can be affected by the qualities of the resin and its ability to create a synergistic impact with the reinforcing components. The study of the results indicates a significant change in attributes based on the ratio of natural to synthetic resin.

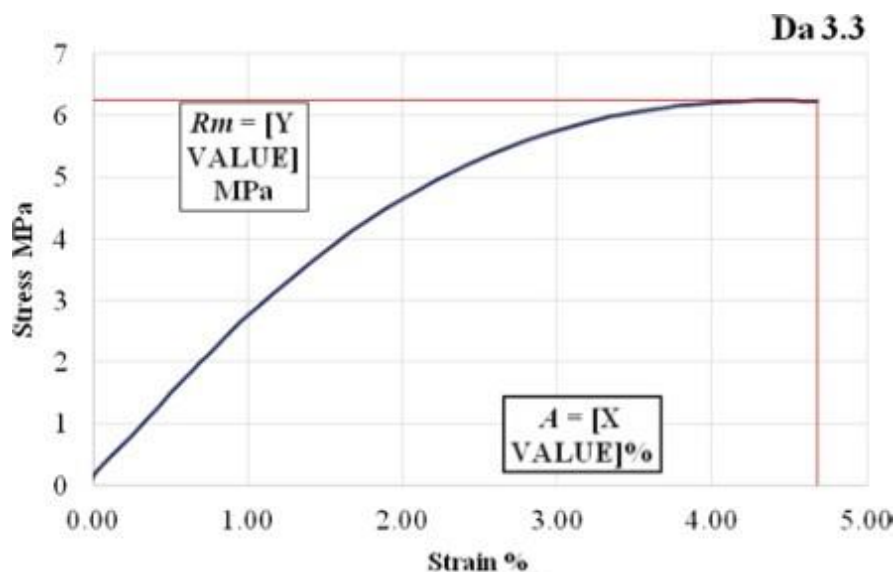


Figure 7 illustrates the characteristic curve for a representative sample of the Da 3.X set.

Table 1: Value thresholds for tensile strength, modulus of elasticity, and extension at breaking

Sample	Tensile strength <i>p</i> /(MPa)	Elasticity modulus <i>p</i> /(MPa)	Elongation at break (%)
Da 1X	20.2–21.4	4990–5690	1.82–2.02
Da 2X	15.3–16.3	2100–2410	2.83–2.98
Da 3X	6.2–6.6	860–950	4.45–4.83

The comparison of data from experiments indicates a significant alteration in mechanical properties with varying ratios of epoxy resin and natural resins. The tensile strength and modulus of elasticity diminish as the volume fraction of natural resins in the mixture increases. While mixes containing a greater quantity of epoxy resin exhibit superior mechanical qualities, it cannot be asserted that a definitive relationship exists between tensile strength, modulus of elasticity, and the volume fraction of epoxy resin. Consequently, the 60% Dammar combination (Da 1) exhibits the most favorable mechanical properties. In comparison, the 70% Dammar mixture (Da 2) exhibits a tensile strength of 76% and a modulus of elasticity of 42%, whilst the 80% Dammar mixture (Da 3) has a tensile strength of 31% and a modulus of elasticity of 17%. A notable decline in mechanical characteristics is observed as the percentage of Dammar in the mixture increases.

Modifications have been made to the forms of the characteristic curves. The characteristic curve of Da 1 resins, with a natural resin percentage of 60%, is nearly linear, whereas the characteristic curve of Da 3 resins, with a natural resin proportion of 80%, exhibits significant nonlinearity. In these instances, plastic behavior is clearly obvious.

We see an increase in elongation at break with the rising amount of Dammar. An 80% rise in the Dammar proportion leads to a deterioration of mechanical characteristics and an extension of hardening time, reaching levels that are unsuitable for the production of composite materials. The qualities of Dammar-based hybrid composites can be adjusted according to the ratio of natural to synthetic resin, allowing for the regulation of the mechanical properties of the composite components derived from these resins.

## References

- [1] Prati S, Sciutto G, Mazzeo R, Torri C, Fabbri D (2011) Application of ATR-far-infrared spectroscopy to the analysis of natural resins. *Anal Bioanal Chem* 399:3081–3091
- [2] Suprakas SR, Mosto B (2005) Biodegradable polymers and their layered silicate nanocomposites: in greening the 21st century materials world. *Prog Mater Sci* 50:962–1079
- [3] Romero-Nogueram J, Martín-Sánchez I, López-Miras MM, Ramos-López JM, Bolívar-Galiano F (2010) Biodeterioration patterns found in Dammar resin used as art material. *Electron J Biotechnol* 13:1–8
- [4] Zakaria R, Ahmad AH (2012) Adhesion and hardness evaluation of modified silicone-Dammar as natural coating materials. *Am J Appl Sci* 9:890–893
- [5] Zakaria R, Ahmad AH (2012) The performance of modified silicone-Dammar resin in nanoindentation test. *Int J Adv Sci Technol* 42:33–44
- [6] Fauzi H, Metselaar HSC, Mahlia TMI, Ong HC, Khanlou HM (2016) Preparation and thermal characteristics of eutectic fatty acids/Shorea javanica composite for thermal energy storage. *Appl Therm Eng* 100:62–67
- [7] Hamdani Rizal S, Riza M, Mahlia TMI (2018) Mechanical properties of concrete containing bees wax/Dammar gum as phase change material for thermal energy storage. *AIMS Energy* 6:521–529
- [8] Nasir KM, Halim NA, Tajuddin HA, Arof AK, Abidin ZHZ (2013) The effect of PMMA on physical properties of Dammar for coating paint application. *Pigm Resin Technol* 42:137–145
- [9] Hsissou R, About S, Berisha A, Berradi M, Assouag M, Hajjaji N, Elharfi A (2019) Experimental, DFT and molecular dynamics simulation on the inhibition performance of the DGDCBA epoxy polymer against the corrosion of the E24 carbon steel in 1.0 M HCl solution. *J Mol Struct* 1182:340–351
- [10] Hsissou R, Dagdag O, Berradi M, El Bouchti M, Assouag M, Elharfi A (2019) Development rheological and anti-corrosion property of epoxy polymer and its composite. *Heliyon* 5:e02789
- [11] Hsissou R, El Bouchti M, El Harfi A (2017) Elaboration and viscosimetric, viscoelastic and rheological studies of a new hexafunctional polyepoxide polymer: hexaglycidyl ethylene of methylene dianiline. *J Mater Environ Sci* 8:4349–4361
- [12] Hsissou R, Elharfi A (2018) Rheological behavior of three polymers and their hybrid composites (TGEEBA/MDA/PN), (HGEMDA/MDA/PN) and (NGHPBAE/MDA/PN). *J King Saud Univ Sci* 32:235–244
- [13] Hsissou R, Berradi M, El Bouchti M, El Bachiri A, El Harfi A (2019) Synthesis characterization rheological and morphological study of a new epoxy resin pentaglycidyl ether pentaphenoxy of phosphorus and their composite (PGEPPP/MDA/PN). *Polym Bull* 76:4859–4878
- [14] Pethe AM, Joshi SB (2013) Physicomaterial, mechanical and film forming studies of novel biomaterial. *Int J Pharm Sci Res* 4:2761–2769

- [15] Ciucă I, Bolcu A, Stănescu MM (2017) A study of some mechanical properties of bio-composite materials with a Dammar-based matrix. *Environ Eng Manag J* 16:2851–2856
- [16] Hidayat AT, Farabi K, Harneti D, Maharani R, Darwati N, Mayanti T, Setiawan AS, Supratman U, Shiono Y (2017) Cytotoxicity and structure activity relationship of dammarane-type triterpenoids from the bark of *Aglaia elliptica* against P-388 murine leukemia cells. *Nat Prod Sci* 23:291–298
- [17] Zhang F, Wang JS, Gu YC, Kong LY (2010) Triterpenoids from *Aglaia abbreviata* and their cyto toxic activities. *J Nat Prod* 73:2042–2046
- [18] Ukiya M, Kikuchi T, Tokunda H, Tabata K, Kimura Y, Arai T, Ezaki Y, Oseto O, Suzuki T, Akihisa T (2010) Antitumor-promoting effects and cytotoxic activities of Dammar resin triterpenoids and their derivatives. *Chem Divers* 7:1871–1884
- [19] ASTM D3039, Standard test method for tensile properties of polymer matrix composite materials. <https://www.astm.org/Standards/D3039>. Accessed on 9 Jan 2019