Mechanical Properties of Composite Materials with Dammar-based Matrices and Reinforced with Paper and Chicken Feathers Waste

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The primary aim of this research was to explore the feasibility of producing environmentally friendly composite materials by employing diverse hybrid matrices consisting of dammar natural resin, supplemented with small proportions of two synthetic resins: one epoxy and the other acrylic. A blend of paper and chicken feathers served as the reinforcing elements. The fabrication of these composite materials utilized a hand layup technique. Targeted for applications in the furniture industry or interior design, their mechanical properties were assessed through various tests. Specimens were obtained from the manufactured samples and subjected to evaluations for tensile strength, compression, flexure, vibrations, Shore hardness, and water absorption. Results indicated that irrespective of the testing method employed, the mechanical strength properties exhibited a decline with an increase in the percentage of dammar in the hybrid resins, whereas the elasticity properties demonstrated an increase with this percentage.

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INTRODUCTION

Feathers from chickens represent waste generated by the poultry industry, amounting to billions of kilograms each year from processing plants. This substantial volume of waste poses a significant solid waste challenge. Typically, around six million kilograms of feathers are produced annually during the processing of chickens in commercial dressing plants. The conventional methods of disposing of chicken feathers, such as incineration, landfill burial, or recycling into low-quality animal feeds, are costly and problematic (Acda 2010; Oladele *et al.* 2018; Ali *et al.* 2021).

New possibilities for utilizing chicken feathers have been explored, one example being the study by Oladele *et al.* (2018). In that research, chicken feathers were used as a reinforcement in polymer-based composite materials. The chicken fibers are proper to be used as reinforcing element in composites because they consist of twisted micro-fibrils arranged in a helical structure, contributing to the fiber's exceptional mechanical strength and resilience. These fibers are cheap, renewable, and biodegradable. Additionally, their hydrophobic and hygroscopic nature, coupled with a distinctive honeycomb structure, accounts for their remarkable thermal resistance properties (Fowler *et al.* 2006; Ahn *et al.* 2011; Dolz *et al.* 2013; Oladele *et al.* 2018). The structural protein and two types of keratins are responsible for the mechanical properties exhibited by chicken feathers (Nguyen *et al.* 2020).

In Ali *et al.* (2021), composite materials reinforced with chicken feathers were fabricated, with an unsaturated polyester resin matrix and methyl ethyl ketone peroxide. The chicken feathers were dried at a temperature of 27^0C and then cut into small pieces using a crushing machine. Various percentages of chicken feathers were used, ranging from 2% to 15%. The samples underwent various mechanical tests (tensile, flexural and thermogravimetric), and the best properties were obtained for samples with 5% and 10% chicken feather content, respectively.

Chicken feathers have been used to fabricate composite materials with CY 230 epoxy resin (Bansal *et al.* 2018, 2021). Various mechanical tests such as tensile, compression, Rockwell hardness, Izod impact test, as well as weight change during immersion in water, mustard oil, soda, milk, and lemon water were conducted. The best mechanical properties were achieved for composites with a 5% chicken feather percentage. In terms of absorption, the least mass changes occurred for the samples immersed in water.

The research conducted by Choudary and Nehanth (2018) highlights the combination of chicken feathers with polypropylene. Mechanical properties were determined through tensile, compression, flexural, hardness, and Charpy impact strength testing. Additionally, the morphology of the samples was investigated using SEM microscopy and X-ray spectroscopy. As the percentage of chicken feathers increases, the impact strength decreases, but other mechanical characteristics (tensile, compression, and flexural strengths) increase.

Chicken feathers can be used in combination with fibers for manufacturing composite materials. For instance, Johri *et al.* (2018) fabricated composite materials with an epoxy resin matrix reinforced with a combination of jute and chicken feathers. The samples were subjected to tensile, static bending and Charpy impact strength tests. The best results were achieved for materials with a composition of 70% epoxy resin, 25% jute, and 5% chicken feathers. A similar study was continued by Johri *et al.* (2019), whereas samples made from epoxy resin and reinforced with jute/chicken feathers were subjected to tensile, compression, static bending, hardness, and Charpy impact tests. The fracture morphology was analysed through scanning electron microscopy. The best matrix-reinforcement adhesion was achieved for composites with a composition of 70% matrix, 20% chicken feathers, and 10% jute.

Another combination encountered in the manufacturing of composite materials involves using synthetic resins reinforced with a combination of chicken feathers and wood elements. Such a study was conducted by Dash and Tripathi (2018), where composite materials were fabricated with an epoxy resin matrix, and teak wood dust combined with chicken feathers were used as reinforcements. The materials were tested for tensile strength and water absorption. The best properties were obtained for samples with 15% teak wood dust and 5% chicken feathers. Adediran *et al.* (2021) investigated the mechanical properties of composite materials made of cement and used paper, with the addition of chicken feathers and wood sawdust. Adding chicken feathers in a higher percentage than sawdust contributed to reducing water absorption and improving flexural strength and increasing the modulus of elasticity. Munang and Yamani (2021) focused on the fabrication of composite materials with a predominantly polyester matrix, reinforced with chicken feathers (ranging from 0% to 20%) and sawdust (ranging from 0% to 20%). The specimens were tested for tensile strength and single-impact bending. The volume fraction with an 80% polyester matrix, 15% chicken feathers, and 5% sawdust exhibited the highest tensile strength, as well as single-impact bending strength. Using the hand layup technique (Mishra 2017), composite materials were fabricated with an epoxy resin matrix (in predominant percentages of 85%, 80%, and 75%), reinforced with sawdust (at percentages of 10%, 15% and 20%) and chicken feathers (5%). The mechanical properties under tensile stress and water absorption were investigated. For tensile strength, the best properties were obtained in specimens with 80% matrix and 20% reinforcement (15% sawdust and 5% chicken feathers). Regarding water absorption, no significant changes were observed.

Recent research includes the incorporation of chicken feathers into construction materials. Ouakarrouch *et al.* (2020) incorporated a percentage of chicken feathers into gypsum plaster for use in mortar for walls and ceiling. Several thermal characteristics were determined, including thermal conductivity, thermal diffusivity, and thermal effusivity. As the mass fraction of feathers was increased, thermal properties decreased as follows: up to 36% for thermal conductivity, 13% for thermal diffusivity, 23% for thermal effusivity, and 16% for volumetric thermal capacity. Mrajji *et al.* (2021) focused also on the use of chicken feathers as an insulating material. Several experimental analyses were conducted, such as energy dispersive analysis, SEM, TGA, DTA, X-Ray, and Fourier transform spectroscopy. Needle-punched insulator materials based on a combination of chicken feathers, wool, and cotton have a thermal conductivity in the range of 0.0313 to 0.04465 W/(m·K) and are comparable in value to conventional insulating materials. In Buragadda and Kompala (2022), composite materials were fabricated from geotextiles made of chicken feathers and jute for the purpose of foundation consolidation. A series of samples with different dimensions were produced, and the use of composite geotextile improved the soil load-carrying capacity from 16.93 times to 18.96 times compared to unconsolidated soils.

The studies were extended to composites with polymeric matrices and reinforcing agents from renewable resources, *i.e.*, reinforced with chicken feathers. In this regard, in Gogoi *et al.* (2019), composite materials were fabricated with polymeric matrices and reinforcing agents from renewable resources (soybean oil), with or without styrene as a reactive monomer, reinforced with chicken feathers. SEM studies revealed that composites without styrene exhibited better adhesion between the fiber and matrix compared to composites containing styrene. Thermal gravimetric analysis indicated that composites prepared without styrene were more thermally stable than those with styrene. The mechanical properties resulting from tensile, flexural, and hardness tests of composites with styrene were almost the same as those of composites without styrene. In Orkhis and Ettaqi (2020), composite materials with a chitosan matrix reinforced with chicken feathers were studied. The chicken feathers were untreated and treated with an alkali, with soaking times ranging from 2 to 6 h. Chitosan was extracted from shrimp crustaceans through chemical treatments, having a deacetylation degree of 83%. Various tests were conducted on the manufactured samples, including tensile tests, FTIR analysis, scanning differential calorimetry, optical microscopy, *etc*. Samples with alkali treatment exhibited superior properties compared to untreated ones. Regarding tensile strength, the best results were achieved for samples treated with alkali for 6 h. The final conclusion was that the proposed material for the study could be used for packaging products. In Sreenivasan *et al.* (2021) composites with a matrix from natural rubber and reinforced with keratin fibre from chicken feather were manufactured. For these materials, the dielectric properties were studied at varying frequencies. The samples underwent alkali, thermal treatments, and treatment with a dry bonding agent composed of three components (hexamethylene-tetramine, resorcinol and nano-silica). There was a decrease in the dielectric constant with the increase in frequency (dipolar and interfacial polarization diminish at higher frequencies). As the percentage of fibers increases and bonding agents were incorporated, there was an increase in the dielectric constant and a decrease in the volume resistivity of the composites.

Biodegradable materials were also investigated in Reddy *et al.* (2014), but this time feathers were used as the matrix, and jute as the reinforcement. Samples were obtained, and their tensile, flexural, and acoustic properties were determined. These properties were subsequently compared with those of composites with polypropylene matrix and jute reinforcement. Superior tensile and flexural properties were achieved, along with similar acoustic properties, compared to samples with polypropylene matrix. The main conclusion was that the chicken feathers can be used as a matrix to develop protein-based composites.

There are known studies based on the examination of dammar resin. In Mittal *et al.* (2010) it is mentioned that the dammar resin originates from India and is found in trees of the Dipterocarpaceae family native to East Asia. To obtain it, incisions are made on the trees and the resin is collected. The main uses of dammar resin include papermaking, wood varnishes, and as a pigment for paintings. From the research conducted by Abdel-Ghani *et al.* (2009), Bonaduce *et al.* (2013), and La Nasa *et al.* (2014), it has been determined that dammar resin has applicability in painting, being applied over blue azurite colour resulting in a green pigment. Additionally, it has been found that dammar resin-based paintings are subject to accelerated degradation when exposed to acetic acid.

From the research conducted by Topp and Pepper (1949), Clearfield (2000), and Mittal *et al.* (2010) it has been found that dammar has a polymeric component called polycaninene, an alcohol-insoluble part called β-resene, and a soluble part called α-resene. In addition to these, it also contains a small percentage of sesquiterpenoids (C15). The resin mainly consists of compounds with a tetracyclic dammarane skeleton, to which pentacyclic derivatives of oleanane, ursane, and hopane are added.

Furthermore, dammar resin can be used as an ingredient in pharmaceutical manufacturing. Research conducted by Sharma *et al.* (2019) highlights the use of dammar as an ingredient in the drug atenolol. The medication was formulated from cross-linked dammar gum with biodegradable hydrogel composites based on polyacrylamide and zirconium. Studies related to combining dammar resin in the manufacturing of hybrid matrices can be found in research by Stănescu (2015), Mirițoiu *et al*. (2020), Franz *et al*. (2021), and Ciucă *et al*. (2022). Chemical compositions and mechanical properties were determined following the combination of natural dammar resin with various synthetic epoxy or acrylic resins. It was found that as the percentage of dammar increased, the mechanical properties of the hybrid resins decreased. For example, if at a 60% value of the dammar percentage in the hybrid resin, a tensile strength ranging between 20.2 and 21.4 MPa was obtained, at 80%, the tensile strength decreased to 6.2 to 6.6 MPa.

In this work, composite materials were fabricated using hybrid matrices with a predominant percentage of dammar natural resin (and a minor percentage of synthetic epoxy and acrylic resins) reinforced with a combination of wood paper and chicken feathers. Several plates were cast, and samples tested for tensile strength, compression, bending, free vibrations, Shore D hardness, and water absorption. The difference from previous research is that, this time, the predominant percentage was allocated to the reinforcement (60 % paper wood/ chicken fiber feathers), with the matrix having a minor percentage (regardless of its type). As the percentage of dammar in the hybrid matrices increased, the elasticity of the samples increased with a decrease in mechanical characteristics (tensile strength, hardness, natural frequency).

EXPERIMENTAL

Materials

Composite materials were fabricated in from matrix formulations and reinforcing fibers:

- With various types of matrices, as follows: synthetic resins such as epoxy Resoltech 1050 type and acrylic Clarocit type; several types of hybrid matrices, consisting of a combination of natural dammar resin with a small percentage of synthetic resins (epoxy Resoltech 1050 and acrylic Clarocit) to accelerate the polymerization process;
- With a single type of reinforcement characterized by wood paper on which chicken feathers were arranged side by side (see Fig. 1.a where a sheet of wood paper with chicken feathers is presented).

The dammar resin was liquefied by immersion in turpentine and stored in sealed containers. All the resins used in this study, including their abbreviations, are summarized in Table 1.

Table 1. Resins Used in this Research Determined in Mass Percentages

Criteria number	Mass percentage of the synthetic resin Rescoltech 1050 (%)	Mass percentage of the dammar resin (%)	Abbreviation
1	100	0	E
2	50	50	DE50
3	40	60	DE60
4	30	70	DE70
	Mass percentage of the synthetic resin Clarocit (%)	Mass percentage of the dammar resin (%)	Abbreviation
5	100	0	A
6	50	50	DA50
7	40	60	DA60
8	30	70	DA70

It is known (for example, from the Stănescu and Bolcu 2019 paper) that natural resins (including dammar resin) require a long time (approximately one year) to fully harden, even when applied in thin layers. This prolonged hardening time limits their use in the manufacture of composite materials (due to low productivity). Furthermore, there are studies mentioning that natural resins do not harden (see, for example, Kanehashi *et al.* 2010; Ishimura *et al.* 2010). In Stănescu and Bolcu (2019) it is mentioned that all the bio-resins studied are actually hybrids and a hybrid resin is characterized by the presence of two components: one organic and the other inorganic. To speed up the hardening process, a small amount of synthetic resin was added to the dammar resin. The addition of the small amount of synthetic resin led to the polymerization of the dammar resin in a much shorter time: the time was reduced from one year to around 10 days. Indeed, the resulting resins were not 100% natural, hence the term "*hybrid resin*" was used for them. However, the advantage of these resins used in the present research compared to 100% synthetic resins can be observed: the majority percentages of their composition consisted of dammar (60% and 70%). The percentage of dammar did not exceed 70%, because it is known that if this value is exceeded, the mechanical properties of the hybrid resin decrease significantly compared to the synthetic resin, which is incorporated alongside dammar to accelerate the polymerization process. Franz *et al.* (2021) found that for a percentage of 80% dammar, the hybrid resin retains only 31% of the tensile strength of the epoxy resin and 17% of the elastic modulus value of the epoxy resin. The use of these hybrid resins contributes to reducing the carbon footprint. To study how the mechanical behavior of composite materials changes under various tests (tensile, compression, bending, *etc.*) depending on the increase in the percentage of dammar, composites made from natural reinforcement with 100% synthetic resins (epoxy and acrylic) were also manufactured. However, these were produced solely to report and compare the mechanical property values obtained for the hybrid dammar-based matrix samples with those made from purely synthetic matrices and natural reinforcement (wood paper and chicken feathers). If these materials had not been manufactured, the study of the influence of dammar resin on the composite would not have been possible.

Mechanical and chemical properties for these type of hybrid resins were previously studied (Stănescu 2015; Mirițoiu *et al*. 2020; Franz *et al*. 2021; Ciucă *et al*. 2022).

Methods

For the manufactured composite materials, a combination of paper made from wood fibers and chicken feathers as the reinforcement. The reinforcement was prepared through the following process: a thin layer of resin was applied with a brush on a sheet of wood paper with a density of 80 g/m^2, and then the feathers were arranged side by side. The application of the thin resin layer aimed to consolidate/ adhere the feathers to the wood paper. This resulted in a reinforced lamina. The same procedure was repeated for another 9 laminae. To obtain a specific type of material, a thin layer of resin was applied to each lamina, they were stacked on top of each other and pressed using a force of 250 daN distributed on an area of 420x297 mm^2.

The materials used and the procedure described above are not highly complex. Firstly, it is mentioned that the hand layup technique was used, which is a simple method for manufacturing composite materials without the need for expensive equipment (such as injection molding machines). Secondly, to ensure the alignment of the feathers along the direction of the applied force (tensile or compression), it was decided to place them on a sheet of paper beforehand. It is desirable for the reinforcement to be aligned along the direction of the applied force so that the analyzed samples possess the best mechanical strength. Initially, casting was attempted without placing the feathers on a paper strip, but the results were unsatisfactory, necessitating a change in the manufacturing technique. In conclusion, it can be mentioned that the method is simple, manual, and relatively easy to reproduce.

The procedure described is known as the hand layup technique. The casting of the samples was carried out at a temperature between 21 and 23 °C. To ensure the complete polymerization for all the studied materials, the specimens with a synthetic resin matrix were trimmed five days post-casting, whereas those with a hybrid resin matrix were cut after a 10 days period from casting. Pictures depicting the preparation of the laminae and the application of resin layers are provided in Fig. 1. An example of the final plate obtained with one of the DE resin is shown in Fig. 2. For all the samples, the next percentages were used: 60% reinforcement and 40% matrix.

Fig. 1. a) A detail regarding the composition of a lamina, highlighting the wood paper and chicken feathers; b) The method of applying resin to consolidate the ten laminae

Fig. 2. An example of a WCDE60 type plate model obtained through the lay-on-hands technique

Fig. 3. An example with the 15 specimens cut for the tensile test from the T WCDE60 group

Since the manufactured materials will undergo various destructive and non-destructive tests (tensile, compressive, bending, vibrations, Shore D hardness, and water absorption), they will be abbreviated to facilitate identification in the text. The abbreviations to be used in the following paragraphs have been compiled in Table 2.

Table 2. Samples Abbreviations

First Letter from the samples name is derived from the test method.	T – tensile test
	C – compression test
	B – bending test
	V – vibration test
	S – shore D hardness test
	Wa – water absorption test
Second and third letter from the samples name is derived from the reinforcement type.	W – wood paper
	C – chicken feathers
Last group of letters come from the resins abbreviations, presented in Table 1.	D – dammar resin
	E – epoxy resin
	A – acrylic resin
	56,60,70 – dammar resin percentages
Last group of numbers correspond to the samples tested for tensile, compression, and bending.	Is the specimen number from 01 to 15, because 15 specimens were tested for each type of material.

Test Standards and Characterizations

Tensile test

For the tensile test, plates were cast reinforced with wood paper/ chicken feathers and the eight types of resins mentioned in Table 1 (2 synthetic and 6 hybrid based on dammar). From each plate, 15 specimens were extracted. An example with the 15 specimens cut for the tensile test from the T WCDE60 group is presented in Fig. 3. The tensile testing was conducted according to the standard ASTM D3039/D3039M-08 (2014), with specimens having the following dimensions: 250 mm length, 25 mm width, and 8 mm thickness. An Instron 1000 HDX universal testing machine was used for the testing.

Compression test

For the compression test, similar plates to those used for tensile testing were cast, with the mention that 19 layers (laminae) were used, and the specimens were cut to approximately 15 mm length x 15 mm width x 15 mm thickness. The compression test was conducted in accordance with the requirements of the standard ASTM D695-23 (2016). A universal testing machine LGB Testing Equipment with a device for compression tests was used. Nineteen layers were used to make the specimens thick enough so that the dominant failure mechanisms would be crushing by compression rather than buckling failure.

Bending test

For the bending test, similar plates to those used for tensile testing were cast, with wood paper/chicken feathers as reinforcement and matrices from all 8 resin types presented in Table 1. The same number of 10 laminae were used as in the tensile test, and from the obtained plates, 15 specimens were cut with the following dimensions: 200 mm – length, 32 mm – width, and 8 mm – thickness.

A universal testing machine type LGB Testing Equipment equipped with a three-point bending device was used for this test. The bending test was conducted in accordance with the requirements of the standard ASTM D790-17 (2017).

Vibration test

Samples employed in the vibration test shared the same dimensions and type as those discussed in the tensile test subsection. The specimens were clamped at one end and were allowed to remain free at the opposite end, where a Bruel&Kjaer accelerometer with a sensitivity of 0.04 pC/ms^{-2} was placed. This accelerometer was linked to a Nexus signal conditioner, which, in turn, was connected to a data acquisition system, SPIDER 8. The SPIDER 8 equipment was connected to a notebook where the experimental values were recorded.

Shore D hardness test

The Shore D hardness test was conducted following the ASTM D2240-15 (2017) standard. Samples with identical dimensions to those specified in the tensile test subsection were utilized. Five measurements were taken at points positioned 50 mm apart along the length of the sample, with the extreme left and right points situated 25 mm from the sample edge. The measurement points were selected at the midpoint of the sample width.

Water absorption

The water absorption test was conducted following ASTM D570 (2022) standards. Samples were weighed and immersed in distilled water placed in Berzelius glasses. The samples, measuring 76.2 mm in length, 25.4 mm in width, and 8 mm in thickness, were removed from the water after 24 h. Any residual surface water was wiped off using a dry cloth, and the samples were then weighed using a SHIMADZU analytical balance with a precision of 0.01g. The weighing process was repeated until the weight difference between consecutive days was below 0.05 g. Subsequently, the samples were air-dried at room temperature for 72 h and the final weight was daily recorded.

RESULTS AND DISCUSSION

Tensile Test

For the tensile strength test, 15 specimens were cut from each type of cast plate with the eight types of resins as listed in Table 1. The specimens were cut along the direction of fibers of chicken feathers, and the tensile testing was conducted along the axis of these fibers, as shown in Fig. 4.

Fig. 4. An example with the tensile test made along the chicken fibers

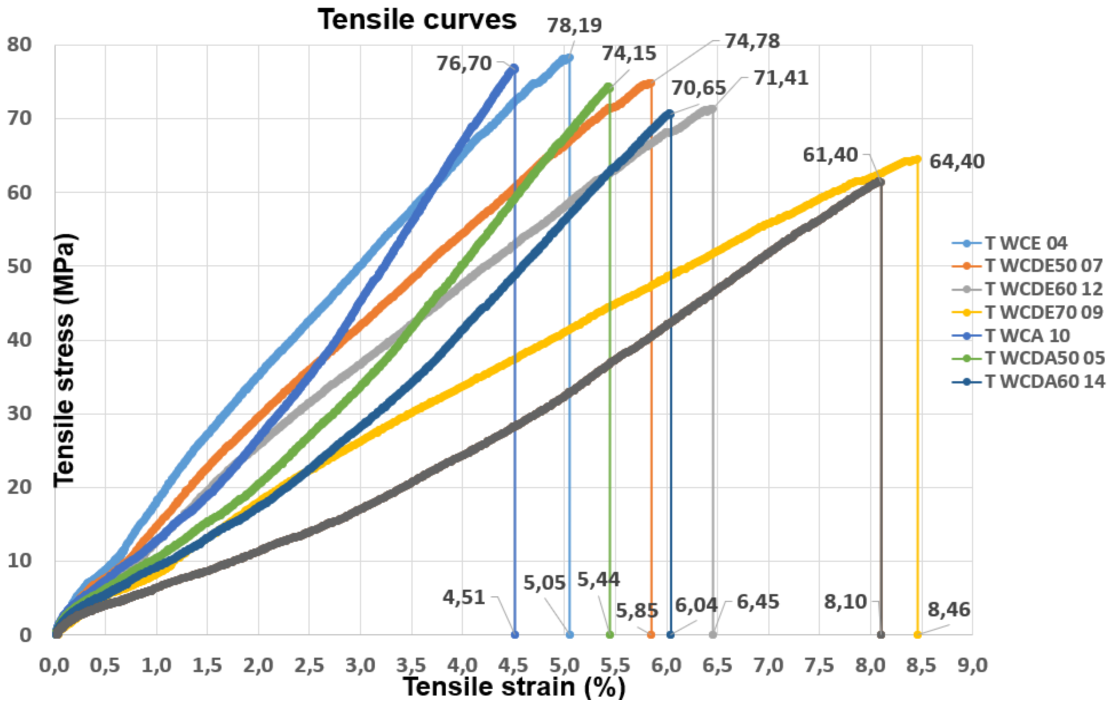


Fig. 5. The stress-stain curves from the tensile test for all the representative samples with the matrix from all 8 types of resins

For each specific material type subjected to testing, the arithmetic average of the obtained mechanical properties was calculated. In the subsequent figures, characteristic curves corresponding to each material type, closely aligning with the arithmetic average values, were graphed on the same plot. Specimens with mechanical properties closely mirroring the arithmetic averages are named as representative samples. For instance, among the 15 specimens of type T WCDA60 tested for tensile strength, specimen 14 displayed mechanical properties in proximity to the arithmetic average values, and its characteristic curve is depicted in Fig. 5. The sample T WCDA60 14 is identified as the representative sample. The decision to present characteristic curves on a shared graph aims to facilitate a clearer observation of the material's behavior during variations in the proportion of dammar natural resin and transitions from synthetic epoxy resin to acrylic resin. The results from the tensile test for all representative samples (stress–strain curves) are illustrated in Fig. 5.

Table 3. Arithmetic Mean Values for the Modulus of Elasticity

Material type	T WCE	T WCDE50	T WCDE60
Modulus of elasticity *E* (MPa)	4550	4505	4405
Material type	T WCDE70	T WCA	T WCDA50
Modulus of elasticity *E* (MPa)	4260	4463	4345
Material type	T WCDA60	T WCDA70	
Modulus of elasticity *E* (MPa)	4250	4130	

The specimens exhibited tensile strength ranging from 61 to 78 MPa and a strain between 4.5% and 8.5%. Samples containing epoxy resin in the matrix composition exhibited superior mechanical properties compared to those with acrylic resin in the matrix composition (increased values for breaking strength and elongation at break). This outcome can be attributed to the inherently enhanced mechanical properties of epoxy resin relative to acrylic resin. As depicted in Fig. 5, tensile strength decreased with the increase in dammar percentage. This observation could be elucidated by the lower breaking strength of natural dammar resin in comparison to synthetic resins. Additionally, another insight from Fig. 5 reveals an increase in elongation at break with the dammar percentage. This result may be explained by the greater elasticity of natural dammar resin compared to synthetic resins, suggesting that a higher dammar percentage contributes to increased ductility in the specimens. The arithmetic mean values of the longitudinal modulus of elasticity for each type of material are provided in Table 3. These values were obtained by averaging the results of the 15 specimens corresponding to each specific type of material. For example, for specimens of type T WCDE60, the modulus of elasticity value was obtained by calculating the arithmetic mean of the values from specimens T WCDE60 01 to T WCDE60 15.

Compression Test

For the compression test, the procedure was similar to the tensile test: 15 specimens were cut from each material, and the characteristic curves for each representative specimen from each tested material category are depicted in Fig. 6.

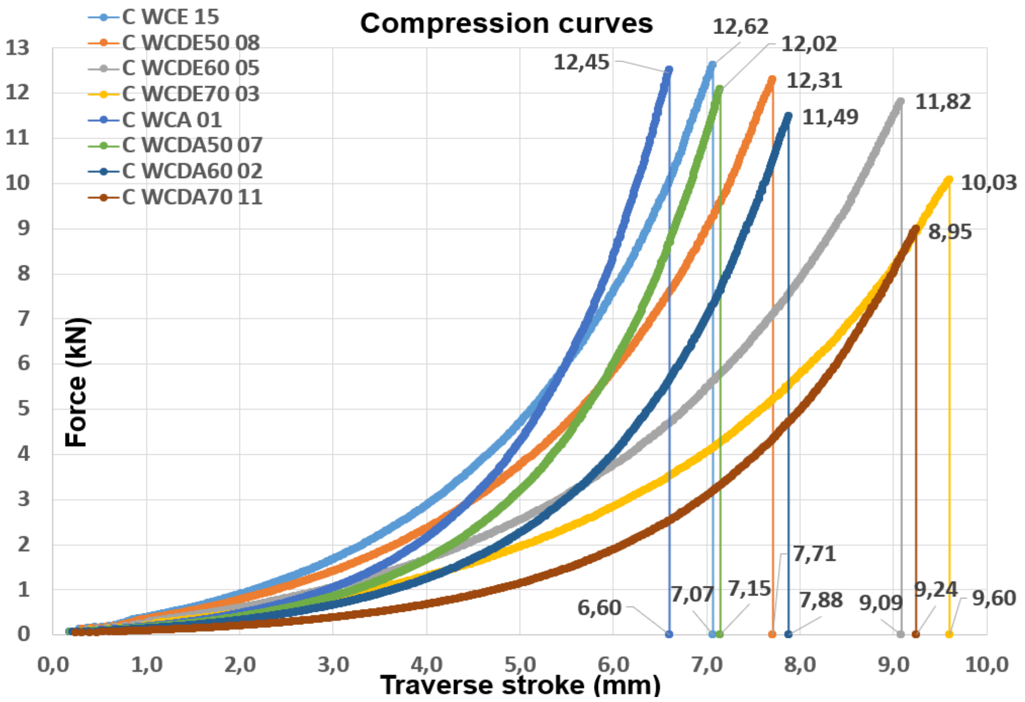


Fig. 6. The force-traverse stroke curves from the compression test for all the representative samples with the matrix from all 8 types of resins

The arithmetic mean values for the breaking strength values from the compression test are presented in Table 4. From the analysis of the characteristic curves, similar trends were observed as in the tensile test, namely: as the dammar percentage increased, the traverse stroke increased, and the compressive strength decreased. The specimens incorporating epoxy resin in the matrix composition demonstrated superior mechanical properties in comparison to those with acrylic resin. As previously mentioned, this outcome could be attributed to the fact that epoxy resin exhibits enhanced mechanical properties compared to acrylic resin.

Table 4. Arithmetic Mean Values for the Compression Breaking Strength Values

Sample type	C WCE	C WCDE50	C WCDE60	C WCDE70
Stress Values (MPa)	56.2	55	52.4	44.8
Sample type	C WCA	C WCDA50	C WCDA60	C WCDA 70
Stress Values (MPa)	55.8	53.9	51.2	40.4

There was a decrease in compression breaking strength values with the escalating dammar percentage. This trend may be explained by the lower breaking strength of natural dammar resin when contrasted with synthetic resins. Additionally, there was an increase in traverse stroke with the dammar percentage. This result might be elucidated by the greater elasticity of natural dammar resin relative to synthetic resins, suggesting that a higher dammar percentage contributes to increased ductility in the specimens.

Bending Test

In the bending tests, the procedure followed was analogous to that of tensile and compression. The characteristic force *versus* stroke curves for representative specimens from each material set are provided in Fig. 7.

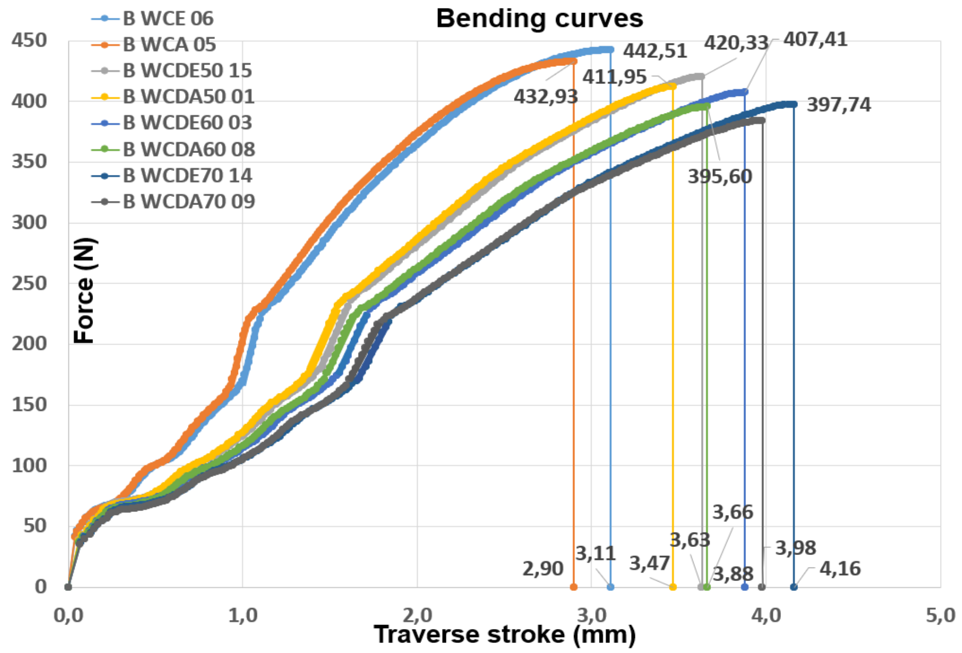


Fig. 7. The force-traverse stroke curves from the bending test for all the representative samples with the matrix from all 8 types of resins

Similar trends to those observed in previous destructive tests emerge, namely that the maximum forces at which the specimens fracture occurs were higher for those with epoxy resin in the matrix compared to those containing acrylic resin in the matrix. This result can be explained by the fact that the acrylic resin possesses inferior properties compared to epoxy resin. As the percentage of dammar increases, the maximum breaking force decreases (this implies a reduced bending strength), and the traverse stroke increases (indicating improved elasticity for the materials). This phenomenon can be attributed to the dammar resin being more elastic compared to synthetic resins but less rigid, resulting in a decrease in strength properties and an increase in material ductility. The arithmetic mean values for the bending strength are presented in Table 5. There was a decrease in bending breaking strength values with the escalating dammar percentage. This trend may be explained by the lower breaking strength of natural dammar resin.

Table 5. Arithmetic Mean Values for the Bending Breaking Strength Values

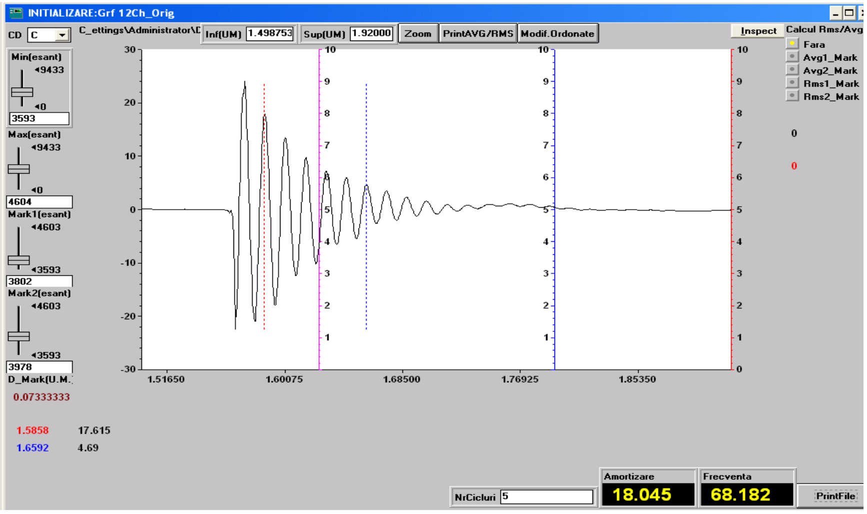
Sample type	B WCE	B WCDE50	B WCDE60	B WCDE70
Stress Values (MPa)	41,45	39,4	38,15	37,25
Sample type	B WCA	B WCDA50	B WCDA60	B WCDA 70
Stress Values (MPa)	40,55	38,6	37,05	36

Vibration Test

To conduct vibration analysis, the specimens were clamped at one end using a jaw vise positioned on a spacious table. For each individual sample the free lengths of 100, 120, 140, 160, and 180 mm were used. The logarithmic decrement method was employed to ascertain the damping characteristics of the system. The computation of the damping factor was carried out utilizing Eq. 1 (Stănescu and Bolcu 2019).

$$\mu = \frac{1}{t_2 - t_1} \cdot ln \frac{v_2}{v_1} \tag{1}$$

Equation 1 incorporates the time values for two peaks, denoted as t_1 and t_2, from the amplitude diagram. Additionally, it includes the peak amplitudes at the corresponding time values, represented as v_1 and v_2. Figure 8 illustrates the obtained results for the damping factor and natural frequency pertaining to the vibrations of the WCDA60 sample.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Sup(UM) 1.92000

Min(esant) 3593

Max(esant) 4604

Mark1(esant) 3802

Mark2(esant) 3978

D_Mark(U.M.) 0.07333333

1.5858 17.615

1.6592 4.69

NrCicluri 5

Amortizare 18.045

Frecventa 68.182

Fig. 8. The vibration recording (damping factor and natural frequency) for the specimen WCDA60 with a free length of 160 mm

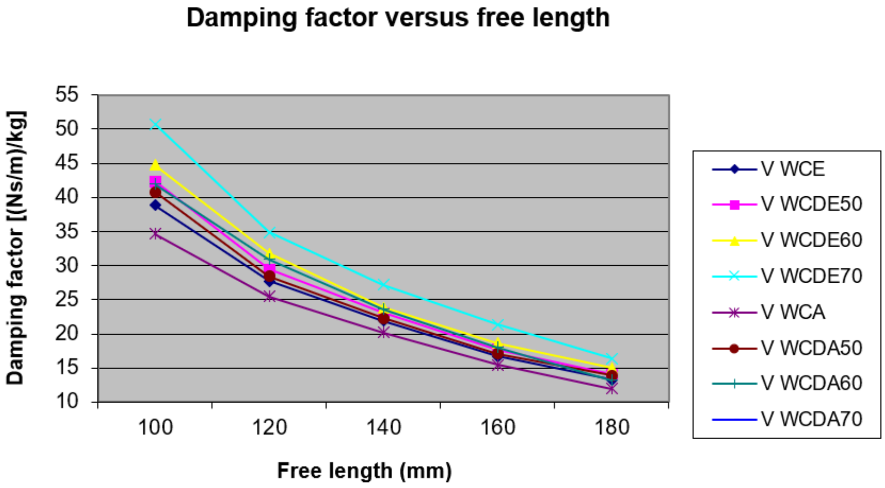

Fig. 9. Results for the damping factor as a function of the free length of the specimens

Figures 9 and 10 showcase the outcomes derived from the vibration test, specifically focusing on the correlation between the damping factor and free length, as well as the natural frequency and free length. In both figures, a noticeable trend can be observed where both the natural frequency and damping factor decreased with an increase in the sample's free length.

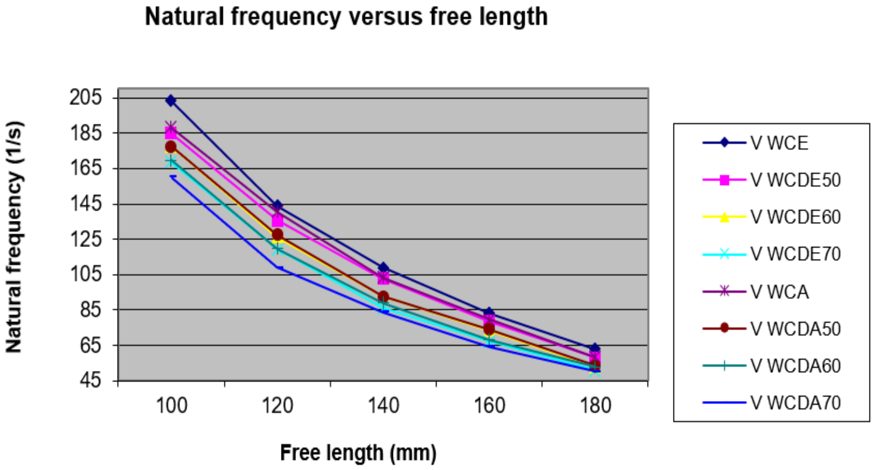

Fig. 10. Results obtained from the vibration test for the natural frequency

The variations in the natural frequency values among the samples can be attributed to discrepancies in the elastic modulus values of the respective materials. Notably, samples composed of acrylic resin (V WCA) or hybrid resin containing an acrylic component (V WCDA50, V WCDA60 and V WCDA70) exhibited a decrease in both natural frequency and damping factor when compared to samples made of epoxy resin or hybrid resin with an epoxy component. This outcome can be rationalized by the inferior mechanical properties of acrylic resin in comparison to epoxy. Consistent with this trend, tensile testing further corroborated the observation, revealing that samples incorporating epoxy resin or a hybrid with an epoxy component displayed heightened breaking strength and breaking elongation in contrast to their acrylic counterparts. Furthermore, the analysis of Figure 10 revealed that samples containing a higher quantity of dammar natural resin exhibit a greater capacity for vibration damping. This phenomenon can be explained by the fact that as the percentage of dammar resin increases, the elasticity of the material also increases, thereby leading to a quicker attenuation of vibrations. Similar conclusions were drawn from destructive testing, where an increase in the elasticity of the material was observed with a higher percentage of dammar in the matrix.

The variations in natural frequency values among the samples can be attributed to differences in the elastic modulus values of the materials utilized. It is evident that specimens composed of acrylic resin (V WCA) or hybrid resin incorporating acrylic components (V WCDA50, V WCDA60, and V WCDA70) exhibited lower natural frequency and damping factor when compared to samples made from epoxy resin or hybrid resin containing epoxy components. This outcome can be ascribed to the inferior mechanical properties of acrylic resin in contrast to epoxy resin. This pattern is also apparent in the tensile test results, where samples containing epoxy resin or epoxy-based hybrids demonstrated higher breaking strength and elongation at break compared to those composed of acrylic materials.

Shore D Hardness Test

The values obtained from the hardness test Shore, scale D are given in Fig. 11. The Shore D values declined with higher percentages of dammar resin. This observation can be attributed to the dammar resin enhancing the elasticity of the samples. Additionally, from Fig. 11, it was evident that samples containing epoxy resin in the matrix exhibited greater Shore D hardness compared to those containing acrylic resin.

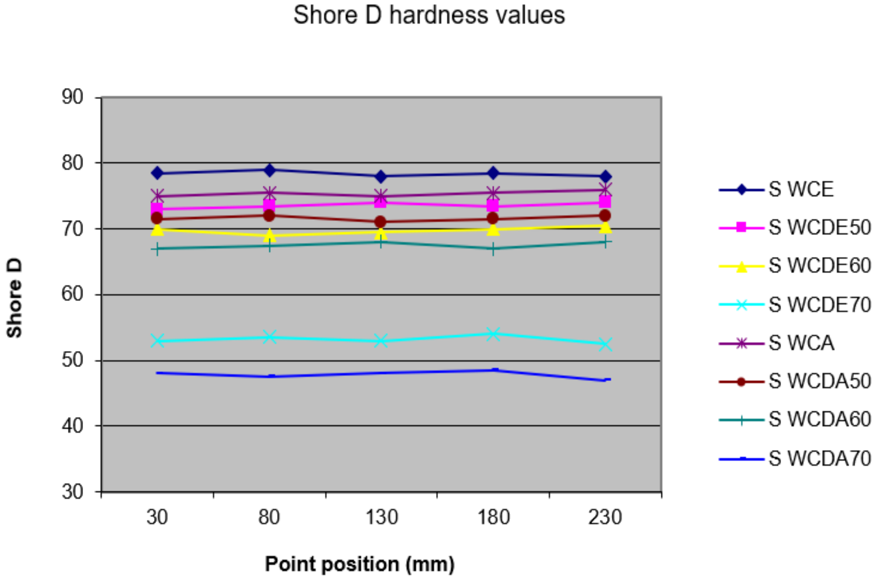

Fig. 11. Experimental results for Shore D hardness values

The rigidity of a body can be defined as its ability to resist deformation under the action of a force. The more it resists, the more rigid it is. In the case of Shore hardness, this is characterized by the penetration of an indenter into the material, and the depth is measured using a gauge on a durometer. The harder the material, the greater its resistance to indentation. This means that it opposes the pressing force of the indenter. Analyzing these two characteristics, it was observed that hardness and rigidity were correlated. Referring, for example, to tensile stress, the cross-section of the samples was the same for all types of materials. It follows that rigidity will be influenced by the values of the elastic moduli. The higher the elastic modulus, the greater the rigidity. The greater the rigidity, the more the material resists the indenter penetrating its structure, implying greater hardness. Comparing the values obtained for Shore hardness and tensile stress, the stated phenomenon was observed: materials with a high elastic modulus also have high Shore D hardness, and *vice versa*. The insertion of dammar into the resin composition contributed to increasing the elasticity of the sample (by decreasing the tensile strength and increasing the elongation at break). The elasticity increased with increasing percentage of dammar. The same trend was observed in Shore D hardness: the increase in material ductility led to a decrease in its tendency to resist the indenter (the material becomes softer). Lower values indicate softer materials that are easier to indent. Since the same type of reinforcement was used for all the studied materials, the differences in hardness can be explained by the different behavior of the hybrid resins with the increasing percentage of natural resin.

Water Absorption Results

All the experimental findings concerning water absorption are presented in Fig. 12.

The samples exhibited a nearly constant daily water absorption amount. The absorption of water was attributed to the presence of paper, as all components of the matrix (both synthetic and hybrid) were insoluble in water. It is known that the chicken feathers absorb water around 13% and contain 60% hydrophobic (moisture resisting) and 40% hydrophilic (moisture absorbing) groups (Johri *et al.* 2019; Barone and Schmidt 2005). It is also known that paper is primarily composed of cellulose, a highly hydrophilic substance. When exposed to water, cellulose leads to a mass increase in the composite immersed in water, as indicated in studies by Adhikary *et al.* (2008), and Tsai *et al.* (2001).

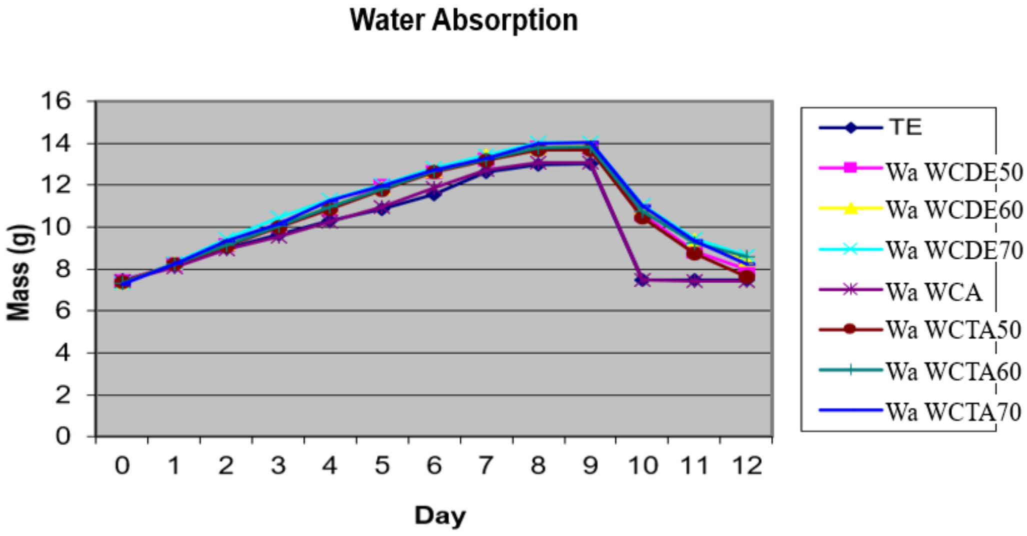

Fig. 12. Experimental results for water absorption

On the 9th day, a mass difference of less than 0.05 g compared to the 8th day was recorded, and thus the water absorption experiment was stopped. The test samples were then left to dry at room temperature for 72 h. The mass of the samples began to decrease after the 9th day due to the evaporation of the water absorbed over the 9 days. It was found that the samples with a matrix of 100% synthetic resins returned to their initial mass much faster than those containing natural dammar resin.

CONCLUSIONS

1. Dammar-based hybrid resins can be utilized as matrices for manufacturing composite materials reinforced with wood paper and chicken feathers.
2. Following the destructive tests conducted, reasonable mechanical properties were obtained, indicating good bonding between the matrix and the reinforcement. Without a proper bond, low mechanical properties would have been achieved, limiting the practical engineering applications of such materials.
3. It is evident that the studied materials exhibited favourable mechanical properties, making them suitable for applications in the furniture industry for crafting furniture components or interior decorations.
4. The conducted research indicates that dammar resin enhances the ductility of the composite material, providing promising results in vibration damping as well.
5. Water absorption occurred due to the paper hydrophilic nature because it has cellulose in its structure.

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