Influence of Dammar Resin on the Mechanical Properties of Composites Reinforced with Corn Husk and Paper Waste

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This study aimed to investigate the influence of dammar resin on the mechanical properties of composite materials reinforced with corn husk and paper waste laminates. Different percentages of dammar resin (50%, 60%, and 70%) were added to the matrix while keeping the reinforcement constant. For all samples, the ratio was maintained at 40% matrix and 60% reinforcement. With the experimental results obtained, statistical analyses were conducted: two-way analysis of variance (ANOVA), Levene's test, Shapiro-Wilk test, and ANOVA *post hoc* (with Bonferroni correction). The null hypothesis stated that dammar resin does not influence the mechanical properties. For all tests considered, the null hypothesis was rejected ($p < 0.05$), the variances were homogeneous ($p > 0.05$), and the data followed a normal distribution ($p > 0.05$). It was found that dammar resin had a significant influence on the mechanical properties as the percentage increased from 50% to 70% ($p < 0.0083$). For each test, based on already known premises, an explanation of the phenomenon that could occur due to the insertion of dammar resin was provided, serving to complement and validate the statistical estimations.

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INTRODUCTION

Agricultural waste refers to leftover materials from cultivating and processing raw agricultural items like fruits, vegetables, meat, and crops (Obi *et al.* 2016). Annually, about 998 million tons of agricultural waste are generated (Agamuthu 2009), with organic waste making up to 80% of farm solid waste. Manure can reach 5.27 kg/day/1000 kg live weight (Overcash *et al.* 1983; Barth 1986; Obi *et al.* 2016). Agricultural waste, though abundant and degradable, is currently of limited significance (Reddy and Yang 2005; Dungani *et al.* 2016). It includes plant materials such as roots, stalks, straw, and natural fibers from crops such as cotton, rice, and corn (Gowda *et al.* 2021; Rajinipriya *et al.* 2021).

Corn husks, the green outer leaves of a corn cob, are flexible, durable, and retain moisture well, making them suitable for weaving (Ahmad *et al.* 2014). They comprise 14% of the corn plant's mass (Reddy and Yang 2015) and are primarily made of parenchyma tissue, which includes 42.3% cellulose, 12.6% lignin, and 4.2% ash, contributing to the husk's structural integrity (Chen 2014; Ginting 2015; Ayuddin 2018). Despite being abundant, corn husks are often discarded, causing resource waste and pollution.

Research has explored their reuse for natural fibers in textiles, insulation, and industrial applications (Joshi *et al.* 2020; Tang *et al.* 2018). They offer advantages in acoustic absorption and thermal conductivity over conventional materials (Fattahi *et al.* 2023).

Corn husks are used as reinforcement materials in composite manufacturing, often combined with synthetic resins. Tumolva *et al.* (2016) created composites using corn husks and an orthophthalic unsaturated polyester resin matrix. The highest tensile modulus was achieved with 15% corn husks, and the best flexural modulus with 20%. Sari and Suteja (2020) studied the impact of fiber content (20% to 60%) and water immersion (24 to 72 h) on these composites, finding that tensile strength improved at 30% fiber content after 24 hours but declined with higher content and longer immersion due to weak fiber/matrix interfaces. Further tests by Sari *et al.* (2020) showed optimal compression and bending properties with 20% to 25% fiber content, while water absorption increased initially with immersion but stabilized over time.

Corn husks have also been combined with polypropylene as the matrix. El-*Zayat et al.* (2020) found that increasing the percentage of corn husks decreases the mechanical, physical, and thermal properties, but this decline is reduced by adding maleic anhydride, which improves fiber-matrix interaction. Huda and Yang (2008, 2009) compared jute-reinforced and corn husk-reinforced polypropylene composites, noting that corn husk composites had inferior properties due to lower aspect ratio and crystallinity. However, treatments like alkali and enzymes improved the compatibility and performance of the corn husk composites.

Composites reinforced with corn husk and an epoxy resin matrix have also been studied. Liu *et al.* (2015) and Karthik *et al.* (2019) compared composites with natural (agave, corn husk, jute) and inorganic (fly ash, carbon, basalt, glass) reinforcements, all using an epoxy resin matrix. Inorganic reinforcements showed higher creep strength due to greater stiffness. Omkumar and Selvakumar (2018) found that increasing the fiber content and reducing the filler (corn husk powder) improved mechanical properties, likely due to better stress transfer at the fiber-matrix interface. Alshahrani and Arun Prakash (2022) achieved optimal properties with 40% corn husk and 2% orange peel, noting improved adhesion and reduced brittleness. Bhattacharyya and Baheti (2023) found that adding 3% corn husk particles reduced creep deformation and improved high-temperature performance, while 5% improved shear strength at the matrix-reinforcement interface.

Research has also explored composites reinforced with corn husk and a polyethylene matrix. Luo *et al.* (2017) studied the influence of different corn plant parts on polyethylene, finding superior tensile and bending properties in composites reinforced with stalks and cobs without kernels, while corn husks produced weaker results due to their high hemicellulose and low lignin content. Dirgantara and Kurniati (2013) found the best tensile strength and elongation at break for composites with 30% corn husk, while the highest modulus of elasticity was achieved at 50%. Youssef *et al.* (2015) produced composites using corn husk powder, observing that higher reinforcement concentrations (5% to 20%) improved tensile strength and elasticity, though hardness decreased, suggesting suitability for packaging applications.

Another type of composite material was created by combining corn husk and polylactic acid. Studies by Levy and Papazian (1990), Mirbagheri *et al.* (2007), and Kwon *et al.* (2014) focused on composites with a polylactic acid matrix reinforced with kenaf fibers and corn husk powder. They found that increasing the corn husk powder content negatively affected the mechanical properties. This was likely because kenaf fibers, having a higher aspect ratio, transfer mechanical stress more effectively to the matrix, enhancing the composite's overall strength compared to corn husk powder.

Another application of corn husk in composite fabrication involves combining it with a cornstarch matrix, as demonstrated by Ibrahim *et al.* (2019). They used husk fiber percentages ranging from 0% to 8%, finding that the addition of husk fibers improved the mechanical, thermal, morphological, and physical properties of the composites. Additionally, corn husk reduced the material's density, moisture content, and biodegradability resistance.

Corn husks have also been used as a fiber component in cement matrices. Alomajaa *et al.* (2023) fabricated construction materials using corn husks and cow hair as reinforcements in a cement matrix. The best mechanical properties were achieved with 85.1% cement, 12.4% corn husks, and 2.5% cow hair, meeting British standards for fiber cement sheets. Ahumada *et al.* (2022) explored using corn husks and rice ash as pozzolanic materials to partially replace cement in adhesives for ceramic tiles. They found that replacing up to 20% of the cement produced results similar to standard samples containing 100% cement.

Natural dammar resin has been extensively studied and is known to originate from India, growing on the bark of trees in the Dipterocarpaceae family, which are native to East Asia. Its primary uses include paper manufacturing, coatings for wooden objects, and as a pigment in drawings (Abdel-Ghani *et al.* 2009; Mittal *et al.* 2010; Bonaduce *et al.* 2013; La Nasa *et al.* 2014).

The chemical composition of dammar resin has been studied extensively. Research by Topp and Pepper (1949), Clearfield (2000), and Mittal *et al.* (2010) identified key components, including a polymeric part called polycaninene, an alcohol-insoluble fraction known as β-resene, and a soluble fraction referred to as α-resene. It also contains a small percentage of sesquiterpenoids (C15) and is mainly composed of compounds with a tetracyclic dammarane skeleton, as well as pentacyclic derivatives of oleanane, ursane, and hopane, as noted in a prior study (Mirițoiu 2024). Research on using dammar resin in hybrid matrices has been documented by Stănescu (2015), Mirițoiu *et al.* (2020), Franz *et al.* (2021), Bolcu *et al.* (2022), and Ciucă *et al.* (2022), which analyzed the chemical compositions and mechanical properties of natural dammar resin combined with various synthetic epoxy or acrylic resins. The findings indicate that increasing the percentage of dammar resin leads to a decrease in the mechanical properties of the hybrid resins.

This research investigated the influence of dammar resin on composite materials reinforced with corn husk and paper waste. Dammar resin was incorporated into the matrices in varying proportions, ranging from 50% to 70%. The novelty of this study lies in the development of composite materials that combine corn husk and paper as reinforcement, along with hybrid matrices based on dammar and two synthetic resins: acrylic and epoxy. A hybrid resin is defined as a matrix composed of both organic and inorganic (synthetic) components. Another innovative aspect of this research is examining how dammar resin affects the mechanical properties of the material. The results were analyzed in terms of the mechanisms at play due to the integration of the natural resin into the matrix, as well as mathematically, using specific statistical tests. These tests facilitate the testing of a null hypothesis through established calculation methods.

EXPERIMENTAL

Materials

The composite materials manufactured in this study used a combination of corn husks and paper waste as reinforcement. For the matrices, two types of synthetic resins were used (one acrylic and the other epoxy) along with six types of hybrid resins incorporating natural dammar resin in proportions of 50%, 60%, and 70%. It is known that dammar resin has a dynamic viscosity between 38.36 and 41.69 MPa·s and a kinematic viscosity between 41.3 and 41.5 cSt (see Kremer Pigmente 2024). It is also known that dammar resin has a density between 1.04 and 1.12 g/cm^3 values and a melting point of approximately 150 °C (see Carl Roth 2024). The dammar resin was purchased from a local supplier (see Foita de Aur 2020) and comes from the genus *Shorea* tree, which belongs to the Dipterocarpaceae family. Among the six types of hybrid resins, three combined natural dammar resin with epoxy resin, while the other three combined natural dammar resin with acrylic resin. All the characteristics of the matrices used are provided in Table 1. The epoxy resin used was Resoltech 1050 with its corresponding hardener, and the acrylic resin was ClaroCit with its corresponding hardener. The synthetic component in the hybrid resins was added according to the proportions suggested by the manufacturer.

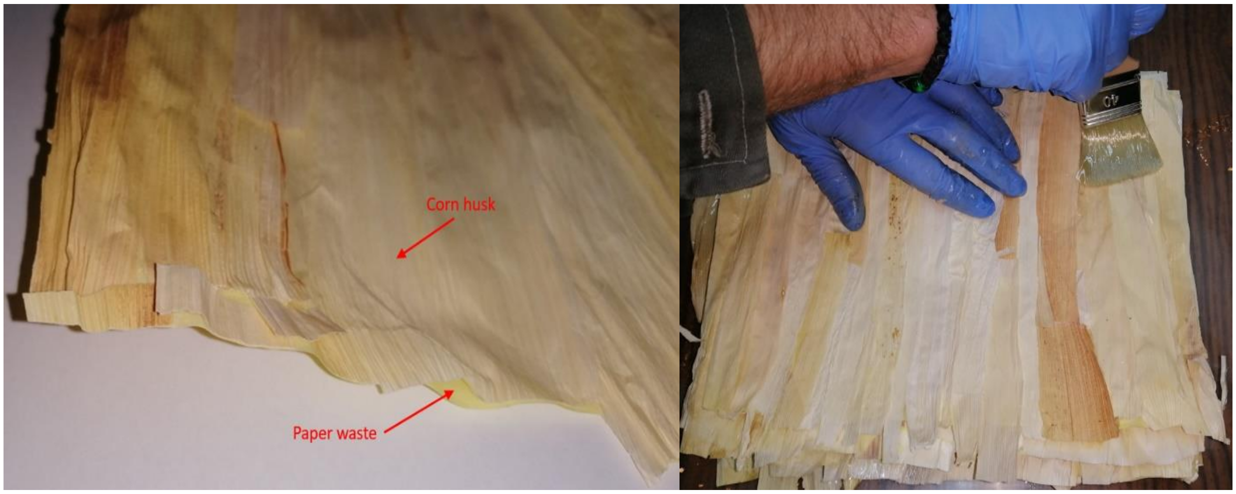
Table 1. The Matrices Used for Composite Materials Manufacturing

Criteria Number	Mass Fraction of the Synthetic Resin Resoltech 1050 (%)	Mass Fraction of the Natural Resin Dammar (%)	Abbreviation
1	100	0	E100
2	50	50	E50
3	40	60	E40
4	30	70	E30
	Mass Fraction of the Synthetic Resin Clarocit (%)	Mass Fraction of the Natural Resin Dammar (%)	Abbreviation
5	100	0	A100
6	50	50	A50
7	40	60	A40
8	30	70	A30

Since this research will also include statistical calculations to study the influence of dammar resin on mechanical properties, the composite materials with a matrix of 100% synthetic resin reinforced with corn husks and paper waste will be referred to as control samples.

Methods

To produce composite materials, paper and corn husk waste were used as reinforcement. The process began by brushing a thin layer of resin onto an 80 g/m² sheet of paper, followed by arranging the corn husks side by side. This thin resin layer was intended to bond the corn husks to the paper, creating a reinforced lamina. This procedure was repeated to create an additional nine laminae. To form the final material, each lamina received another thin layer of resin. Then they were stacked and pressed under a mass of 450 kg distributed over an area of 420 × 297 mm². The samples were cast at temperatures between 21 and 23 °C. To ensure complete polymerization, specimens with a synthetic resin matrix were trimmed five days after casting, whereas those with a hybrid resin matrix were cut ten days post-casting. Figure 1 illustrates the preparation of the laminae and the application of resin layers, while Fig. 2 shows an example of the final plate produced with one of the A30 type of resins. For all samples, the composition consisted of 60% reinforcement and 40% matrix.



a) **b)**

Fig. 1. a) A notable aspect of the lamina's composition is the inclusion of paper and corn husk wastes; b) The technique for consolidating the ten laminae using resin application

Fig. 2. An example with A30 type plate model that was crafted through the application of the lay-on-hands method

Figure 3 presents an example of 15 specimens that were cut for tensile testing from composite materials reinforced with corn husk and paper waste and an A30 type matrix.

Fig. 3. An illustrative case that involves the 15 specimens, which were cut from the A30 group, prepared specifically for the tensile test

Test Standards and Characterizations

Tensile test

For the tensile test, plates were cast using paper and corn husks waste as reinforcements, along with the eight types of resins listed in Table 1 (which include 2 synthetic resins, and 6 hybrid resins based on a combination between dammar and synthetic resins). From each plate, 15 specimens were extracted. Figure 3 shows an example of the 15 specimens cut for the tensile test with A30 matrix and reinforced with paper and corn husk wastes. The tensile testing followed the ASTM D3039/D3039M-08 (2014) standard, with specimen dimensions measuring 250 mm in length, 25 mm in width, and 8 mm in thickness. The tests were conducted using an Instron 1000 HDX (Instron, Norwood, MA, USA) universal testing machine.

Compression test

For the compression test, plates akin to those employed for tensile testing were created, with the distinction of utilizing 19 layers (laminae). The specimens were subsequently trimmed to roughly 15 mm in length, width, and thickness. This compression test adhered to the ASTM D695-23 (2016) standard requirements. An LGB universal testing machine (LGB Testing Equipment, Azzano San Paolo, Italy), equipped with a compression test apparatus, was utilized for this purpose. The inclusion of 19 layers was intended to ensure that the specimens were sufficiently thick, promoting crushing by compression as the primary failure mechanism instead of buckling.

Bending test

For the bending test, plates similar to those used in tensile testing were cast, incorporating corn husks and paper waste as reinforcements and matrices from all eight resin types listed in Table 1. As with the tensile test, 10 laminae were used. From these plates, 15 specimens were cut to dimensions of 200 mm in length, 32 mm in width, and 8 mm in thickness. The bending test was conducted on an LGB Testing Equipment machine (LGB Testing Equipment, Azzano San Paolo, Italy), which was equipped with a special three-point bending device. This test was carried out in accordance with the ASTM D790-17 (2017) standard requirements.

Vibration test

The samples used for the vibration test had identical dimensions and characteristics to those described in the tensile test section. The specimens were fixed at one end, while the other end remained free, with a Bruel and Kjaer (HBK Hottinger Brüel & Kjær, Darmstadt, Germany) accelerometer (sensitivity: 0.04 pC/ms^{-2}) attached. The length of the tubes in the console was 160 mm. Fifteen measurements were taken for each type of composite material separately (the reinforcement was kept constant while the matrices varied according to the references in Table 1). This accelerometer was connected to a Nexus signal conditioner, which was further linked to a Spider 8 (HBK Hottinger Brüel & Kjær, Darmstadt, Germany) data acquisition system. The Spider 8 was interfaced with a notebook to record experimental data.

Shore D hardness test

The Shore D hardness test was conducted following the ASTM D2240-15 (2017) standard. Samples with dimensions matching those used in the tensile tests were employed for this procedure. Hardness measurements were taken at 15 locations spaced 10 mm apart along the sample's length, with the outermost points positioned 30 mm from each edge. The measurement points were selected centrally across the width of the sample.

Statistical Interpretation of Experimental Data

As specified in the introduction, this research aimed to investigate the impact of dammar resin on the mechanical properties of composite materials reinforced with corn husk and paper waste, and using matrices composed of hybrid resins (which contain varying percentages of natural dammar resin). Additionally, composite materials reinforced with corn husk and paper waste, and matrices that were 100% synthetic—one epoxy type from Resoltech and one acrylic type from ClaroCit—were produced. These will be referred to as control samples (15 control samples with 100% epoxy matrix and 15 control samples with 100% acrylic matrix). Subsequently, statistical tests were conducted to determine, from a statistical perspective, whether dammar resin influenced the mechanical properties observed in the experimental tests. The statistical tests were made in Microsoft Excel (Microsoft Corp., Redmond, WA, USA).

A two-way ANOVA test was first conducted to determine if dammar resin had any influence on the experimentally determined mechanical properties. This test is a statistical method used to determine whether there are significant differences between the means of three or more independent groups. If the means of these groups are approximately equal, then the null hypothesis is accepted as true. Otherwise, the alternative hypothesis is accepted, indicating that at least the mean of one group is different from the others. For this research, these concepts are interpreted as follows: if the means of the results are equal, then dammar resin does not have a significant influence on tensile strength. Conversely, if the means are not equal, dammar resin has a significant influence, and the null hypothesis is rejected (Ott and Longnecker 2021).

According to Zar (1999), in the two-way ANOVA test for two A and B factors, the mean (grand mean) of all values was determined with Eq. 1, where X_{ij} are the individual values and N is the total amount of data in all groups:

$$\bar{X} = \frac{\sum X_{ij}}{N} \tag{1}$$

Then, there is determined the total sum of sqares with Eq. 2.

$$SST = \sum\left(-\bar{X} + X_{ij}\right)^2 \tag{2}$$

The, the sum of squares for factors A and B are determined with Eqs. 3 and 4:

$$SSA = \sum_i \left(-\bar{X} + \frac{\sum X_i}{j}\right)^2 \tag{3}$$

$$SSB = \sum_j \left(-\bar{X} + \frac{\sum X_j}{i}\right)^2 \tag{4}$$

In Eqs. 3 and 4 i and j are the numbers of rows and columns, $\sum X_i$ and $\sum X_j$ are the sums or row i and column j.

The sum of squares for error (Eq. 5) is determined by subtracting from Eq. 2 the values from Eqs. 3 and 4.

$$SSE = SST - SSA - SSB \tag{5}$$

The degrees of freedom are determined for both B and A factors with Eqs. 6 and 7, where k_B and k_A are the number of levels for both B and A factors.

$$df_B = k_B - 1 \tag{6}$$

$$df_A = k_A - 1 \tag{7}$$

The degrees of freedom for error (Eq. 8) are determined by multiplying Eq. 6 with Eq 7.

$$df_E = df_A \cdot df_B \tag{8}$$

The mean squares for both B and A factors are determined with Eqs. 9 and 10.

$$MSB = SSB \cdot df_B^{\ -1} \tag{9}$$

$$MSA = SSA \cdot df_A^{\ -1} \tag{10}$$

The mean square for error (Eq. 9) is determined by dividing Eq. 5 to Eq. 8.

$$MSE = SSE \cdot df_E^{\ -1} \tag{11}$$

The F-values (Eqs. 12 and 13) are determined by dividing Eq.10 to Eq.11 for A values and by dividing Eq.9 to Eq.11 for B values.

$$F_A = SSA \cdot SSE^{-1} \tag{12}$$

$$F_B = SSB \cdot SSE^{-1} \tag{13}$$

The F-values are compared to the critical values from the F-distribution for the appropriate degrees of freedom to obtain the p-value (which is defined as the probability of obtaining an F-value at least as large as the calculated one, under the null hypothesis that the group means are equal).

This was followed by Levene's test for homogeneity of variances, which checks whether the null hypothesis—stating that the variances of the populations from which the samples are drawn are equal (homogeneous)—is valid. If the test results indicate significant differences in variances, this assumption is violated, potentially affecting the validity of statistical tests that rely on variance homogeneity. Specifically, if variances are not homogeneous, the assumptions underlying the ANOVA test may be unreliable (false) (Tărâță *et. al.* 2020; Ott and Longnecker 2021).

According to Zar (1999), in Levene's test for homogeneity of variances, first the group means is determined. Then, for each observation j the absolute deviation from the group mean is determined with Eq. 14, where X_{ij} is the value of j observation in group I, and $\overline{X_\imath}$ is the mean of group i.

$$D_{ij} = \left|X_{ij} - \overline{X_\imath}\right| \tag{14}$$

The mean deviation was determined with Eq. 15 and the overall mean deviation with Eq. 16, where n_i is the number of observations in group I and N is the total number of observations across all groups:

$$MD_i = \frac{\sum D_{ij}}{n_i} \tag{15}$$

$$OMD_i = \frac{\sum D_{ij}}{N} \tag{16}$$

There is determined the sum of squared between and sum of squares within with Eqs. 17 and 18:

$$SS_B = \sum n_i \cdot (MD_i - OMD_i)^2 \tag{17}$$

$$SS_W = \sum\sum\left(-MD_i + D_{ij}\right)^2 \tag{18}$$

The degrees of freedom are determined (similar like in Eqs. 6 and 7), and then the mean squared values within and between are determined with Eqs. 19 and 20:

$$MS_B = \frac{\sum n_i \cdot (MD_i - OMD_i)^2}{k-1} \tag{19}$$

$$MS_W = \frac{\sum\sum\left(-MD_i + D_{ij}\right)^2}{-k+N} \tag{20}$$

The F-value is determined by dividing Eq. 19 to 20 and it is compared with critical values from the F-distribution for the appropriate degrees of freedom to obtain the p-value. Then, the p-value is compared with the significance level.

Next, the Shapiro-Wilk test was performed to assess whether the data are normally distributed within each group. This test evaluates whether a dataset follows a normal distribution. If the data does not exhibit a normal distribution, the assumptions for the two-way ANOVA test may be compromised (Shapiro and Wilk 1965).

According to Riffenburgh (2006), the p-value from Shapiro-Wilk can be determined with Eq. 21, where n is the number of observations, x_i is the value of the data and a_i are the coefficient specific to Shapiro-Wilk test, and $\bar{x}$ is the arithmetic mean of the considered data:

$$p = \frac{\left(\sum_{i=1}^{n} a_i \cdot x_i\right)^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{21}$$

The final statistical test conducted was a *post hoc* ANOVA with Bonferroni correction. This method identifies which specific pairs of groups differ significantly after an ANOVA has indicated the presence of significant differences between groups. The Bonferroni correction was applied to control the Type I error rate (false positives) that may occur when making multiple comparisons. *Post hoc* tests are necessary because ANOVA alone does not specify where the differences lie, only that significant differences exist (Foster *et al.* 2018). The same calculation formulas are used as in the two-way ANOVA method, except that this time, the significance level must be divided by the total number of comparisons made between the analyzed data groups.

These statistical methods were used because they are the most common and quickest ways to investigate whether a parameter (in this case, dammar resin) influences the experimental data obtained for several mechanical characteristics (Popescu *et al.* 2023).

RESULTS AND DISCUSSION

Tensile Test

For the tensile testing, 15 samples were cut from each of the 8 types of materials produced according to the methodology specified in the *Methods* section. Each test sample was cut from cast plates using a hand saw to the dimensions specified by the testing standard. It is important to note that the study involved 8 different composite materials, all with the same reinforcement (corn husks and paper waste) but varying matrices. These matrices included two 100% synthetic types (epoxy and acrylic) and six hybrid matrices with different proportions of dammar resin (50%, 60%, and 70%), as detailed in Table 1. To achieve the highest tensile strength value, the samples were cut and tested along the fiber direction (see Fig. 4 for illustration). The percentage of dammar was kept maximum up to 70% because exceeding this limit significantly reduces the mechanical properties of the hybrid resin compared to the synthetic resin used to accelerate polymerization. Franz *et al.* (2021) found that above 70% dammar, the hybrid resin has a strength that is 3.22 times lower and a longitudinal elastic modulus that is 5.88 times lower compared to the synthetic resin.

Because the influence of dammar resin on mechanical properties was studied, the following figures will display the tensile strength and elongation at break for all 8 types of materials. The values will correspond to the 15 samples cut from each material plate (for each of the 8 different material types). All results obtained for these two parameters (tensile strength and elongation at break) are presented in Figs. 5 and 6.

Fig. 4. An example of the tensile test conducted along the fibers of the sample

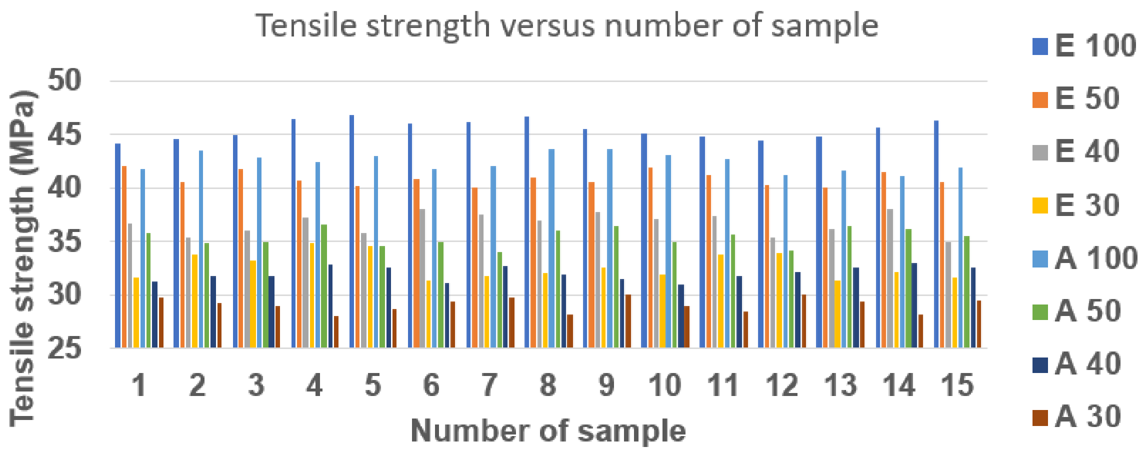


Fig. 5. Variation in tensile strength with respect to the number of samples

As specified, the primary objective of this study was to investigate the effect of dammar resin on the mechanical properties of composite materials reinforced with corn husks and paper waste and using various matrices (2 synthetic and 6 hybrid). Initially, the study focused on determining statistically whether dammar resin affects tensile strength and elongation at break. A two-way ANOVA test was conducted as follows: Samples with epoxy resin matrices were grouped into one category, while samples with acrylic resin matrices were grouped into another. Control samples, which did not contain dammar resin in the matrix, were 15 samples from the 100% epoxy category and 15 samples from the 100% acrylic category.

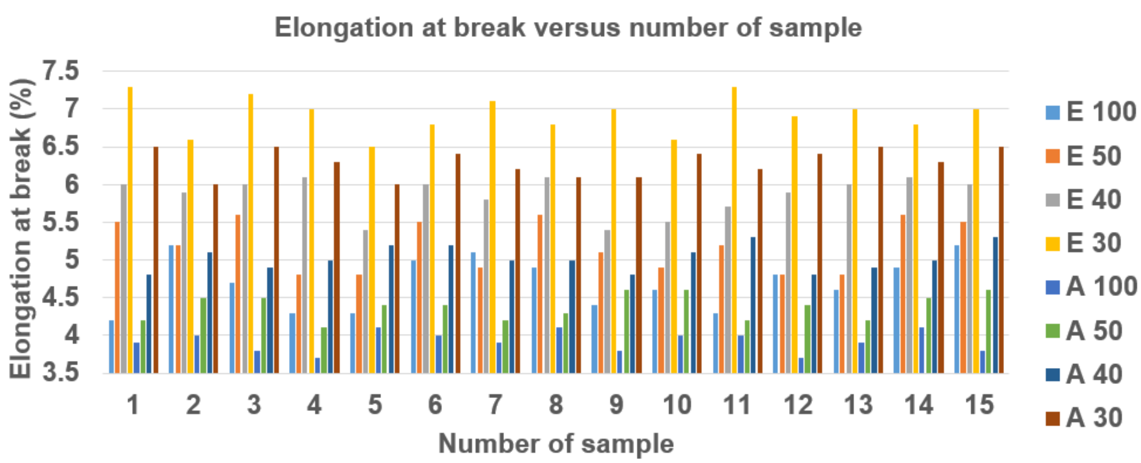


Fig. 6. Variation in elongation at break with respect to the number of samples

In the next stage, the statistical parameter p was calculated. A significance level of 0.05 was chosen. The null hypothesis adopted was that dammar resin does not have a significant effect on tensile strength or elongation at break. If the p-value is greater than 0.05, the null hypothesis is accepted as true. Otherwise ($p < 0.05$), the null hypothesis is rejected, indicating that dammar resin does influence tensile strength or elongation at break. The p-value was calculated for each category and for each mechanical parameter (tensile strength and elongation at break). The values of the p statistic obtained by applying the two-way ANOVA test are summarized in Table 2.

Table 2. The Two-way ANOVA Test Results for the Tensile-tested Specimens

Parameter	Samples	p-value	Null Hypothesis	α
Tensile strength	E100, E50, E40, E30	$1.4 \cdot 10^{-32}$	Reject	0.05
	A100, A50, A40, A30	$2.9 \cdot 10^{-36}$	Reject	
Elongation at break	E100, E50, E40, E30	$4.8 \cdot 10^{-25}$	Reject	
	A100, A50, A40, A30	$5.4 \cdot 10^{-34}$	Reject	

In Table 2, the significance level was noted with α. From Table 2, it is observed that for all categories of analyzed samples, the p-value was much smaller than the reference value (0.05), which means that the null hypothesis, stating that dammar resin does not influence tensile strength or elongation at break, is rejected. In Table 2, the categories of test samples (E or A) were treated separately.

If the mechanical characteristics (i.e., breaking strength and elongation at break) are analyzed together, then the results of the two-way ANOVA test will be summarized in Table 3.

Table 3. The Two-way ANOVA Test Results for the Tensile-tested Specimens (second case of study)

Parameter	Samples	p-value	Null Hypothesis	α
Tensile mechanical properties (breaking strength and elongation at break)	E100, E50, E40, E30	$1.72 \cdot 10^{-7}$	Reject	0.05
Tensile mechanical properties (breaking strength and elongation at break)	A100, A50, A40, A30	$8.28 \cdot 10^{-8}$	Reject	

In this case, it is observed that the p-value is less than 0.05, thus the null hypothesis, which states that dammar resin does not influence the tensile mechanical properties, is rejected.

The statistical study was continued with Levene's test for homogeneity of variances, which checks whether the null hypothesis—stating that the variances of the populations from which the samples are drawn, are equal (homogeneous)—is valid. A significance level of 0.05 was adopted. The p-value was calculated, and if its value is higher than the reference value, the variances are homogeneous. Otherwise, the variances are non-homogeneous, and the previously stated assumption with the two-way ANOVA test is incorrect. The data obtained from the 15 samples with E 100 and A 100 resins were considered as control samples. Subsequently, tests were conducted comparing, one by one, the results of the samples with other hybrid resins (E 50, E 40, E 30, A 50, A 40, and A 30) against those of the control samples. Each time, the p-value was calculated and compared to the reference value. The p-values obtained from the tensile strength results are written in Table 4. The p-values obtained from the elongation at break results are written in Table 5.

Table 4. The Levene's Test Results for the Tensile Strength Data

Groups	E50/E100	E40/E100	E30/E100	A50/A100	A40/A100	A30/A100
p-value	0.185	0.406	0.07	0.31	0.177	0.232
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05					

Table 5. The Levene's Test Results for the Elongation at Break Data

Groups	E50/E100	E40/E100	E30/E100	A50/A100	A40/A100	A30/A100
p-value	0.987	0.103	0.09	0.114	0.428	0.179
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05					

From Tables 4 and 5 it can be observed that the variances were homogeneous (because $p > 0.05$), and the null hypothesis is confirmed. Therefore, the assumptions made with the two-way ANOVA test were judged to be valid.

The statistical tests were continued with the Shapiro–Wilk test to check if the data is normally distributed for each group. The same significant level of 0.05 was adopted. The hypothesis that the data is normally distributed was formulated. The p-value was determined, and if it is greater than 0.05, there is insufficient evidence to reject the null hypothesis, meaning that the data is normally distributed, and the results stated with the ANOVA test are valid. The p-values obtained for the tensile strength and elongation at break results are written in Tables 6 and 7.

Table 6. The Shapiro–Wilk Test Results for the Tensile Strength Data

Groups	E100	E50	E40	E30	A100	A50	A40	A30
p-value	0.941	0.930	0.928	0.882	0.942	0.935	0.943	0.939
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05							

Table 7. The Shapiro–Wilk Test Results for the Elongation at Break Data

Groups	E100	E50	E40	E30	A100	A50	A40	A30
p-value	0.924	0.832	0.820	0.95	0.912	0.903	0.923	0.891
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05							

The final statistical test performed was a *post hoc* ANOVA with Bonferroni correction. This method identifies which specific pairs of groups differ significantly after ANOVA has indicated the presence of significant differences between groups. This makes it possible to determine whether dammar resin has significant effects as its proportion increases. More precisely, it was possible to ascertain whether, for example, a 70% dammar content had a significant impact compared to a 60% dammar content in terms of tensile strength and elongation at break, with both percentages being added to the matrix composition. The results of samples containing epoxy resin in the composition were compared in pairs, one by one. Then, using the same methodology, the results of samples containing acrylic resin in the composition were compared. A total of 6 *post hoc* tests were performed for each type of matrix (with epoxy and with acrylic). To better illustrate this, the methodology for conducting the *post hoc* tests for matrices containing epoxy resin was exemplified as follows: E50 compared to E100, E40 compared to E100, E30 compared to E100, E40 compared to E50, E30 compared to E50, and finally, E30 compared to E40. The significance level in this case is 0.05. The significance level must be divided by the total number of comparisons made between the analyzed data groups. Data groups refer to the set of samples that contain a single type of synthetic resin (either epoxy or acrylic) and for which a single type of mechanical characteristic/property (breaking strength or elongation at break, as in the case of tensile testing for example) has been determined. In the present case, six comparisons have been made (see the groups line in table 7), so the 0.05 value (significance level) was divided by 6. A value of 0.008(3) was obtained and it was approximated with 0.0083. This (the 0.0083 parameter) is also known as the corrected threshold.

In the next stage, the statistical parameter p was calculated. The null hypothesis adopted was that dammar resin does not have a significant effect on tensile strength or elongation at break. If the p-value is greater than 0.0083, the null hypothesis is true. Otherwise ($p < 0.0083$), the null hypothesis is rejected, indicating that dammar resin does influence tensile strength or elongation at break. The p-values were obtained with the tensile strength and elongation at break results are written in Tables 8 and 9.

Table 8. The *Post hoc* ANOVA with Bonferroni Correction Test Results for the Tensile Strength Data

Groups	E50/E100	E40/E100	E30/E100	E40/E50	E30/E50	E30/E40
p-value	$5.37 \cdot 10^{-16}$	$4.21 \cdot 10^{-21}$	$2.36 \cdot 10^{-24}$	$1.04 \cdot 10^{-13}$	$6.89 \cdot 10^{-20}$	$1.22 \cdot 10^{-10}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
Groups	A50/A100	A40/A100	A30/A100	A40/A50	A30/A50	A30/A40
p-value	$1.35 \cdot 10^{-19}$	$1.93 \cdot 10^{-25}$	$3.09 \cdot 10^{-28}$	$9.45 \cdot 10^{-13}$	$1.54 \cdot 10^{-19}$	$1.05 \cdot 10^{-12}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
α	0.0083					

Table 9. The *Post hoc* ANOVA with Bonferroni Correction Test Results for the Elongation at Break Data

Groups	E50/E100	E40/E100	E30/E100	E40/E50	E30/E50	E30/E40
p-value	0.00053	$2.87 \cdot 10^{-11}$	$2.78 \cdot 10^{-18}$	$9.23 \cdot 10^{-7}$	$9.58 \cdot 10^{-16}$	$2.05 \cdot 10^{-12}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
Groups	A50/A100	A40/A100	A30/A100	A40/A50	A30/A50	A30/A40
p-value	$7.04 \cdot 10^{-9}$	$7.42 \cdot 10^{-18}$	$2.67 \cdot 10^{-26}$	$4.1 \cdot 10^{-11}$	$1.06 \cdot 10^{-22}$	$7.05 \cdot 10^{-18}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
α	0.0083					

Statistically speaking, it can be observed from all the results that the p-value was lower than 0.0083 (the significance level). Therefore, it can be concluded that adding dammar resin percentages (from 50% to 70%) to the matrix composition brought significant changes to the tensile strength and elongation at break properties.

This statistical conclusion can also be explained in terms of the phenomena (changes) occurring in composite materials due to the addition of dammar resin to the matrix composition. It is well known that dammar resin is softer and has lower strength compared to synthetic resins (Miritoiu 2024). This causes the addition of dammar resin to the matrix used for manufacturing composite materials, to lead to a decrease in tensile strength and an increase in elasticity (*i.e.*, elongation at break) in the final material. This can also be observed in Figs. 1 and 2, where the highest tensile strengths and the lowest elongations at break were seen in materials with a 100% synthetic matrix. When a hybrid matrix was used (50% dammar and 50% synthetic resin), a decrease in tensile strength was observed, along with an increase in elasticity. This phenomenon can only be explained by the presence of dammar resin in the matrix composition, which influences these two mechanical properties. Additionally, it was observed that increasing the dammar resin percentage to 60% and 70% results in a more pronounced decrease in tensile strength, accompanied by an increase in elongation at break. These phenomena were also validated by statistical tests, which likewise indicate that the influence of dammar percentages in the matrix composition is significant.

Compression Test

For the compression test, 15 specimens were cut from each type of material studied according to the methodology specified in the *Methods* section. It is important to note that the study involved 8 different composite materials, all with the same reinforcement (corn husks and paper waste) but varying matrices. These matrices included two 100% synthetic types (epoxy and acrylic) and six hybrid matrices with different proportions of dammar resin (50%, 60%, and 70%), as detailed in Table 1. It is also noted that the specimens had 19 reinforcement layers to ensure sufficient thickness, promoting crushing by compression as the primary failure mechanism instead of buckling.

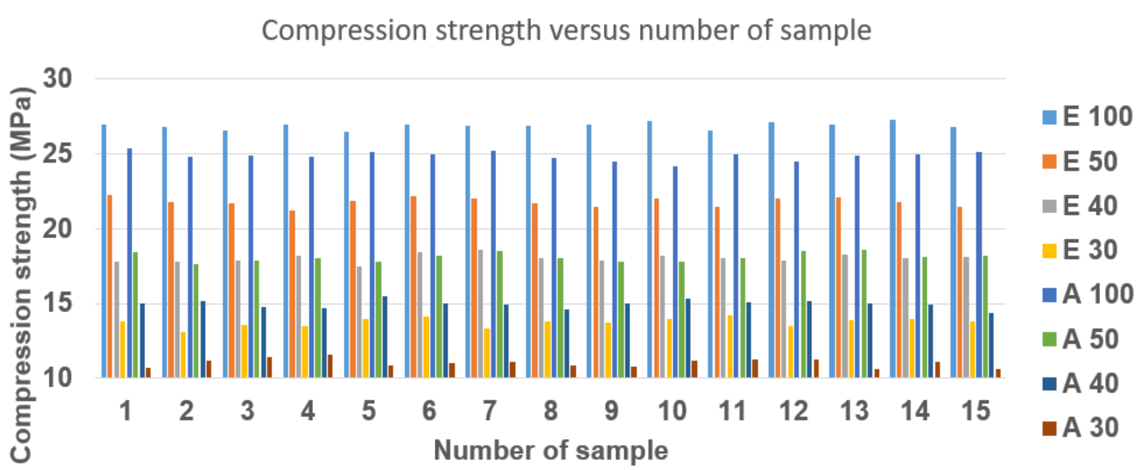


Fig. 7. Variation in compression strength with respect to the number of samples

Because the influence of dammar resin on mechanical properties were studied, the following figures (Figs. 7 and 8) display the compression strength and traverse stroke for all 8 types of materials. The results correspond to the 15 specimens cut from each type of material.

Table 10. The Two-way ANOVA Test Results for the Compression-tested Specimens

Parameter	Samples	p-value	Null Hypothesis	α
Compression strength	E100, E50, E40, E30	$1.1 \cdot 10^{-56}$	Reject	0.05
	A100, A50, A40, A30	$2.9 \cdot 10^{-54}$	Reject	
Traverse stroke	E100, E50, E40, E30	$4.1 \cdot 10^{-28}$	Reject	
	A100, A50, A40, A30	$5 \cdot 10^{-31}$	Reject	

To shorten the presentation, the statistical results will be summarized (not as detailed as in the Results and Discussion - Tensile Test section) and presented in tabular form.

In Table 10, the results of the two-way ANOVA statistical test are presented. The null hypothesis adopted was that dammar resin does not have a significant effect on compression strength or traverse stroke. In Table 10, the categories of test samples (E or A) were treated separately. If the mechanical characteristics (i.e., compression strength and traverse stroke) are analyzed together, then the results of the two-way ANOVA test will be summarized in Table 11.

Table 11. The Two-way ANOVA Test Results for the Compression-tested Specimens (second case of study)

Parameter	Samples	p-value	Null Hypothesis	α
Compression mechanical properties (compression strength and traverse stroke)	E100, E50, E40, E30	$2.6 \cdot 10^{-6}$	Reject	0.05
Compression mechanical properties (compression strength and traverse stroke)	A100, A50, A40, A30	$3.1 \cdot 10^{-6}$	Reject	

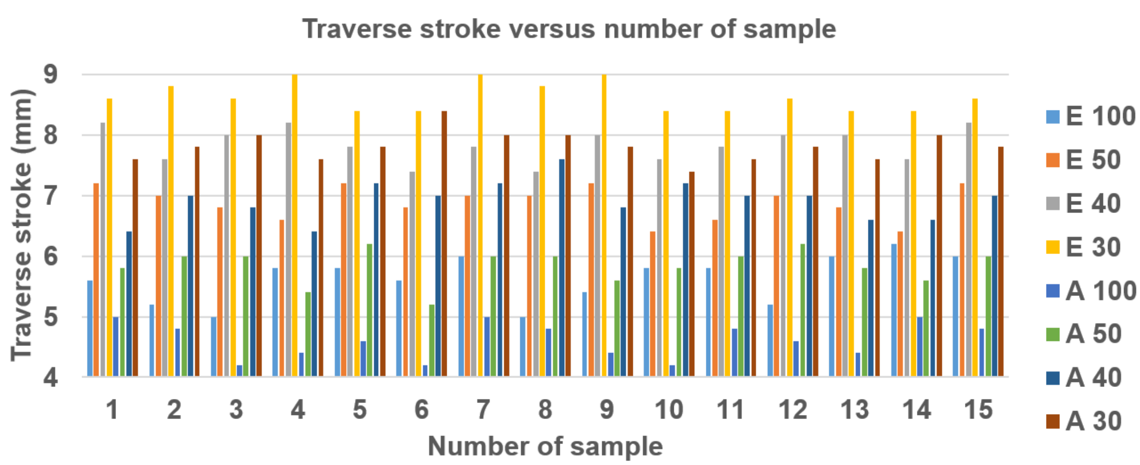


Fig. 8. Variation in traverse stroke with respect to the number of samples

In conclusion, from the Table 10 results it can be stated that the dammar resin has an influence on both compression strength or transverse stroke because the null hypothesis is rejected ($p < 0.05$). In the second case of study, it is observed that the p-value is less than 0.05, thus the null hypothesis, which states that dammar resin does not influence the compression mechanical properties, is rejected.

In Tables 12 and 13, the statistical results for Levene's test for homogeneity of variances are presented. The p-value was calculated, and if its value is higher than the reference value (0.05), the variances are considered homogeneous.

Table 12. The Levene's Test Results for the Compression Strength Data

Groups	E50/E100	E40/E100	E30/E100	A50/A100	A40/A100	A30/A100
p-value	0.231	0.524	0.229	0.825	0.696	0.857
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05					

Table 13. The Levene's Test Results for the Traverse Stroke Data from the Compression Test

Groups	E50/E100	E40/E100	E30/E100	A50/A100	A40/A100	A30/A100
p-value	0.194	0.165	0.051	0.591	0.977	0.174
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05					

In conclusion, according to the results from Tables 12 and 13, the null hypothesis was checked ($p > 0.05$), so the variances were judged to be homogeneous.

In Tables 14 and 15, the statistical results for Shapiro–Wilk test are presented. The hypothesis that the data is normally distributed was formulated. The p-value was calculated, and if its value is higher than the reference value (0.05), then the data is normally distributed for each group.

Table 14. The Shapiro–Wilk Test Results for the Compression Strength Data

Groups	E100	E50	E40	E30	A100	A50	A40	A30
p-value	0.947	0.969	0.973	0.954	0.963	0.946	0.980	0.967
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05							

Table 15. The Shapiro–Wilk Test Results for the Traverse Stroke Data from Compression Test

Groups	E100	E50	E40	E30	A100	A50	A40	A30
p-value	0.918	0.799	0.912	0.764	0.889	0.893	0.940	0.917
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05							

In conclusion, according to the results from Tables 12 and 13, the null hypothesis was checked ($p > 0.05$), so the data was judged to be normally distributed.

The final statistical test performed was a *post hoc* ANOVA with Bonferroni correction. A total of 6 *post hoc* tests were performed for each type of matrix (with epoxy and with acrylic). A significance level of 0.0083 was chosen. The null hypothesis adopted was that dammar resin does not have a significant effect on compression strength or traverse stroke. If the p-value is greater than 0.0083, the null hypothesis is true. Otherwise ($p < 0.0083$), the null hypothesis is rejected, indicating that dammar resin does have an effect on compression strength or traverse stroke. The results are written in Table 16 for the compression strength data, and in Table 17 for the traverse stroke data.

Table 16. The *Post hoc* ANOVA with Bonferroni Correction Test Results for the Compression Strength Data

Groups	E50/E100	E40/E100	E30/E100	E40/E50	E30/E50	E30/E40
p-value	$1.54 \cdot 10^{-29}$	$5.06 \cdot 10^{-37}$	$6.82 \cdot 10^{-41}$	$5.6 \cdot 10^{-25}$	$2.05 \cdot 10^{-33}$	$2.12 \cdot 10^{-26}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
Groups	A50/A100	A40/A100	A30/A100	A40/A50	A30/A50	A30/A40
p-value	$2.31 \cdot 10^{-31}$	$2.21 \cdot 10^{-36}$	$4.53 \cdot 10^{-40}$	$1.31 \cdot 10^{-22}$	$5.34 \cdot 10^{-32}$	$2.03 \cdot 10^{-25}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
α	0.0083					

Statistically speaking, it can be observed from all the results that the p-value was lower than 0.0083 (the significance level). Therefore, it can be concluded that adding dammar resin percentages (from 50% to 70%) to the matrix composition brings significant changes to the compression strength and traverse stroke values.

Table 17. The *Post hoc* ANOVA with Bonferroni Correction Test Results for the Traverse Stroke Data

Groups	E50/E100	E40/E100	E30/E100	E40/E50	E30/E50	E30/E40
p-value	$6.26 \cdot 10^{-11}$	$5.14 \cdot 10^{-17}$	$5.09 \cdot 10^{-21}$	$3.18 \cdot 10^{-10}$	$3.59 \cdot 10^{-17}$	$3.96 \cdot 10^{-9}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
Groups	A50/A100	A40/A100	A30/A100	A40/A50	A30/A50	A30/A40
p-value	$3.73 \cdot 10^{-12}$	$3.16 \cdot 10^{-18}$	$1.14 \cdot 10^{-23}$	$2.18 \cdot 10^{-10}$	$2.54 \cdot 10^{-18}$	$3.36 \cdot 10^{-9}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
α	0.0083					

This statistical conclusion can also be explained in terms of the phenomena (changes) occurring in composite materials due to the addition of dammar resin to the matrix composition. As observed from the tensile tests, the addition of dammar resin (which is more elastic and less resistant compared to synthetic resins) to the composite material matrix leads to a slight increase in elasticity accompanied by a decrease in strength. Because the reinforcement was kept constant for all eight types of materials and only the matrices varied, it can be concluded that this phenomenon (increase in elasticity and decrease in strength) was caused by the presence of natural dammar resin as a component of the matrix. Additionally, it is noted that the highest strength and the lowest deformations occurred in samples with a matrix made of 100% synthetic resin, which reinforces the conclusion that dammar resin is the factor influencing the evolution of the two parameters (compression strength and traverse stroke) during compression testing.

Bending Test

For the bending test, the same statistical analyses was carried out based on the experimental results, as in the case of the tensile and compression tests. In Figs. 9 and 10, the values of bending strength and traverse stroke are provided for all 15 samples cut from 8 different types of composite materials (for which the reinforcement was kept constant, while the type of matrix used varied: 2 synthetic and 6 hybrid).

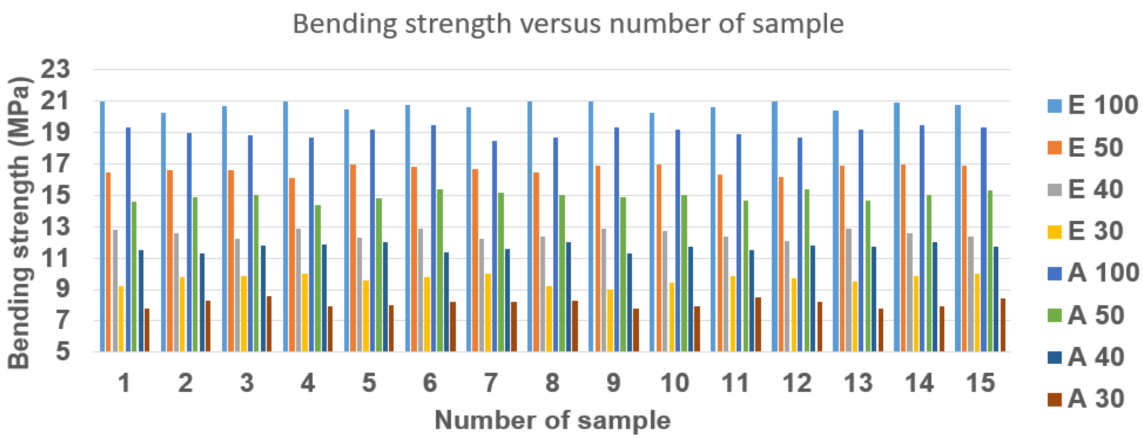


Fig. 9. Variation in bending strength with respect to the number of samples

The first statistical test performed was a two-way ANOVA for each sample, separately. The results are recorded in Table 18. The null hypothesis adopted was that dammar resin does not significantly affect the flexural strength and traverse stroke. A significance level of 0.05 was chosen. The p-value was determined, and because its values were lower than the reference value of 0.05, the null hypothesis was rejected.

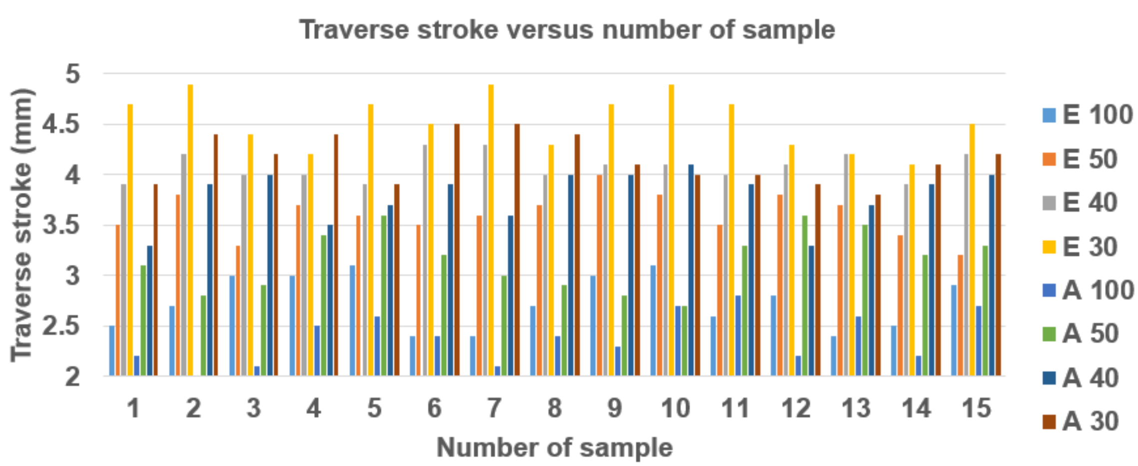


Fig. 10. Variation in traverse stroke, at the bending test, with respect to the number of samples

Table 18. The Two-way ANOVA Test Results for the Bending-tested Specimens

Parameter	Samples	p-value	Null Hypothesis	α
Bending Strength	E100, E50, E40, E30	$2.67 \cdot 10^{-50}$	Reject	0.05
	A100, A50, A40, A30	$1.79 \cdot 10^{-51}$	Reject	
Traverse Stroke	E100, E50, E40, E30	$1.88 \cdot 10^{-24}$	Reject	
	A100, A50, A40, A30	$1.19 \cdot 10^{-20}$	Reject	

If the mechanical characteristics (i.e., bending strength and traverse stroke) are analyzed together, then the results of the two-way ANOVA test will be summarized in Table 19.

Table 19. The Two-way ANOVA Test Results for the Bending-tested Specimens (second case of study)

Parameter	Samples	p-value	Null Hypothesis	α
Bending mechanical properties (bending strength and traverse stroke)	E100, E50, E40, E30	$4.7 \cdot 10^{-8}$	Reject	0.05
Bending mechanical properties (bending strength and traverse stroke)	A100, A50, A40, A30	$7.49 \cdot 10^{-8}$	Reject	

And in this case, it is observed that the p-value is less than 0.05, thus the null hypothesis, which states that dammar resin does not influence the bending mechanical properties, is rejected.

There was also homogeneity of the variances, according to Levene's test ($p > 0.05$, where 0.05 is the significance level value). The p-values for the statistical test are written in Tables 20 and 21.

Table 20. Levene's Test Results for the Bending Strength Data

Groups	E50/E100	E40/E100	E30/E100	A50/A100	A40/A100	A30/A100
p-value	0.638	0.587	0.357	0.364	0.119	0.354
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05					

Table 21. The Levene's Test Results for the Traverse Stroke Data from Bending Test

Groups	E50/E100	E40/E100	E30/E100	A50/A100	A40/A100	A30/A100
p-value	0.163	0.769	0.888	0.476	0.969	0.805
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05					

From the Shapiro-Wilk test it was found out that the data were normally distributed for each group ($p > 0.05$). The p-values for the statistical test are written in Tables 22 and 23. The ANOVA *post hoc* analysis with Bonferroni correction shows that the influence of dammar resin at percentages of 50%, 60%, and 70% was statistically significant in terms of bending strength and traverse stroke. The dammar resin, with the increase in percentage, influences the two mechanical properties (stress and deformation) resulting from the bending test ($p < 0.0083$). All the p-value results are written in Tables 24 and 25.

Table 22. The Shapiro–Wilk Test Results for the Bending Strength Data

Groups	E100	E50	E40	E30	A100	A50	A40	A30
p-value	0.873	0.908	0.898	0.954	0.924	0.929	0.980	0.913
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05							

Table 23. The Shapiro–Wilk Test Results for the Traverse Stroke Data from Bending Test

Groups	E100	E50	E40	E30	A100	A50	A40	A30
p-value	0.893	0.972	0.912	0.916	0.943	0.945	0.866	0.913
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05							

Table 24. The *Post hoc* ANOVA with Bonferroni Correction Test Results for the Bending Strength Data

Groups	E50/E100	E40/E100	E30/E100	E40/E50	E30/E50	E30/E40
p-value	$4.32 \cdot 10^{-26}$	$8.69 \cdot 10^{-35}$	$1.62 \cdot 10^{-37}$	$9.23 \cdot 10^{-26}$	$2.5 \cdot 10^{-31}$	$5.47 \cdot 10^{-21}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
Groups	A50/A100	A40/A100	A30/A100	A40/A50	A30/A50	A30/A40
p-value	$2.77 \cdot 10^{-25}$	$3.19 \cdot 10^{-33}$	$1.58 \cdot 10^{-37}$	$3.78 \cdot 10^{-24}$	$1.81 \cdot 10^{-32}$	$1.09 \cdot 10^{-25}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
α	0.0083					

Table 25. The *Post hoc* ANOVA with Bonferroni Correction Test Results for the Traverse Stroke Data from Bending Test

Groups	E50/E100	E40/E100	E30/E100	E40/E50	E30/E50	E30/E40
p-value	$1.16 \cdot 10^{-10}$	$1.42 \cdot 10^{-16}$	$4.45 \cdot 10^{-17}$	$6.7 \cdot 10^{-8}$	$4.45 \cdot 10^{-11}$	$3.85 \cdot 10^{-6}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
Groups	A50/A100	A40/A100	A30/A100	A40/A50	A30/A50	A30/A40
p-value	$2.77 \cdot 10^{-8}$	$6.76 \cdot 10^{-15}$	$6.3 \cdot 10^{-18}$	$1 \cdot 10^{-6}$	$6.78 \cdot 10^{-11}$	0.000383
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
α	0.0083					

From the perspective of the results obtained following the bending tests, it can be observed that there was a decrease in strength and an increase in deformation (in the traverse stroke parameter) as the percentage of dammar increased. Because the reinforcement type (paper strips with corn husks) and percentage were the same, it can be concluded that these changes were due to the presence of dammar resin in the matrix. Regarding the deformation results, one possible explanation is that natural dammar resin was more elastic compared to synthetic resins, and as its percentage in the matrix increases, it leads to greater elasticity in the final composite material. Concerning bending strength, a possible explanation is that natural dammar resin has lower strength compared to synthetic resins, and as its percentage increases, the final composite's strength decreases. It can be seen that the observed trends were closely related to the results recorded during tensile and compression tests. As the indenter roller of the three-point bending device made contact with the upper face of the test sample, the first fiber failure occurred on the lower face (which corresponded to the stretched fibers). When the indenter roller contacted the upper face (which corresponded to the compressed fibers), local crushing of the fibers was observed.

Vibrations Test

For the vibrations test, the same statistical analyses were carried out based on the experimental results (natural frequency and damping factor), as in the case of the previous tests. In Figs. 11 and 12, the values of natural frequency and damping factor are provided for all 15 samples cut from 8 different types of composite materials (for which the reinforcement was kept constant, while the type of matrix used varied: 2 synthetic and 6 hybrid).

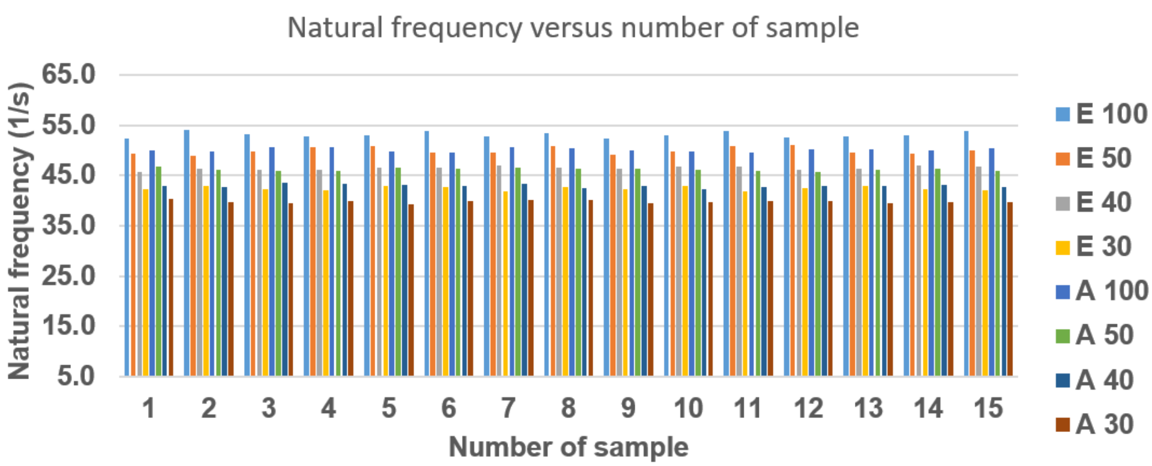


Fig. 11. Variation in natural frequency with respect to the number of samples

For the natural frequency and the damping factor, the Eqs. 22 and 23 were used (see Stănescu and Bolcu (2020) and Mirițoiu *et.al* (2020), where a similar experimental setup was used).

$$\mu = \frac{1}{t_2 - t_1} \cdot ln \frac{v_2}{v_1} \tag{17}$$

$$\nu = \frac{k}{t_2 - t_1} \tag{18}$$

Equations 17 and 18 include the time values for two peaks, labeled as t_1 and t_2, derived from the amplitude diagram, along with the peak amplitudes at those times, denoted as v_1 and v_2. In the formula for calculating the natural frequency (Eq. 18), the parameter k represents the number of cycles between the time periods t_1 and t_2.

The first statistical test performed was a two-way ANOVA. The results are recorded in Table 26. In Table 2, the categories of test samples (E or A) were treated separately. The null hypothesis adopted was that dammar resin does not significantly affect the natural frequency or damping factor. A significance level of 0.05 was chosen. The p-value was determined, and because its values were lower than the reference value of 0.05, the null hypothesis was rejected.

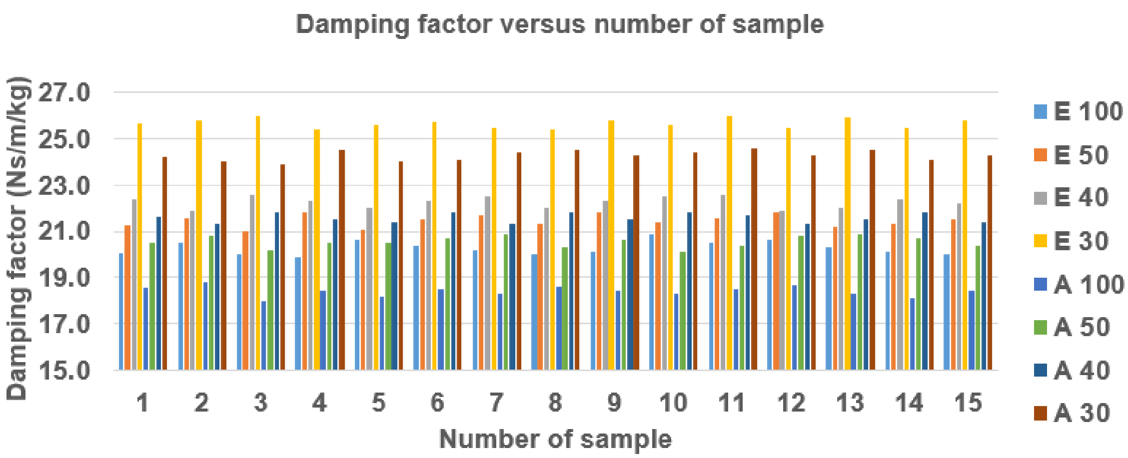


Fig. 12. Variation in damping factor with respect to the number of samples

Table 26. The Two-way ANOVA Test Results for the Vibration-tested Specimens

Parameter	Samples	p-value	Null Hypothesis	α
Natural frequency	E100, E50, E40, E30	$7 \cdot 10^{-41}$	Reject	0.05
	A100, A50, A40, A30	$1.4 \cdot 10^{-49}$	Reject	
Damping factor	E100, E50, E40, E30	$5.1 \cdot 10^{-41}$	Reject	
	A100, A50, A40, A30	$6.9 \cdot 10^{-44}$	Reject	

Table 27. The Two-way ANOVA Test Results for the Vibrations-tested Specimens (second case of study)

Parameter	Samples	p-value	Null Hypothesis	α
Vibration properties (natural frequency and damping factor)	E100, E50, E40, E30	0.01479	Reject	0.05
Vibration properties (natural frequency and damping factor)	A100, A50, A40, A30	0.04945	Reject	

If the vibration characteristics (*i.e.*, damping factor and natural frequency) are analyzed together, then the results of the two-way ANOVA test will be summarized in Table 27. And in this case, it is observed that the p-value is less than 0.05, thus the null hypothesis, which states that dammar resin does not influence the vibration properties, is rejected.

There was also homogeneity of the variances, according to Levene's test ($p > 0.05$, where 0.05 is the significance level value). The p-values for the statistical test are written in Tables 28 and 29.

Table 28. The Levene's Test Results for the Natural Frequency Data

Groups	E50/E100	E40/E100	E30/E100	A50/A100	A40/A100	A30/A100
p-value	0.447	0.063	0.227	0.088	0.199	0.152
Null Hypothesis	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05					

Table 29. The Levene's Test Results for the Damping Factor Data

Groups	E50/E100	E40/E100	E30/E100	A50/A100	A40/A100	A30/A100
p-value	0.604	0.423	0.094	0.425	0.656	0.754
Null Hypothesis	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05					

From the Shapiro-Wilk test it was found out that the data were normally distributed for each group ($p > 0.05$). The p-values for the statistical test are written in Tables 30 and 31. The ANOVA *post hoc* analysis with Bonferroni correction shows that the influence of dammar resin at percentages of 50%, 60%, and 70% was statistically significant in terms of natural frequency and damping factor.

Table 30. The Shapiro–Wilk Test Results for the Natural Frequency Data

Groups	E100	E50	E40	E30	A100	A50	A40	A30
p-value	0.912	0.817	0.939	0.707	0.733	0.221	0.066	0.155
Null Hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05							

Table 31. The Shapiro–Wilk Test Results for the Damping Factor Data

Groups	E100	E50	E40	E30	A100	A50	A40	A30
p-value	0.834	0.831	0.532	0.712	0.529	0.702	0.509	0.718
Null Hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05							

The dammar resin, with the increase in percentage, influences the two mechanical properties (natural frequency and damping) resulting from the vibration test ($p < 0.0083$). All the p-values results are written in Tables 32 and 33.

Table 32. The *Post hoc* ANOVA with Bonferroni Correction Test Results for the Natural Frequency Data

Groups	E50/E100	E40/E100	E30/E100	E40/E50	E30/E50	E30/E40
p-value	$2.37·10^{-14}$	$8.19·10^{-26}$	$5.89·10^{-31}$	$8.27·10^{-17}$	$2.29·10^{-25}$	$3.51·10^{-22}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
Groups	A50/A100	A40/A100	A30/A100	A40/A50	A30/A50	A30/A40
p-value	$5.98·10^{-24}$	$1.82·10^{-30}$	$3.9·10^{-35}$	$6.54·10^{-23}$	$2.34·10^{-31}$	$8.18·10^{-22}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
α	0.0083					

Table 33. The *Post hoc* ANOVA with Bonferroni Correction Test Results for the Damping Factor Data

Groups	E50/E100	E40/E100	E30/E100	E40/E50	E30/E50	E30/E40
p-value	$3.05·10^{-12}$	$3.61·10^{-18}$	$6.16·10^{-31}$	$2.14·10^{-9}$	$8.05·10^{-29}$	$9.94·10^{-27}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
Groups	A50/A100	A40/A100	A30/A100	A40/A50	A30/A50	A30/A40
p-value	$6.92·10^{-21}$	$1.14·10^{-26}$	$8.88·10^{-34}$	$8.55·10^{-13}$	$2.19·10^{-27}$	$8.58·10^{-25}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
α	0.0083					

From a phenomenological point of view, the statistical results can be explained. By adding natural dammar resin to the matrix composition, as observed from the tensile, compressive, and bending tests, there is an increase in elasticity concomitant with a decrease in strength. The increase in elasticity leads to a reduction in the rigidity of a body (rigidity being, in fact, the property of the body to resist deformation under the action of forces). It is known (Miritoiu *et al.* 2020) that there is a directly proportional relationship between natural frequency and the rigidity of a body, with the frequency decreasing as rigidity decreases. This conclusion was also validated by the experimental results obtained and summarized in Fig. 11. Additionally, increased elasticity implies better vibration damping. This hypothesis was confirmed by the experimental results obtained and summarized in Fig. 12, where an increase in the damping factor is observed with the increase in the percentage of dammar in the matrix.

Shore D Hardness Test

For the Shore D hardness test, the same statistical analyses was carried out based on the experimental results, as in the case of the previous tests. In Fig. 13 the values of Shore hardness scale D are provided for all 15 points measured on the samples that were cut from 8 different types of composite materials (for which the reinforcement was kept constant, while the type of matrix used varied: 2 synthetic and 6 hybrid). A digital Shore D durometer was used.

The first statistical test performed was a two-way ANOVA. The results are recorded in Table 30. The null hypothesis adopted was that dammar resin does not significantly affect the Shore D hardness. A significance level of 0.05 was chosen. The p-value was determined, and because its values were lower than the reference value of 0.05, the null hypothesis was rejected.

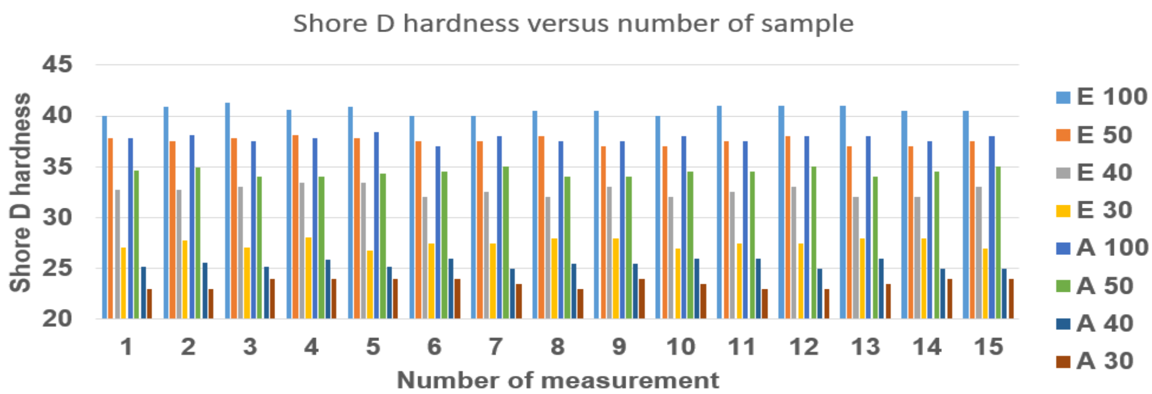


Fig. 13. Variation of Shore D hardness with respect to the number of measurements

There was also homogeneity of the variances, according to Levene's test ($p > 0.05$, where 0.05 is the significance level value). The p-values for the statistical test are written in Table 34.

Table 34. The Two-way ANOVA Test Results for the Shore D Tested Specimens

Parameter	Samples	p-value	Null Hypothesis	α
Shore D value	E100, E50, E40, E30	$2.3 \cdot 10^{-48}$	Reject	0.05
	A100, A50, A40, A30	$6.9 \cdot 10^{-51}$	Reject	

Table 35. The Levene's Test Results for the Shore D Data

Groups	E50/E100	E40/E100	E30/E100	A50/A100	A40/A100	A30/A100
p-value	0.543	0.289	0.972	0.654	0.375	0.135
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05					

From the Shapiro-Wilk test it was found out that the data were normally distributed for each group ($p > 0.05$). The p-values for the statistical test are shown in Table 36. The ANOVA *post hoc* analysis with Bonferroni correction shows that the influence of dammar resin at percentages of 50%, 60%, and 70% was statistically significant in terms of Shore D hardness. The dammar resin, with the increase in percentage, influenced the Shore hardness values ($p < 0.0083$). All the p-values results are written in Table 37.

Table 36 The Shapiro–Wilk Test Results for the Shore D Hardness Data

Groups	E100	E50	E40	E30	A100	A50	A40	A30
p-value	0.879	0.885	0.869	0.883	0.922	0.852	0.841	0.768
Null hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Accept	Accept
α	0.05							

The statistical results showing that natural dammar resin influences the Shore hardness values on the D scale can also be explained from a phenomenological perspective. It is known that dammar is more elastic and less resistant than synthetic resins. Thus, as the percentage of dammar resin in the matrix increases, the elasticity also increases, meaning the material deforms more under external loads and becomes less rigid. Having lower rigidity implies lower hardness, a fact that can be observed in experimental determinations: the material's hardness decreases as the percentage of natural resin increases.

Table 37. The *Post hoc* ANOVA with Bonferroni Correction Test Results for the Shore D Hardness Data

Groups	E50/E100	E40/E100	E30/E100	E40/E50	E30/E50	E30/E40
p-value	$2.95 \cdot 10^{-18}$	$9.13 \cdot 10^{-28}$	$6.69 \cdot 10^{-35}$	$1.68 \cdot 10^{-22}$	$2.70 \cdot 10^{-32}$	$1.91 \cdot 10^{-22}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
Groups	A50/A100	A40/A100	A30/A100	A40/A50	A30/A50	A30/A40
p-value	$3.26 \cdot 10^{-20}$	$1.04 \cdot 10^{-35}$	$8.6 \cdot 10^{-34}$	$2.47 \cdot 10^{-31}$	$4.72 \cdot 10^{-33}$	$1.2 \cdot 10^{-12}$
Null hypothesis	Reject	Reject	Reject	Reject	Reject	Reject
α	0.0083					

CONCLUSIONS

1. The null hypothesis (for statistical tests) was adopted: natural dammar resin does not significantly influence the mechanical characteristics (strength, deformation, hardness, frequency, and damping factor). In all cases, the statistical parameter *p* was smaller than the reference value (0.05), which means that this null hypothesis was rejected.
2. From a statistical point of view, it was found that natural dammar resin has an influence on the mechanical properties (in all ANOVA tests, the null hypothesis was rejected).
3. Regardless of the type of mechanical testing, the addition of dammar resin in the matrix led to a decrease in strength, an increase in elasticity, a decrease in natural frequency, and an increase in damping factor.
4. Based on the experimental results obtained, it can be concluded that the materials studied in this work can be used for the production of interior decorations or furniture items (such as cabinet doors, shelves, window sills, countertops, *etc*.).

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