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# Determination of Mechanical Properties of Natural Sandwich Composites Produced by Using Waste Material

H Ersen Balcıoğlu*[1], Raif Sakin[2]

## Abstract

In the recent year, with the development of technology the acceleration of the manufacturing of new products has increased the use of raw materials in the industry. In addition to decreasing underground resources, increased environmental pollution has opened the way for the use of natural materials in the industry. Also, the reuse of materials, which were recycled by recovery methods, is both conservation and economical method in terms of raw material deficiency. In this study, mechanical properties of sandwich composites made of natural and recycled material were investigated. In this context, core material with different thicknesses (4 mm, 8 mm and 12 mm) were produced using different size granules (1 mm, 2 mm and 4 mm), which were recycled from the used vehicle tire. Sandwich composite materials have become final with the combination of core materials with natural jute fabric reinforced laminated composites. In order to test the usability of the produced sandwich composite materials as building material, the mechanical behaviours of the sandwich composite were investigated under tension and compression load. Test results show that mechanical behaviour of the material varies according to the granular size, thickness of the core material, and fiber orientation of reinforcement fabric.

**Keywords:** sandwich composites, mechanical properties, recycling, natural fiber, granule size, core thickness

## 1. INTRODUCTION

Nowadays, production methods of more economical and durable materials are being investigated in order to meet the unlimited needs of people. Thereby, materials obtained by physically combining more than one material with special methods have gained importance in terms of research and using. Composite materials are formed by combining at the macro level at least two materials having different properties, which cannot dissolve in one another, in order to develop some features that are not available or limited in conventional materials. Fiber reinforced polymer matrix composite materials are used in many industrial building materials such as aerospace, automobile, defense and construction. Synthetic fibers such as glass, carbon, aramid and boron are the most commonly used reinforcing fiber types. The attention for natural fiber or bio-fiber reinforced composite materials is rapidly increasing due to usable in engineering structures and fundamental research. Usage of petroleum based product creates the environmental problems during disposal and emission which increases interest in development of natural fiber composites for low and medium load applications. Moreover, the production costs of synthetic fibers are higher than natural fibers.

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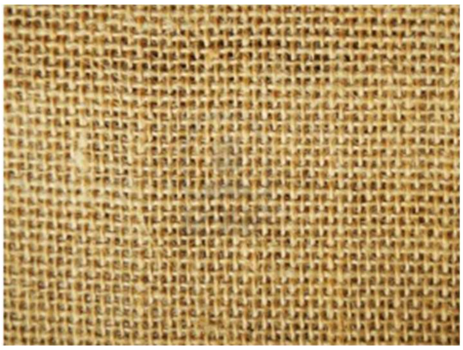
Some of the fibers of plants such as jute, sisal, bamboo, banana fiber is some of the natural fibers used as reinforcing phase in composite materials (Figure 1). Natural fibers are cheaper in terms of their economic quiddity. They also have a biodegradable structure compared to synthetic fibers due to their partial or complete degradation in nature. Although their mechanical properties arenot sufficient when compared with synthetic fibers, natural fibers are good alternative materials in low and medium load applications [1].

Woven fabric reinforced natural composites have superior mechanical properties when compared to random oriented short fiber composite, so that it is important to improve the properties of composites for medium load application [2]. Exhaustive amount of research has been carried out on the characterization of mechanical properties of different kinds of natural fiber reinforced polymer composites by reinforcing the natural fiber in short and random orientation form.



(a)

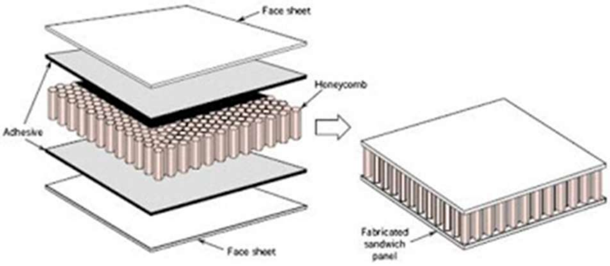
(b)

(c)

(d)

Figure 1. Natural fibers used as reinforcement are (a) jute, (b) sisal, (c) bamboo and (d) banana fiber

In case of out-of-plane loading, thick-walled structures are more advantageous compared to the thin. On the other hand, thick structures have a disadvantage in terms of their weight. Sandwich composites are used in many engineering fields due to their low weight compared to their thickness. Sandwich composites are composed of two main components such as sheet and core. Thick and light materials such as foam, honeycomb and balsa are used in the core part. For the surface part, relatively thin and high strength materials are used. (Figure 2).



(a)

Figure 2. Example of sandwich composite, using honeycomb core

The main purpose in the production of sandwich composites is to obtain durable material with respect to its weight. In addition to their strengths, sandwich composites also function as thermal insulation or thermal transfer according to the properties of the used core and sheet materials. Moreover, the core material having flexible properties have significant contributes to the damping of noise and vibration. Many researches have presented studies about mechanical properties of sandwich composites.

Karahan et al. [3] have investigated the effects of core material thickness and core density under three point bending loading for the flexural strength of sandwich composites having woven fabric reinforced surface material. Balcioglu [4] have investigated the flexural behaviors of sandwich composites manufactured by using natural and recycled material were investigated. Test results showed that the granule size, which used in core material, and core thickness directly affect the flexural strength and damage mechanism of the composite structure. Wang et al. [5] have investigated the mechanical properties of compressive, bending and shear increase with increasing of the densities of 3D sandwich structure with core reinforced by composite columns. Shiah et al. [6] examined the elastic modulus and impact properties of 3D integrated sandwich composites. Lee et al. [7] performed dynamic response of the sandwich plate, which have carbon/epoxy face materials and polyurethane foam core, due to low velocity impact, experimentally and numerically. Van Vuure et al. [8] examined the behavior of sandwich composites under pressure and shear loads. Test results showed that sandwich composites having a foam core having a thickness of more than 15 mm were suitable for structural applications at medium load level.

Last few decades, due to environmental and health awareness, increase the using of natural fiber reinforced composites have been targeted by improve of their mechanical properties. Joshi et al. [9] analysed the major advantages of natural fiber composite in automotive application and found that replace of light-weight natural fiber composites increases the fuel efficiency. Campilho et al. [10] have evaluated experimentally and numerically the inter-laminar fracture behavior of natural fiber reinforced jute/epoxy laminated composites in Mod I loading state. In finite element analysis, they used J-integral method to calculate fracture toughness. The biggest problem to be encountered in outdoor applications of natural fiber reinforced composites is the humidity of the environment. Salleh et al. [11] have investigated the water absorption reaction on the fracture toughness of long kenaf/woven glass hybrid laminated composites. For this aim, hybrid test samples were exposed rain, distilled, and sea water from 1 day to 4 weeks. Test results showed that exposuring of the natural fiber composite material to different conditions such as distilled water, sea water and rain water results in decreasing of fracture toughness. Wong et al. [12] have studied the effect of fiber lengths and volume fractions on the fracture behavior of bamboo/polyester laminated composites. Test results showed that, the highest fracture toughness is achieved at 10 mm crack length and 50 vol.% fiber reinforced composite, with 340% of improvement compared to neat polyester. Lui and Dai [13] have enhanced the mechanical performance of jute/polypropylene laminated composites by using treated jute mat with NaOH and Maleic anhydride-grafted polypropylene (MPP) emulsion. Rajulu [14] have investigated the mechanical properties of short, natural fiber hildegardia populifolia-reinforced styrenated polyester composites. For this aim, tensile modulus, compression strength at first deformation, flexural modulus, and izod impact strength of these polymer composites were determined. Monteiro et al. [15] studied the mechanical performance of coir fiber reinforced polyester composites and found that 50 wt % fiber loading gives better mechanical properties. Jawaid et al. [16] analyzed the tensile properties of jute-oil palm hybrid composites and found that 1:4 ratio of oil palm-jute resulted in higher tensile property. Sarasini et al. [17] have studied mechanical and thermal properties of injection-moulded short basalt fiber, hemp fiber and hemp/basalt fiber hybrid high density polyethylene (HDPE) composites. Lu and Oza [18] have studied hemp fiber reinforced composites based on recycled high density polyethylene and virgin high density polyethylene. In order to increase fiber/matrix compatibility, hemp fibers were treated with 5 wt% NaOH.

Tons of waste tires is left to the nature as paralel to the increasing number of vehicles every year. Storing these tires in nature is a growing problem for countries in terms of environmental pollution and human health. On the other hand, eliminating of the tires to way with burning causes tons of harmful compounds to spread to the atmosphere. These components that spread to the atmosphere cause pollution of soil and water and threaten human health. According to European Union regulations, the disposal of waste tires is prohibited; as an alternative they should be recovered and recycled. By mechanically breaking of used tires, granular rubber and steel is obtained. Scientists are investigating the use of the obtained granular parts in different industrial areas. Gheni et al. [19] have investigated durability properties of rubber fiber powder reinforced cement mortar. For this aim cement mortar was reinforced at the ratios of 5, 10, 15, 20, and 25% with granule fiber that obtained by recycling of used vehicle tires. Test results showed that mortar mixtures with up to 20% RFP showed an improved reinforcement corrosion resistanceby increasing both bulk and surface electrical resistivity. Pasandin and Perez [20] have studied fatigue performance of bituminous mixtures made with recycled concrete aggregates and waste tire rubber. Gill and Mittal [21] have presented an experimental study on the use of waste tire in shallow footings subjected to eccentric loading. Czajczynska et al. [22] have conducted a research on the use of prolytic gas, which obtained by recycling the waste tires with pyrolysis method, as a fuel.

In this study, mechanical behaviours of woven jute fabric reinforced natural sandwich composites, whose core part were made from detrited vehicle tires, were investigated. In this context, core materials having three different thicknesses (4mm, 8mm, and 12mm) were produced by using granules with 3 different diameter sizes (1mm, 2mm, and 4mm). The core material is combined with natural jute fabric reinforced layered composite material to produce sandwich composites. The produced sandwich composites were cut according to the standards and samples were tested under tension and compression loads. The effect of granule diameter, core thickness, and fiber direction of sheet materials on the mechanical behaviours of sandwich composites were investigated.

## 2. MANUFACTURING OF SANDWICH COMPOSITES

Granular materials, which have 1 mm, 2 mm and 4 mm diameters size and were produced from detrited vehicle tire, were used for the production of core material. The detrited tires were granulated using physical methods. The granular material does not contain any piece of metal wire, which is in the structure of the tire (Figure 3a).

Three component polyester resin is used to compound the granules. 1200gr polyester resin was prepared by adding 60gr cobalt and 60gr Methyl-Ethyl-Ketone Peroxide (MEK). Prepared polyester resin is poured onto 3 kg of granular material and mixed with mechanical mixer (Figure 3b). Then, prepared mixture was poured into molds to produce core material having desired thickness (Figure 3c). Finally, the molded mixture was finished by pressing in the temperature-controlled hydraulic presser at 70°C for 20 min (Figure 3d).

(a)

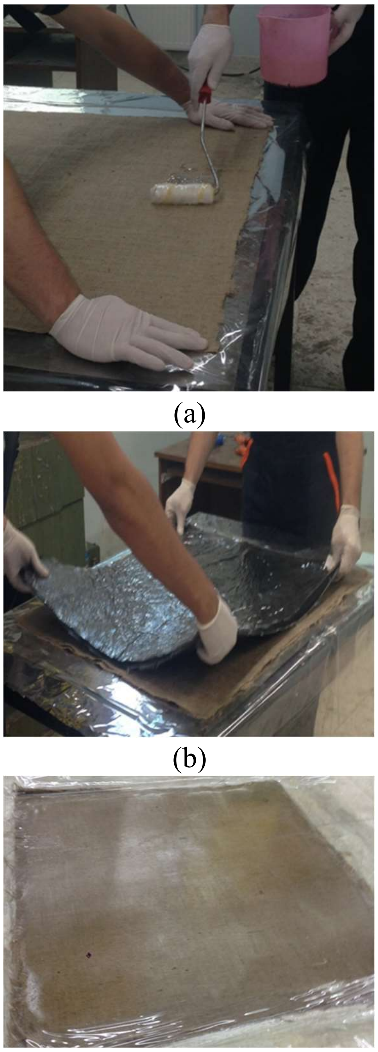
(b)

(c)

(d)

Figure 3. Manufacturing step of core materials

For sheet materials of sandwich composites, jute/epoxy laminated composites were manufactured by hand lay-up method. In this context, four layers woven jute fabrics having weight of 300 gr/m2 were impregnated. Epoxy resin having two components was used as matrix material. DTE 1100 epoxy and DST 1105 catalyst were used for matrix material. They were mixed in a ratio of 76/24 in weight. Epoxy resin were saturated on woven jute fabric, which is sheet material of sandwich composite, with roll (Figure 4a).


(a)
(b)
(c)
Figure 4. Manufacturing step of sandwich composite having sheet materials

Two layers of jute fabric were saturated with epoxy resin to create bottom sheet and then core material was placed on it. The upper sheet was laminated with two layers of fabric on the core (Figure 4b). Manufacturing process was made in a mold, coated with a mold release agent. Finally, the prepared semi-finished sandwich composite was cured in temperature-time-pressure controlled press at 70°C under a pressure of 6MPa along 60min (Figure 4c).

Table 1. Material configuration and density of core materials

| Granule Diameter (D) (mm) | Core Material Thickness (T) (mm) | Core material density (kg/m$^3$ ) | Material Configuration |
|---|---|---|---|
| 1 | 4, 8, 12 | 685.7 | D1-T4, D1-T8, D1-T12 |
| 2 | 4, 8, 12 | 569.2 | D2-T4, D2-T8, D2-T12 |
| 4 | 4, 8, 12 | 483.4 | D4-T4, D4-T8, D4-T12 |

The information on the natural sandwich composites produced for the experimental studies is given in the Table 1. As can be seen from Table 1, three different thickness of core material (4mm, 8mm, and 12mm) were produced using three different granule diameters (1mm, 2mm, and 4mm). Nine different types of materials were manufactured to investigate the mechanical performance of sandwich composites that produced by using recycled and natural fiber materials. The density of the core material with the smallest granule diameter was found to be the highest at 685.7 kg/m3. As the granule diameter increased, the density of the core material decreased and decreased to 483.4 kg/m3. In the material configuration column, the letter D represents the granular diameter value and the letter T represents the thickness value of the core material.

## 3. MECHANICAL TEST

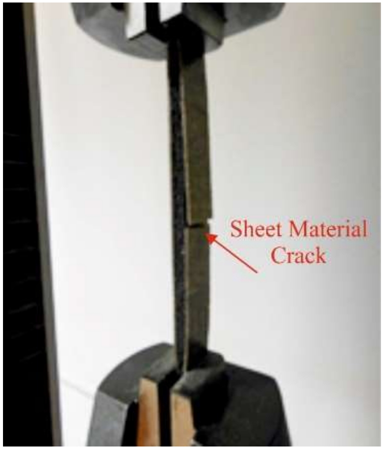
Tensile, edgewise compression and flatwise compression tests were applied to natural sandwich composites within the scope of mechanical test works. Tensile and edgewise compressions tests have been performed in two directions, that longitudinal fiber and transverse fiber direction of sheet material. In the flatwise compression tests, the applied load direction is same with direction of surface normal, so no fiber direction is assumed.

### 3.1. Tensile Test

The test specimens were sized according to ASTM D 3039M-93 standard to determine the tensile strength of the produced sandwich composites [18]. Tensile tests were achieved at U-Test brand 50kN capacity universal tensile test machine at constant velocity of 1 mm/min.

Five repetitions were made to determine the tensile strength in direction of longitudinal fiber and perpendicular to fiber. Instantaneous load-deformation data of the tensile test was recorded by computer-controlled test machine. The tensile strength of the sample was calculated by dividing the maximum force value, at which the test sample was damaged, by the sample cross-sectional area.

(a)



(b)

Figure 5. Specimen under tensile loading (a) before and (b) after loading

Five repetition averages were accepted as tensile strength of sandwich composite material. Test configuration and the specimen under tensile loading can be seen in Figure 5.

## 3.2. Compression Test

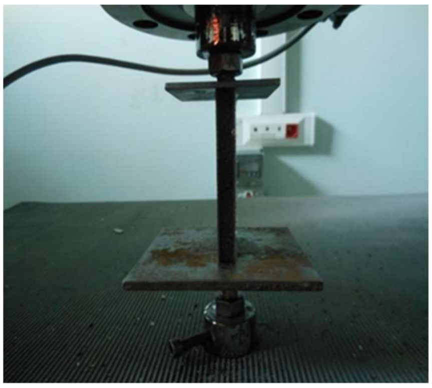
Compression tests were carried out in two steps. Edgewise compression tests were achieved in order to determine the strength between the core and sheets. Other hand, flatwise compression tests were performed to determine sheet material pressure resistance.

### *3.2.1. Edgewise Comparison Test*

ASTM C 364-99 test standart were employed to determine the compressive properties of flat structural sandwich construction in a direction parallel to the sandwich face sheet and to obtain energy absorption characteristics and collapse modes of the composite sandwich panels [19]. Edgewise compression test specimens were dimensioned by cutting according to sizes given in Table 2. The sandwich composite specimens were tested by being forced into contact with a flat surface and longitudinally supported (Figure 6).

Table 2. Dimensions of edgewise test specimens according to the thickness of core material

| Thickness of core materials | 4 mm | 8 mm | 12 mm |
|---|---|---|---|
| Dimensions of edgewise test specimens | 50 x 80 | 50 x 100 | 50 x 150 |



(a)

(b)

Figure 6. Edgewise test compression (a) before and (b) after loading

Edgewise compression tests were performed at a crosshead speed of 1 mm/min. under room condition. Test configuration and the specimen under edgewise compression loading can be seen in Figure 6. At least five specimens were tested and force versus stroke values was recorded using U-Test universal test machine. During the tests, load-displacement graphs for each sandwich composite material were obtained by helping of computer. The edgewise compressive strength is obtained by dividing the maximum damage load of the material by the cross-sectional area.

### *3.2.2. Flatwise Compression Test*

The flatwise compressive characteristics of the natural sandwich composite was determined according to ASTM C 365-0 test standart. [20]. For this purpose, compression test specimens were sectioned as square form having 52x52mm edge dimension. Edgewise compression tests performed using the mechanical test machine at a crosshead speed of 0.5 mm/min. At least five specimens and load versus strain values was recorded using a U-Test universal test machine. The average of these five test results were accepted as edgewise compression strenght. Test configuration and the specimen under flatwise compression loading can be seen in Figure 7.

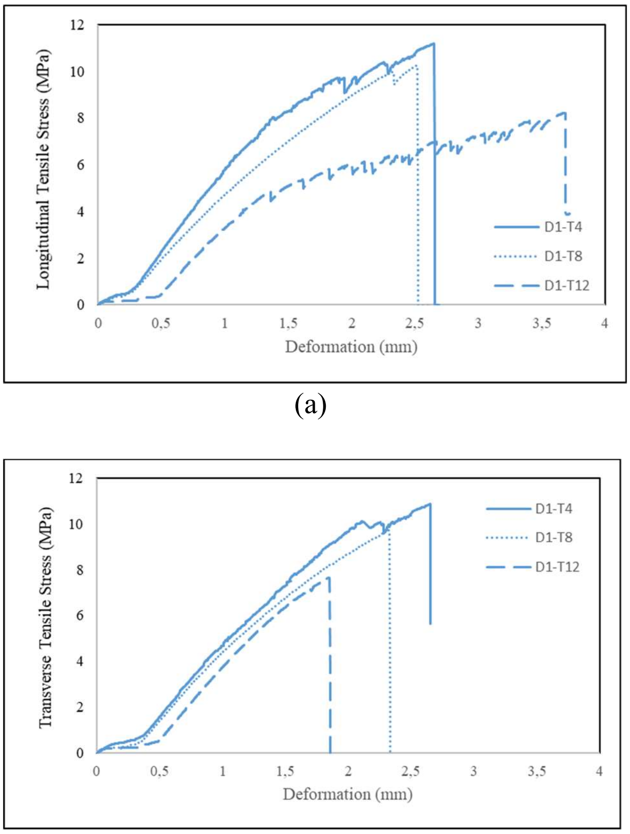
Figure 7. Flatwise compression test configuration

## 4. RESULTS AND DISCUSSIONS

In this study, the effects of granule diameter and core material thickness on the mechanical behavior of natural sandwich composite material were investigated experimentally. For this purpose, total of 9 different core materials having 3 different thicknesses (4, 8, 12mm) were produced by using 3 different granule diameter (1, 2, 4mm). The core material produced from the recycled material was combined with natural fibers reinforced jute/epoxy laminated sheet material. The produced environmentally friendly sandwich composites were tested under tensile and compressive loads.

### 4.1. Tensile Test Results

The stress-displacement curves, which were obtained from tensile test achieved in fiber and perpendicular to fiber direction, of the natural sandwich composites were showed in Figure 8. Warp and weft are terms for the two basic components used in weaving to turn thread or yarn into fabric. The lengthwise or longitudinal warp yarns are held stationary in tension on a frame or loom while the transverse weft is drawn through and inserted over-and-under the warp. In this study; the longitudinally fiber direction was selected as the wrap direction in the woven jute fabrics. On the other hand, longitudinally fiber direction was accepted as the weft direction. As seen in Figure 8, natural sandwich composites exhibit a brittle behavior under tensile loading.



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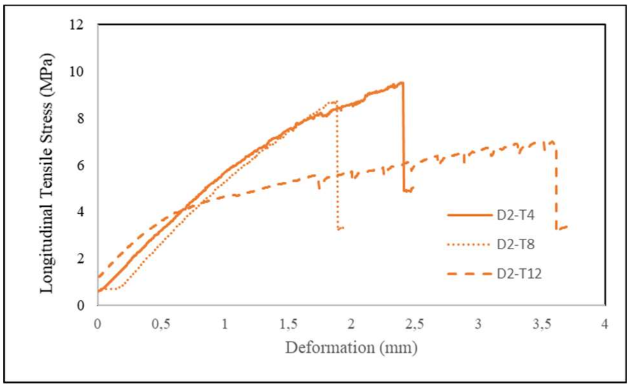

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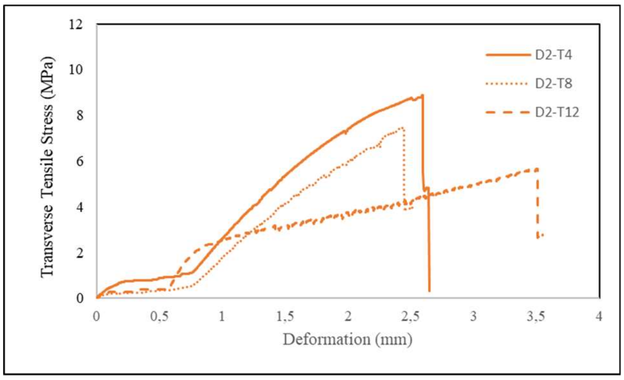

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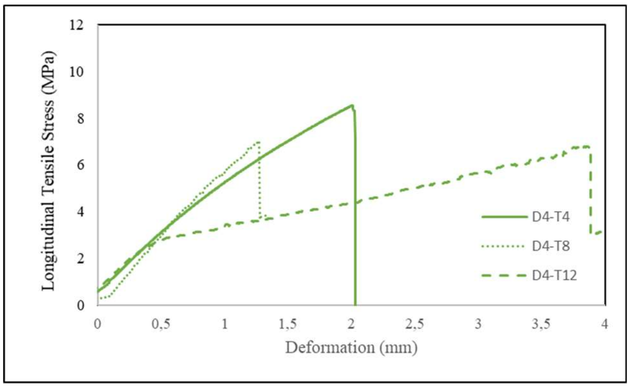

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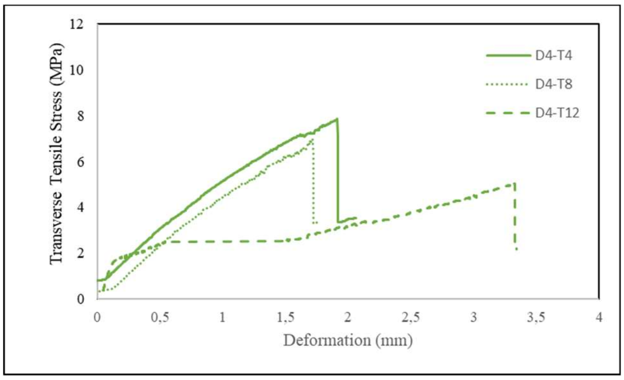


(f)

Figure 8. Longitudinal tensile stress of specimens having core with (a) 1mm, (c) 2mm, and (e) 4mm granule diameter, and transverse tensile stress of specimens having core with (b) 1mm, (d) 2mm, and (f) 4mm granule diameter

In general, four different types of failure mechanism have been observed in tensile tests of sandwich composites, such as core failure, adhesive failure, cohesive failure and sheet material failure [21]. Decreasing in the strength occurred in the cohesive, which bonds the core and sheet material, with increasing of tensile load. This losing value increased over time, causing the core and sheet material to separate. Thus, the first type of damage, the cohesive failure, took place. Then, the sheet material lost its ability of deformation and cracked brittle with increasing displacement. The breakage of the surface material significantly affected the load carrying capacity of the sandwich composite negatively, causing the sandwich composite to become unusable.

The polyester resin bonds which hold the granules together were broken under high deformation. So it was observed that the adhesion failure, which is the 3rd damage mechanism. Immediately after the adhesion failure, the granules were separated from each other and the core damage was observed to occur. Another result obtained from tensile test is that if the thickness of the core material increased, the deformation ability of the sandwich composite increased.

The tensile strengths in longitudinal fiber direction ($\sigma_L$) and transverse fiber direction ($\sigma_T$) of natural sandwich composites were given in Tables 3. Also, the numbers given in parentheses refer to the standard deviations of the relevant experiments. The maximum tensile strength of longitudinal fiber direction was 11.191 MPa (D1-T4) and the tensile strength of minimum fiber direction was 6.792 MPa (D4-T12). The maximum and minimum tensile strengths for the tests made in transverse fiber direction were found as 10.862 and 5.054 MPa, respectively.

Table 3. Tensile strength on the longitudinal and transverse fiber direction of natural sandwich composites

| Core Thickn | Granule Diameter (mm) | | |
|---|---|---|---|
| | 1 | 2 | 4 |

| | $\sigma_L$ $(MPa)$ | $\sigma_T$ $(MPa)$ | $\sigma_L$ $(MPa)$ | $\sigma_T$ $(MPa)$ | $\sigma_L$ $(MPa)$ | $\sigma_T$ $(MPa)$ |
|---|---|---|---|---|---|---|
| 4 mm | 11.191 | 10.862 | 9.532 | 8.885 | 8.552 | 7.859 |
| | (1.606) | (1.067) | (1.014) | (1.145) | (1.013) | (0.746) |
| 8 mm | 10.253 | 9.730 | 8.744 | 7.475 | 7.042 | 6.985 |
| | (1.401) | (0.742) | (1.070) | (1.290) | (1.095) | (1.491) |
| 12 mm | 8.215 | 7.650 | 7.018 | 5.667 | 6.792 | 5.045 |
| | (1.360) | (0.800) | (0.510) | (0.934) | (1.048) | (0.954) |

*(Standard deviation)

Tensile test results show that the fiber orientation of sheet material, the granule size, core thickness directly affects the tensile strength of the natural sandwich composite. It is seen that the tensile strength decreases as the granule diameter and core thickness increase for both loading directions. It was also found that jute fibers oriented longitudinally in jute reinforcing fabric are more resistant than transverse oriented jute fibers. When compared tensile strengths of specimens having same thickness core material and different granule sizes with each other, specimens with small granules is more durable 45.6% in fiber direction and 51.6% in the direction perpendicular to the fibers. Similarly, if compared tensile strengths of specimens having same granule sizes and different thickness core material with each other, specimens with small granules is more durable 36,2% in fiber direction and 56,8% in the direction perpendicular to the fibers.

## 4.2. Edgewise Compression Test Results

Edgewise compression tests were also carried out in longitudinal fiber direction and transverse fiber direction. Figure 9 have presented the stress-deformation curve of natural sandwich composites that obtained from edgewise compression test. The sandwich composite specimens showed more ductile behavior in edgewise compression test according to the tensile test

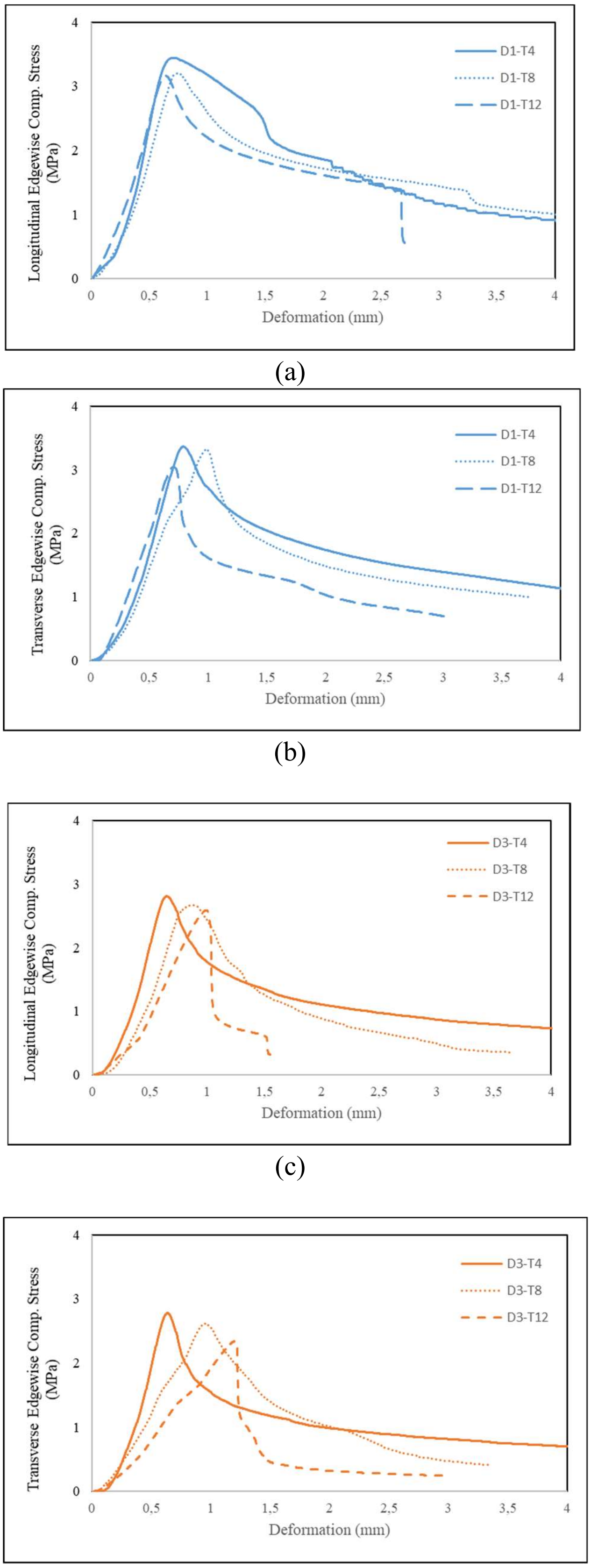
The edgewise compression strengths in longitudinal and transverse fiber direction of natural sandwich composites were given in Table 4. The maximum edgewise compression strength in longitudinal fiber direction was 3.446MPa (D1-T4) and the edgewise compression strength in minimum longitudinal fiber direction was 2.503MPa (D4-T12).

The maximum and minimum edgewise compression strengths for the tests made in direction of transverse fiber were found as 3.367MPa and 2.345MPa, respectively. The test results show that there is no visible difference for the edgewise compression strength between longitudinal and transverse fiber direction. The reason of this is that the fibers used in the sheet material do not exhibit resistance in the direction of compression. The strength value obtained under the compression load depends on the quality of the adhesive which forms on the interface between the fiber and the matrix, rather than the structure and orientation of the fibers.

Table 4. Longitudinal ($\sigma_{LEC}$) and transverse ($\sigma_{TEC}$) edgewise compression stress of natural sandwich composites

| Core Thickness | Granule Diameter (mm) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | | 2 | | 4 | |
| | $\sigma_{LEC}$ $(MPa)$ | $\sigma_{TEC}$ $(MPa)$ | $\sigma_{LEC}$ $(MPa)$ | $\sigma_{TEC}$ $(MPa)$ | $\sigma_{LEC}$ $(MPa)$ | $\sigma_{TEC}$ $(MPa)$ |
| 4 mm | 3.475 | 3.323 | 3.243 | 2.881 | 2.871 | 2.523 |
| | (0.084) | (0.278) | (1.050) | (0.292) | (0.538) | (0.317) |
| 8 mm | 3.340 | 3.171 | 2.822 | 2.616 | 2.661 | 2.200 |
| | (0.426) | (0.424) | (0.141) | (0.145) | (0.328) | (0.343) |
| 12 mm | 2.900 | 2.535 | 2.643 | 2.624 | 2.387 | 1.916 |
| | (0.313) | (0.657) | (0.144) | (0.387) | (0.273) | (0.587) |

If compared edgewise compression strengths of specimens having same thickness core material and different granule sizes with each other, specimens with small granules is more durable 34.71% in longitudinal fiber direction and 36.81% in the transverse fiber direction. Similarly, when compared edgewise compression strengths of specimens having same granule sizes and different thickness core material with each other, specimens with small granules is more durable 8.91% in fiber direction and 18.90% in the direction perpendicular to the fibers.



(a)

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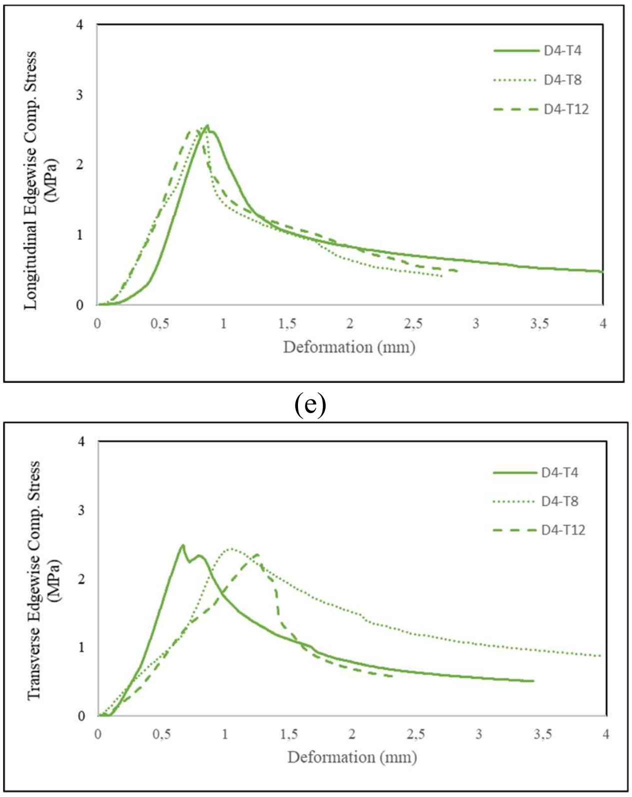

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Figure 9. Longitudinal edgewise compression stress of specimens having core with (a) 1mm, (c) 2mm, and (e) 4mm granule diameter, and transverse edgewise compression stress of specimens having core with (b) 1mm, (d) 2mm, and (f) 4mm granule diameter

The ultimate failure modes of the two types of sandwich specimens are given in Figure 10 for further understanding of the compression response. For natural sandwich composites specimens, the intensively contacted interface between sheet and core kept bonded during the compressive process. If the strength of the interface and the core is sufficiently high in compression, the bending strength forces sheet and core materials to global buckling. The interface connection loses its strength over time as a result of buckling. Then, the first damage occurs at the interface between the core and the sheet material and that the debonding of the core and the sheet material began when the pressure force reached the maximum damage load. As a result of the interface debonding, the compression load on the sample forced to damage the sheet and the core material, separately. It was observed that there was delamination damage on the sheet material having laminated structure. The core material, which is thicker than sheet material resisted the most of axial compression forces. Although, granule obtaining from the used vehicle tire were combined with brittle polyester resin, it deformed as ductile under compression load.

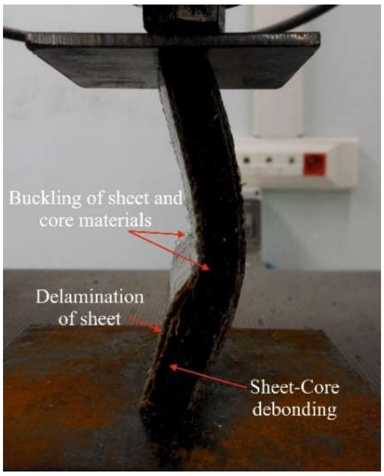


Figure 10. Failure modes of sandwich composite specimens under edgewise compression load

### 4.3. Flatwise Compression Test Results

Similar failure modes were observed for all-natural sandwich composite configurations for flatwise compression tests. All configurations had a peak load followed by a small drop in load followed by a plateau. Load was removed after a sufficient plateau was noticed. After the load was removed, it was observed that the sheet material was disintegrated and the granules forming the core material were separated (Figure 11).

The axial stress, which obtained by calculated by dividing the applied force by the cross-sectional area of the specimens, versus cross-head displacement curves in Figure 12. Natural sandwich composite specimens showed nonlinear elastic behavior in flatwise test. This nonlinearity was characterized by a stiffness reduction at the compressive yield stress of elastic granule material, followed by slight stress reductions and the development of a plateau corresponding to the plastic deformation of granules. This situation took place due to the elastic behavior of the granular structure. Under critical pressure load the resin holding the granule together loses its strength and the granules begin to separate from each other. In such a case the deformation under constant load becomes a flat plateau.

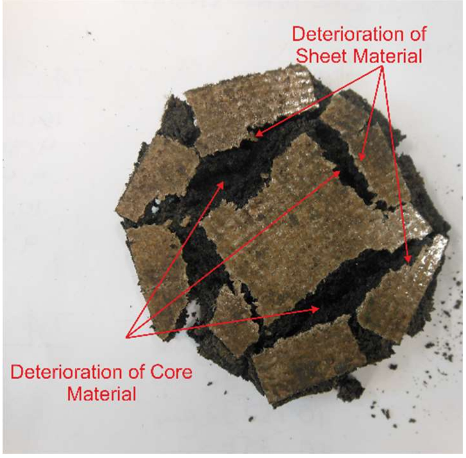
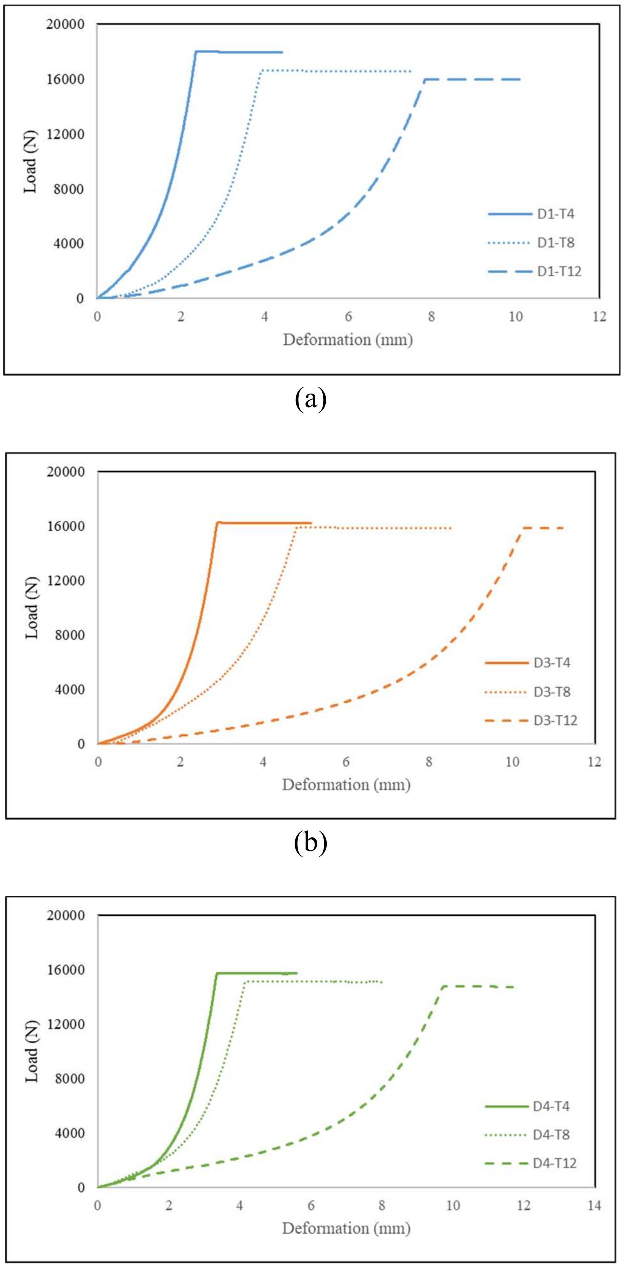


Figure 11. Types of damage observed in flatwise compression test

Due to the mixing and molding step of the granular material with the polyester resin was performed in an open-air environment, some air gaps occurred in the core material. These air gaps caused the material to take on a porous structure. When the core thickness increases or larger granules are used, the number of pores between the granules increases. Sandwich composite specimens with thicker core material or core having larger diameter granular have more deformability than thinner ones. During deformation, the granules slip into these voids and gain more deformation capability. On the other hand, the voids between the granules form the points at which the structure begins to damage. These air gaps (pores) can be thought of as crack initiation points within the material. The increase in the number of voids in the structure causes damage to the structure at lower force values.



(a)

(b)

(c)

Figure 12. Flatwise compression stress of specimens having core with (a) 1mm, (c) 2mm, and (e) 4mm granule diameter

Table 5 have presented the flatwise compression strength of natural sandwich composites. According the test results, granule diameter and core material thickness are not very effective on the flatwise compressive strength of natural sandwich composites. The maximum flatwise compression strength 6.282MPa obtained from sandwich composite, which had core material made from 1mm granule diameter and 4mm thickness (D1-T4). the minimum flatwise compressive strength was obtained to be 5.385 from natural sandwich composite, which had core material made 4 mm granule diameter and 12 mm thickness (D4-T12).

When take account to results in Table 5, compared flatwise compression strengths of specimens having same core material thickness and different granule sizes with each other, specimens with small granules is more durable up to 10.76%. On the other hand, when compared flatwise compression strengths of specimens having same granule sizes and different thickness core material with each other, specimens with small granules is more durable 10.81%.

| Core Thickness (mm) | Granule Size (mm) | | |
|---|---|---|---|
| | 1 | 2 | 4 |
| 4 | 6.282 | 5.895 | 5.671 |
| | (0.288) | (0.291) | (0.197) |
| 8 | 5.955 | 5.754 | 5.528 |
| | (0.077) | (0.254) | (0.240) |
| 12 | 5.669 | 5.577 | 5.385 |
| | (0.363) | (0.330) | (0.223) |

When the deformation axis is examined in the graphs given in Figure 9, it can be seen that sandwich composites having thick core material or core material, which were produced using big diameter granules have more deformation before damage.

## 5. CONCLUSIONS

In this study, mechanical behaviors of natural sandwich composites produced from used vehicle tires and natural jute fiber woven fabric were investigated. In this context, the effects of granule diameter, core thickness and fiber direction on the tensile and compressive strength have been investigated. Tensile and compression tests have shown that different loading types initiate different damage mechanisms in the specimens and as a result the bonding forces holding the granules together in the core material are weakened and fragmented. In addition, granules, the main component of the core material, are elastic and highly deformable under load. The deformability of the core material is directly related to the size of these granules. So there is no question of the disintegration of the granules during the dissolution of the core material.

Elastic core and stiff surface material have shown different reaction against to tensile and compression loads due to having different mechanical properties. Therefore, different mechanisms of damage progress have been observed.

The concluding remarks can be summarized as follows:

- When the tensile strength of the samples with the same granule diameter and core thickness is compared, the samples loaded in the wrap (longitudinal fiber direction) direction have greater tensile strength than weft (transverse fiber direction) direction.
- Among the samples having same thickness, the tensile strength of natural sandwich composites having core material made from fine granule is higher.
- Among samples having the same granule diameter, the tensile strength of natural sandwich composites with thicker core is lower.
- The coarse granules have a lower adhesion quality, although they have a larger surface area than fine granules. Damage under load was progressing starting from the gaps between the granules. In fine grained structures the damage starts at higher force values as there are less inter-granular voids.
- Thick core material had more errors and voids due to adhesive joining, according to thin core material. Therefore, the mechanical strengths of natural sandwich composites having thick core material are lower under tensile and compression loads.

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