

Characteristic properties of glass fiber reinforced sugarcane bagasse medium density fiber board

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Abstract

Medium density fiberboard (MDF) is one of the wood composites which are used widely in the furniture industry. Therefore, its strengthening is required. Sandwiched material is manufactured by inserting sugarcane bagasse medium density fiberboard between the glass fiber reinforced laminates in just the same fashion as a sandwich. A hand lay-up technique is used to prepare the sandwiched specimen, in which the medium density fiberboard plate is put in between two woven layers of glass fiber epoxy laminates. Tensile and bending tests are done to investigate efficiently the tensile and flexural behaviors for the MDF strengthening process. In addition, compact tension and center notch specimen tests are carried out to obtain the effect of the modification performed for the MDF main material on fracture toughness. Moreover, a water soaking test is held out, and fungal bioassay resistance is investigated to obtain some of the novel material environments. The results illustrate that both tensile and flexural strength are extremely modified and increased. Besides, the results show compatibility and bonding between layered material and medium density fiberboard plate. The fracture toughness is greatly increased, and both tests can be met as regards fracture toughness tests for such novel composite material. The novel material has high resistance to fungal creation, which helps it to be utilized in medical furniture. Finally, it is found that only a very little percentage of absorption is established for the novel produced material.

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Keywords: tensile strength; medium density fiber board; flexural strength; glass fiber.

1. Introduction

Fiberboard is the types of composite material which are constructed of natural fiber bonded together with polymer resin under heat and pressure. There are many advantages which distinguished medium density fiber (MDF) boards such as; edge-screwing, painting properties, and good machining. This wood-based composite is most widely employed in housing furniture [1]. Ümit Büyüksarı et al. [2] studied the mechanical and physical properties of medium density fiberboard (MDF) panels with veneer sheets which are made up by compression at varying pressure and temperature. The results illustrated that both Young's and flexural modulus of the specimens increased with

pressure and temperature increase. Oliveira et al. [3] carried out testing on three types of reinforcement fiber; Eucalyptus, Pinus, and sugarcane bagasse which are used in MDF manufacturing, for a mechanical and physical characteristic. They concluded that sugarcane bagasse had competitive and good physical and mechanical properties. The study did not illustrate the strength and fracture of the produced specimens.

Li et al. [4] attempted to modify soybean protein in the preparation of MDF with sodium dodecyl sulfate (SDS). They investigated the influences and interactions of initial moisture content (IMC), temperature and pressing time on mechanical and water soaking characteristics of MDF. The results confirmed that there was a solid relation between mechanical and water soaking properties of MDF and process parameters. It was concluded that mechanical and soaking properties improved with (IMC) increment, and influenced temperature and pressed

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time. Another modification was carried away to enhance fiberboard mechanical properties [5,6]. While the modification which was based on chemical oxidation could protect wood against biological degradation [7].

Sugiarto and Darsono [8] had performed surface coating on MDF using pigmented epoxy acrylate resin with varying thickness. The mechanical, chemical and physical properties of cured MDF samples were measured to study the effect of coating thickness. The curing process is performed using electronic beams accelerator. The results demonstrated that the mechanical properties gave little increase with the coating thickness increment, while an observable decrease in physical properties but the chemical ones were remaining similar with the varying of pigmented thickness. Tsunoda et al. [9] used zinc borate to protect MDF from fungal and termite attack. But the treatment was done during manufacturing of MDF. It was performed as the chemical blend with MDF main materials. The modification treatment protected the MDF from fungal and termite attack at special conditions. Kercher, Nagle [10] studied mechanical, structural and electrical properties of carbonized MDF (c-MDF). It was found that volume fraction of large turbostratic crystallites increased with carbonization temperature. The (c-MDF) materials were isotropic with a modulus of elasticity. The electric sensitivity for such materials is increasing and varying in magnitude. This carbonized process is costly and needs special equipment.

Alsoufi et al. [11] investigated numerically the tensile and flexural properties of MDF compared with sandwich MDF using finite element methods, and their results were found to be in full agreement with the experimental ones. Ozdemir et al. [12] studied the humidity effect on adhesion strength of coated MDF with polyurethane finish using a pull-off test. They concluded that the failure occurred within line at coating MDF interface. Matsumoto and Nairn [13] measured the fracture toughness of MDF using energy analysis as protection from scattering. The crack length was measured using digital image correlation (DIC). They tested two different densities, with two thicknesses and for both in-plane and through the thickness cracks. It was found that all R-curves increased linearly with the crack length. The work only takes into account the bridging effect of MDF fiber though crack growth in extended compact tension specimen. Mohebbi and Ilbeighi [14] hydrothermally treated the MDF industrial fiber in stainless steel reactor at three different temperatures

for three different holding time. The produced hydrothermally MDF then tested for both moduli of elasticity and rupture, internal bond, and water soaking. The results were concluded that both modulus and internal bond were decreased. While the water little improvement in the case of thickness swelling. This study modified the MDF through the manufacturing process which makes it as a complementary process in the industry, therefore the total manufacturing cost may increase. Lunguleasa et al [15] performed thermally treatment on MDF with two different temperatures at two different holding time. The aim of their study to compare characteristic properties of treated MDF with that untreated. The results showed a generally low level in characteristic physical properties (water absorption and thickness swelling), and a decrease in both bending strength and Brinell hardness. This can be attributed to that thermal treatment waken natural fiber strength [16]. Christoforo [17] studied effect of different types of fiber reinforced epoxy laminates on both moduli of elasticity and rupture of wood. They summarized that good results obtained with fiberglass. But their study did not give details about mechanical and physical properties and methods of manufacturing.

There are very little studies to enhance fracture, mechanical and physical properties of MDF using glass fiber reinforced epoxy laminated. Therefore, the current work presents a novel technique to enhance MDF product with composite laminates.

1.1. The novelty of the present research

The novelty of the present work can be outlined as following: to improve the tensile, flexural strength and fracture toughness of MDF in order to increase its field of applications with a practical, and inexpensive technique; and to enhance the fungal bioassay and absorption resistance of the MDF. To achieve these goals, MDF plates are sandwiched between two plates of laminated fiberglass.

2. Experimental work

2.1. Material behavior and characterization

The present study used three types of materials; medium density fiberboard of 7 mm thickness, epoxy and glass fiber. Medium density fiberboard (MDF) is considered a composite wood panel product. It is manufactured from sugarcane bagasse fibers, and urea-formaldehyde adhesive, and is denser than both

plywood and particleboard. MDF is smooth on both sides and has an even density throughout. Standard MDF is available in a range of sizes, 2400 × 1200 mm and 3600 × 1200 mm with the most common sheet sizes. The composite laminate is manufactured from woven glass fiber of constituent characterizations that are listed in Table 1 [18,19]. The sandwich plate is produced using a hand lay-up technique [20,21] (see Fig. 1a). A mold consists of two glass plates, the upper surface of these (800 × 500 mm) treated with a release agent (wax). A layer of epoxy resin is spread on that glass plate, and the first layer of woven glass fiber is placed on the resin. The fibers are impregnated with epoxy by rolling. Rolling also removes any excess epoxy and eliminates air bubbles. Layer of epoxy is then spread followed by the woven fiber layer. The third layer of epoxy is spread, and a plate of (MDF) is then placed over this. The sequence is repeated over the (MDF) plate with epoxy and woven fiberglass. A glass plate is placed on the cellophane paper, and equal weights are distributed on the glass plate to obtain an almost constant thickness of the composite laminate. The glass plate and the cellophane paper are removed after 24 hrs. (see Fig. 1b). And the laminate is completely cured at room temperature for 21 days. Margins of nearly 10 mm from the laminate edge are cut, then the test specimens are taken away from the edge by approximately 30 mm [21]. The fiber volume fraction, V_f , was determined experimentally using the ignition removal technique according to ASTM D3171-99 standard [22]. The average value of V_f was 8%. Two layers of glass fiber composite laminates are chosen to be cost effective with about 20% increments in quantities' cost. The produced composite specimen of sandwiches MDF has a thickness of 9 mm.

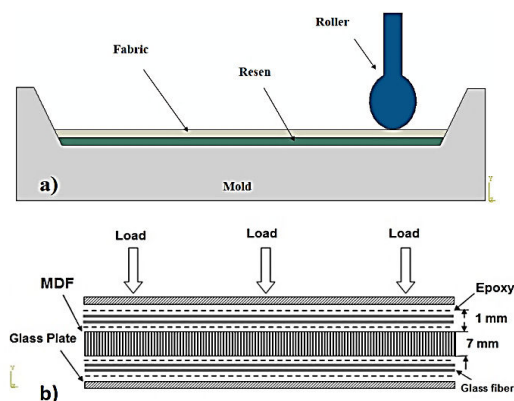


Fig. 1. Hand lay-up technique: a) schematic drawing of open mould, b) hand lay-up sequences.

Table 1. Mechanical and physical properties of E-glass fiber and epoxy resin [18,19,23].

| Properties | E-glass | Kemapoxy (150RGL) |
|-----------------------------|---------|-------------------|
| Density(kg/m ³) | 2540 | 107 ±2 |
| Tensile strength (MPa) | 2000 | 50-100 |
| Tensile modulus (GPa) | 76 | 1.2-4.5 |
| Passion ratio | 0.25 | 0.35 |
| In plane shear modulus | 30.8 | 1.24 |
| Failure strain | | 1.7 |

2.2. Tension and bending tests

Tension and bending tests are carried out on MDF and glass fiber reinforced MDF according to ASTM D3039 and ASTM D790–10 tests standards [24,25] respectively. The tensile specimen is of the dimension shown in Fig. 2a, whereas bending specimen is of the dimension shown in Fig. 2b. All tests are carried out at a universal testing machine (Model Machine WDW-100) of normal load capacity 200 kN and at a controlled speed of 2 mm/min.

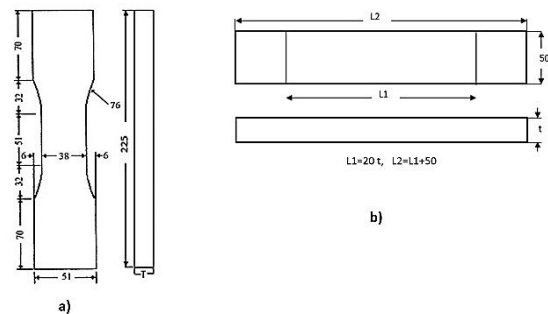


Fig. 2. Testing samples: (a) tensile test sample and (b) bending test sample.

2.3. Fracture toughness

Fracture toughness measuring has a marked intensity in MDF application. Fracture toughness of material is considered a crack resistance parameter. There is no available exact standard to measure that important characteristic parameter. Therefore, two standard fracture toughness specimens are chosen to standardize the MDF fracture testing. Compact tension (CT) is used to study plane fracture toughness related to fiber breakage in tension for medium density fiberboard (MDF) and sandwich panels. The dimension of the compact tension specimen is illustrated in Fig. 3a [26]. These test methods are based on ASTM D 5045 [27] and involve loading a notched specimen which has been pre-cracked and exhibits tension (compact tension). The step procedure is used to produce a crack tip in the (CT) specimens.

The specimen features scale with the crack line width, W , the crack length, a , which is measured from the crack tip to the center of the pin loading holes. Another fracture specimen is used to obtain standardization of the test. The tension of the center crack plate specimen is carried out according to the Soutis-Flick model [28] to measure the surface release energy of such hybrid composite laminates. The manufacturing technique used in the CT specimen is once again employed. The test is simple to perform and can be summarized as follows: The specimen of MDF, the sandwich panel, and their dimensions are illustrated in Fig. 3b. Five specimens are used: width $W = 45$ mm, gauge section length $L = 90$ mm, thickness $t = 7$ mm for MDF panel and $t = 9$ mm for sandwiched MDF, finally the center crack length ($2a$) = 15 mm. After manufacturing the five specimens for each material, they were loaded until failure, and that specimen's failure load was obtained.

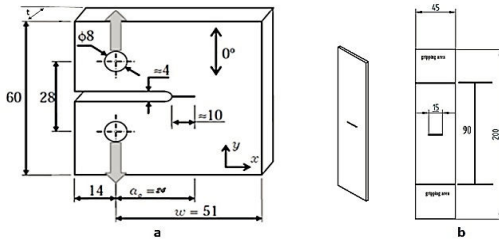


Fig. 3. Fracture toughens sample, (a) compact tension test sample with $t = 9$, or 10 [26] and (b) center crack specimen.

2.4. Water soaking test

A water soaking test is performed on medium density fiberboard and sandwich panel specimens to evaluate the effect of water immersion on thickness swell (TS), linear expansion (LE), and water absorption (WA). It is measured according ASTM D1037-06a standard test method [27]. Square specimens of (50 mm × 50 mm) are soaked in water for (24 ± 1 hrs.) at room temperature. The sides of the sandwich panel are coated with epoxy resin to protect it from water. Thickness, length, and weight are measured before and immediately after soaking. The measured dimensions before and after soaking are used to calculate LE, TS, and WA, which are stated as percentages of the data after soaking for comparison to data before soaking.

$$TS(\%) = \frac{T_f - T_i}{T_i} \times 100 \quad (1)$$

where, T_f is the final thickness after soaking for 24 hours and T_i is the initial thickness.

$$LE(\%) = \frac{L_f - L_i}{L_i} \times 100 \quad (2)$$

where, L_f is the final length after soaking for 24 hours and L_i is the initial length.

$$WA(\%) = \frac{W_f - W_i}{W_i} \times 100 \quad (3)$$

where, W_f is the final weight after soaking for 24 hours and W_i is the initial weight.

2.5. Microbial bioassay test (decay resistance test)

MDF products have attractive demands in traditional wood applications that require decay resistance. Therefore, a microbial bioassay test is carried out using types of bacteria and fungi which are listed in Table 2.

Table 2. The types of fungi and bacteria.

| Fungi | Bacteria |
|-----------------|---------------------|
| Aspergillus sp. | Bacillus sp. |
| Penicilium sp. | Corynebacterium sp. |
| Rhizoctonia sp. | Pseudomonas sp. |
| Rhizopus sp. | |

The microorganisms that can degrade wood are developed from a hydrocarbon contaminated soil by the enrichment method using nutrient agar (NA) and potato dextrose agar (PDA) media. The media is autoclaved at 121 °C. Ten plugs of microbes are added to the liquid media and incubated for 2 days. The fungal inoculum is prepared by growing each fungus on potato extract agar plates at 25°C for 3 days. Flasks are agitated at 120 rpm at 25°C and filtered through filter paper under sterile conditions. Mycelia is then transferred to each vial containing the fresh medium. Experiments are performed in 100-mL Erlenmeyer flasks containing 20 mL of liquid culture, as the strains have different growth rates. All media are sterilized by autoclaving at 121 °C for 20 minutes. Three flasks are obtained by punching out with a bacterial inoculum an actively growing culture of bacteria which is inoculated into a flask containing 20 mL of liquid medium supplemented with three specimens of (MDF) and three specimens of the sandwich panel (MDF). The period of incubation is varied from 5 to 7 days in order to achieve similar radial growth and to minimize variation in the starting inoculums.

3. Results and discussion

The stress-strain diagram for sandwiched and non-sandwiched MDF is shown in Fig. 4, and it is clear that the tensile strength of the sandwiched MDF is higher than that of the MDF material only (see Table 3). This is attributed to the increased stiffness of glass fiber reinforced epoxy laminates. The deboning between the layers of composite laminates is very good as it illustrates in modes of failure as shown in Fig. 5. The delamination through MDF plates clearly appears as the upper, and lower layers of the glass fiber reinforced epoxy laminates are diffused in the MDF plate. The fiber braking matrix cracking is shown in Fig. 6.

Table 3. Comparison tensile strength of sandwiched MDF and non-sandwiched MDF.

| Specimen | σ_u , MPa | SD | σ_y , MPa | SD | E, GPa | SD | δ , mm |
|----------------|------------------|------|------------------|-----|--------|--------|---------------|
| MDF | 14.78 | 3.22 | 6.022 | 1.5 | 0.678 | 205.87 | 2.7 |
| Sandwiched MDF | 35.66 | 6.4 | 3.2 | 1.3 | 0.532 | 202 | 9.32 |

σ_u =tensile strength, δ =elongation, σ_y =yield strength, E=Young's modulus

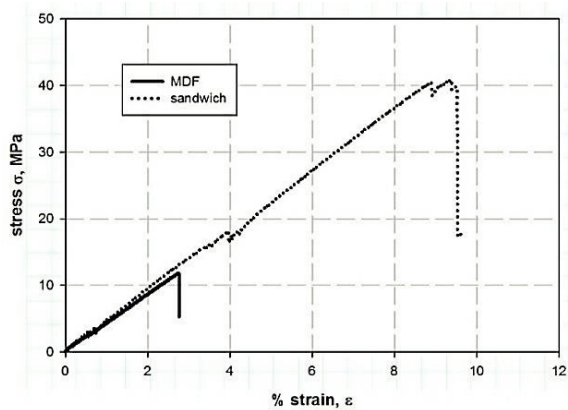


Fig. 4. Tensile stress strain diagram for MDF and MDF with glass fiber reinforced epoxy layers.

The low strength of MDF material return to presence of medulla in sugarcane bagasse [28]. The flexural strength is greatly enhanced (see Fig. 7) for sandwiched MDF, which is due to the high stiffness of glass fiber composite laminate bonded to MDF plate. Strength distribution for through thickness deboning is illustrated in Fig. 8, as it decreases from outer surface to the depth of the inner thickness surface.

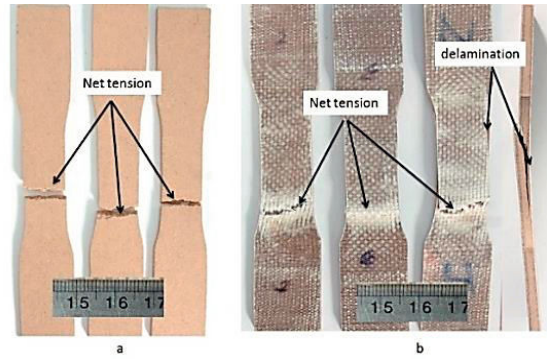


Fig. 5. Mode of failure for (a) MDF and (b) MDF glass fiber/epoxy sandwich.

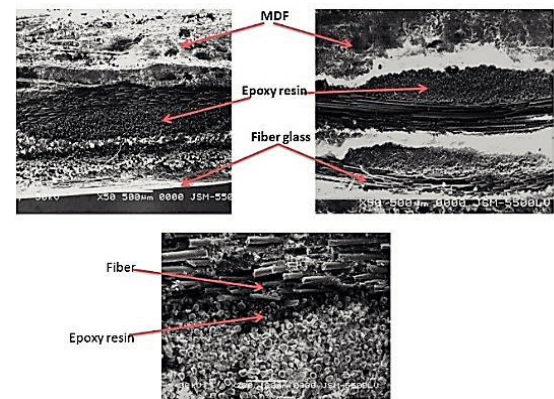


Fig. 6. SEM microstructure analysis of fracture at breaking plane of Sandwich MDF.

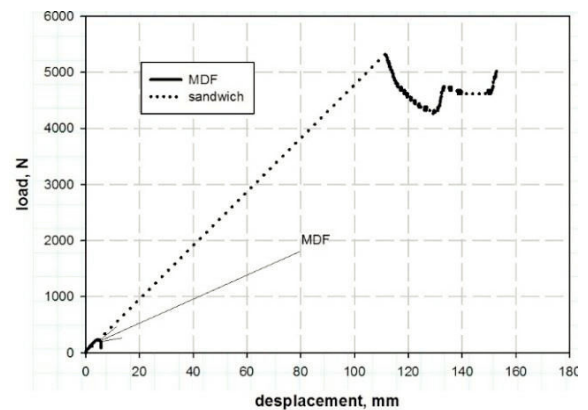


Fig. 7. Load deflection curve for MDF and Modified MDF.

It also illustrates in the bending test modes of failure (Fig. 9). It is seen that the bending mode of failure has become mode II of failure as delamination exists in all bending test specimens.

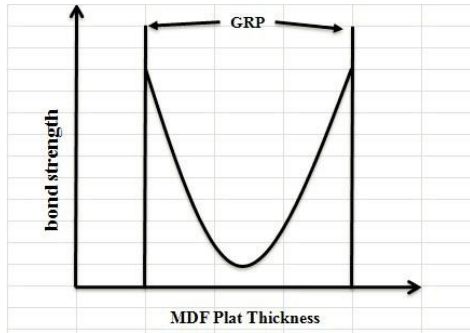


Fig. 8. Imaginary stress distribution for through thickness debonding of MDF fiber glass/epoxy sandwich.

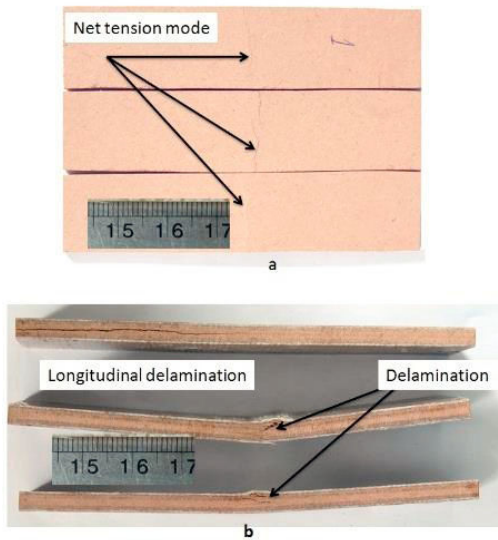


Fig. 9. Modes of failure in bending of MDF.

The delamination also can be attributed to the fact that epoxy resin has better diffusability and debondability than the urea-formaldehyde adhesive used in manufacturing the MDF itself. The flexural strength, σ_f , and strain, ϵ_f , for the central supporting beam can be calculated using the following equations [29]:

$$\sigma_f = \frac{3fl}{2bd^2} \tag{4}$$

$$\epsilon_f = \frac{6Dd}{l^2} \tag{5}$$

where, f is the central maximum bending force, l the supporting span, b is test beam width, d depth of test beam and D is the maximum beam deflection. Whereas the flexural Young’s modulus can be measured using the following [29]:

$$E_f = \frac{l^2m}{4bd^3} \tag{6}$$

where, m is the gradient (i.e., slope) of the straight line of the load deflection. The flexural properties are listed in Table 4.

Table 4. Flexural properties of MDF and Sandwich MDF.

| specimen | Flexural strength, (MPa) | SD | Flexural Young’s modulus (GPa) | SD |
|----------------|--------------------------|------|--------------------------------|--------|
| MDF | 24 | 2.96 | 1.925 | 340.74 |
| Sandwiched MDF | 354.66 | 0.23 | 1.902 | 18.97 |

3.1. Fracture properties

Figures 10a and b show the load displacement curve for MDF and sandwich MDF compact tension specimen respectively. It is clearly demonstrated that modified or sandwich MDF with a thin layer of glass fiber reinforced epoxy laminates has an improved crack resistance and ductility.

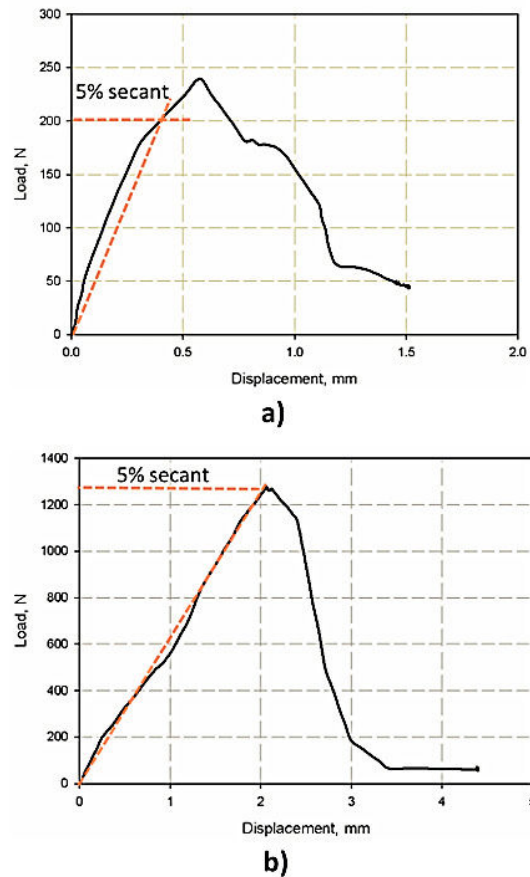


Fig. 10. Load displacement curve of CT test of (a) MDF and (b) sandwich MDF.

The fracture loads (P_Q), which are obtained from the tests of five specimens to determine (K_{IC}) values in ($MP\sqrt{m}$) are used as a measure of fracture toughness by using the following data reduction scheme. According to ASTM standard E399 [30], valid for an isotropic material, the critical stress intensity factor for a fracture load, P_Q , is given by [26]:

$$K_{IC} = \frac{P_Q}{h\sqrt{W}} f(a/W) \tag{7}$$

where, h is specimen thickness, mm, W is specimen width, mm, a is crack length, mm, P_Q is load at 5% secant and $f(a/w)$ shape correction factor [26]. The critical energy release rate of the laminate can be calculated from, K_{IC} , as [26,31]:

$$G_{IC} = J_{IC} = \frac{K_{IC}^2}{E} \tag{8}$$

The average load values at 5% secant from the Figs. 10a and b equal (246) and (1250) for both tested materials with the sample dimension and total crack length ($a_0 + a_{FPZ}$), where (a_{FPZ}) is the average fracture processing zone length and is shown in Fig. 11 and measured experimentally as approximately 1.5 mm and 2.5 mm, respectively. The average value is given as there is a tendency for the crack depth to vary through the thickness. Substituting these results in Eq.7, the average fracture toughnesses (K_{IC}) are measured as 7.96 and 10.72 ($MP\sqrt{m}$) and are listed in Table 5 for both MDF and sandwich MDF. Modes of failure for MDF is net tension with a sharp surface (see Fig. 11a) while in sandwich MDF fiber bridging observed in Fig. 11b, the crack propagation path is enhanced to be exactly straight.

Soutis and Flecks [32] showed that the fracture toughness of iso-brittle laminate is independent of the center-crack size. Therefore, the number of specimens that need to be tested is decreasing (only one length of the center crack was used).

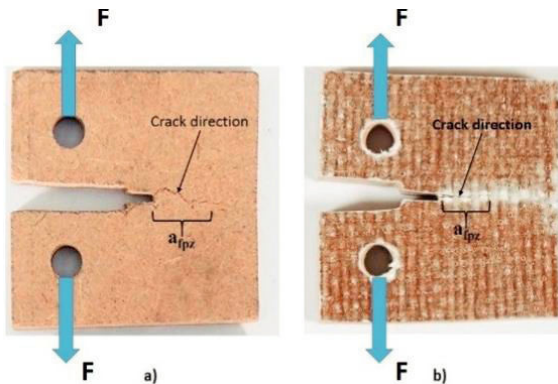


Fig. 11. Failure modes I of compact tension test.

Table 5. Compact tension test Fracture data.

| Specimen | Fracture toughness | |
|----------------|--------------------|-------|
| | Avg. | SD |
| MDF | 7.96 | 1.9 |
| Sandwiched MDF | 10.72 | 1.088 |

Figs. 12a and b show the load displacement curve for the center cracked test specimens of both MDF and sandwiched MDF respectively; it is observed that the curve is smooth, a little jump seen. The curve which is obtained from a compact specimen of MDF has a longer length compared to one obtained from a center-cracked MDF specimen, because the gradient of K in a compact specimen decreases whereas the gradient of K in a center-cracked specimen increases.

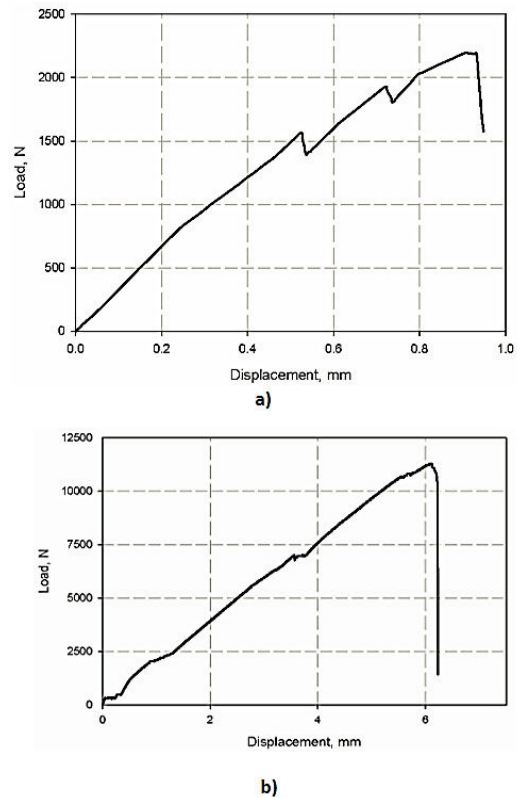


Fig. 12. Load displacement curve for center cracked specimens (a) MDF and (b) Sandwich MDF.

The post-failure load is determined from the load displacement curve for each material and with the help of Eq. 9. After measuring the failure stress for each sample, the fracture toughness is determined by using the real dimensions of the sample [33]:

$$K_{Ic} = \sigma \sqrt{\pi a} \sqrt{\sec\left(\frac{\pi a}{w}\right)} \tag{9}$$

where, σ is failure stress, a is half crack length and w specimen width. Modes of failure for center cracked specimen are net tension at breaking crack face while these modes are enhanced to net tension mode without crack face breaking, fiber bridging is clearly seen in Fig. 13.

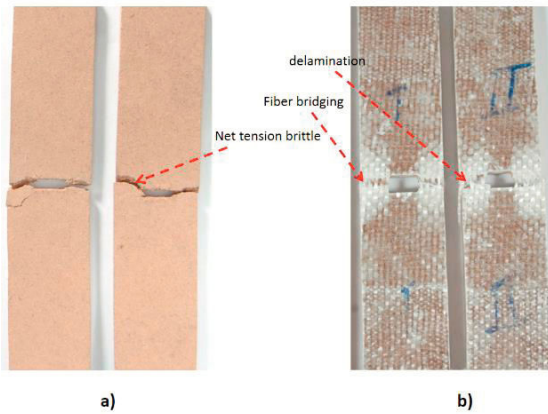


Fig. 13. Modes of failure for a) MDF and b) sandwiched MDF.

3.2. Water soaking properties

The water soaking properties for MDF and a sandwiched MDF panel are shown in Fig. 14 and listed in Table 6 after immersion in water approximately 24 h at room temperature. It is found that the percentage of water soaking properties are enhanced in sandwiched MDF to a greater extent than for MDF only and that they are approximately 67.5 %, 23% and 22 % for water absorption, linear expansion, and thickness swelling respectively. This is attributed to the fact that glass fiber composite laminates are completely resistant to water.

Table 6. Water soaking properties of MDF.

| Sp. | WA% | SD | (LE)% | SD | (TS)% | SD |
|----------|-------|------|-------|-------|-------|------|
| MDF | 72.42 | 2.39 | 1.014 | 0.014 | 14.29 | 0.01 |
| Sandwich | 23.7 | 0.53 | 0.78 | 0.34 | 11.11 | 0.01 |

3.3. Fungal bioassay

This is a mixture of agar and other nutrients where microorganisms, including bacteria and fungi, can be cultured and observed under the microscope. To obtain a growth medium an agar plate or petri dish can be used.

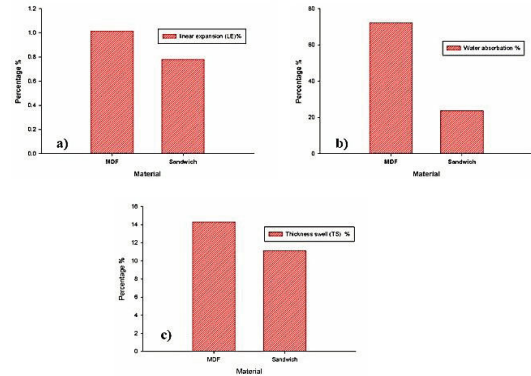


Fig. 14. Water soaking test results for MDF and sandwiched MDF.

Agar is unreadable as types of organisms so microbial growth has no effect on the gel used and it remains stable [5]. Fig. 15a depicts growth bacteria and fungi in MDF specimens so clearly MDF panel is easily attacked by bacteria and fungi. In contrast, in Fig.15b, the sandwich panel specimens do not allow bacteria and fungi to grow through the panel.

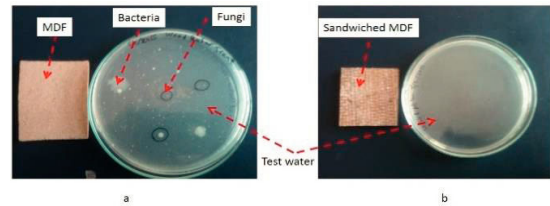


Fig. 15. Microbial bioassay test for (a) MDF and (b) sandwiched MDF.

3.4. Simple economy study

Composite material manufactured using natural fiber are of great intense in polymer science. These natural fibers are distinguished by low cost with high specific properties and low density [16]. Sugarcane bagasse fibers are supplied by sugarcane industry which spread in the Upper Egypt area. This natural fiber is considered a waste product in such industry. It is the main raw material of MDF manufacturing, therefore, the global cost of MDF panel is low. The modification process used totally 4 layered commercial woven glass fiber reinforced epoxy. The layers have a very small thickness which makes the total quantity is very low. The strengthening process of MDF carried out using the cheapest process which is hand lay-up technique. But this method takes larger time. But it is suitable for small industry field [20].

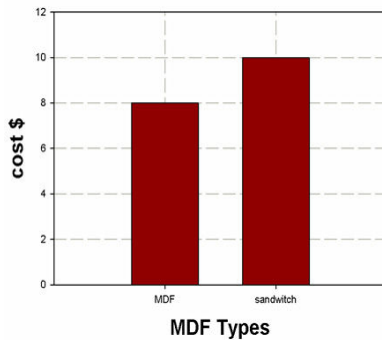


Fig. 16. Cost study of material.

Hence, the global manufacturing cost is low as shown in Fig. 16. It is clear that the total amount of cost by respect to a wide range of applications is nearly 20%. It is considered low.

4. Conclusions

This work demonstrates that a novel coating technique with glass fiber reinforced resin is attractive for modifying the strength of medium density fiberboard with low quantities cost and about 20% increase in main material cost. The bonds between the root plate MDF and the laminated layers appear to be very good. Both tensile and flexural strength increased about 141% for tensile strength and nearly 1360% for bending strength. Also, elongation due to stress is increased with the modification process. This enhancement was performed with an economical industrial technique. The water soaking properties are enhanced to a considerable degree with the sandwich technique for MDF. Fungal bioassay is enhanced, and the sandwiched MDF is protected well with that technique in contrast to MDF only, therefore, it becomes very attractive for medical housing and furniture.

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