Investigations of the Influence of Fiber Orientation on Strength Properties of Agrostone Composites

Ephrem Zeleke, Mulugeta Eshetu(✉), Taye Meheretu, Mehiret Betemariam, and Samuel Melkamu

Faculty of Mechanical and Industrial Engineering, Bahir Dar University, Bahir Dar, Ethiopia
karrakorea@gmail.com, mulugetaeshetu88@gmail.com

Abstract. Agrostone is a construction material and a substitute for concrete that used as an exterior wall and interior partition. It is composed of Magnesium Oxide Powder (MgO), Magnesium Chloride ($MgCl_2$), Bagasse, Glass fiber and Pumice. The Agrostone panel has improved damage tolerance, environmental resistance, fire resistance, and recyclability, good strength, lightweight and potential for fast processing. However, the influence of fiber orientation on tensile, compressive and bending strength of agrostone panel is not studies from the previous researchers. The aim of this experimental study is investigate the influence of different fiber orientation arrangements on tensile, compressive and bending strength of agrostone panel. The testing specimens for experimental analysis prepared by hand layup process using a mixing ratio of 1.5 kg Magnesium oxide Powder (MgO) and 2 L Magnesium Chloride ($MgC1_2$). Waste recyclable bagasse 0.15 kg, 0.065 kg Fiber Glass and 0.2 kg of Pumice based on ASTM standard D 3039/D 3039M for tensile testing, D 3410/D 3410M – 03 for Compressive testing and D 790 – 02 for Flexural testing at 0°, 45°, 90°, cross and random arrangement are prepare. From the experiment, the tensile, compressive and bending result of 0° is higher than the other arrangements that has the value of 191.87 MPa, 178 MPa and 181 MPa respectively, therefore it means 0° fiber orientation give a better strength values in general for tensile, compressive and bending loading as compare to others.

Keywords: Agrostone composites · Mechanical properties · Fiber orientation · ASTM standard

1 Introduction

Understood of characterized, statistically based, material property data are essential to an efficient engineering development process; material suppliers, engineering users, and system end-users. Composites used throughout the history back to early 20th century. In 1940, fiberglass was first used to reinforce epoxy. I.e., straw in bricks, metal rod-reinforced concrete and lightweight aerospace structures. Fiber reinforced polymer matrix composite materials are presented in military systems and in the Department of Defense's effort to lighten the force. However, polymer matrix composites have natural

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temperature restriction based on their hydrocarbon structure. The high temperature alternative to high-density metals is ceramics, offering weight savings as well high temperature capability and oxidation resistance [1].

The sustainable construction materials and innovative technology are the main problems of the construction industry in developing countries. Furthermore, the building materials cost has shared about 70% of the construction. Finally, the cost effective local material and construction technology of composite agrostone material is obtainable as a practical workable solution for the building of equitable housing units [2].

A composite material can be express as a combination of two or more macro elements that are vary in nature and organic arrangement and which are insoluble in each other. The two-macro elements are reinforcement and a matrix. That effects in superior properties than the individual components used alone. Composite materials are light in weight, high strength and stiffness compared to the bulk materials. The reinforcing phase materials are better strength and stiffness than the matrix phase materials [3]. Composite materials are classified based on reinforcement shape [4] (Fig. 1).

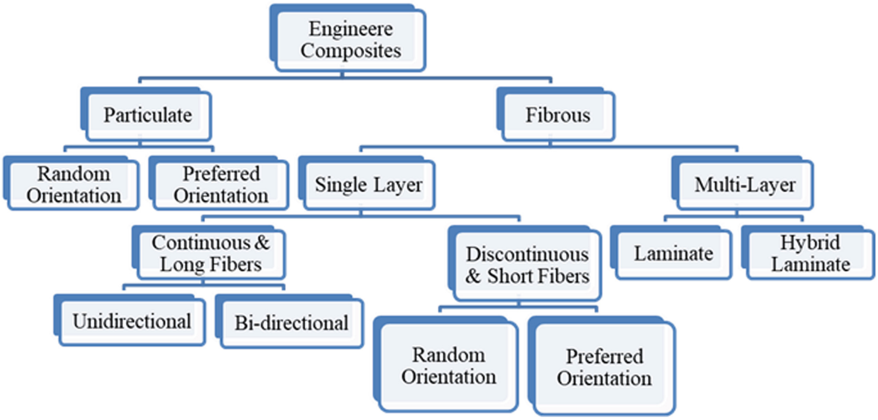

Fig. 1. Classification of composites

Fiber reinforced magnesium matrix composites are the representative of advanced composites, which have important potential in automotive, aviation, aerospace and national defense industries, etc., due to their lightweight, excellent mechanical properties, low thermal expansion coefficient, and high damping capacities. The growing applications of fiber reinforced magnesium matrix composites make it more important to understand and forecast their mechanical properties. Many endeavors have mainly motivated on the effects of the fiber volume fraction and the interfacial adhesion between the fiber and matrix, which guaranteed the effective transfer of stress. However, it was pointed out that the mechanical properties of composites also depended strongly on the fiber direction and fiber aspect ratios [5] (Fig. 2).

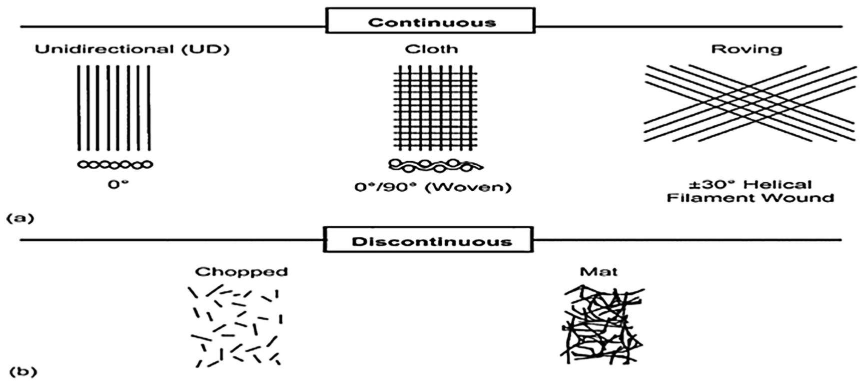

Fig. 2. Typical reinforcement types

The influence of the fiber direction on the mechanical reaction when the samples are stretch along different angles with respect to the orientation of the fiber evaluated using the stress-strain measurements and their respective young modulus and yield point. PVDF fiber morphology and properties are affect by processing parameters including initial polymer solution, solvent evaporation and collection procedure, allowing the collection of random or oriented fibers. This can explained once the force is apply along the same direction of the fibers, leading mainly to an actual stretching of the fibers, contrary to what happens in 45° and 90°, [6] where the force has more influence on the fibers reorientation to the stretching direction. This result is expected, since in the samples with a random fiber orientation, there exist a higher number of fibers along the stretching direction, independently of the direction of stretching, excepting for the stretching of the fibers along 0°.

The effect of fiber location under mechanical stretching is particularly applicable for tissue engineering applications once it has implications for mechanically guided maturation of specific tissues. Thus, it has been demonstrated that the orientation of mesenchymal stem cells and changes in nuclear morphology were PVDF electro spun fiber mats with aligned and randomly oriented fibers were produced and subjected to mechanical stretching along three different directions. 0°, 45° and 90°, relative to the fiber orientation within the fiber mats in order to study the variation in fiber mats morphology and mechanical response. Additionally, there is an increase of the strain value at break when subjected to stretching at the same direction of fibers orientation, but a decrease when the angle between the stretching direction and fiber orientation is 900. These variations must be quantitatively taken into account when the fiber composite mats are used as scaffolds for tissue engineering applications [7].

From the study of [8] Young's modulus of unidirectional glass fiber reinforced polymer (GFRP) composites for wind energy applications were studied using analytical, numerical and experimental methods. In order to explore the effect of fiber orientation angle on the Young's modulus of composites, from the basic theory of elastic mechanics, a procedure which can be applied to evaluate the elastic stiffness matrix of GFRP composite as an analytical function of fiber orientation angle (from 0° to 90°), was developed. The results of the investigation provide some design guideline for the microstructural optimization of the glass fiber reinforced composites and it shows relation between them is nearly linear.

Polymer materials reinforced with glass fiber have received tremendous attention in both scientific and industrial communities due to their extraordinary enhanced properties, such as lower weight, higher toughness and higher strength characteristics. In response to these requirements, research on composites has attracted much attention, which results in numerous publications [9–19]. In order to evaluate the mechanical behaviors of composites materials, different approaches, including experimental investigation, numerical simulations and theoretical modeling, were employed [20–24]. In the present work, theoretical analysis, finite element models as well as experimental investigations used to study the stiffness, i.e. Young's modulus, of glass fiber reinforced composites.

The effect of fiber orientation on Young's modulus for unidirectional GFRP studied by theoretical analysis, finite element numerical simulations as well as experimental investigations. All results indicate that Young's modulus of the composites strongly depends on the fiber orientation angles. A U-shaped dependency of the Young's modulus of composites on the inclined angle of fiber is find. At the same time, there is slight difference among analytical, simulated and experimental results. The difference is that the fiber orientation angle is around 45° when Young's modulus reaches its lowest value for experimental case and the fiber orientation angle is around 60° when Young's modulus reaches its lowest value for numerical and analytical cases. This is cause by:

1. The material properties for analytical, simulations and experiments are not completely the same;
2. For the experimental case, there are many facts affect the results. Nevertheless, for simulation and analysis, the model is simplified and some conditions are ideal.

In addition, analytical results also indicate that the shear modulus Gp has significant effect on the composites Young's modulus. Lower value of Gp led to lower Young's modulus at the same fiber orientation angle and the angle for the least Young's modulus decreases with the smaller Gp. simulated results indicate the relationship between Young's modulus and fiber volume content is nearly linear. The more glass fiber in the composites, the higher Young's modulus of the composites. Use the rule-of-mixture when loading direction alone the fiber axes for fiber-reinforced composites if the fiber/matrix interface is suppose as strong interface.

The effects of SGF and SCF incorporation on the tribological properties of PES composites were also investigated [25]. The incorporation of SGFs results in a monotonic increase of the friction coefficient of the PES composites, and a maximum increase of 48.8% is achieve with the addition of 30% SGFs. However, the friction coefficient of SCF/PES composites decreases with the addition of SCFs, and a maximum drop of 29.8% compared with pure PES is reached with the addition of 20-vol. % SCFs. The wear process of fiber-reinforced composites includes fiber-matrix debonding followed by fiber breakage because of micro cracking, micro cutting, and micro-pulverization due to reciprocating shearing stress [26, 28]. In general, the mechanical property enhancement effectiveness of SCFs is better than that of SGFs for injection molded PES composites. As for the tribological performance, the specific wear rate of PES is significantly reduce by the incorporation of either SGFs or SCFs.

Paper [29] is analysis in ceramic matrix composite materials for investigation on effect of fiber orientation on failure behavior of 3DN C/SiC torque tube. On the study a simplified FEM model is use to analyze failure behaviors. Torsional tests conducted using special attachments to a universal material test machine to obtain the stress strain curves and failure strength. Failure analysis made according to the fracture mopholo-gies of SEM.

In the experiment, torque tubes with fiber orientation of ±45° exhibited a higher torque capacity and modulus than fiber orientation of 0°/90°, it shows good agreement with simulation results. Failure behaviors and changes in predominant failure factors among specimens observed. Both 0°/90° and ±45° fiber orientation belong to tensile failure mode. From the analysis of stress distribution simulation and SEM image, we obtained that the predominant failure factor of M02 torque tube is the failure of the short-cut fiber lamina, and the predominant failure factor of M04 torque tube is the failure of the non-woven fiber lamina. Failure analysis is of great benefit to engineering design, and helps to improve our fabrication process for high property components.

On [30] paper the researcher examine the effect of fiber orientations on surface grinding process of the unidirectional C/SiC composites by diamond grinding wheel conducted and the effect of fiber orientation on grinding force and surface quality discussed. The main effects of cutting conditions (depth of cut, feed speed, cutting speed) on CFCC grinding at the three typical directions (to the reinforced fibers) were systematically analyzed.

The effects of the fiber orientation and fiber aspect ratio on the tensile strength of Csf/Mg composites, several different representative volume units generated by using the random sequential adsorption algorithm. From The research, it showed that the angles between the fiber orientation and applied load played a significant role on the properties improvement of Csf/Mg composites. The tensile strength of Csf/Mg composites gradually decreased with the fiber orientation angle increasing from 00 to 600 and slightly increased with the fiber orientation angle increasing from 600 to 900 [31]. Author [32] examined on Influence of Thickness and Fiber Orientation on a Tensile and Flexural Properties of a Hybrid Composite on 300, 450 and 600 fiber orientation of Carbon, S-glass and E-glass fiber reinforced polymer composites. The study conclude that the 300 arrangement gives greater result as compare to others.

From the previous literature the authors considers the influence of 00, 900 and random fiber orientation on the tensile and bending strength of the composite material for natural fiber and some other polymer material. However, the effect of glass fiber orientation on tensile, compressive, bending and other tribological aspects based on different fiber orientations are not that much detail investigated on the previous liter-atures. Nevertheless, the studied of the above listed parts leads for a better finding of new material. Therefore, the aim of this paper is to test and investigate the influence of fiber orientation on mechanical properties of Agrostone at different fiberglass arrangement, prepare an organized document and to recommend an appropriate fiberglass orientation for the advancement of the new agrostone material with better strength and properties.

2 Material and Methodology

2.1 Material

Bagasse, pumice and diatomite are use as fillers. Magnesium Oxychloride Cement (MOC) known as Sorel is used as binder. MOC is a non-hydraulic binder, which is form by mixing Magnesium Oxide (MgO) with Magnesium Chloride ($MgCl_2$).

Factors for the selection of Matrices and Fibers:

- Most matrices materials are locally available
- The majority of agrostone factories used those products
- Mixing ratio of matrices materials

Advantages of the Matrix material:

- It is the naturally available material in Ethiopia, which are abundant.
- Cost of the material is cheap.
- Utilization of these materials reduces the wastes accumulation and unvalued goods becomes valued.

Reason for selecting the fiber material

- Fiber strengthens the matrix material.
- The fiber selected for this application are available.
- Cheap cost and abundantly available in Ethiopia.
- It has good strength in normal atmosphere when comparing with other type of fiber materials.

2.2 Mould Preparation

A mould is made up of plastic material with a dimension of ASTM standard is prepared. Casting of the composite materials is done in this mould by hand layup process. Later specimens are cut from the prepared casting according to the ASTM Standards (Fig. 3).

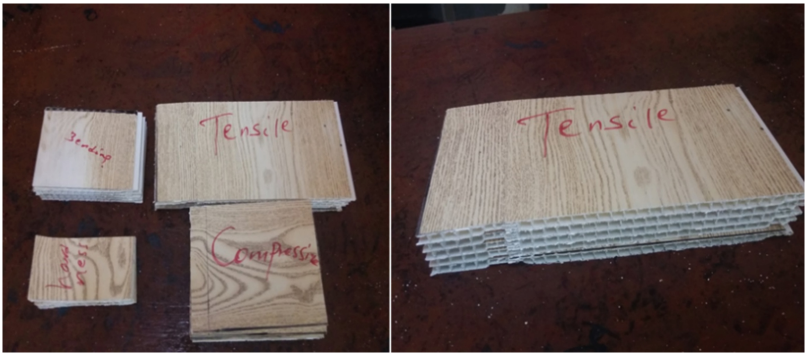

Fig. 3. Finally prepared mold

2.3 Specimen Preparation

Based on the working consistency of Agrostone Production Center mix proportion 1.5 kg of Magnesium Oxide (MgO) powder by weight and 2 L of Magnesium Chloride ($MgC1_2$) were mixed along with 0.2 kg of pumice powder. Estimated quantity of filler, 0.15 kg bagasse and 0.06 kg of fiberglass added until a working consistency of the mix. The mix work done in an open pan type mixer of 4-liter capacity. The casting of the composite made by hand layup process for different fiber orientations such as 0°, 45°, 90°, cross and random, as shown in Fig. 4.

Fig. 4. Hand layup techniques preparation of specimens for testing

The samples for tensile test cut from the molded composite to a size of (250 × 25 × 2.5) mm as per ASTM D-3039 for tensile specimens and (155 × 25 × 3) mm as per ASTM D-3410 for compressive specimens and (127 × 12.7 × 3) mm as per ASTM D-790 for bending specimens. Shown in Fig. 5.

Fig. 5. Slicing specimen of all testes

Testing of Specimens
The experiments conducted on a calibrated universal testing machine (UTM) for tensile, compressive and bending specimens by appropriately changing the grips and the loading procedure. In case of tensile testing, the specimens are placed in the upper and lower grips, and then the computer setting is adjusted according to the specimen dimensions, type of material and grip length. After entering the data related to above parameters, loading is started and continued until the specimen is failed. The result is displayed on the screen of the computer. Loading adjustments for tensile, compressive and bending specimens is shown in Fig. 6.

Fig. 6. Specimens on the UTM

3 Result and Discussion

3.1 Tensile Strength

The average ultimate strength of the Agrostone composite for 0° fiber arrangement is 191.87 MPa. For 45° fibers orientation, the strength value is 144 MPa. For 90° orientation of fiber, the strength value is 146 MPa. For cross fibers, the tensile strength is higher than for the above orientation. Even for random fiber, the strength is less than that of 90° orientations, equal to 145 MPa. It can be noted that maximum strength of composite is obtained only for fibers oriented in the direction of loading and the next better value is obtained for the cross fiber laminate. The strength is reduce for the orientations from 0° to 90° for unidirectional fiber composites. It shows that the full strength of the fibers and the matrix are sharing the load when the loading is inline. The values of ultimate tensile strength of composite with different fiber orientations are present in Fig. 7.

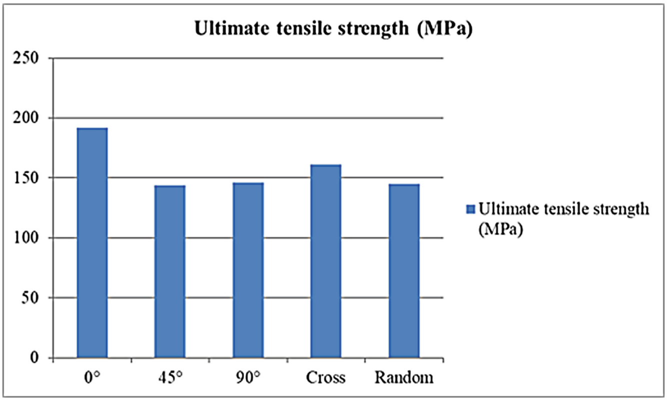

Fig. 7. Ultimate tensile strength and force with fiber arrangement

3.2 Compressive Strength

The highest value of ultimate compressive strength for 00 fibers is 178 MPa and 145 MPa for 45° fibers. For 90° fibers, the strength is 172 MPa and for cross fibers, it is equal to 175 MPa, which is next to that of 0° fibers. For random fibers, the strength is 165 MPa. The pattern of strength is similar to that of tensile loading. The compressive strength values are higher for composites with 90°, cross and random orientation compared to that of tensile strength values. The values of compressive strength for different fiber orientations are shown in Fig. 8.

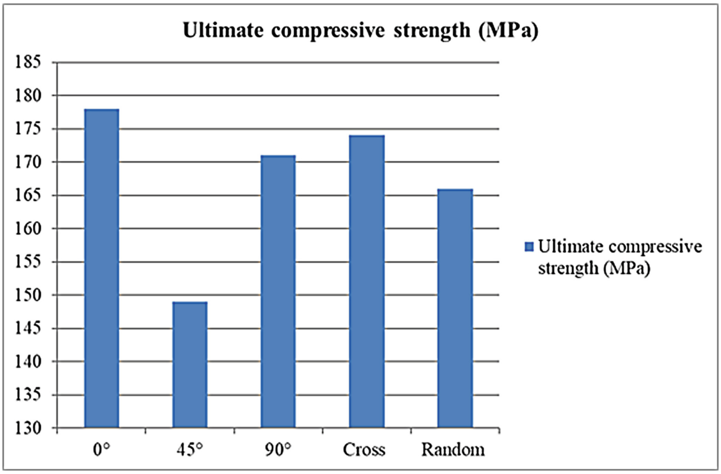

Fig. 8. Ultimate compressive strength and force with fiber arrangement

3.3 Bending Strength

The bending strength for cross fiber orientation is 181 MPa and for random fibers, it is equal to 173 MPa. For 0° fibers, it is equal to 162 MPa and for 45° orientations, it is equal to 153 MPa and for 90°, it is 142 MPa. The values of bending strength for composites with different orientations are shown in Fig. 9. It noted from the results, that the composite has higher bending strength if the fibers are cross and random. The strength is much less for unidirectional composite.

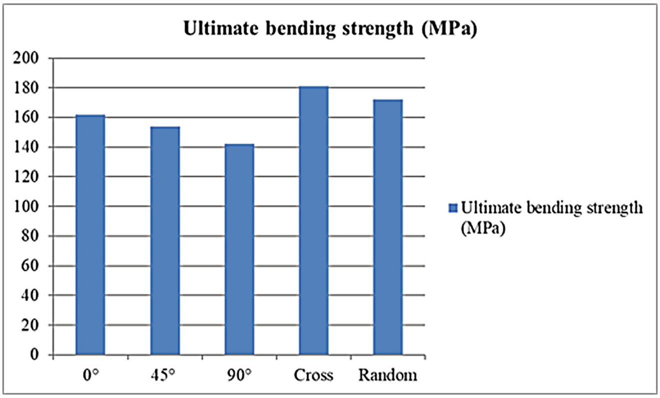

Fig. 9. Ultimate bending strength and force with fiber arrangement

4 Conclusion

The tensile and compressive strength values for 0° fibers is much higher compared to other orientations. The compressive strength values are higher for 90°, cross and random fiber orientation compared to tensile strength values. For 45° orientation, the strength values are minimum in both the cases. It clearly indicates that the strength of composite has higher bearing on the strength of the reinforcing fibers. Especially, it is higher if the loading is in the direction of fiber orientation.

However, in case of bending, the composite has exhibited highest strength for cross fiber composite and next higher value is for random fiber composite. For bending loads, the spreading of fibers in different orientations, in more layers will increase its strength than for composites unidirectional fibers of any orientation.

It can be concluded that 0°, cross and random orientations can be preferred for composites with a general kind of loading compared to other fiber orientation.

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