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Studies on the Mechanical Properties of Hybrid Fiber Reinforced Plastics

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Abstract— Natural fibre composites are sustainable alternative to conventional glass and carbon fibre composites. Natural fibers are used as reinforcements into polymer matrices because of their low-density, good mechanical properties, abundant availability and biodegradability. In the present work, hybrid Bagasse (B)-Glass (G) Fiber Reinforced Composites and hybrid Jute (J)-Glass (G) Fiber Reinforced Composites were manufactured by the compression moulding process. The composite specimen consists of total 5 layers of stacking sequence to obtain 5 types of fiber reinforced composites; G-G-G-G-G, B-B-B-B-B, G-B-G-B-G, J-J-J-J-J and G-J-G-J-G. The mechanical properties of the hybrid fiber reinforced plastics were evaluated.

Keywords— Glass Fiber, Epoxy resin, Compression moulding machine, Mechanical properties.

I. Introduction

Fibre reinforced plastic composites have played a dominant role for a long time in a variety of applications for their high specific strength and modulus. Recently, there has been an increasing interest in the completely biodegradable composites reinforced with natural fibres, because they are renewable, biodegradable and environmentally friendly, not withstanding their use in low-cost applications. The advantages of natural fibres over traditional reinforcing materials have been due to their acceptable specific strength properties, low cost, low density, good thermal properties, enhanced energy recovery and biodegradability. Natural fibres such as jute, sisal, pineapple, abaca and coir have been studied as a reinforcement and filler in composites.

In general, the shortcomings of natural fibre-reinforced composites have been their high moisture absorption, poor wettability and poor fibre–matrix adhesion. In order to improve the mechanical properties of these composites, alkali treatment has been considered as a good technique to modify the fibre surface to obtain better adhesion between the fibre and the matrix (Cao et al, 2006) [1]. Fiber reinforced composites made up of carbon, boron, glass and kevlar fibers have been accepted widely as the materials for structural and non-structural applications (Gowda et al, 1999) [2]. Fiber reinforced composites have become the alternatives of conventional structural materials such as, steel, wood or metals in many applications.

Typical areas of composite applications are car industry, aircraft fabrication, wind power plant, boats, ships, etc. During the human history, composites made occasionally large breakthroughs in construction and other materials. Nowadays, the situation has been the same with modern fiber reinforced composites for which mass production of polymers provided stable background (Varga et al, 2010) [3].

Natural fibre composites represent an environmentally sustainable alternative to conventional glass and carbon fibre composites. Fibres derived from plants are renewable and have low levels of embodied energy compared to synthetic fibres. They are also low cost, low density, have high specific properties, are non-abrasive and less harmful during handling. Composite materials offer higher specific strength, stiffness and energy absorption than metals which is driving their use across many industry sectors. They are used extensively in motorsport and increasingly in the automotive sector because of their potential to reduce mass. The mechanical properties of a composite are dependent on the strength of the bond between fibre and matrix. The strength of a fibre–matrix interface is dependent upon the degree of mechanical, chemical and electrostatic bonding and level of inter-diffusion between the matrix and fibres (Meredith et al, 2012) [4]. Natural fibers, such as flax, cordenka, hemp, jute, ramie, kenaf, bamboo, caraua and sisal, have been employed as reinforcement to prepare green composites and are basically composed of cellulose, hemicelluloses and lignin. The resulting composition of those elements varies depending on the harvesting area and agricultural conditions. Cellulose and hemicelluloses comprise polysaccharides, whereas lignin consists of amorphous polyphenolic macromolecules (i.e., three kinds of phenylpropanes) (Jang et al, 2012) [5].

The jute fibre is an important bast fibre and comprises bundled ultimate cells, each containing spirally oriented microfibrils bound together, which has similar structures of other natural fibres like hemp, flax, sisal, etc. The major part of the cellulose consists of a micro-crystalline structure with high order of crystalline regions. Generally, higher cellulose content leads to higher stiffness, in turn the cellulose content and microfibril angle have a major influence on the mechanical properties of the resultant composites. Other components of the jute fibre are hemi-cellulose, lignin, pectin, waxy and water soluble substances. Because of the structural features, the high level of moisture absorption and poor wettability of the natural fibre material results in insufficient adhesion between fibres and polymer matrices leading to debonding during use and aging (Doan et al, 2006) [6].

Sugarcane bagasse (SCB), an agro-industrial residue produced in sugar and alcohol industry, is considered as one of the largest natural fibre resources because of its high cellulose

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content, high yield and annual regeneration capacity. At present, the main conventional uses of SCB are for energy in the sugar factories through burning, electricity generation, pulp and paper production.

There are also some other applications of SCB, such as the productions of ethanol and protein-enriched cattle feed. But these technologies are complex or immature, and the processes have been demonstrated to be uneconomical, which limit their extensive uses in industries. Moreover, the remaining SCB still lead to adverse impacts on environment. Thus, utilization of SCB in composites can more efficiently use this bioresource. Like other lignocellulosic fibres, SCB is approximately composed of 50% cellulose, 25% hemicellulose and 25% lignin, and they associate with each other by hydrogen bonds and some other covalent bonds. Much of the cellulose in SCB is in a crystalline structure, and the microfibril bundles of cellulose are weakly bound through hydrogen bonding. Lignin, an amorphous heteropolymer, gives the SCB structural support, impermeability, and resistance against oxidative stress and microbial attack. Hemicellulose, also an amorphous polymer, serves as a connection between the cellulose and lignin fibres and gives more rigidity to the whole cellulose–hemicellulose–lignin network. The elementary unit of a cellulose macromolecule is anhydro-d-glucose, which contains three hydroxyl (OH) groups. These hydroxyl groups form hydrogen bonds inside the macromolecule itself (intramolecular) and between other cellulose macromolecules (intermolecular) (Huang et al, 2012) [7].

In recent years, there has been a renewed interest in hybridization of natural fibers with synthetic fibers as reinforcement in composite materials. In hybrid composites, two different fibers are combined in a single matrix in order to compensate the drawback of one fiber by the other. These hybrid composite materials provide high specific stiffness, strength and lightweight which makes them attractive materials for secondary load bearing applications. The properties of composites are significantly related to the properties of composite constituents, i.e., fiber, matrix and the interphase between them (Anbusagar et al, 2014) [8].

Natural fibre reinforced composites have been in considerable demand due to their lower cost, light weight, high strength to weight ratio, renewability, lower density, less wear and tear in processing, lower energy requirements for processing, biodegradability, wide availability and relative non abrasiveness over traditional reinforcing fibres such as glass and carbon. Application of natural fibre reinforced composites has been restricted due to its hygroscopic nature, poor wettability, low thermal stability during processing and poor adhesion with the synthetic counterparts. Most of the drawbacks of natural fibres can be overcome by effective hybridization of natural fibre with synthetic fibre or natural fibre. Among the natural fibres, jute fibre is the most promising reinforcement material due to its high content of cellulose (Jawaid et al, 2012) [9].

The toughening mechanisms due to the addition of particles to polymers are localised inelastic matrix deformation and void nucleation, particle debonding, crack deflection, crack pinning, crack tip blunting, particle deformation or breaking at the crack tip (Battistella et al, 2008) [10]. Natural fibers are considered as potential replacement for man-made fibers in composite materials.

Although natural fibers have advantages of being low cost and low density, they are not totally free of problems. A serious problem of natural fibers is their strong polar character which creates incompatibility with most polymer matrices. Chemical treatments can increase the interface adhesion between the fiber and matrix, and decrease the water absorption of fibers. Therefore, chemical treatments can be considered in modifying the properties of natural fibers. Stearic acid ($CH_3(CH_2)_{16}COOH$) in ethyl alcohol solution treatment removed non-crystalline constituents of the fibers, thus altering the fiber surface topography. The treated flax fibers were more crystalline than the untreated ones and stearation decreased the fiber surface free energy (Li et al., 2007) [11].

II. EXPERIMENTAL

E-glass fiber chopped strand mat (GFCSM) (G) of 300 gsm and an average thickness of 0.8 mm was used as the reinforcement material. The bagasse fibers (BF) (B) were obtained after the sugarcane was crushed for extracting juice by using a hand crushing machine. The bagasse fibers cut to dimension of 15 mm x 240 mm and thickness 0.9 mm were dried in atmospheric temperature for 24 hours and then kept in a furnace for 6 hours at 80 ^{0}C to remove the moisture content (Figure 1). The minor scale is in mm and major scale is in cm of the upper scale. The bagasse fiber is of 880 gsm and thickness of 0.9 mm. The bagasse fibers ((B) were subjected to stearic acid chemical treatment. The bagasse fibers were soaked in a stainless steel vessel containing 1% stearic acid solution for 1 hour. Then the bagasse fibers were washed with distilled water and dried in hot air oven for 3 hours at 70 °C.

Fig 1. The bagasse fiber

Woven jute mat (WJM) (J) (Jute plain weave fabric) 60·55 (60 yarns in warp direction and 55 yarns in weft direction per 100 mm), of 250 gsm and an average thickness of 1 mm was also used as reinforcement material. The WJM was subjected to stearic acid chemical treatment. The plain WJM was soaked in a stainless steel vessel containing 1% stearic acid solution for 1 hour. Then the treated WJMs were washed with distilled water and dried in hot air oven for 3 hours at 50 °C.

A mild steel frame type mould of inside size was 240mm x 240mm x 4mm is kept on top of a mild steel plate coated with wax to enable easy removal of the manufactured fiber reinforced plastics (FRP). The hybrid FRP composites based on Glass (G)/Bagasse (B)/Jute (J) were manufactured by compression moulding method with 5 layers of different stacking to obtain 5 types of FRPs i)G-G-G-G-G ii)B-B-B-B-B iii)G-B-G-B-G iv)J-J-J-J-J and v)G-J-G-J-G. The epoxy resin was mixed hardener polyamine in the ratio 10: 1 by mechanical stirring. Initially a releasing agent wax was spread over the bottom mould mild steel plate to enable easy removal of the manufactured FRP. Above this releasing agent layer, a thin layer of the mixed epoxy resin was applied. Reinforcement in the form of GFCSM or 16 numbers of bagasse fiber (BF) closely placed parallel or WJM cut as per the mould size was then placed at the surface of mould. The mixed epoxy resin was then poured onto the surface of GFCSM/ BF/WJM already placed in the mould and it is uniformly spread with the help of brush. A roller was moved with a mild pressure on the GFCSM/BF/WJM - mixed epoxy resin layer to remove any air trapped. Again a thin layer of mixed epoxy resin was applied. The next layer of GFCSM/BF/WJM was then placed above. The process was repeated for each layer of mixed epoxy resin and GFCSM/BF/WJM, till the 5 layers of GFCSM/BF/WJM are stacked. Finally a thin layer of the mixed epoxy resin was applied. Then top mould mild steel plate coated underside with wax, was kept above the mild steel mould.

Figure 2 shows the drawing of the mould assembly sub components consisting of top mould plate, mould and bottom mould plate. The photograph of mould assembly sub components consisting of top mould plate, mould and bottom mould plate is shown in figure 3. Subsequently the mould assembly consisting of bottom mild steel plate, mild steel mould of inside size 240mm x 240mm x 4mm and top mild steel were placed in the platen of the compression moulding machine (Figure 4). In the present work, the moulding temperature is 55^{0}C and clamping force is 4 tonnes. The compression moulding time is 3 hours. The total thickness of the entire manufactured FRP specimen was 4 mm.

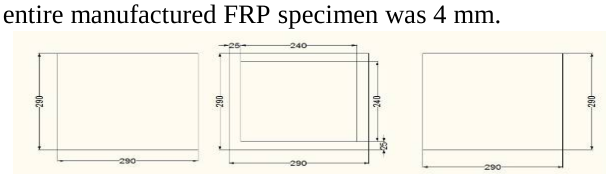

Figure.2. Drawing of the mould assembly sub components

Figure.3. The photograph of mould assembly sub components

Figure. 4. Compression moulding machine

The tensile test was conducted in the Universal testing machine as per ASTM: D638 standard. The three point flexural test was conducted in the Universal testing machine as per ASTM: D790 standard. The impact test was conducted in the Izod Impact testing machine as per ASTM: D256 standard.

III. Results And Discussions

The mechanical properties for the different types of FRP are presented in table 1. The tensile strength, flexural strength and impact strength of the specimen G-G-G-G-G are higher than that of the specimen G-J-G-J-G, which are higher than that of the specimen J-J-J-J-J, which are higher than that of the specimen G-B-G-B-G, which are higher than that of the specimen B-B-B-B-B. This is attributed to the higher strength of GFCSM than that of WJM, which is higher than that of BF.

IV. Conclusion

In the present work, hybrid Bagasse (B)-Glass (G) Fiber Reinforced Composites and Hybrid Jute (J)-Glass (G) Fiber Reinforced Composites were fabricated by the compression moulding process. The mechanical properties of the specimen G-G-G-G-G are higher than that of the specimen G-J-G-J-G, which are higher than that of the specimen J-J-J-J-J, which are higher than that of the specimen G-B-G-B-G, which are higher than that of the specimen B-B-B-B-B. This is attributed to the higher strength of GFCSM than that of WJM, which is higher than that of BF. The development of hybrid fiber reinforced composites revealed that these materials can be used to the advantage for many applications.

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