Materials Research Express

PAPER

Mechanical properties of waste copper slag filled surface activated jute fiber reinforced composite

G Kalusuraman\(^1\), S Thirumalai Kumaran\(^\circ\), M Aslan\(^2\) and K Mayandi\(^1\)

\(^1\) Faculty of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil—626126, Tamil Nadu, India
\(^2\) Faculty of Engineering, Department of Metallurgical and Materials Engineering, Karadeniz Technical University, Trabzon, Turkey

E-mail: thirumalaikumaran@yahoo.com

Keywords: surface treatment, polyester, natural fiber, copper slag

Abstract

In this work, the fabrication of the jute fibre reinforced composites are made with the help of the compression moulding technique using the optimum pressure (17 Mpa) along with various fiber dosage (i.e. 0\%, 40\%, 50\%). The optimized condition is obtained for the 40\% fiber loading composites in the mechanical properties, then fiber activation is followed by using the NaOH and Ca(OH)\(_2\). The treated fibers composites by adding the copper slag in the range of 0\%, 5\%, 10\%, 15\% for the optimized 40\% fiber dosage are produced using the unsaturated polyester as matrix. The ejected the specimen is cut as per ASTM to find the mechanical properties such as tensile, flexural and impact. Result revealed that the Ca(OH)\(_2\) treated composite shows better tensile, and impact strength for the 10\% copper slag filled composite material and yields higher for 15\% for copper slag filled composites in the case flexural strength. Nearly 25\% and 22\% increase in tensile strength and impact strength was observed for the Ca(OH)\(_2\) treated composite with 10\% copper slag inclusion. The 15\% copper slag inclusion composite yielded the higher flexural strength. The SEM mechanism revealed the higher mechanical strength for the Ca(OH)\(_2\) treated composite than other composites produced with activated fiber.

1. Introduction

Recently, there is great attention for low strength materials instead of synthetic materials for the automotive, aircraft and structural applications. So, the requirement of industries needs low cost, eco-friendly, high stiffness, high specific strength, easy availability, and biodegradability of the materials for their appropriate applications [1]. The natural fiber provides all the benefits as the said above and also is one of the good reinforcement in the thermoset and thermoplastic materials [2, 3]. Indeed, it is most essential to find the details about the composite to realize the performance of the natural fiber composites. Many research works are reported for the characterization of the natural fibers like coir, jute, hemp, banana, sisal, oil palm, pineapple, borassus, palmyra, tamarind in a polymer matrix, for innumerable engineering application [4–10]. Mayandi \(et\ al\) [11] examined that the Mechanical performance on Cissus quadrangularis polyester composite and reported that the better mechanical properties were found at 40\% fiber loading and 40 mm fiber length. Kalusuraman \(et\ al\) [12] examined that the friction studied on the luffa cylindrica reinforced polyester composite with the effect of surface treatment and reported that treatment of the surface morphology significantly modifies the friction coefficient. Hamdy M. Naguib \(et\ al\) [13] examined that the mechanical properties and physical of the green bagasse polyester composite and conclude that the increased in mechanical properties after the chemical treatment was attained. Sreenivasan \(et\ al\) [14] mechanical properties of randomly oriented the short Sansevieria cylindrica polyester composites and stressed that the optimum mechanical properties found at 40\% fiber loading and 30 mm fiber length. Velmurugan \(et\ al\) [15] studied that randomly oriented short palmyra fiber reinforced composite and identified that the 50\% fiber loading and 50 mm fiber length as optimum. Apart from the other consent, the introduction of filler is another important parameter in the making of the composite to

\(^\circ\) Correspondence author.
improve the properties [16]. Several fillers such as fly ash, graphite, polyethylene bags, calcium carbonate, cement kiln dust, silica microparticles, and alumina particles are used in the composite to increase the properties which suitable of structural applications [17]. Raghavendra et al [18] investigated the effects on the addition of micro/nanofiller alumina on the mechanical properties of jute/glass hybrid nanocomposite. They reported that nanofiller added composite showed better results when compared with and without micro filler included composites. Sathiyamurthy et al [19] studied that calcium carbonate-impregnated on mechanical behaviours of short coir fiber/polyester composites.

Even though many works are focussed on the natural fiber composite as the filler materials, there is no work reported on the waste materials like copper slag as filler in the natural fiber composites. The copper slag (approx. 6 Ton/annum) is the waste product from the Sterlite India Industries Limited, Tuticorin, Tamil Nadu, India. The waste material can be used for the users by reinforcing them into natural fiber composites. This made authors to do novel work. In this work, the copper slag is introduced as filler material in the jute fiber/polyester composites. The mechanical properties such as tensile, impact, flexural are studied to find the influence of the copper slag in the proposed composites.

2. Materials and methods

2.1. Materials

The jute fibers are purchased from the market near Rajapalayam, Tamil Nadu. India. The unsaturated polyester resin is used as a matrix in this work. Methyl ethyl ketone peroxide and cobalt naphthalene were used catalyst and accelerator respectively. The copper slags (waste product) obtained from Sterilite India Industries Ltd, Tuticorin, Tamil Nadu, India. Figure 1 shows that the particle distribution of copper slag used in this study. The copper slag particle is in the range of the 10–700 μm. The average of the particle size for copper slag was noted as 90 μm which was used this work. The FTIR for the copper slag as shown in Figure 2.

2.2. Mercerization of the fibers

NaOH treatment (NT): The jute fibres were allowed to submerge in the 1 mol l⁻¹ of alkali solution (40 g of NaOH in 1000 ml of distilled water) for one hour. With the deionized water, the NaOH treated fibers are allowed to wash thoroughly in order to remove excel NaOH in the fiber. After that, it was kept in the hot oven for 60° for 8 h.

Ca(OH)₂ treatment (CT): The jute fibers were allowed to immerse in the solution which is prepared by adding 74 gm in one liter of distilled water for an hour. Then treated fibers were washed thoroughly in the distilled water and then kept in the hot oven for 60° for 8 h.

2.3. Fabrication of composite

The jute fiber/polyester composite is fabricated in the size of 300 mm × 125 mm × 3 mm by using the compression moulding technique. Initially, the fibers are subjected to the pre-compressing process using the same machine in the closed mould. The catalyst and accelerator are mixed 15% each in the required quantity of resin. The catalyzed resin is applied in each layer of the mate. Here the wax is used as the releasing agent, which is applied to the mould at the initial stage. Then the mould is closed and put up in the machine by applying the pressure of 17 MPa and allowed for the room temperature for 24 h. After that, the samples are cut as per the ASTM standard for testing. The composites are fabricated at 30%, 40%, 50% fiber dosage. The same procedure
Figure 2. FTIR for the copper slag.

Figure 3. Process of preparing composite.

Figure 4. Effect of copper slag on the tensile properties of treated and untreated composites.
is adopted for the composite having 5%, 10%, 15% copper slag in the 40% fiber dosage composite. Figure 3 shows the process of preparing composite.

2.4. Mechanical testing of composite
The composites were tested for tensile testing as per the ASTM-D3039 [20]. Tensile testing of the composite was carried out, in accordance with ASTM-D3039. The diamond tip cutter was used to cut the given sample in the size 200 mm $\times$ 20 mm $\times$ 3 mm the three-point testing was conducted by according to the ASTM-D790 [10] to recognize the flexural properties of composites for the specimen size of 127 mm $\times$ 13 mm $\times$ 3 mm. In order to find the impact strength, the Charpy test was conducted on the specimen size of 65 mm $\times$ 13 mm as per the ASTM-D256 [10]. The five sampled were tested in each property and the average was reported.

3. Result and discussion

3.1. Mechanical properties
The tensile testing and flexural testing of the composites (30%, 40%, 50%) fiber loading Untreated composites (UT) is shown in table 1. It is observed that the 40% fiber loading composites show that the good mechanical properties, while comparing the other two. Thus, the effect of copper slag addition is performed for the 40% fiber loading condition to study the mechanical properties.

| Description | Tensile strength (MPa) | Flexural strength (MPa) | Impact strength (kJ m$^{-2}$) |
|-------------|------------------------|-------------------------|-----------------------------|
| UT 30       | 25.57                  | 32.55                   | 12.19                       |
| UT 40       | 32.58                  | 41.56                   | 12.47                       |
| UT 50       | 29.50                  | 37.63                   | 13.98                       |

![Figure 5. Tensile stress-strain plot.](image)

Table 1. Mechanical properties of the composite.
distribution of stress transfer in the longitudinal direction under the applied loading condition. Moreover, the composite shows significant enhancement in the tensile strength as the copper slag filler increased from 0% to 10%. Later on, higher inclusion of the copper slag leads to decrease the tensile strength. This is could be the reason that the 15% inclusion of the copper slag, will break the good bond between the fiber and matrix. Moreover, the higher tensile strength is found to be as 45.705 MPa for CT composite with 10% copper slag, this could be nearly 9% increase in tensile strength over the same UT condition. At 15% copper slag inclusion, the composites show less strength as compared to other low percentage copper slag inclusion of the composite. As the effect of copper slag the tensile strength is increased up to the 41.56 MPa, 42.24 MPa, 45.70 MPa for the UT,
NT, CT composite respectively. The stress-strain plot for the various composites is shown in figure 5 for 10% addition of copper slag composites. Figure 6(a-c) shows the SEM image of the UT, NT, CT of jute reinforced 10% copper slag composites. It is observed from figure 6(a), more cracks are propagated during the tensile testing, leads to easy removal of fiber from the matrix for producing the lower tensile strength. The lower strength of the fractured sample may be due to the debonding of the fiber and traces of the fiber pull out, cracks initiation and fiber breaking. This makes discontinuity of the stress transfer between the matrix and fiber. Figure 6(b) shows that the interfacial gap, and some crack propagation, leads to less stress transfer. Comparatively, good interfacial bonding has been observed for NT composites that the UT composites. It is observed that the white colour part has been identified as copper slag in all the specimens. From figure 6(c) it is observed that some twisting of fiber, less crack initiation, less fiber pulls out, good bonding of copper slag confirms to have the higher strength than the other composites.

3.3. Flexural strength

The bending properties of the composite were performed using the three-point bending test. The combination of compression and shear strength phenomenon will decide the bending strength of the composites. The effect of copper slag on the flexural properties of various composites is shown in figure 7.

The flexural strength was found to be higher in the 15% of copper slag filled in 40% jute fiber loading CT composites (70.16 MPa). As far as the individual concern, in terms of the copper slag, the 15% copper slag included composites provides better flexural strength. Generally, it is observed that the increase in copper slag which in turn increase in flexural strength of the composites. It could be observed that the copper slag acted as a strong agent to bind the fiber and matrix in order to improve the flexural properties. As far as the treatment
concern, chemical treatment improves the flexural properties of the composites. Nevertheless, the addition of the copper slag inhibited the fiber breakage, and also increase in flexural strength is total of the adhesion of the filler. It is also inferred that the addition of the 15% copper slag increased the flexural strength for CT composite.
3.4. Impact strength
The impact strength is depending on the interfacial adhesion and interlaminar of the matrix between fiber. The effect of fillers on the impact properties of treated and untreated composites is shown in figure 8. It implies that the structure and individual fiber constituent also influence the impact properties of the composites, apart from the parameter like fiber-matrix interface, preparation and geometry of the composites as said by the others [21]. It may be noted that the impact strength of composites increased as in the case of the treated composites. It might be noted that the interfacial strength exclusively adjudicates the impact properties of the composites. It is clearly seen that the inclusion of copper slag also play a key role in the impact strength of composites and the addition of copper slag enhances the impact properties of all type of the composites.

The increase in the impact strength for the addition of copper slag up to 15% was observed. Later on, the properties start decreasing, because more copper inclusion leads to less creation of the bonding between the fiber and matrix. The impact strength of the CT composites for 10% copper addition was found to be 12.05 kJ m$^{-2}$, whereas the NT and UT composites were 11.025 kJ m$^{-2}$ and 10.89 kJ m$^{-2}$ respectively. An increase of 22% impact strength for CT composite is observed while the addition of 10% copper slag. It is also observed that the 10% increases in impact strength for CT composites (10% copper slag) in comparison to the UT composites. This could be the reason that treatment could create a better bonding of fiber and matrix.

SEM image of the fractured specimen during impact is shown in figures 9(a)–(c). The study of the energy absorption of the specimen can be done using the microscopic image of the produced sample. The fiber braking, tearing fiber pullout is attributed to lower impact strength reported by the others [22]. From figure 9(a), it is observed that the fiber breaking and traces of the fiber pull out leads to the lowest energy absorption capability. The less fiber breaking and less trace of fiber were observed comparatively than the UT composites in figure 9(b) to have higher the impact properties than UT composites. The CT composites hold higher energy absorption than the other two composites since the better interfacial bond between the fiber and matrix observed from figure 9(c).

4. Conclusions
The composites are successfully fabricated with the addition of the copper slag by a compression moulding technique. The use of the copper slag as potential filler in the natural fiber composites enhances the mechanical properties of the composites. The tensile strength of CT composites produced 41.56 Mpa when 10% of copper slag is added. The addition of 15% of copper slag produced a higher flexural strength in the CT composites. The addition of 10% copper slag for the CT composites increases the impact strength to 10.05 kJ m$^{-2}$. The ranking of the Ca(OH)$_2$ treatment is higher than the NaOH treatment for all the conditions tested.

ORCID iDs
S Thirumalai Kumaran @ https://orcid.org/0000-0001-8737-6796
M Aslan @ https://orcid.org/0000-0003-2299-8417

References
[1] Arumuga Prabu V, Thirumalai Kumaran S and Uthayakumar M 2018 Influence of red mud particle hybridization in banana/sisal and sisal/glass composites Part. Sci. Technol. 36 402–7
[2] Thakur K, Kalia S, Kaith B S, Pathania D, Kumar A, Thakur P and Totaro G 2016 The development of antibacterial and hydrophobic functionalities in natural fibers for fiber–reinforced composite materials Journal of environmental chemical engineering 4 1743–52
[3] Singh A S and Thakur V K 2008 Mechanical properties of natural fibre reinforced polymer composites Bull. Mater. Sci. 31 791–9
[4] Pothen L A and Thomas S 2003 Polarity parameters and dynamic mechanical behaviour of chemically modified banana fiber reinforced polyester composites Compos. Sci. Technol. 63 1231–40
[5] Luyt A S and Malunka M E 2005 Composites of low-density polyethylene and short sisal fibres: the effect of wax addition and peroxide treatment on thermal properties Thermochim. Acta 426 101–7
[6] Rout J, Misra M, Tripathy S S, Nayak S K and Mohanty A K 2001 The influence of fibre treatment on the performance of coir–polyester composites Compos. Sci. Technol. 61 1303–10
[7] Ma H and Joo C W 2011 Structure and mechanical properties of jute—polylactic acid biodegradable composites J. Compos. Mater. 45 1451–60
[8] Sawpan M A, Pickering K L and Fernhough A 2013 Analysis of mechanical properties of hemp fibre reinforced unsaturated polyester composites J. Compos. Mater. 47 1513–25
[9] Reddy K O, Shukla M, Maheswari C U and Rajulu A V 2012 Evaluation of mechanical behavior of chemically modified Borassus fruit short fiber/unsaturated polyester composites J. Compos. Mater. 46 2987–98
[10] Thiruchirambal M and Shanmugam D 2012 Influence of pre-treatments on the mechanical properties of palmyra palm leaf stalk fiber–polyester composites J. Reinf. Plast. Compos. 31 1400–14
[11] Mayandi K, Rajini N, Pitchipoo P, Jappes J W and Siva I 2015 Mechanical performance of Cissus quadrangularis/ polyester composite Materials Today Communications 4 222–32
[12] Kalusuraman G, Siva I, Jappes J W and Kumar S A 2016 Effects of fiber surface modification on the friction coefficient of luffa fiber/polyester composites under dry sliding condition J. Polym. Eng. 36 837–46
[13] Naguib H M, Kandil U F, Hashem A I and Boghdadi Y M 2015 Effect of fiber loading on the mechanical and physical properties of 'green' bagasse–polyester composite Journal of Radiation Research and Applied Sciences 8 544–8
[14] Sreenivasan V S, Ravindran D, Manikandan V and Narayanasamy R 2011 Mechanical properties of randomly oriented short Sanseveria cylindrica fibre/polyester composites Mater. Des. 32 2444–55
[15] Manikandan V, Ponnambalam S G and Sabu Thomas V R 2004 Mechanical properties of short and uni-directional palmyra fiber reinforced composite International Plastics Technology 8 205–16
[16] Chaudhary S N, Borkar S P and Mantha S S 2010 Sunnhemp fiber-reinforced waste polyethylene bag composites J. Reinf. Plast. Compos. 29 2241–52
[17] Silva I J, Panzera T H, Velloso V R, Rubio J C C, Christoforo A L and Scarpa F 2013 Statistical design of polymeric composites reinforced with banana fibres and silica microparticles J. Compos. Mater. 47 1199–210
[18] Raghavendra G, Ojha S, Acharya S K and Pal S K 2013 Influence of micro/nanofiller alumina on the mechanical behavior of novel hybrid epoxy nanocomposites High Perform. Polym. 27 342–51
[19] Sathiyamurthy S, Thaheer A S A and Jayabal S 2012 Mechanical behaviours of calcium carbonate-impregnated short coir fibre-reinforced polyester composites Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl. 226 52–60
[20] Sathishkumar P, Navaneethakrishnan P and Shankar S 2012 Tensile and flexural properties of snake grass natural fiber reinforced isophthalic polyester composites Compos. Sci. Technol. 72 1183–90
[21] Mwaikambo L Y and Martin P A 2002 Chemical modification of hemp, sisal, jute, and kapok fibers by alkalinization J. Appl. Polym. Sci. 84 2222–34
[22] Atiqah A, Maleque M A, Jawaid M and Iqbal M 2014 Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications Composites Part B: Engineering 56 68–73