Green Composites using Waste Metal Scrap and Bio-fibres

Ganesh S. Kadam and Onkar V. Potadar*

Department of Mechanical Engineering
SIES Graduate School of Technology, Nerul, Navi Mumbai 400706, Maharashtra, INDIA

Abstract

Composites are the combination of a matrix and a reinforcement material, which give better mechanical and physical properties than their individual counterparts. Conventional composites generally have reinforcement materials as fibres of carbon, glass, metal, etc. and resin being used for matrix. But the cost of the same is also on higher side. The current trend is towards manufacturing products having environmentally friendly approach from different perspectives with an additional focus on economy. Considering this the present work primarily focuses on preparation of green composites economically using bio-fibres and waste materials, and then testing its properties. For this, fibres of jute and coconut as well as their combinations and metal scrap from machining, were used as reinforcing material to prepare different composites with epoxy resin as the matrix binder. Jute and coconut fibres were taken in natural as well as chemically treated conditions, while metal scrap was taken in the form of waste chips generated due to drilling. Further the manufactured composites were tested for an important mechanical property - tensile strength. Results indicate that the manufactured green composites have varying tensile strengths depending on the type of fibres and their combinations used. Ultimately, the manufactured green composites were better in terms of strength, lighter in weight, lower in cost and also mainly environmentally friendly as they incorporated waste bio-fibres or metal scrap. The large scale production and actual usage in practical applications of the same can be the next step towards sustainable manufacturing and environmentally-friendly products.

Keywords: Composites, Jute, Coconut, Coir, Epoxy, Resin, Fibres, Tensile strength, Environmentally-friendly.

1. INTRODUCTION

Due to the tremendous advancements in product design, the conventional materials cannot effectively satisfy the growing demand on product capabilities and performance. This dictates the need of composite materials which provide the required properties in much superior manner than that by conventional materials. Composites are basically the combination of a matrix and a reinforcement material, which give better mechanical and physical properties than their individual counterparts. Conventional composites generally have reinforcement materials as fibres of carbon, glass, metal, etc. and mostly resin being used for matrix. Plenty of composites are available in the market today ranging from the most popular standard glass fibre reinforced composites (GFRP) as well as carbon fibre reinforced composites (CFRP) [1] to the rare bio-composites. There is also another highly emerging group of composites called as green composites [2]. Green composites can be broadly termed for that class of composite which may incorporate bio-materials like bio-fibres or agro-waste, or waste scrap as fibres or matrix, or even composites made of bio-degradable materials, etc. In general, green composites should consist of some eco-friendly or natural material/s, or should be sustainable from manufacturing and usage point-of-view, or even easily feasible in recycling towards their end of shelf-life. Now natural fibre composites also called as bio-composites, a category of green composites, are also slowly gaining popularity due to their great potential for mass production as well as applications [3-5]. These composites use natural fibres as a reinforcement material along with a binding agent matrix mostly being resins.

Considering some of the notable works carried out in the past on bio-composites, researchers have mainly focussed on utilisation of various natural fibres like regenerated cellulose fibres [6], flax fibres [7, 8], kenaf fibres [9], coir fibres [10], jute and bamboo fibres [11]. It is understood that natural fibre composites are widely used in many commercial industries and also for household applications [12, 13]. Talking about the environmental aspects, replacing synthetic fibres with natural fibres could be a good step in reducing the greenhouse gases in the atmosphere especially CO_2 and thus also eliminating or reducing the use of fossil fuels. Apart from using natural fibres for producing composites, we can also produce composites from industrial wastes that still have a decent mass which could be well utilized to get the desired strength [14]. One such waste is metal chips generated while machining which is treated as a waste for industries calling it as a machining scrap. The metal chips that are generated from various machining process of different sizes and shapes could be made standardized to particular physical size and then could be used as a reinforcement material for metal-scrap composite. Metal-scrap composites produced from machining chips are new type of composites. These composites are not used commercially and are yet not popular across the globe. So there needs to be work done to observe and study the properties of these composites too.

Currently the various types of composites present in the market also have some merits and demerits, like a composite with high strength may be very uneconomical for the industry or a composite which is very economical may not be having the desired mechanical properties in it. Thus there is a need to produce composites which are optimum in both cost and property, so that they can be used in mass production and thus can make their presence in every corner of the world. With this perspective, this paper discusses the manufacturing and mechanical testing of green composites particularly by using bio-fibres and metal scrap as fibre materials and resin as matrix.

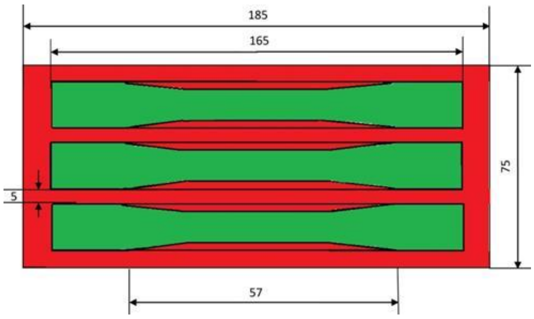
*Author to whom correspondence should be made, Email: onkarhubli@gmail.com ; onkar.potadar@siesgst.ac.in

ISBN: 978-93-80689-28-9

2. EXPERIMENTAL WORK

2.1 Mould Preparation

The first step in preparation of composite is the design and preparation of mold cavity. Since the ultimate green composites were to be economical, additional focus was also given through implementing low cost manufacturing techniques. Hence cheaper but effective mould preparation was given prime consideration. Thus GI sheet of gauge 24 was used as initial raw material for mould. The sheet was bent in such as fashion so as to form a tray like structure with dimensions 185×75×8 mm (see Fig. 1a and b). This enabled for getting a composite moulding of around 183×73×7 mm dimensions (see Fig. 1c) from which later the experimental test specimens were cut.



(a)

(b) (c)

Fig. 1. (a) Schematic of mould layout for composite moulding along with layout of specimen pattern, (b) Mould with composite under curing, (c) Manufactured composite

2.2 Fibre Preparation

The physical properties of the composites are mainly dependent upon the preparation of fibres. For bio-composites incorporating un-treated fibres, the jute and coir fibres were just carefully chosen so that they are continuously uniform along length, untangled and do not consist any visible impurities (see Fig. 2a). Considering the bio-composites incorporating treated fibres, the jute and coir fibres were additionally chemically treated with alkaline solution which consisted of soaking the fibres in 5% NaOH. The period of soaking for jute fibres was 4 hours while that for coir fibres was 30 minutes. These fibres were then subjected to acid bath of 5% dilute acetic acid so as to reduce the pH, as otherwise the fibres may reach with epoxy resin later. Finally then the fibres were thoroughly washed with water and dried for around 24 hours and were used later for manufacturing composites.

Considering the metal-scrap composites, scrap metal chips generated after the machining operation of drilling were used as fibres (see Fig. 2b). Since the composites were to be tested experimentally, uniformity of fibre material is necessary. Hence considering this, short metal chips less than 2 cm were only selected as fibres. Further the chips which were longer than 2 cm were first put in shredder so as to get uniformity within size limits. Further to avoid the deviation in properties of composite due to rusting phenomena of chips, the chips were immediately collected after machining operation and this was subsequently followed by manufacturing of composites.

(a) (b)

Fig. 2. (a) Jute (upper) and coir (below) fibres in un-treated condition, (b) Metal scrap in form of chips from drilling

2.3 Matrix Material Preparation

The matrix material too plays a crucial role in composites as it binds the fibres together and provides the necessary strength. The thermosetting resin, with commercial name as 'Loctite Tough' from Asian Paints Ltd. India, was used as matrix material. It was available in a combo pack of epoxy resin and hardener that gives high-strength adhesive bonding [14]. Selection of it was done since it is available in liquid state and can be well used in combination with hardener. Further it has low viscosity at room temperature and is thus best suited for hand-lay-up process. Also being reactive, it gives a short pot life and rapid cure at normal ambient temperatures. The matrix material thus consisted of resin and hardener mixed in equal proportions.

2.4 Preparation of Composite

If the matrix resin is directly poured in the mould cavity then it will get stuck to the mould and removal of the composite would be difficult and tedious. Thus to avoid this, a polypropylene-based adhesive tape was applied to the inner surface of the mould. Further a thin layer of oil was applied uniformly over the tape. The oil creates a film between the resin and the tape and thus aids in easy removal of cured composite. Once the above was done, the mould was then placed on a flat surface so as to ensure that there shall not be a concentration difference in quantity of resin once poured throughout the mold. If the mold is else placed on an inclined surface the matrix resin will flow down and more of it will be concentrated at the lower gradient side which is not desirable. Checking of mold for its correct placement on a flat surface was ensured with the help of sprit level. Now the mould was filled with matrix resin and fibres in layers form for formation of composite.

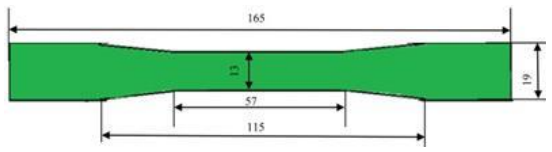
For bio-composites, the matrix material was poured in the mold so as to from first layer at bottom. Then second layer was formed above it by placing the desired bio-fibres on the first layer and was then followed by light pressing with wooden block so as to ensure submersion of fibres in matrix. Over it again a layer of matrix material was poured uniformly so as to from the third layer. This was again similarly followed by layer of fibres and matrix so as to from the fourth and fifth layer respectively. In case of metal scrap composites consisting metal chips as fibres, above similar technique was followed; however the total layers were three so that the intermediate is formed by metal chips and the peripheral ones by matrix material. Even if the composites were manufactured in layers form, the fibres got evenly distributed and dispersed into the matrix with passage of time. After this, lid in the form of flat plate was kept over the mould and above it an additional load of 500 gm was placed. This was to so as give squeezing to bio-fibres/metal chips through pressure in order to ensure proper bonding between fibre-matrix. The mould was then kept at normal atmospheric conditions to cure for a period of approximately one day. Thus by the above mentioned process the bio-fibre composites as well as metal-scrap composite mouldings were prepared.

Total seven different variants of composites were prepared by changing the composition and type of fibres as given in Table 1 [15]. From the mouldings, desired shaped specimens in the shape of dog bone structure were then cut by using hand-held disc grinder carefully and safely (see Fig. 3). These specimens were then subjected to mechanical testing.

Table 1
Composite variants manufactured for experimental testing

Variant No.	Reinforcing Material/s	Matrix Materials	Type
1	Jute		
2	Jute (*ct*)		
3	Coir	50% *R* + 50% *H*	*BC*
4	Coir (*ct*)		
5	50% Jute + 50% Coir		
6	50% Jute + 50% Coir (*ct*)		
7	Metal chips		*MSC*

ct = chemically treated; *R* = epoxy resin; *H* = hardener; *BC* = Bio-composite; *MSC* = Metal-scrap Composite; % → by vol.



(a)


(b)

Fig. 3. (a) Schematic of specimen for mechanical testing, (b) Actual cut specimen variant of manufactured composite

2.5 Mechanical Property Testing

For any given composite, the mechanical properties are most important from application point-of-view and thus its testing becomes necessary. In the current work, tensile strength was considered as it is an important mechanical property desired for majority of the applications. Thus for measuring the same, the standard setup of universal testing machine available in strength of materials lab was used. The specimens were cut to standard sizes as discussed in previous section and were tested for the tensile strength according to the ASTM D638 testing standards.

3. RESULTS AND DISCUSSION

The variation of tensile strengths for different composite variants is shown in Fig. 4. It is observed that different variants have quite varying levels of tensile strength. This variation is dependent on the type of the fibres as well as their combinations incorporated.

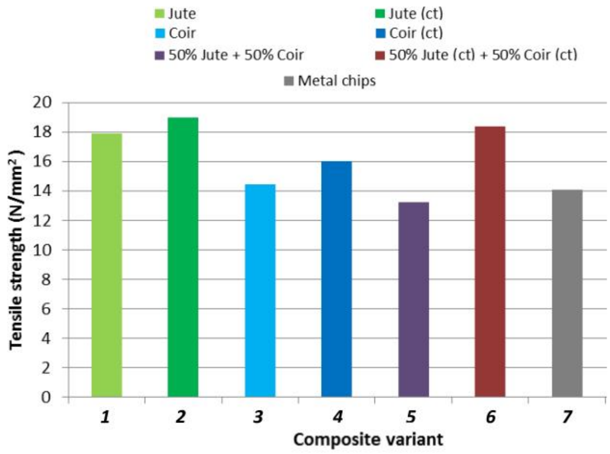


Fig. 4. Tensile strength for different composite variants

Considering the composites made from jute fibres (variant no. 1 and 2), their strengths are better in general as compared to other variants. However, the composite made with chemically treated jute fibres showed better strength than the ones without treatment. This can be attributed to the fact that the properties of jute fibres are enhanced due to chemical treatment which additionally enhances the strength of the composite. Considering the composites made from coir fibres (variant no. 3 and 4), the trend was similar to the ones with jute fibres although the values were lower than the same. In this case also the composites made from chemically treated coir fibres showed improvement in strength, the reason for it being the same as mentioned earlier.

Further considering the composites made by incorporating both, jute as well as coir fibres (variant no. 5 and 6), the trend was again similar to the ones with jute fibres and coir fibres. But the composite made from basic jute and coir fibres (variant no. 5) showed relatively less strength than the other composite variants. However, when the composite was prepared using chemically treated jute and coir fibres (variant no. 6), a tremendous increment in strength was noticed. This is mainly because the chemically treated fibres of both, jute and coir, contribute together for the overall increment in strength of the composite. But the strength of this composite was slightly less than the ones made from chemically treated jute fibres (variant no. 2). This is because the volume of chemically treated jute fibres as in variant no. 2 is being replaced to 50% of jute and 50% of coir fibres for the variant no. 6. Thus since the percentage of jute fibres is getting reduced and replaced by less strength coir fibres, it is overall affecting the composite strength thus leading to reduction in its tensile strength.

For the case of metal-scrap composite (variant no. 7), its strength was comparatively lower for almost all variants except variant no. 5. This is because the fibres consisting metal scrap in the form of chips were not that effective as like jute or coir in embarking the necessary strength to the composite. Also we know that the chips are formed due to metal shearing process during machining and are also subjected to thermal stresses in the same process on account of high cutting temperatures. Thus mechanical and thermal stresses degrade the properties of the chips through subjecting it to indirect heat treatment further causing a reduction in their strength through metallurgical changes. Thus the composite manufactured from such metallurgically altered material obviously leads to its poor strength characteristics. However it's worth appreciable that the metal-scrap composite is still better, the reason for the same being that its tensile strength is more than that of composite made from jute cum coir fibres (variant no. 5).

Overall almost all the composites made of bio-fibres, simply termed as bio-composites, are in general better in terms of tensile strength as compared to metal-scrap composite. These bio-composites should be effectively used for suitable applications demanding higher tensile load bearing capacities on a mass scale. Metal-scrap composite also can still find suitable applications, even though on limited basis, as its strength is appreciably better in certain aspects. Thus manufacturing of green composites and their incorporation in practical applications should be primarily given due consideration on account of its economic as well as environmental view-points driven towards sustainability.

4. CONCLUSIONS

The experimental investigation leads to the following conclusions.

- All the manufactured green composite variants, be it bio-composites or metal-scrap composites, had varying tensile strengths depending on the incorporated fibres.
- Chemical treatment of fibres leads to increase in the strength of the composites, irrespective of whether the fibres are of jute or coir or even their combination.
- Bio-composites made through incorporating jute fibres showed comparatively overall better strength and thus can be given primary consideration during selection of bio-composite for typical applications.
- Metal-scrap composites, even though being lower in strength in comparison to majority of the manufactured and investigated bio-composites, still have wide scope for applications on account of its better properties as well as due to potential for waste scrap utilisation in an alternate useful manner.
- Both green composites, bio-composites and metal-scrap composites, are economic as well as environmentally friendly and thus need to be utilized in applications.

References

[1] M.E. Ibrahim, Nondestructive evaluation of thick-section composites and sandwich structures: A review, *Composites: Part A*, 64 (2014) 36-48.

[2] Michael P.M. Dicker, Peter F. Duckworth, Anna B. Baker, Guillaume Francois, Mark K. Hazzard, Paul M. Weaver, Green composites: A review of material attributes and complementary applications, *Composites: Part A*, 56 (2014) 280-289.

[3] V. Mittal, R. Saini, S. Sinha, Natural fiber-mediated epoxy composites - A review, *Composites Part B*, 99 (2016) 425-435.

[4] K.L. Pickering, M.G. Aruan Efendy, T.M. Le, A review of recent developments in natural fibre composites and their mechanical performance, *Composites: Part A*, 83 (2016) 98-112.

[5] N. Saba, M. Jawaid, Othman Y. Alothman, M.T. Paridah, A review on dynamic mechanical properties of natural fibre reinforced polymer composites, *Construction and Building Materials*, 106 (2016) 149-159.

[6] A. Mader, A. Kondor, T. Schmid, R. Einsiedel, J. Mussig, Surface properties and fibre-matrix adhesion of man-made cellulose epoxy composites - Influence on impact properties, *Composites Science and Technology*, 123 (2016) 163-170.

[7] Josep Claramunt, Lucia J. Fernandez-Carrasco, Heura Ventura, Monica Ardanuy, Natural fiber nonwoven reinforced cement composites as sustainable materials for building envelopes, *Construction and Building Materials*, 115 (2016) 230-239.

[8] Bo Madsen, Mustafa Aslan, Hans Lilholt, Fractographic observations of the microstructural characteristics of flax fibre composites, *Composites Science and Technology*, 123 (2016) 151-162.

[9] Neng Sri Suharty, Hanafi Ismail, Kuncoro Diharjo, Desi Suci Handayani, Maulidan Firdaus, *Procedia Chemistry*, 19 (2016) 253-258.

[10] K Deepak, N Srinivasa Reddy, T V Seshaiah Naidu, Thermosetting Polymer and Nano Clay based Natural Fiber Bio-Composites, *Procedia Materials Science*, 10 (2015) 626-631.

[11] Subhankar Biswas, Sweety Shahinur, Mahbub Hasan, Qumrul Ahsan, Physical, Mechanical and Thermal Properties of Jute and Bamboo Fiber Reinforced Unidirectional Epoxy Composites, *Procedia Engineering*, 105 (2015) 933-939.

[12] Emad Omrani, Pradeep L. Menezes, Pradeep K. Rohatgi, State of the art on tribological behavior of polymer matrix composites reinforced with natural fibers in the green materials world, *Engineering Science and Technology*, 19 (2016) 717-736.

[13] David B. Dittenber, Hota V.S. GangaRao, Critical review of recent publications on use of natural composites in infrastructure, *Composites: Part A*, 43 (2012) 1419-1429.

[14] Asian Paints Ltd. India, Loctite Tough, *Weblink: https://www.asianpaints.com/product/adhesives.loctite-tough.html*

[15] Ganesh S. Kadam, Ayush Labroo, Vignesh Mudaliar, Rohan Bhandikeri, Atluri Vamsi, Concocting and analysis of composites from machining scrap and biomaterials, *Unpublished Thesis - SIES GST*, Nerul, Navi Mumbai, M.S., India, 2017.