

Effective Utilisation Of Textile Waste In Green Composite Manufacturing

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Abstract: *The global textile industry is unlike before has branched and become multiverse with a production rate increased in multi-folds. The increasing population, their increasing rate of consumption, quick changing fashion trends have also fuelled these rate of the apparels being discarded before the end of their lifetime which is a raising environmental concern. These fabric scraps if effectively used in making composite materials could open up to whole new areas of application. In the past decade, natural fiber composites based on petroleum based thermoplastics or thermosets matrices have been used in various industrial sectors. However, these natural fiber composites are not fully environmentally friendly because matrix resins are non-biodegradable. Therefore, biodegradable composites based on natural fibers and biodegradable polymeric matrix made from cellulose, starch, and other natural resources are called “green composites” and have been developed because of their environmentally beneficial properties. Natural fibers offer good opportunities as a reinforcement material for composites providing the positive benefit to the ecological and environmental advantage and the attractive mechanical properties. The explorations of natural fiber as green materials are alternative for synthetic polymer fibre in composite because of their advantages such as low cost, low density, renewability, biodegradability and acceptable specific strength. These natural fiber can be utilized for structural or semi-structural materials in various fields including aerospace, automotive, building, furniture, packaging and sport articles.*

Keywords-Composite, Textile Recycling, Bio-composite

1. INTRODUCTION

Textile materials are a major part of our day to day lives. They have become an indispensable part of our lifestyle with their versatile number of applications. The global textile industry is unlike before has branched and become multiverse with a production rate increased in multi-folds. Textile production processes requires high volume of water, energy and chemicals with generation of wastes in every step in the production line and after its lifetime it is discarded as waste. The increasing population, their increasing rate of consumption, quick changing fashion trends have also fuelled these rate of the apparels being discarded before the end of their lifetime. And this alarming rate of increase in consumption of apparels and home textile products demands increases the rates of production which in turn consumes a large amount of resources along-side generating

large quantities of textile wastes that are disposed, which is a raising environmental concern. These disposed wastes are of many categories and they have been classified and sorted according to their types and made use of for years. But not all the products that are discarded can be recycled or reused, those that cannot be made use of in any form are being incinerated or sent to land-fills which is an unlikely way of disposal as it possess a threat to the environment. Even though these recycling processes have been in practice all these years, further optimization and newer techniques and easier, simpler processing methods can efficiently make use of these abundant amount of textile wastes by reducing environmental pollution whilst utilizing the materials, maintaining the sustainability in all levels of energy resources and environmental context. These fabric scraps if effectively used in making composite materials could open whole new areas of application. In the past decade, natural fiber composites based on petroleum based thermoplastics or thermosets matrices have been used in various industrial sectors, especially in automobile industry such as door panels, seat backs, headliners, package trays, dashboards, and interior parts [1,2].

However, these natural fiber composites are not fully environmentally friendly because matrix resins are non-biodegradable [3]. Therefore, biodegradable composites based on natural fibers and biodegradable polymeric matrix made from cellulose, starch, and other natural resources are called “green composites” and have been developed because of their environmentally beneficial properties [4–8]. In general, the research and development of natural fiber biodegradable composites from renewable resources for a wide range of applications is increasing due to their advantages, such as eco-friendliness, lightweight, carbon dioxide reduction and biodegradable characteristics.

Several studies have shown that natural fibers have a slight impact on the environment when compared with the inorganic fibers such as glass fiber due to their biodegradability. Most of researchers agree that healthier ecosystem can be attained with the natural fibers while their low cost and high performances are very interesting for industry and the researchers. Another advantage of using natural waste in the composite production is their recyclability. Many studies have been done about the natural fiber reinforced composites. For example, Iannace et al. (2001) used sisal fibers in the composites for their researches while reinforcement or filler element in polymeric matrix to minimize the usage of plastics. Utilization of wastes in this way is expected to be both economical and environmentally useful in the near future. Natural fiber offer good opportunities as a reinforcement material for composites providing the positive benefit to the ecological and environmental advantage and the attractive mechanical properties. The explorations of natural fiber as green materials are alternative for synthetic polymer fiber in composite because of their advantages such as low cost, low density, renewability, biodegradability and acceptable specific strength. The natural fiber have been utilized for structural or semi-structural materials in various fields including aerospace, automotive, building, furniture, packaging and sport article [1-4]

2. MATERIALS AND METHODS

A. Cotton

The fabrics sourced primarily include fabric cut wastes from various garments industries which are left on the floor during pattering. The fabric parameters can be obtained from the industry as it is pre-consumer waste. And it was sorted according based

on the nature of its raw material as natural and synthetic fibre. These fabrics thus obtained are scraps that are of irregular dimensions and hence they were cut into smaller pieces to impart uniformity in them and the fabric chosen for the preparation of the composite is 100% cotton kintted and denim fabric.

B. Coir

Coconut fibres were purchased from the commercially available stores, dried and conditioned in room temperature for 24 hours after which it was subjected to alkaline treatment.

C. Epoxy resin – Epoxy resin LY556

(Bisphenol A Diglycidyl ether), is used as matrix material. Low temperature curing epoxy resin (araldite LY 556) and corresponding hardener (HY951) was purchased by Covai Seenu & Company were mixed in the ratio of 1:2 and 1:5 by weight for experimental purpose.

D. Polyester Resin

Polyester resin tends to have pale yellowish tint, and is suitable for most backyard projects. Its weaknesses is that it is UV sensitive and can tend to degrade over time, and thus generally is also coated to help preserve it [4]. The viscosity, specific gravity, gel time at 25°C is about 500-600 cP, 1.120-1.140 gm/m³, 15-25 min. The amount acid value is 23-27 mg KOH/gm and the volatile content 33-37% is available. Its hardener is a MEKP, and is mixed at 14 drops per oz. MEKP is composed of methyl ethyl ketone peroxide, a catalyst. When MEKP is mixed with the resin, the resulting chemical reaction causes heat to build up and cure or harden the resin.

E. Hardener- Methyl Ethyl Ketone Peroxide (MEKP)

Methyl ethyl ketone peroxide (MEKP) is organic peroxide, a high explosive similar to acetone peroxide. MEKP is a colourless, oily liquid, MEKP is slightly less sensitive to shock and temperature, and more stable in storage. The first to be reported was a cyclic dimer, C₈H₁₆O₄, in 1906. Later studies found that a linear dimer is the most prevalent in the mixture of products typically obtained, and this is the form that is typically quoted in the commercially available material from chemical supply companies

F. Accelerator - Cobalt (II) Naphthenate

Cobalt (II) naphthenate is a mixture of cobalt (II) derivatives of naphthenic acids. These coordination complexes are widely used as oil drying agents for the autoxidative cross linking of drying oils. Metal naphthenates are not well defined in conventional chemical sense that they are mixtures. They are widely employed catalysts because they are soluble in the non polar substrates, such as the alkyd resins or linseed oil. The fact that naphthenates are mixtures helps to confer high solubility. A second virtue of these species is their low cost. A well-defined compound that exhibits many of the properties of cobalt naphthenate is the cobalt (II) complex of 2-ethylhexanoic acid.

G. PLA

Poly-lactic acid (PLA) is the widely used thermoplastic aliphatic polymer produced from a lactic acid monomer through fermentation of renewable resources such as sugar cane, corn starch, sugar beet, etc. PLA has high strength, good stiffness, environment friendly, compostable and low elongation at break. It has been widely used

in several applications such as automotive parts, food packaging, medical applications and degradable plastic bags.

H. Composite from waste fabric

Various Composites were developed from denim fabric and knitted fabric in different weight ratios with epoxy resin and polyester resin as matrix and the fabric as the reinforcing material using hand layup technique. A teflon trough and of 45cm length and 20cm width with a thickness of 2.5cm owing to the ASTM standards required for tensile testing was taken as the mould for the making of the sample preparation. The samples for test procedure is to be further cut to the sample specific dimensions required for the test.

Table I
 Matric and reinforcement composition

Sample name	1	2	3	4	5	6	7	8	9	10	11	12
Name of reinforcement 1	Denim	Denim	Denim	Denim	Denim	Denim	Denim	Denim	Knitted	Knitted	Knitted	Knitted
Name of Matrix 1 (Resin)	Epoxy resin Ly556	Epoxy resin Ly556	Epoxy resin Ly556	Epoxy resin Ly556	GP resin G-0051	GP resin G-0051	GP resin G-0051	GP resin G-0051	GP resin G-0051	GP resin G-0051	Epoxy resin Ly556	Epoxy resin Ly556
Name of Matrix 2 (Hardener)	Epoxy hardener Hyper 951	Epoxy hardener Hyper 951	Epoxy hardener Hyper 951	Epoxy hardener Hyper 951	MEK P	MEK P	MEK P	MEK P	MEK P	MEK P	Epoxy hardener Hyper 951	Epoxy hardener Hyper 951
Name of Matrix 3 Accelerator	-	-	-	-	Cobalt Acid	Cobalt Acid	Cobalt Acid	Cobalt Acid	Cobalt Acid	Cobalt Acid	-	-
Weight of fabric	20	40	20	40	20	40	20	40	20	40	20	40
Weight of matrix 1	237.5	237.5	247.5	247.5	243.75	243.75	243.75	243.75	243.75	243.75	237.5	237.5
Weight of matrix 2	12.5	12.5	2.5	2.5	3.75	3.75	3.75	3.75	3.75	3.75	12.5	12.5
Weight of matrix 3	0	-	-	-	2.5	2.5	2.5	2.5	2.5	2.5	-	-

Matrix:												
Reinforcement weight ratio	12.5:01	06.5:01	12.5:01	06.5:01	12.5:01	06.5:01	12.5:01	06.5:01	12.5:01	06.5:01	12.5:01	06.5:01

The fabric was cut into smaller pieces and placed in the mould, The resin and the hardener was taken in the various ratios and mentioned in the Table 1 for varying weight ratios of the matrix and fabric respectively for 12 different combinations. The exact weight of the resin, hardener and accelerator in the case of polyester resin are mentioned in the Table 1 that is below. This was done to ensure that the components were mixed together thoroughly and then added to the mould, to ensure proper impregnation the fabric the in the resin.

I. Preparation of dry pre-pregs

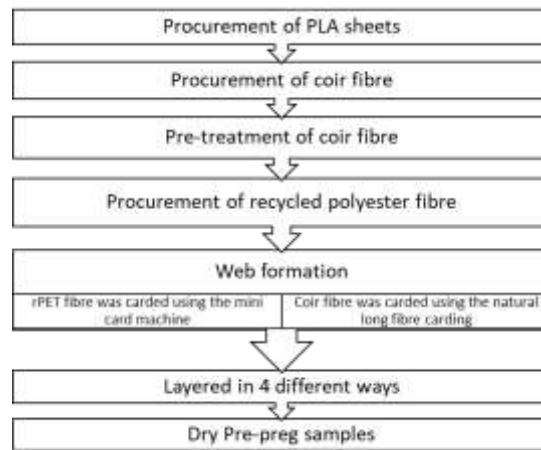


Fig 1 Process flow of preparation of dry pre-pregs.

Four different types of composites has been fabricated with four different types of layering methods with PLA sheets, coir fibre, and recycled polyester fiber taken together and subjected to compression moulding in the subsequent stage.

Alkaline treatment for coir fibre

For this process the coir fibre is taken an to remove the soluble extractives and to facilitate adhesion between fibres and matrix, the untreated coconut fibres were modified by pre-treatment with alkaline solution 5% (w/v). Furthermore the fibres were filtered in a filter and fibres were washed with distilled water. Then, solutions were left to drain and fibres were dried in an oven at 100 Degree Celsius for 8 hours.

Web preparation:

Following which the fibres and then subjected to a carding process using the natural fibre carding machine in PSG College of Technology, where the coir web was thus obtained. Then the recycled polyester fibre was also carded using the mini card machine also available in the PSG College technology. The webs thus formed where then stacked along with the PLA sheets which would melt during the compression molding process. The Fig 1 below shows the process flow sequence of the dry pre-preg

preparation method. The samples were prepared in weight ratios of the matrix PLA and recycled polyester fiber to reinforcement coir in 60 to 40 weight ratios. The layering methods were taken in four different ways to determine the changes in the final composite due to the modifications in the layering which is due to the interaction of the material which are in contact with each other and how the PLA resin and the recycled polyester fibre web reacts and binds with the subsequent layer that is adjacent to it. The weight proportions of the four samples along with the order in which they were layer is as mentioned in the Table 2. The Fig 2 shows an illustrative diagram of how the layers where placed.

Table II
 Bio-composite composition

	S1		S2		S3		S4	
	Name of Material	Material weight (g)	Name of Material	Material weight (g)	Name of Material	Material weight (g)	Name of Material	Material weight (g)
Layer 1	Coir	7.5	rPET	2.5	PLA	15	PLA	15
Layer 2	PLA	15	Coir	7.5	rPET	2.5	Coir	7.5
Layer 3	rPET	5	PLA	30	Coir	15	rPET	5
Layer 4	PLA	15	Coir	7.5	rPET	2.5	Coir	7.5
Layer 5	Coir	7.5	rPET	2.5	PLA	15	PLA	15

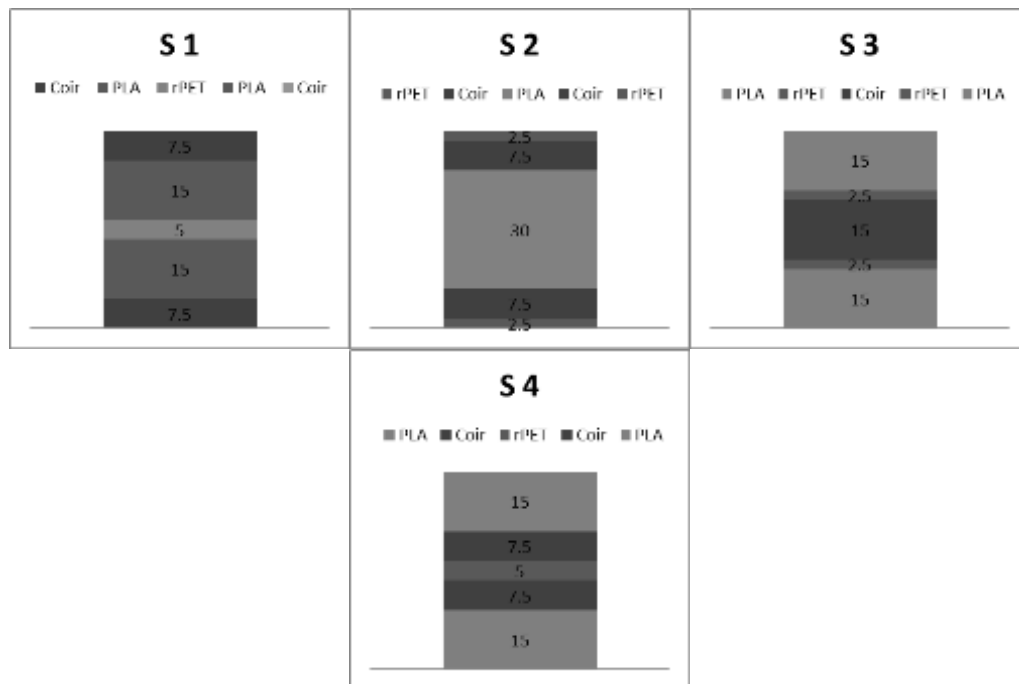


Fig 2 Layering of bio composite

Compression molding:

The samples that were layered according where then subjected to compression moulding process in the compression moulding machine at PSG college of Technology where they were subjected to a pressure of 85 bar for a time period of 15 minutes at 200 degree Celsius. The pressure, time and temperature were unaltered for all four samples.

J. Determination of Theoretical Density, Weight Fraction and Volume Fraction

Using these formulas the theoretical density, weight fraction and volume fraction is to be calculated.

$$V_f = W_f \times \frac{\rho_c}{\rho_f} \dots\dots\dots (I)$$

$$V_m = W_m \times \frac{\rho_c}{\rho_m} \dots\dots\dots (4.2)$$

$$W_f = \frac{w_f}{w_c} ; V_f = W_m \times \frac{\rho_m}{\rho_c} \dots\dots\dots (III)$$

$$\frac{1}{\rho_c} = \frac{W_f}{\rho_f} + \frac{W_m}{\rho_m} \dots\dots\dots (4.4)$$

3. RESULTS AND DISCUSSIONS

The composite samples were developed by the methodology as mentioned and the resulting samples were obtained for further testing. The samples were prepared according to the ASTM test specimen dimension specifications so as to be tested in accordance to it.

A. Hand Lay-up

The samples that were made in hand-layup method using synthetic resins were found to cure at room temperatures and slightly elevated temperatures over a time period

of 24 hours remaining undisturbed. Out of n number of trails carried out and the number of samples prepared for varying weight ratios of resin and fiber, those with a higher proportion of matrix than the reinforcement was found to be successful, with completely curing within 24 hours. Fig. 3 Shows the polyester resin/knitted fabric in taken in the ratio of fabric : reinforcement = 1 :8. The slight yellowish tinted appearance in the composite is due to the colour of the accelerator that is taken to speed up the curing action of the polyester composite.



Fig 3 Knitted fabric/GP resin [F:R= 1:8]

Fig. 4 shows Denim fabric and Epoxy resin taken in the ratio of fibre : reinforcement = 1:8 with a 2% hardener was found to have clearer looking appearance with uniform distribution of the fabric pieces in the resin. The Fig.5 shows denim fabric with epoxy resin taken in the same ratio as that of the previous one in fabric : reinforcement = 1: 8 with a hardener percentage slightly higher than the previous sample as 5%, was found to be completely cured with a neat clear almost see through appearance in the regions where the fabric was scarce with a slight pinkish tint owing to the colour of the hardener that is taken which on curing imparts the slight shade when the material was left undisturbed for a slightly longer time period than that of the polyester resin composite samples which cured at a relatively lesser time in 24 hours but here even though the epoxy curing takes place within a few minutes of addition of hardener. In order to ensure the complete curing of the sample, the sample had to be left undisturbed for a time period of 72 hours in room temperature.



Fig 4 Denim fabric/Epoxy resin [F:R = 1:8] 2%H



Fig 5 Denim fabric/Epoxy resin [F:R = 1:8] 5% H

The Fig.6 Shows Polyester resin with denim fabric taken in the ratio of 1 : 8 in its weight fraction was found to be successfully cured at room temperature when left undisturbed for a time period of 24 hours, which is followed by the Fig 7 that shows that epoxy resin with denim fabric taken in the weight ratio of fabric : resin in 1:4 showed successful curing with the addition of 5% hardener taken to result in the complete curing after 72 hours.



Fig 6 Denim/GP [F:R=1:8] 5% H



Fig 7 Denim/Epoxy [F:R=1:4] 5% H

The Fig 8 shows the knitted fabric sample in epoxy resin which was taken in the ratio of 1 : 1 with a 5% hardener which showed that the composite did not cure completely even after a time period of 72 hours and also there was improper distribution of the resin and the fabrics were not completely impregnated in the resin. And hence we can say that for the resins to properly cure and bond with the fabric the fabric that are taken has to be completely immersed in the resin with a very high amount of resin

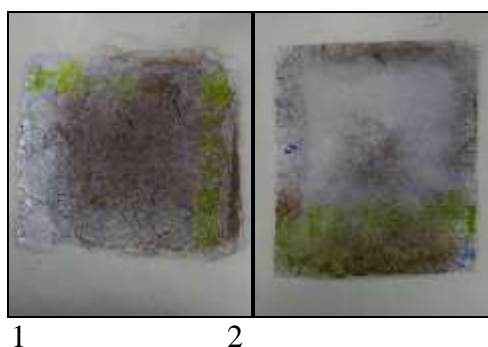
resulting in composites with very high resin content as compared to its fabric content. The presence of minute voids can be observed when viewed closely on the under-side of the composite, whereas the side that was exposed to the air had a better smoother surface. The materials were found to be sturdy and hard and it is safe to say they may have retained the mechanical strength and other physical properties of the epoxy resin as it is also taken in larger quantities as compared to the proportion fabric in them.



Fig 8 Knitted/Epoxy [F:R=1:1] 5% H

B. Compression Moulded

The samples that were made from coir and PLA resin along with the recycled polyester fibre was compression moulded after layering them in four different ways. The Fig. 9 shows the first coir composite sample which has recycled polyester web as core layered with PLA on both sides followed by a layer of coir web as the outermost layer was found have a good bonding between coir and PLA, where the PLA has melted completely and spread evenly. the PLA resin was found on the outmost surface which proves that the resin has melted and penetrated through the coir web also evenly impregnating and bonding with the coir. The sample 2 with recycled polyester fibre web as the outermost layer also shows thta the PLA resin covering over the recycled polyester web beneath which lies the coir web on both sides and the core containing PLA, hence in this case the PLA in the coir has managed to penetrate through the layers of coir and the recycled polyester thus making sure that there is proper impregnation on coir and recycled polyester fibre which undergoes Tg at the 180degree Celsius also bonds with the deformed recycled polyester making the surface smooth and even.



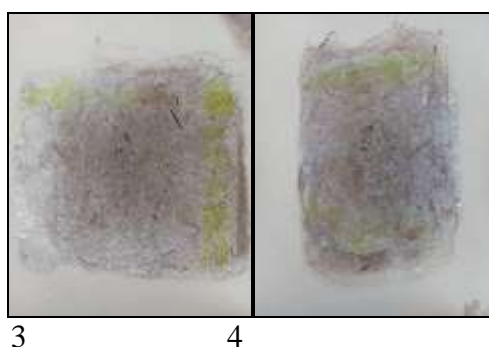


Fig 9 Compression Molded Samples

The sample 3 shows the sample that contains PLA as the outermost layer on both the sides beneath which is a layer of recycled polyester and the coir as the core. This sample was found to have PLA evenly melted and distributed throughout the surface of the sample because it was placed as the outmost layer and since polyester was beneath the PLA layer the penetration of PLA to the inner core coir was restricted and the polyester reaching Tg forms a layer which does not allow the penetration of PLA to the coir core. This sample was found to be more flexible than the others. Sample.4.shows the sample with PLA on the inside and coir beneath the PLA with recycled polyester in the core. This sample was found to be more evenly distributed with PLA on the surface almost completely impregnated on to the coir beneath it.

C. Determination of Theoretical Density, Weight Fraction and Volume Fraction

From the Table 2, calculation of theoretical density of the composite samples can be made using the weight of the components taken and the formula using weight fraction. From the weight fraction calculation the volume fraction of the samples developed can be calculated from which the volume fraction of the matrix and reinforcement is calculated. The samples that have a higher weight fraction of matrix than reinforcement were successfully cured and those that did not have higher weight fraction of matrix were uncured and failed.

4. CONCLUSION

Waste management is a versatile area that requires immediate attention due to the increasing generation of waste and its ineffective management, which if subjected to proper utilisation has high potential in the area of sustainable textile production. The various techniques in which the pre-consumer and post-consumer waste can be utilised without reprocessing mechanically or chemically dissolving it, is studied. Some of the existing methods of manufacturing the commercially available products such as rugs, mats, shoddy products that are developed through various up-cycling methods by small scale industries that collect these fabric wastes from textile manufacturing units as second hand goods or recyclable materials were also studied, to arrive at a new and alternate development technique to utilise these waste fabrics with better efficiency. The major materials that are filling up the landfills and polluting the soil and environment is the polyester which is the major contributor, following which is the cotton fibre. Utilising them in the making of composites that could be used to replacement for wooden chip board and temporary partitioning structures were developed using the waste knitted fabric scraps and denim fabric scraps along with epoxy and polyester resin resulted in sturdy structures that could easily serve the purpose of of being a replacement for wooden board

but these resins are not environmental friendly and hence an alternate for these synthetic resins were sort and PLA was chosen as it was found to be a versatile and reusable polymer which can be easily processed and made into composites as desired. These PLA based composites however cannot wet or impregnate the fabric scraps effectively and hence a natural fibre, coir was taken along as the reinforcing material.

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