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The effect of sisal fibre on the mechanical properties of polypropylene

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Abstract— Natural Fibre Composites (NFC's) nowadays are slowly replacing aluminum and other such metallic materials in automobile and aircraft industries. Interest is shown on NFC's due to their advantages including low environmental impact and low cost. In this study short sisal fibres of length 10mm were taken and reinforced in a thermoplastic such as Polypropylene (PP), using compression moulding technique. The specimens were cut according to ASTM standards and mechanical testing was carried out. Results were obtained and its mechanical properties such as Tensile, Flexural and Impact strength was analyzed for different weight fraction of sisal fibre i.e. 10%, 20%, 30% and 40%. In that, short fibre of 10% weight showed good mechanical properties in almost all cases. The mechanical properties of sisal fibre reinforced PP can be improved by suitable fibre treatment.

Index Terms— Sisal fibres, Polypropylene, Compression moulding, NFC's, Mechanical properties.

1 INTRODUCTION

A composite can be defined as Two inherently different materials that when combine together produce a material with properties that exceed the constituent materials. In other words, Composites material can be defined as a combination of a matrix and a reinforcement, which when combined gives properties superior to the properties of the individual components. Nowadays, composite materials are used in large volumes in various engineering structures including spacecrafts, airplanes, automobiles, boats, sports equipment, bridges and buildings. Widespread use of composite materials in industry is due to the good characteristics of its strength to weight ratio. The possibility of increase in these characteristics using the latest technology and various manufacturing methods has raised application range of these materials [1]. However, during the last decade, the study of filled plastic composites has simulated immense interest in meeting the future shortage of plastics materials. In fact, synthetic fibres such as nylon, rayon, aramid, glass, polyester and carbon are extensively used for the reinforcement of plastics. Nevertheless, these materials are expensive and non-renewable resources [2]. The reinforcement fibres can be cut aligned placed in different ways to affect the properties of the resulting composite. The matrix, normally a form of resin, keeps the reinforcement in the desired orientation. It protects the reinforcement from chemical attack, and it bonds the reinforcement so that applied loads can be effectively transferred [3]. The commercial Aerospace industry, which has largely been the driver of composite usage, is expected to grow at 5.5% by 2022. In 2016, global demand for Carbon fibre increased at a healthy rate of 12% to 70000 metric tonnes. Composites are extensively used in Marine industry in the manufacturing of Yachts which used around 1200 tonnes of composites till 2016.

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Polymer Matrix Composites (PMC): A polymer matrix composite (PMC) is a composite material composed of a variety of short or continuous fibre bound together by an organic polymer matrix. PMCs are designed to transfer loads between fibres through the matrix. Some of the advantages with PMCs include their lightweight, high stiffness and their high strength along the direction of their reinforcements along with good abrasion resistance and good corrosion resistance. PMCs are divided into two categories: reinforced plastics and advanced composites. The plastics are classified into 2 types, 1) Thermoplastic and 2) Thermosetting Polymer.
Thermoplastic: Thermoplasics are the plastics that, when heated, do not undergo chemical changes in their composition and so can be molded again and again
Examples: Polypropylene, Polyethylene, Polystyrene, Polyninyl chloride. Themosets or Thermosetting can melt and take shape only once, after they have solidified, they stay solid. In the Thermosetting process, a chemical reaction occurs that is irreversible. Example: Acrylonitrile butadiene styrene (ABS).

1.1 Natural fibre composites

Natural fibre composites are those in which fibres from natural resources are used. Mainly there are two types of fibres, synthetic fibres and natural (vegetable) fibres. In recent years, polymer composites containing vegetable fibres have received considerable attention both in literature and in industry. The interest in natural fibre reinforced polymer composites is growing rapidly due to the high performance in mechanical properties, significant processing advantages, low cost and low density. Natural fibres are renewable resources in many developing countries of the world; they are cheaper, pose no health hazards and, finally, provide a solution to environmental pollution by finding new use for waste materials. Furthermore, natural fibre reinforced polymer composites form a new class of materials which seem to have good potential in the future as a substitute for scarce wood and wood based materials in structural applications. Fibres obtained from the various parts are known as vegetable fibres. These fibres are classified into three categories depending on the part of the plant from which are extracted.

- Bast or Stem fibres (jute, mesta, banana etc.)
- Leaf fibres (sisal, pineapple, screw pine etc.)
- Fruit fibres (cotton, coir, oil palm etc.)

Vegetable fibres can be considered as naturally occurring composites consisting mainly of cellulose fibrils embedded in lignin matrix. These cellulose fibrils are aligned along the length of the fibre, irrespective of its origin, i.e. whether it is extracted from stem, leaf or fruit. It appears that such an alignment renders maximum tensile and flexural strengths. Since natural fibres are strong, light in weight, abundant, non-abrasive, non-hazardous and inexpensive, they can serve as an excellent reinforcing agent for plastics. Vegetable fibres posses moderately high specific strength and stiffness and can be used as reinforcing materials in polymeric resin matrices to make useful structural composite materials [2].

1.2 Structure and Properties of Sisal Fibre

Sisal fibre is obtained from the leaves of the plant *agave sisalana,* which was originated from Mexico and is now mainly cultivated in East Africa, Brazil, Haiti, India and Indonesia. It is grouped under the broad heading of the "hard fibres" among which sisal is placed second to manila in durability and strength. The name "sisal" comes from a harbour town in Yucatan, Maya, Mexico. It means cold water. Agave plants were grown by the Maya Indians before the arrival of the Europeans. They prepared the fibres by hand and used it for ropes, carpets and clothing. It is one of the most extensively cultivated hard fibre in the world and it accounts for half the total production of textile fibres. The reason for this is due to the ease of cultivation of sisal plants, which have short renewing times, and is fairly easy to grow in all kinds of environments. A good sisal plant yields about 200 leaves with each leaf having a mass composition of 4% fibre, 0.75% cuticle, 8% other dry matter and 87.25% moisture. Thus a normal weighing about 600g yields about 3% by weight of fibre with each containing about 1000 fibres. The diameter of the fibre varied from 100 microns to 300 microns [2].

1.3 Polypropylene

Polypropylene, also known as polypropene, is a thermoplastic polymer used in a wide variety of applications. An addition polymer made from the monomer propylene, it can be produced in a variety of structures giving rise to applications including packaging and labelling, textiles, plastic parts and reusable containers of various types, laboratory equipment, automotive components, and medical devices. It is a white, mechanically rugged material, and is resistant to many chemical solvents, bases and acids [4]. As polypropylene is resistant to fatigue, most plastic living hinges, such as those on flip-top bottles, are made from this material. However, it is important to ensure that chain molecules are oriented across the hinge to maximise strength. A common application for polypropylene is as bi-axially oriented polypropylene (BOPP). These BOPP sheets are used to make a wide variety of materials including clear bags. When polypropylene is bi-axially oriented, it becomes crystal clear and serves as an excellent packaging material for artistic and retail products. Polypropylene, highly colourfast, is widely used in manufacturing carpets, rugs and mats to be used at home.

Polypropylene is in many aspects similar to polyethylene, especially in solution behaviour and electrical properties. The methyl group improve mechanical properties and thermal resistance, although the chemical resistance decreases. The properties of polypropylene depend on the molecular weight and molecular weight distribution, crystallinity, type and proportion of comonomer (if used) and the isotacticity [5]. The density of PP is between 0.895 and 0.92 g/cm^3. Therefore, PP is the commodity plastic with the lowest density. With lower density, moldings parts with lower weight and more parts of a certain mass of plastic can be produced. The Young's modulus of PP is between 1300 and 1800 N/mm^2 [5]. Perfectly isotactic PP has a melting point of 171^{0}C. Commercial isotactic PP has a melting point that ranges from 160 to 166^{0}C depending on atactic material and crystallinity. Syndiotactic PP with a crystallinity fo 30% has a melting point of 130^{0}C. Below 0^{0}C, PP becomes brittle. The thermal expansion of PP is very large, but somewhat less than that of polyethylene. The melt flow rate (MFR) or melt flow index (MFI) is a measure of molecular weight of polypropylene. The measure helps to determine how easily the molten raw material will flow during processing. Polypropylene with higher MFR will fill the plastic mold more easily during the injection or blow-molding production process. As the melt flow increases, however, some physical properties, like impact strength, will decrease.

1.4 Compression Moulding

Compression molding is a well known technique to develop variety of composite products. It is a closed molding process with high pressure application. Two matched metal molds are used to fabricate composite product. In compression molder, base plate is stationary while upper plate is movable. Reinforcement and matrix are placed in the metallic mold and the whole assembly is kept in between the compression molder. Heat and pressure is applied as per the requirement of composite for a definite period of time. The material placed in between the molding plates flows due to application of pressure and heat and acquires the shape of the mold cavity with high dimensional accuracy which depends upon mold design. Curing of the composite may carried out either at room temperature or at some elevated temperature. After curing, mold is opened and composite product is removed for further processing. In principle, a compression molding machine is a bkind of press which is oriented vertically with two molding halves (top and bottom halves). Generally, hydraulic mechanism is used for pressure application in compression molding. If applied pressure is not sufficient, it will lead to poor interfacial adhesion of fiber and matrix. If pressure is too high, it may cause fiber breakage, expulsion of enough resin from the composite system. If temperature is too high, properties of fibers and matrix may get changed. If temperature is low than desired, fibers may not get properly wetted due to high viscosity of polymers especially for thermoplastics. If time of application of these factors (pressure and temperature) is not sufficient (high or low), it may cause any of defects associated with insufficient pressure or temperature. The other manufacturing factors such as mold wall heating, closing rate of two matched plates of the plates and de-molding time also affect the production process.

2 MATERIALS

For this study, Polypropylene is used as matrix material which is having a melting point in the range of 150-165^{o}C (deg. celcius) and density of 0.9 g/cm^3 in pellet form. It was supplied by Mangal Plastics, Mangalore. The fibre used was sisal fibre in short form, of length 10mm and of diameter 100-300 microns which was supplied by Shrilaxmi Group Cheprukpalli, Guntur, Andra Pradesh. The density of sisal fibre was 1.5 g/cm^3 and Tensile strength is 300Mpa.

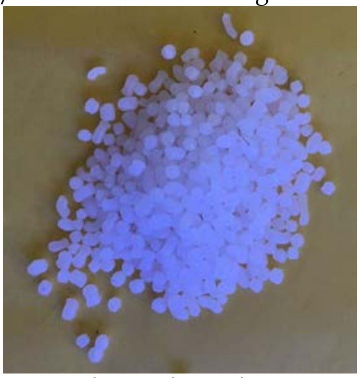

Fig. 1: Polypropylene

Fig. 2: Short Sisal Fibre

3 PRODUCTION OF COMPOSITES

The complete work of production of composite was done at The Energy and Resource Institute (TERI), Bangalore. Prior to compression moulding, the matrix and the fibre were thoroughly blended. The machine used for this was Plastograph EC plus Brabender at an rpm of 25 and at a temperature of 150^{0}C. The blended product was a thick paste of both the constituents. It is also called as pre-preg. After this the blend was taken into the compression moulding machine, where the blend was pressed at a pressure of 80bar and a temp. of 150^{0}C for 60 minutes. After that, compressed sheet is allowed to cool for 45 minutes in the mould. Then the pressed sheets were taken out and cut according to ASTM standards for Tensile, Flexural and Impact testing.

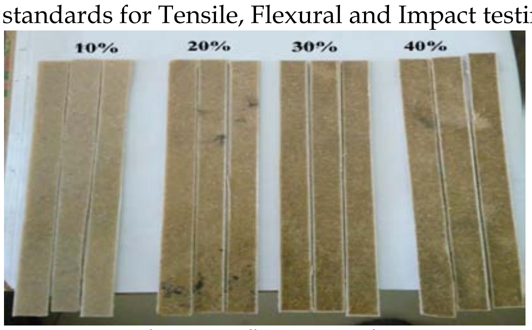

Fig. 3: Tensile Test Specimens

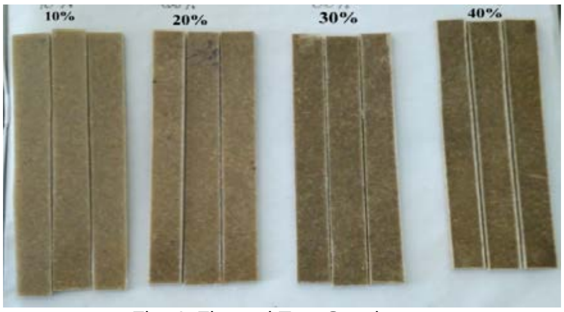

Fig. 4: Flexural Test Specimens

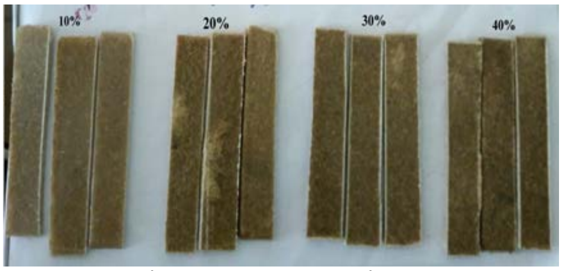

Fig. 5: Impact Test Specimens

4 RESULTS AND DISCUSSION

4.1 Tensile Test

The specimen which was cut as per ASTM standard was tested in Zwick/Roell machine. Strain rate result obtained when ultimate tensile v/s % weight graph is drawn following trend is obtained.

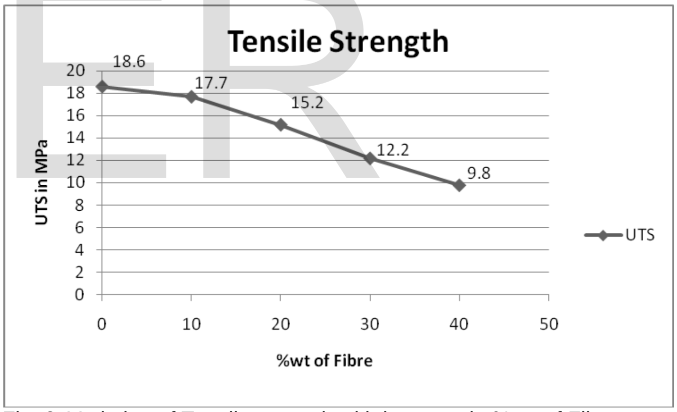

Fig. 6: Variation of Tensile strength with increase in % wt of Fibre

Tensile strength of pure polypropylene is 18.6MPa. From the above figure it can be seen that 10 percent fibre weight composite showed maximum strength of 17.7 MPa. The minimum strength of the composite is observed at 40 percent fibre weight of the composite. As the fibre weight of the composite increases, strength of the composite decreases. The decrease in strength is mainly due to the poor bonding between fibre and matrix.

4.2 Flexural Test

The specimen which was cut as per ASTM standard was tested in Zwick/Roell machine. Strain rate result obtained when Flexural Strength v/s %weight graph is drawn following trend is obtained.

The Flexural strength of pure polypropylene is 29.2MPa. From the above figure it can be seen that 10% fibre weight composite has the maximum Flexural strength of 29.6MPa. The minimum strength of 26.4MPa is obtained for 30% fibre weight composite. The Flexural strength is maximum at 10% and decreases upto 30%, but suddenly increases to 27MPa at

40% weight of fibre. This again may be due to poor bonding between fibre and matrix.

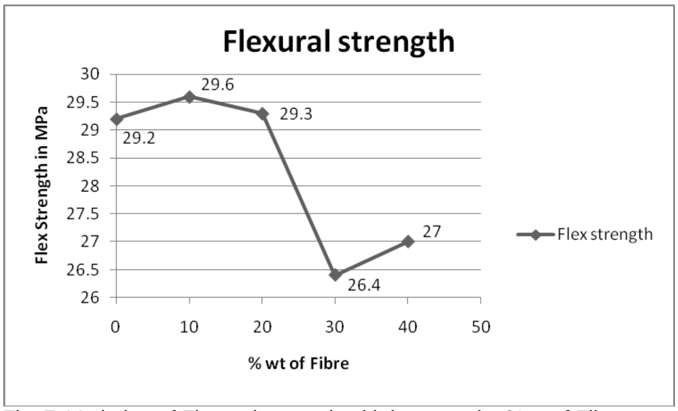

Fig. 7: Variation of Flexural strength with increase in %wt of Fibre

4.3 Impact Test

The specimens which were cut as per ASTM standard was tested in Zwick/Roell machine. Strain rate result obtained when Impact Strength v/s %weight graph is drawn following trend is obtained.

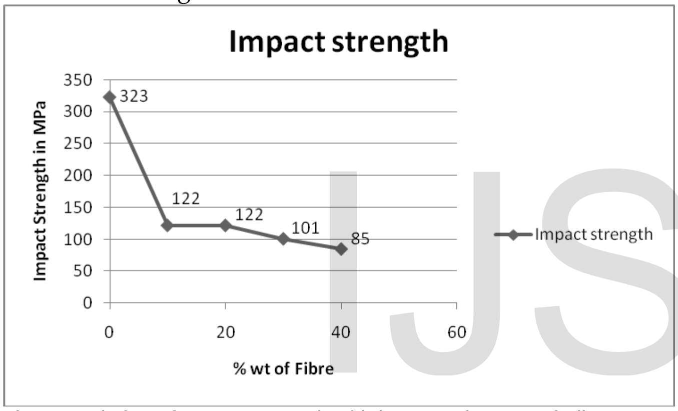

Fig. 8: Variation of Impact strength with increase in % wt of Fibre

Impact strength of pure polypropylene is 323MPa. From the above figure it can be seen that 10 and 20% fibre weight composite showed same maximum strength of 122MPa. The minimum Impact strength of the composite is observed at 40% weight of fibre, which is 85MPa. As the fibre weight increases the Impact strength decreases. This may be due to poor bonding of fibre and matrix.

When all three properties are combined and analysed, the 10% fibre weight composite showed best results for Tensile, Impact and Flexural strength compared all other fibre weight composites.

4.4 Scanning Electron Microscope (SEM) Images

When the broken surfaces are examined with the help of SEM, images shows that fibres are randomly distributed throughout the matix and it is also visible that there is fibre pull out from the matrix. The poor bonding between the fibre and matrix resulted in poor strength of the composite.

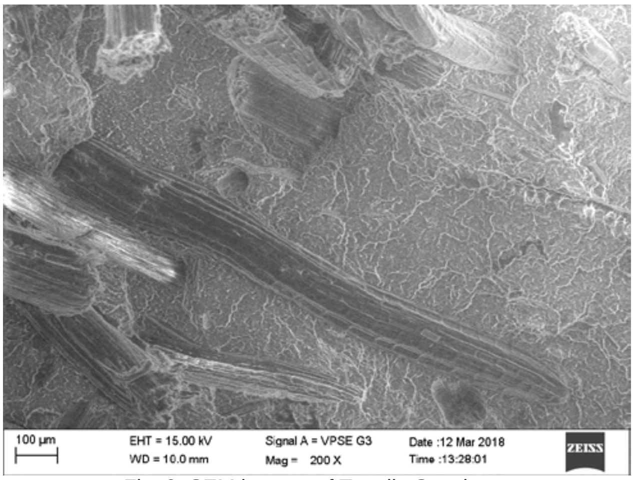

Fig. 9: SEM images of Tensile Specimen

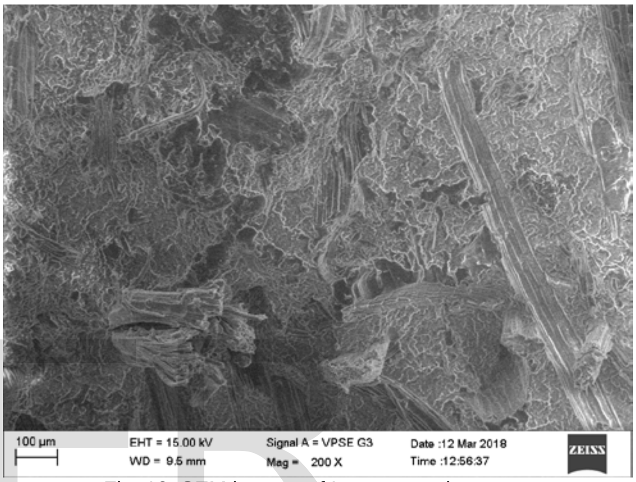

Fig. 10: SEM images of Impact specimen

5. CONCLUSION

Sisal fibre reinforced Polypropylene Composites can be manufactured using compression moulding technique. When its properties were evaluated following conclusions were made. 10% weight short sisal fibre reinforced composite showed good mechanical properties compared to the all other composites. In all composites with different fibre ratio, as the fibre weight percentage increases there was a decrease in strength. The decrease of strength may be due to the improper bonding between fibre and matrix which can be seen in SEM images. The strength of the composites can be improved by the suitable fibre treatment methods. So it becomes a necessary criteria of fibre treatment before fabricating sisal fibre reinforced polypropylene composite for better strength.

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