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Experimental Analysis of Wheat Bran Composite for Lightweight Fuel Tank Applications

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Abstract: Since last 50 years, awareness about finding a suitable alternative to steel as a material for fuel tank, has been increased in order to eliminate the demerits of steel like corrosive nature and higher weight. Polymers are looked upon by researchers as a promising option for fuel tank material. Among the polymers, High Density Polyethylene (HDPE) is extensively researched in the last three decades of twentieth century. But by considering complex geometry of fuel tank, the flexibility of Linear Low-Density Polyethylene (LLDPE) is found to be very helpful and LLDPE also allows to further reduce the weight of the fuel tank. In last two decades there is extensive research on further improving the properties of LLDPE by making composite using plant fiber. Wheat Bran (WB) is a waste material from agro industries and is recycled by using as a reinforcement material to LLDPE. So, LLDPE-WB composite as a material for the fuel tank, formed using compression moulding technique, is considered in this study. Tensile properties of the LLDPE-WB composite are experimentally evaluated and compared with LLDPE (without reinforcement). It has been found that the tensile strength of the LLDPE-WB decreases while the tensile modulus of the LLDPE-WB increases, as compared to LLDPE. Percentage elongation at break decreases drastically for LLDPEWB composite as compared to LLDPE, which is very widely observed behaviour in case of any plant fiber composite of LLDPE.

Index Terms - Nonwovens; Polyester fibres; Cold weather apparel; Thermal insulation.

1.INTRODUCTION

1.1 Polymers as a material for fuel tank

Steel has been used for fuel tanks since cars were first produced. Corrosivity has been shown to be one of this material's main drawbacks. This started to be a problem from the interior of the product, while underbody sealing (using PVC plastisols, for example) had been effective at preventing corrosion from the outside. Additionally, when cars began to include a growing number of advanced technical elements, the space available for the gasoline tank shrank. The fuel tank was originally intended to fit in the car trunk or behind the final row of seats, but it eventually became standard practise to put the fuel tank under the rear half of the automobile. In order to fulfil numerous needs, such as maximising trunk volume, safety features, and availability of enough room for the back axle and muffler, additional forming requirements had to be made. Realizing the intricate fuel tank geometries using metal stampings got more and more challenging[1].

Polymers appeared to provide enough advantages over traditional metal items. They were corrosion-free and certainly lightweight. Connections become simpler to form. Even while the walls were thicker than in metal tanks and filled the entire underbody area, there was also an increase in filling volume. Due to the ability of polymers to get moulded, optimal tank shapes were made possible with little interference from production restrictions, as evidenced in saddle tanks for four-wheel-drive vehicles.

1.2Matrix for plant fiber composite

In composites, the reinforcing components are held together by surface connection using a matrix. A form of thermoplastic material from the polyolefin family is polyethylene. Both amorphous and crystalline regions can be found in polyethylene. Because of the more effective packing of molecules provided by linear polymer chains, crystallinity is increased. However, sidechain branching lessens the crystallinity to some extent. However, it decreases stress-crack resistance, permeability, and impact strength while increasing density, stiffness, hardness, tensile strength, heat and chemical resistance, creep resistance, and barrier characteristics.

1.2.1 Linear Low Density Polyethylene (LLDPE)

The structure of LLDPE has a linear backbone, but like the longer branches of LDPE, it also features short, uniform branches that keep the polymer chains from packing tightly together. The gas-phase LLDPE method has demonstrated the most versatility in producing resins across the whole commercial range.

Table 1 Types of Polyethylene with its characteristics

Material	Chain Structure	Density (g/cm^3)	Crystallinity (%)	Process
LDPE	Branched	0.912–0.94	50	High pressure
LLDPE	Linear/less branched	0.92–0.94	50	Low pressure
HDPE	Linear	0.958	90	Low pressure

LLDPE has a significantly stronger stress-crack resistance than LDPE with the same melt index and density. Puncture resistance, tensile strength, tensile elongation, and low- and high-temperature toughness can all be compared similarly. LLDPE enables the producer to create a product that is stronger at the same gauge or equivalent at a smaller gauge. Many architectures (such as blow moulding, injection moulding, rotational moulding, etc.) can be processed with LLDPE using the same machinery now in use for processing LDPE.

The key benefits of LLDPE are that the polymerization conditions use less energy and that the properties of the polymer may be changed by adjusting the kind and quantity of its chemical constituents. LLDPE is an excellent material for components for home goods, closures, lids, extruded pipe and tubing, toys, bottles, and drum liners, wire and cable insulation and jacketing applications.

1.3 Plant fibers

The dimensions, crystallite content, orientation, and thickness of the cell walls all affect the properties of a single fibre. Despite being more rigid than brittle synthetic fibres, plant fibres do not fracture during processing. Similar to glass fibres, plant fibres have similar specific strength and stiffness characteristics. A retting process is used to remove the bast fibres from the stem ribbon. This kind of fibre is reasonably priced, performs well, and is widely accessible. It also has a moderately high tensile strength and stiffness. When strength, weight, and noise absorption are crucial, as they are in the building and automobile industries, this fibre is more appropriate. Except for those grown in temperate regions with heavy pesticide use, the majority of plant fibres are considered as eco-friendly fibres because they are biodegradable and have no harmful effects on the environment (e.g., flax) [2].

The advantages of plant fiber over synthetic fiber are that these are less expensive, lightweight, have higher flexibility, renewable, biodegradable, have good thermal and sound insulation properties, eco-friendly, nontoxic, lower energy consumption, zero residues when incinerated and no skin irritations. Plant fiber composites have acceptable mechanical properties such as elongation, ultimate breaking force, flexural properties, impact strength, acoustic absorption, suitability for processing, and crash behaviour, which also increases its demand for automobile components. So, these plant fibers can become a viable alternative for expensive and non-renewable synthetic fibers.

1.4 Moulding technique

For producing many useful products of polyethylene, compression moulding is a popular technique. The process consists of heating the polymer in a closed mould and the external pressure is applied during compression moulding, which results in formation of products in the form of sheet. From the valuable research of various researchers, it can be concluded to suggest that among polyethylene, LLDPE is widely preferred for compression moulded product. So, compression moulding should be selected for moulding of LLDPE composites formed by using plant fibers.

1.5 Tensile properties

The tensile properties of plant fiber composites are mainly affected by the interfacial adhesion between the resin and fibers. An optimum amount of physical modification of the fiber and resin enhances the tensile properties of composites. Tensile properties that can be used for understanding material behaviour under tensile loading are tensile strength (TS) and tensile modulus (TM).

2. LITERATURE REVIEW

A study by Vishnu et al. [3] uses the composite material of LLDPE made using Areca fiber as a reinforcement material, formed by compression moulding. Two compositions of LLDPE/Areca composite material are formed by adding 5 and 25 weight percentage of Areca fiber fillers. The performance of LLDPE/Areca composite material, in terms of tensile strength, Young's modulus, toughness and percentage elongation, is found to be significantly decreasing as compared to LLDPE material. Increasing percentage of Areca fiber lowers the performance of LLDPE/Areca composite material.

A study by Nestore et al. [4] uses the composite material of LLDPE made using textile waste fiber of cotton, flax, and hemp as a reinforcement material, formed by compression moulding. Four samples of composite material using LLDPE are prepared by considering the percentage of reinforcement material to be 10%, 20%, 30% and 40% (with fiber length of 1 mm). The LLDPE/Hemp composite material with 30% of reinforcement material is found to be having highest tensile and flexural strength while the LLDPE/Cotton composite material with 40% of reinforcement material is found to be having highest elastic modulus in bending. The LLDPE/Hemp and LLDPE/Flax composite material with 30% of reinforcement material is also studied by having five different fiber lengths of 0.25 mm, 0.5 mm, 1 mm, 2 mm and 3 mm. The LLDPE/Hemp and LLDPE/Flax composite material with 30% of reinforcement material are performing better when the fiber length is 1 mm.

A study by Jirimali et al. [5] uses the composite material of LLDPE made using waste eggshell-derived calcium oxide (E-CaO) and hydroxyapatite (E-HAP) as a reinforcement material, formed by melt compounding followed by injection moulding. Five samples are prepared by considering the percentage of reinforcement material to be 1%, 2%, 3%, 4%, and 5%. It has been found that even with the increase in the percentage of reinforcement material in amount as low as 5%, the performance of the LLDPE/CaO, in terms of tensile strength, Izod impact strength, and hardness (Shore D), gets improved significantly.

A study by Banat et al. [6] uses the composite material of LLDPE made using olive pomace flour (OPoF) [7], formed by extrusion and hot press processing, followed by compression moulding. Four samples are prepared by considering the percentage of reinforcement material to be 5%, 10%, 20%, and 40%. The tensile stress at yield and Young's modulus are found to be higher for LLFPE/OPoF composite than LLDPE except for the sample with 40% reinforcement. The tensile stress at rupture slowly goes on decreasing with increase in amount of reinforcement in LLFPE/OPoF composite, when compared with LLDPE. The Izod impact strength drastically goes on decreasing with increase in amount of reinforcement in LLFPE/OPoF composite, when compared with LLDPE.

A study by Balaed et al. [8] uses the composite material of LLDPE made using Typha latifolia fiber (TLF) as a reinforcement material, formed by compression moulding. Four samples are prepared by considering the percentage of reinforcement material to be 15%, 30%, 45%, and 60%. The tensile strength found to be lower for LLFPE/TLF composite than LLDPE but the decrement of tensile strength with increment in reinforcement higher than 30% is almost negligible. As the amount of reinforcement in LLFPE/TLF composite increases above 30%, the modulus of elasticity increases slowly, when compared with LLDPE. The percentage elongation at break drastically goes on decreasing with increase in amount of reinforcement in LLFPE/TLF composite, when compared with LLDPE.

A study by Zaman et al. [9] uses the composite material of LLDPE formed using Coir fiber (CF) and Abaca fiber (AF), as a reinforcement material, formed by compression moulding. Two separate samples of LLDPE/CF and LLDPE/AF are prepared by considering the amount of reinforcement material to be 30%. The performance of LLDPE/CF and LLDPE/AF is found to be improved very significantly in terms tensile strength, flexural strength, percentage elongation at break, tensile modulus, and flexural modulus when compared with LLDPE.

A study by Boujelben et al. [10] uses the composite material of LLDPE formed using almond shell powder (ASP), as a reinforcement material, formed by compression moulding. Five samples are prepared by considering the amount of reinforcement material to be 5%, 10%, 20%, 30% and 40%. The tensile strength is found to be decreasing slowly with increase in amount of reinforcement when compared with LLDPE. The tensile modulus and hardness (Shore D) of LLDPE/ASP is found to be increasing significantly with increase in amount of reinforcement as compared to LLDPE.

A study by Abhilash and Singaravelu [11] uses the composite material of LLDPE formed using Bamboo fiber (BF), as a
reinforcement material, formed by rotational moulding. Three samples are prepared by considering the percentage of reinforcement material to be 5%, 10%, and 15%. In terms of tensile strength, flexural strength, impact strength, the performance of LLDPE/BF composite material is found to be improved by 5% reinforcement, and beyond that, the performance is reverted.

The performance of LLDPE/BF composite material in terms of hardness (Shore D) is found to be declined when compared with LLDPE.

A study by Sam et al. [12] uses the composite material of LLDPE formed using soya powder (SP), as a reinforcement material, formed by compression moulding. Six samples are prepared by considering the amount of reinforcement material to be 5%, 10%, 15%, 20%, 30% and 40%. The tensile strength and percentage elongation at break is found to be decreasing significantly with increase in amount of reinforcement when compared with LLDPE. The tensile modulus is found to be increasing slowly with increase in amount of reinforcement when compared with LLDPE.

3. RESEARCH PLAN

3.1 Wheat Bran for reinforcement

It has been noticed in earlier studies involving the addition of wheat bran to polymer matrixes that there is a positive impact of protein content on the melt flow index of polymer melt [13, 14]. The flowability of composites comprising brewers' spent grain, a by-product of the brewing industry, which comprises over 21 wt % of proteins, showed the greatest improvement with the addition of wheat bran when compared to that of olive stone flour. Wheat bran was successfully used as a low-cost substitute for the conventional lignocellulosic fillers used in the production of WPCs, such as wood flour, according to Formela et al. [15]. Wheat bran application produced a comparable level of mechanical performance. It demonstrated a positive impact on the processing of natural rubber composites, reducing torque during curing, due to the greater quantity of amorphous cellulose and the presence of amino acids. So, a plant reinforcement material in the form of wheat bran has been selected for LLDPE composites to study the amount of reinforcement on tensile properties.

3.2 Compression moulding for making LLDPE-WB composite

One of the primary methods for producing composites is sheet moulding, a sort of compression moulding. In this method, a precise amount of a particular resin is poured into the plastic carrier film using a paste reservoir before the film is run through a chopper to cut the fibres into the surface. The fibres are inserted into the resin paste and then a further sheet is put on top. The sheets are then compressed and transferred to the take-up roll where the goods will be stored. After the carrier film is taken off, the material is divided into charges and heated and compressed to form the composite into the desired shape. After complete curation, the product is finally removed from the mould.

3.3 Characterization of material

The tensile properties are usually considered as an indication of usefulness of any composite material. Therefore, for LLDPE composites formed by using plant fibers, the mechanical properties like Tensile strength, Tensile modulus, and Elongation at break will be evaluated from tests carried out using Universal Testing Machine.

4. EXPERIMENTATION

4.1 WHEAT BRAN

Wheat bran utilised in this study is characterized by a density of 1.268 g/cm^3. The particle size distribution of the wheat bran (WB) filler has indicated that most of the wheat bran (87.47% of total wheat bran) is retained on particular sieves of size 0.05 mm to 0.25 mm. While plant filler in the shape of particles varies in size, polyethylene powder is distinguished by comparable particle size. The majority of the polyethylene particles fall between 200 and 500 µm in size. The largest WB particles are comparable in size to PE’s, however significant amounts of smaller fractions and fillers with high aspect ratios have been found.

4.2 Compression moulding

The manufacture of materials and products based on plant fibre composite materials through transformation methods like thermos-compression was the subject of several investigations.[16]. The melt flow index of LLDPE used as a matrix in produced composites is 5 g/10 min (2.16 kg, 190 ºC). LLDPE-WB, or linear low density polyethylene wheat bran fibre composite, is produced as 180 mm × 180 mm × 2 mm panels. Panels are produced by compression moulding in a hot plates press using a closeup stainless steel mould. In order to create the composite, LLDPE powder and varied amounts of wheat bran fibre (depending on the amount of reinforcement needed for the sample) are sandwiched between Teflon films, making sure the mat completely fills the mould. The sample is compression moulded at 170 ºC and 10 MPa for 8 min. Based on a mass balance, the fiber weight fraction of the composite in different samples is maintained at around 4%, 8%, 12%, and 16% (% wt/wt).

4.3 Measurement of tensile Properties

The interfacial adhesion between the resin and fibres has a significant impact on the tensile characteristics of plant fibre composites. The fibre and resin can be physically and chemically altered to improve the composites’ tensile properties. The tensile strength, tensile modulus and elongation at break are estimated following American Society for Testing and Materials (ASTM) D638-14 standard, using dumbbell shaped samples.

5. RESULT AND DISCUSSION

5.1 Tensile strengt*h*

Figure 1 indicates the effect of amount of reinforcement of Wheat bran on tensile strength of LLDPE–WB composite. It can be seen that with increase in amount of reinforcement, the tensile strength of LLDPE–WB composite is decreasing. This result trend is similar to that of previous study [17] on composites formed using plant fiber particles as a reinforcement material. Generally, the aspect ratio of plant filler in the form of particles is low, and it transfers stress poorly. Therefore, the addition of WB reduced the tensile strength of LLDPE matrix.

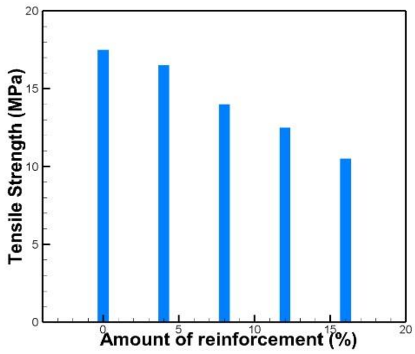

Figure 1 Effect of amount of reinforcement of Wheat bran on tensile strength of LLDPE–WB composite

Additionally, the inadequate stress transfer between the filler-matrix was attributed to the weak interfacial interaction between the hydrophilic WB and hydrophobic LLDPE matrix. However, some polymeric-coupling agents can be used to enhance the properties of LLDPE-WB composites. The use of polyethylene-grafted acrylic acid (PEAA) as a polymeric-coupling agents has previously studied and found to be enhancing the properties of composites [18].

5.2 Tensile modulus

Figure 2 indicates the effect of amount of reinforcement of Wheat bran on tensile modulus of LLDPE–WB composite. It can be seen that with increase in amount of reinforcement, the tensile modulus of LLDPE–WB composite is increasing. Due to the filler's greater rigidity than the matrix, which resulted in stiffer and more rigid composites, the tensile modulus presumably rose with WB content. Other researchers also reported a comparable outcome.

It has been found that by using palm kernel shell powder as a reinforcement material for low-density polyethylene composites, the tensile modulus is enhanced by using PEAA [19].

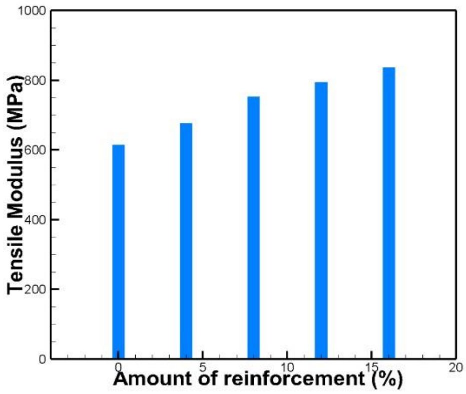

Figure 2 Effect of amount of reinforcement of Wheat bran on tensile modulus of LLDPE–WB composite

5.3 Elongation at break

Figure 3 indicates the effect of amount of reinforcement of Wheat bran on elongation at break of LLDPE–WB composite. As is typical for thermoplastic composites with plant fillers, distortion of the polymer's crystallinity caused the percentage of elongation at break to substantially decrease as filler content was increased in LLDPE-WB composites. Due to the formation of larger gaps, which causes fracture at very low elongation, the percentage of tensile elongation, which is extremely high for LLDPE, was significantly reduced by 90% in LLDPE-WB composite. This is a general phenomenon found in thermoplastics with bio-fillers

When stress is applied, the presence of WB particles acts as a stress concentrator and may cause a micro-crack to form. As a result, the LLDPE-WB composites fracture easily after some initial elongation, at break.

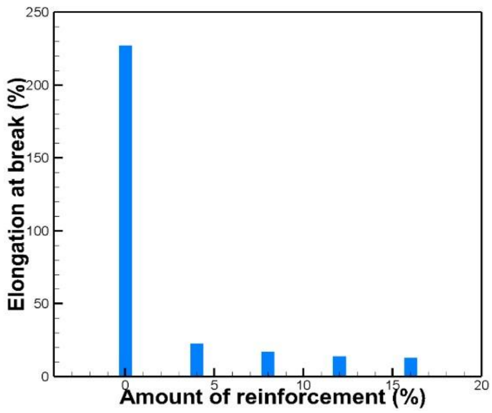

Figure 3 Effect of amount of reinforcement of Wheat bran on elongation at break of LLDPE–WB composite

6. CONCLUSIONS

LLDPE-WB composite is fabricated using compression moulding technique and the tensile properties are evaluated and compared with LLDPE.

- Decrease in tensile strength has been observed which indicates the reduction in the stress, the material can withstand, prior to failure by tensile and bending load.
- Increase in tensile modulus has been observed which indicates the increase in stiffness of the material while resisting the tensile and bending load.
- Very widely observed phenomena in case of plant fiber composites in the form of drastic reduction in elongation at break, is also observed in case of LLDPE-WB composites.
- Changes in the trend and values of the mechanical properties may be observed by adopting the different moulding techniques like rotational moulding and injection moulding.

Statements & Declarations

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Competing Interests -

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