Influence of Short Glass Fibers on the Mechanical Performance of PA66/PA6 Blend Composites for High Strength Tribo Applications

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Abstract— the polymer blend of Polyamide66 and Polyamide6 (PA66/PA6) (80wt. %/20wt. %) were selected for the study. These blends were reinforced with 10,20 and 30wt. % of silane treated short glass fibers(SGF) and these composites were prepared by using melt mixing method with the help of twin screw extruder. The mechanical properties such as tensile strength, flexural strength, impact strength were studied in addition to hardness of the blend composites as per ASTM. The results revealed that the addition of SGF into PA66/PA6 blend enhanced the mechanical properties of the polymer blend. Low loading of SGF into the blend experienced deterioration in tensile and flexural strength. But the higher loading of SGF into the blend increased the strength of the composite remarkably. The density of PA66/PA6 blend increased after the SGF addition. The impact strength of the studied composites was appreciable after higher loading of SGF into the blend. The decreasing trend was due to the immiscible nature of PA66 and PA6 phases due to different structural geometry in the polymer chain. However, the effect of higher loading of SGF into the blend on the mechanical behavior is greatly appreciable.

Key words: Mechanical, PA66/PA6, Shortglass Fibers, Blends, Flexure, Hardness

I. INTRODUCTION

Polymer and their composites are finding ever increasing usage for numerous industrial applications such as bearing material, rollers, seals, gears, cams , wheels, clutches etc.[1]. The mechanical strength, modulus and wear resistance of polymers largely determine the suitability of these materials for the above said applications [2]. Furthermore, polymer gears and bearings can accommodate shock loading, shaft misalignment and bending better than metal parts. In these applications, the material having both strong mechanical strengths and triboperformance can only suits the situation. It is often found that such properties are not attainable with a homopolymer. This has led to the development of copolymers, fiber-reinforced polymer and polymer blending. One among these is polymer blending which seems to be fascinating, because it has simple processing and unfolds unlimited possibilities of producing materials with variable properties. Polyamide66 (PA66) is a semi crystalline, thermoplastic commodity polymer that finds widespread use in applications that require considerable strength but low toughness. It possesses an outstanding combination of properties such as low density, easy processing, good strength and solvent resistance. Polyamide6 (PA6) is a linear polymer with high crystallinity, strong, stiff and tough engineering material with lower coefficient of friction. It has excellent thermal stability.

A lot of research has been made to improve the mechanical properties by means of incorporation of fibers with various neat polymers. Polymers are reinforced with fibers to improve the strength and stiffness of the matrix. Glass and carbon fibers are the most widely used reinforcing agents in thermoplastic matrix because of good balancing properties. These fibers are usually sized to permit good bonding with the matrix, producing a material of high flexural and tensile strength. The addition of reinforcing agents such as glass and carbon particularly in the form of fibers enhances the mechanical properties of polymers. M.Palabiyak and S.Bahadur [3] studied the mechanical behavior of PA6/HDPE blends reinforced with short glass fibers. They showed that the addition of 5-15wt. % of SGF into 80wt. % PA66-20% wt. %HDPE improved the tensile strength of the blend from 20 – 60 % respectively. Yuqin and Junlong [4] reported the mechanical properties of carbon fiber reinforced POM composites. They reported that the addition of short carbon fibers improves the tensile strength of Polyoxymethylene (POM).Zhaobin Chen and co-workers [5-6] studied the effect of short glass/carbon fibers on the mechanical properties of PA66/PPS blend. They showed that the addition of 20-30wt. % of SGF greatly improved the mechanical properties of PA66/PPS Blend. On the other hand, 30vol. % of SCF had the best mechanical properties of PA66/PPS even though it has negative effect on the same. Experimental investigation on the effect of glass fibers on the mechanical properties of PP and PA6 plastics were reported by AbdulkadirGullu[7]. They showed that SGF filled PA6 and PP had exhibited better mechanical properties. Investigation on the mechanical properties of Polyphenylenesulphide/carbon fiber (PPS/SCF) composites and polyamide6 filled PPS/SCF composites were studied by Jian and Tao [8]. They showed that better flexural strength was obtained for 25wt. % of SCF in PPS. Also they proved that the addition of 6wt. % of SCF into PA66/SCF composites exhibited better flexural strength than PPS/ SCF composites. Shofan Cao et al [9] reported the effect of basalt fiber in Ultra-High Molecular Weight Polyethylene (UHMWPE). Increase in basalt content in the composite led to decrease in toughness and increase in strength, hardness and creep resistance. Manojkumar et al. [10] studied the effect of banana fiber reinforced high density polyethylene/PA66 blend composites. They revealed that treated banana fibers had good effect on the mechanical properties of HDPE/PA66 blend. Ultra-High Molecular Weight Polyethylene (UHMWPE). Increase in basalt content in the composite led to decrease in toughness and increase in strength, hardness and creep resistance. S.Y.Fu et al [11] studied the tensile properties of SGF and SCF reinforced PP composites. The results about the composite strength and modulus were interpreted using the modified rule of mixtures equations by introducing two fiber efficiency factors, respectively, for the composite strength and modulus. It was found that for both types of composites the fiber efficiency factors decreased with increasing fiber volume fraction and the more brittle fiber namely carbon fiber corresponded to the lower fiber efficiency factors than glass fiber. Yuan et al.[12] studied the effect of coupling agent on mechanical properties of glass fiber reinforced short carbon fiber filled high density polyethylene composites. They showed that increasing coupling agent will improve the bonding strength between glass fibers and the matrix. Improving the mechanical behavior of SGF reinforced SCF/HDPE composites. Polypropylene hybrid effects reinforced long glass fibers and particulate filler was studied by Hartikainen et al [13]. They studied the effect of Long glass fibers reinforced Polypropylene. Addition of LGF into PP improved the tensile strength and fracture toughness appreciably. In spite of the fact that polymer composites are used in such structural applications, no data are reported on the influence of PA6 in polyamide 66 as blend with short glass fiber (SGF). Keeping this in view, a series of PA66/PA6 blend reinforced with different weight percentage of short glass fibers were investigated for tensile, flexure and impact properties. Efforts were also made to study the role of short glass fibers on the relevant strength properties in addition to the hardness of PA66/PA6 blend.

II. MATERIALS AND PROCESSING

A. *Materials*

The materials used in the present investigation are PA66, PA6 and silane coated short glass fibers and are listed in Table 1. The details of materials and their source are also tabulated in the given table.

Materials	**Composition of weight percentage of composites**					
	Designation	**Form**	**Size (µm)**	**Trade Name**	**Manufacturer**	**Density (g/cc)**
Polyamide	PA66	Granules	---	Zytel 101L NC010	Dupont co.Ltd.	1.14
Polyamide	PA6	Granules	---	Zytel 101L NC010	Dupont co.Ltd.	1.04
Short glass fiber	SGF	Cylindrical	Length = 2 -3 mm	----	Fine organics, Mumbai	2.5

Table 1: Properties of the Materials Used In the Study

Composition of weight percentage of Composites				
Material ID	Composition	PA66	PA6	SGF
1Z	Blend(PA66/PA6)	80	20	---
2Z	Blend(PA66/PA6)/SGF	80	20	10
3Z	Blend(PA66/PA6)/SGF	80	20	20
4Z	Blend(PA66/PA6)/SGF	80	20	30

Table 2: Formulations of weight percentage of composites

B. *Fabrication of Blends and Their Composites*

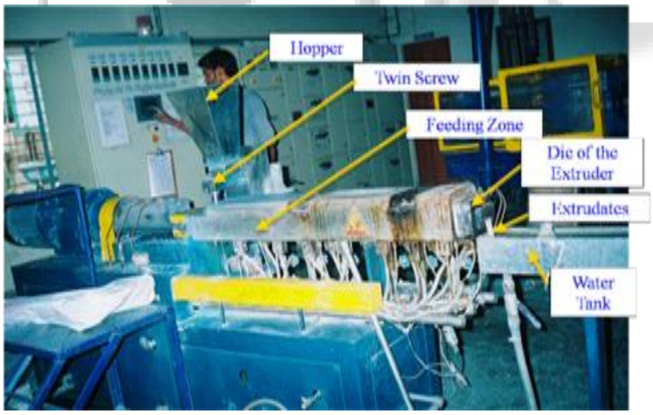

Fig. 1: Barbender Co- Rotating Twin Screw Extruder

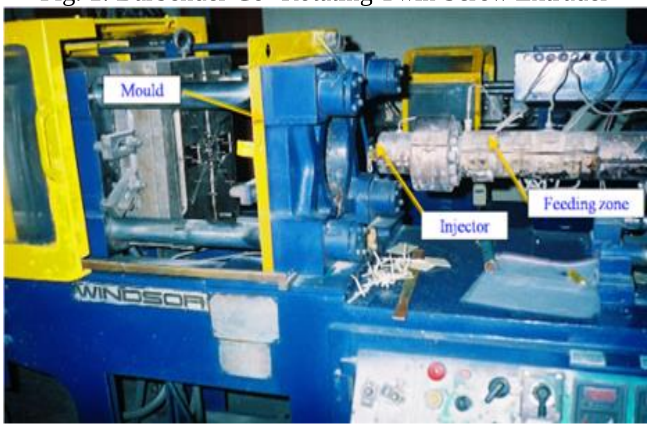

Fig. 1: Injection Molding Machine

The polymers PA66 and PA6 with proper proportions were dried at 800C for 48 hours before mixing to avoid plasticization, hydrolyzing effects from humidity and to obtain the sufficient homogeneity. The saline coated sized short glass fibers were mixed in proper proportion into the thermoplastic materials. The materials are mixed and the mixture was extruded using Barbender co-rotating twin-screw extruder (Make: CMEI, Model: 16CME, SPL, chamber size 70cm^3). The extruder consists of five heating zones where the temperature maintained in these zones of the extruder barrel were zone1 (220ºC), zone2 (235ºC), zone3 (240ºC), zone4 (265ºC) and zone5 (270ºC) respectively and the temperature at the die was set at 2200C. The extruder screw speed was set at 100 rpm to yield a feed rate of 5 kg/h. The extrudates obtained was in the form of cylindrical rod which was quenched in cold water and then palletized by using Palletizing machine. During initial stage, around 1 to 1.5 kg of initial extrudate was removed to get the pure blend and to remove impurities of extrudate of previous stroke of the extrusion. Before injection moulding, all polymer blended composite pallets were dried at 1000C in vacuum oven for 24 hours. All test specimens were injection molded from the pelletized polyblend material obtained from co-rotating extruder. The temperature maintained in the two zones of the barrel were zone1 (265ºC) and zone2 (290ºC) and mold temperature was maintained at 650C. The screw speed was set at 10 – 15 rpm followed by 700-800 bar injection pressure. The injection time, cooling time and ejection time maintained during injection molding were 10, 35 and 2 s, respectively. All the molded specimens as per ASTM were inspected and tested visually and those found defect were discarded for the testing.

III. MEASUREMENT OF MECHANICAL PROPERTIES

The mechanical properties such as tensile strength, flexural strength, Impact strength along with Density and hardness of the blends were measured as per ASTM. The tensile strength and the tensile elongation at break were measured using Universal testing machine (JJ Lloyd, London, United Kingdom, capacity 1-20KN) in accordance with ASTM D 638. Tests were performed at constant strain rate of 5mm/min. ASTM D 638 Type 1 standard dimensions are used. Flexural strength or three point bending were carried out on the same machine by changing the jaws of the set up and the specimen acts as simply supported beam subjected to point load at the middle . The flexural strength and flexural modulus were determined at the rate of 2mm/min as per ASTM D790.The standard specimen dimensions for the flexural strength is 125mm x12.7mmx3.2 mm. The Izod impact strength was determined using ASTM D 256 by using Izod impact testing machine at the striking rate of 3.2mm/s. The density of the blend composites were determined as per ASTM D756. The ASTM standards for these mechanical testing were shown in the figure 3. All these tests were conducted at the room temperature. Minimum of three samples were tested for the data representation. On the other hand, the density and the hardness (Shore D) of the blended composites were determined as per ASTM D792 and ASTM D224 respectively.

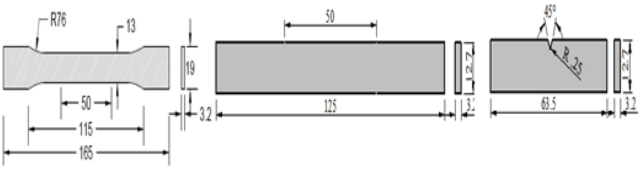

Fig. 3: Specimen standards :(a) ASTM D 638(Tensile Test) (b) ASTM D790 (Flexure Test) and (c) ASTM D256 (Impact Test)

IV. RESULTS AND DISCUSSIONS

A. *Density and Hardness of SGF filled PA66/PTFE Blends:*

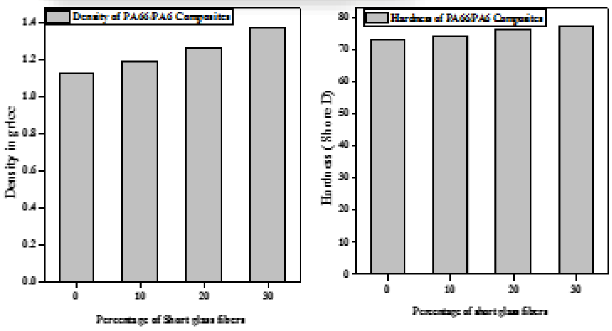

Fig. 4: Variation of properties of SGF filled PA66/PA6: (a) Density and (b) Hardness (Shore D)

The variation of density with the addition of Short glass fibers into PA66/PA6 blends is shown in the figure 4 (a). The density of the blend 80wt. % PA66-20wt. % PA6 increased after successive addition of short glass fiber into it. This is due to the addition of hard and dense glass fibers into the blend. The blend with 30wt. % SGF had appreciable density in the studied blend composites. The inclusion of PTFE into the PEEK increased the density of the blend PEEK/PTFE [14]. Similarly, the effect of SGF addition on the hardness of the blend was shown in the figure 4(b). The hardness of the blend after short glass fiber reinforcement almost remained constant even for higher loading of SGF. This might be due to the brittle and the coarse nature of the SGF filled PA66/PA6 composites. The lower hardness was obtained for 10 wt. % of SGF whereas, higher hardness was obtained for 30wt. % of SGF in the blend.

B. *Tensile behavior of SGF filled PA66/PTFE Blends:*

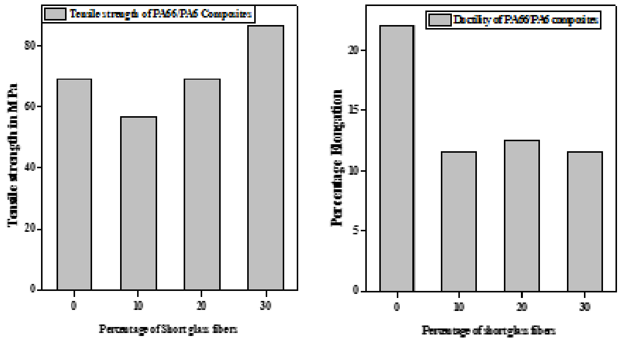

Fig. 5: Tensile behavior of SGF filled PA66/PA6: (a) Tensile strength and (b) % Elongation

The tensile strength of 80wt. % PA66-20wt. %PA6 blend was 69N/mm2. After reinforcing 10wt. % of SGF into the blend, the tensile strength of the blend was 56.8 N/mm2 which is around 18% decrease. Similarly, addition of 20 and 30wt. % of SGF into the blend results in increased tensile strength which was in the order of 1% and 30% respectively. The decrease in the tensile strength after the addition of 10 wt. % of SGF into the blend may be attributed to the immiscible phase of PA66 and PA6 which may cause the incompatibility. But after further addition of SGF into 80wt. %PA66-20wt. % PA6 blend exhibited better tensile strength. This is due to the strong adhesion between SGF and the matrix of PA66/PA6 blend. The greater specific surface area of the glass fibers leads to increase the specific strength of the composite materials. Enhanced surface area of contact due to the slenderness ratio of the short glass fibers enhanced appreciably tensile strength of the polymer blend composites. The silane acts as the coupling agent for the glass fibers to develop adhesive forces at the interface of SGF and PA66/PA6 blend surfaces. This leads to develop strong adhesive bond between the SGF and the polymer blend matrix to develop good strength. The strain at break decreases after the addition of 10wt. % SGF into the blend and further loading of SGF results in almost no change in the elongation of the material. This clearly indicates that the material transformation from the ductile phase to the brittle nature. This may leads to increase the hardness and also the density of the blend.

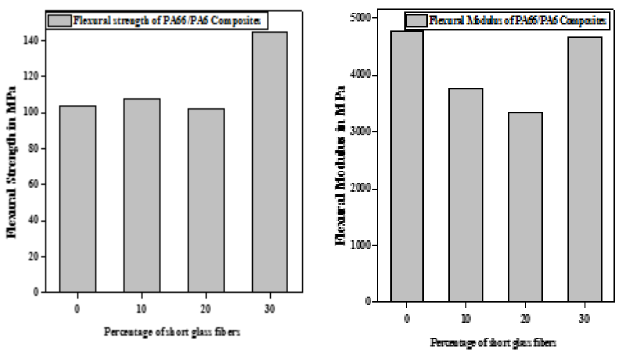

Fig. 6: Flexural behavior of SGF filled PA66/PA6: (a) Flexural strength and (b) Flexural Modulus

The flexural strength of 80wt. %PA66-20wt. %PA6 was 103.5 N/mm2. The addition of 10wt. % of SGF increased the strength to 107.5N/mm2 which is 4% increase. With the presence of 20 wt. % of SGF in the polymer blend decreased the flexural strength in the order of1.5%. Further, higher loading of SGF (30wt. %) into the blend increased the strength by almost 40% than that of the neat blend. These results revealed that there was a good compatibility between the fiber and the matrix in the blend based composites. The improved properties of the studied polyblends and their micro composites can be attributed to uniform distribution of SGF and strong adhesion of polymer blends to the SGF. The applied load penetrates the matrix and transforms it across the surface of the fibers instead of breaking it. This may cause fiber rupture. The load shared by the fibers and the blend matrix associative improved the flexural strength of the polyblend composites. The flexural modulus of the SGF filled PA66/PA6 blend was excellent. Improved flexural strength and flexural modulus of the thermoplastics were revealed by many researchers [13]. However, 30wt. %SGF filled PA66/PA6 blend had the best flexural properties. The flexural modulus of the composites decreased after the addition of SGF into the blend. But after reinforcing 30wt. % of SGF, the appreciable improvement in the flexural modulus was observed.

C. Impact strength of SGF filled PA66/PTFE Blends:

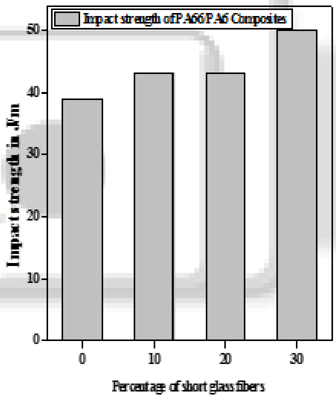

Fig. 6: Impact behavior of SGF filled PA66/PA6 blends

The impact strength of 80wt. % PA66-20wt. % PA6 was 39J/m. but the addition of 10wt. % of SGF improved the impact strength by 10%. This may be due to the brittle nature of the blend material. After successive addition of SGF into the studied blend, increased the impact strength appreciably. This may be due to the brittle and dense nature of the composites after higher loading of SGF into the blend. In addition, the synergistic effect between PA66/PA6 and SGF made the composite to become tough in terms of impact and also in terms of mechanical behavior. The composite having 30wt. % of SGF in PA66/PA6 blend had the highest impact strength of around 50J/m which is around 28% increase over low fiber loading of SGF in the blend (10wt. %).

V. CONCLUSIONS

- The mechanical behavior of SGF filled PA66/PA6 blend composites are promising composites for the structural applications
- The suitable combinations of weight percentages of SGF are 10,20 and 30% for the better mechanical properties of the studied polymer blend.
- Short glass fiber reinforced 80wt. %PA66-20wt. % PA6 composites exhibited excellent tensile strength. Composites with 30wt.% of SGF had better tensile strength when compared to other fiber loading
- The flexural strength of PA66/PA6 blend decreased initially linearly due to the effect of SGF. 30wt. % of SGF in the studied polymer blend had better flexural strength and flexural modulus.
- The impact strength of the SGF reinforced blend decreased initially and then increased drastically due to the effect of dense short glass fibers.
- The hardness of the SGF reinforced PA66/PA6 blend increased due to increase in dense nature of the short glass fibers.
- The density of the SGF reinforced PA66/PA6 blend composites increased with increase in percentage of SGF in the blend

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