Physical and Mechanical Properties of Polyester-Based Hybrid Composites with Blast Furnace Slag and Banana Fibre as Reinforcement

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Abstract –In this investigation, a new class of polymer composites withpolyester as a matrix material, micro-sized blast furnace slag (BFS),and short banana fibre (SBF) as a filler material is developed. The composites are fabricated using a simple hand la-up method. The samples are prepared by keeping the content of BFS constant at 10 wt. % and the content of banana fibre varied from 0 wt. % to 5 wt. %. The effect of filler loading on different physical and mechanical propertiesof the prepared sampleisstudied and presented. The various physical properties under investigation are density, void content and water uptake rate whereas the mechanical properties under investigation are tensile strength, flexural strength, compressive strength and hardness. From the experimental results, it is found that the inclusion of BFS in polyester increases the density of the composite whereas, when banana fibres are added, the density of the composites decreases with filler loading. Enhancement of either filler content unwillingly increases the composite's void content and water uptake rate. Under mechanical testing, it is observed that with the addition of 10 wt. % of the BFS, all the mechanical properties under investigation gainfully increase. The mechanical properties like tensile strength, flexural strength and compressive strength remarkably improve with the addition of short banana fibre as secondary filler material, though the addition of short banana fibre as a secondary filler marginally improves the hardness of the material.

Keywords: Polymer matrix composites, polyester, blast furnace slag, banana fibre, physical properties, mechanical properties.

I. INTRODUCTION

There is a sudden enhancement in the quantity and types of waste with an increase in urbanization by the new concept of industrialization. The increment in industrial waste also results from the innovation in technology in different fields in the last two decades. The various sources of waste include mining, industries, domestics and different agricultural activities. Among all, the major and harmful waste is generated from the industries. This disturbs the balance of the environment. This is the major source of land, air and water pollution as this waste is disposed of in the nearby land or nearby water bodies. So, for sustainable development, proper utilization of this waste is the need of an hour. Among the various waste, blast furnace slag is the waste generated in huge quantities. Though considerable work is reported by the research fraternity to utilize this waste.

For the last many years, BFS has been used in various civil engineering applications like road construction, as a mixture of Portland cement for the manufacturing of concrete etc. Though, the investigation on the usage of BFS as a functional filler is still limited so far. Few reports are available on exploring BFS as a filler material in the polymer for the development of polymer composites. Mostafa et al. [1] studied the effect of micro-sized BFS on polypropylene and polystyrene and studied their mechanical and thermal behaviour. They reported achieving improvement in the various properties of the polymer under investigation by the inclusion of BFS particulates. Later, Mostafa et al. [2] used silane-modified BFS as filler material and found improvement in the thermal conductivity of the material. Though the surface modification of silane had not had much effect on the mechanical properties of the composites. Akkoyun and Akkoyun [3] reported that the strength of thepolyurethane increases with the inclusion of BFS when the content of BFS is in a limited quantity of 10 wt. % only. Against that, they found that the thermal conductivity is maximum when the BFS content is maximum. Gunes et al. [4] evaluated the hardness and sliding wear rate of epoxy filled with BFS as a function of filler loading. From the analysis, they found that the inclusion of BFS remarkably improves the hardness of the material. With improvement in hardness, the sliding wear resistance of the material also improves. Following the same, Erdogan et al. [5] studied the wear rate of epoxy/BFS composites as a function of applied load and sliding distance. In their analysis, they kept the content of BFS Constant. From the analysis, they found that the wear rate increases with an increase in applied load and sliding distance.

The inclusion of BFS particles in combination with synthetic or natural fibres has also been explored by many researchers to study the effect of hard particulate BFS on fibre-reinforced polymer composites. Padhi and Satapathy

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[6] studied the influence of BFS content on the hardness and erosion wear rate of epoxy/bi-directional glass fibre composites and found improvement in either of the properties. Again, Padhi et al. [8] studied the sliding wear behaviour of the same combination of materials and found improvement in the wear resistance behaviour of the material. In their other work, Padhi et al. [9, 10] performed sliding wear and erosion wear analysis along with the mechanical characterization for polypropylene-based composites with glass fibre and BFS particles as filler material. They reported achieving an overall improvement in the properties. Patnaik et al. [11] performed the mechanical test and abrasive wear test of BFS-filledneedle-punched nonwoven viscose fabric epoxy hybrid composites. It has been observed that the enhancement in properties is high when the BFS is used in combination with some fibre. Yadav et al. [12] used a combination of epoxy with BFS and sisal fibre and found appreciable improvement in the various mechanical properties of the material. Though it is also observed that the combination of BFS with natural fibres is rarely explored. Hence, in the present work, banana fibres in their short form are explored in combination with BFS for the development of polyester-based hybrid composites. Banana fibre is a well-established natural fibre and has been explored by various researchers for the development of natural fibre composites [13, 14]. Given this, the present work comprises the utilization of blast furnace slagand bananafibrein the polyester matrix for originating a new class of hybrid polymer composites. The physical and mechanical properties of the hybrid composites are evaluated in the current investigation to check their potential for light-duty structural applications.

II. MATERIALS AND METHODS

A. *Material considered*

The presently used matrix is a thermoset polymer polyester along with its accelerator and catalyst.The polyester resin is procured from Carbon Black composites, Mumbai, India.The density of the polyester used is 1.12 g/cm3 which is very low and helpful in delivering increased specific strength material. the industrial waste, BFS is generated in maximum quantity. BFS are cheap and abundantly available as each ton of iron produces approximately 0.3 tons of BFS. The density of BFS is 2.4 g/cm^3. The BFS used in the present investigation is collected from the Rourkela steel plant, in Odisha.Banana fibre, natural fibre is used in the present investigation as a secondary filler material.Banana fibrehas good mechanical strength and has an appreciable specific property, even comparable to glass fibre. In addition to that, it possesses lower density than glass fibres. Apart from good specific properties, smaller elongation, fire resistance quality, great potentialities and biodegradability are the major advantages of this fibre.

B. *Composite Fabrication*

A simple hand lay-up technique is used in the present investigation for the fabrication of polyester-based hybrid composites. The fabrication of composite using the hand lay-up method involves the following steps:

1. First the room-temperature curing polyester resin is added with the given percentage of BFS micro-particulates and mixed well through hand-stirring.
2. This is followed by the addition of short banana fibre in the combination of polyester/BFS for the development of hybrid composites. If a single filler composite is required banana fibre is not added.
3. Later 1 wt. % of the cobalt accelerator is added to the mixture and mixed well through hand stirring.
4. This is followed by the addition of 1 wt. % MEKP catalyst and the combination is mixed properly through hand stirring over a period of around one minute.
5. A coating of silicon spray is mandatory over the mould before pouring the mixture into it, a silicon spray is done over the mould so that it will be easy to remove the composite after curing. The uniformly mixed dough is then slowly poured into the mould.
6. The cast is then cured for 2 hours before it was taken from the mould.

Composites were fabricated with different weight fractions of filler The composite fabricated under the investigation is given in table 1.

TABLE I
POLYESTER COMPOSITES FILLED WITH BFS AND BANANA FIBRE

Samples	**Composition**
PS	Neat Polyester
2	Polyester + 10 wt. % BFS
3	Polyester + 10 wt. % BFS + 1 wt. % Banana Fibre
4	Polyester + 10 wt. % BFS+ 3 wt. % Banana Fibre
5	Polyester + 10 wt. % BFS+ 5 wt. % Banana Fibre

C. *Mechanical Characterization*

The density of the composites is measured using the Archimedes method as per ASTM D 792-91 standard. Theoretically, density is evaluated using the rule of the mixture model [15]. Void content is evaluated with the two different densities value. Water intake rate is measured per the ASTM D 570 standard [16]. The tensile strength, flexural strength and compressive strength of the composites are measured with a computerized Tinius Olsen universal testing machine.The hardness test was carried out by ASTM D-2240 using a PosiTector SHD Shore hardness Durometer. [17].

III. RESULTS AND DISCUSSION

A. *Density and void content*

The density and the voids content for all sets of samples under investigation are presented in figure 1 and figure 2 respectively. It is seen that the measured density rises with the inclusion of BFS in the polyester matrix. The density of neat polyester is 1.12 g/cm^3 which increases to 1.162 g/cm^3 with an increment of 3.75 %. The increasing trend was obtained because the intrinsic density of BFS is more than the density of the polyester.

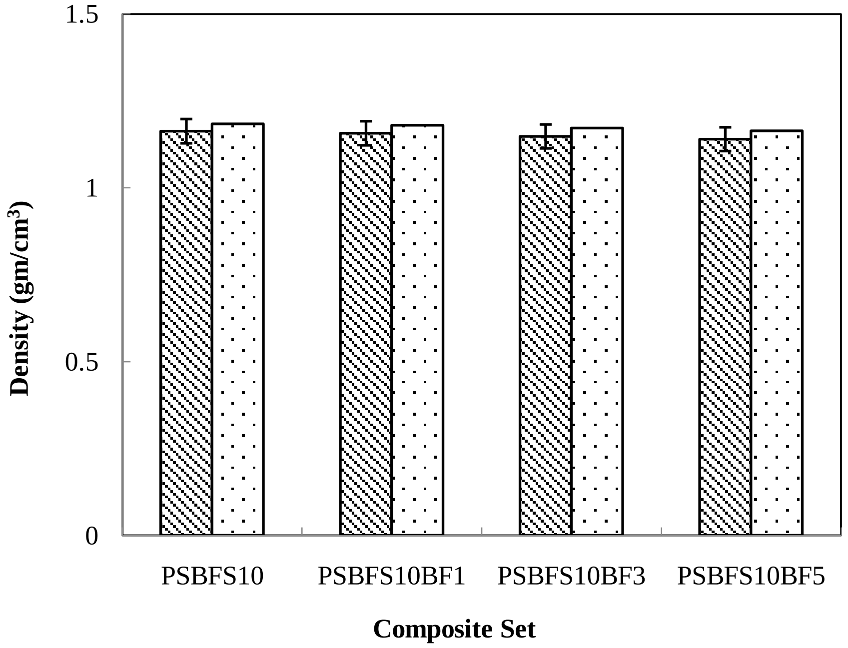

Figure 1 Density of Polyester/BFS/Banana fibre composites

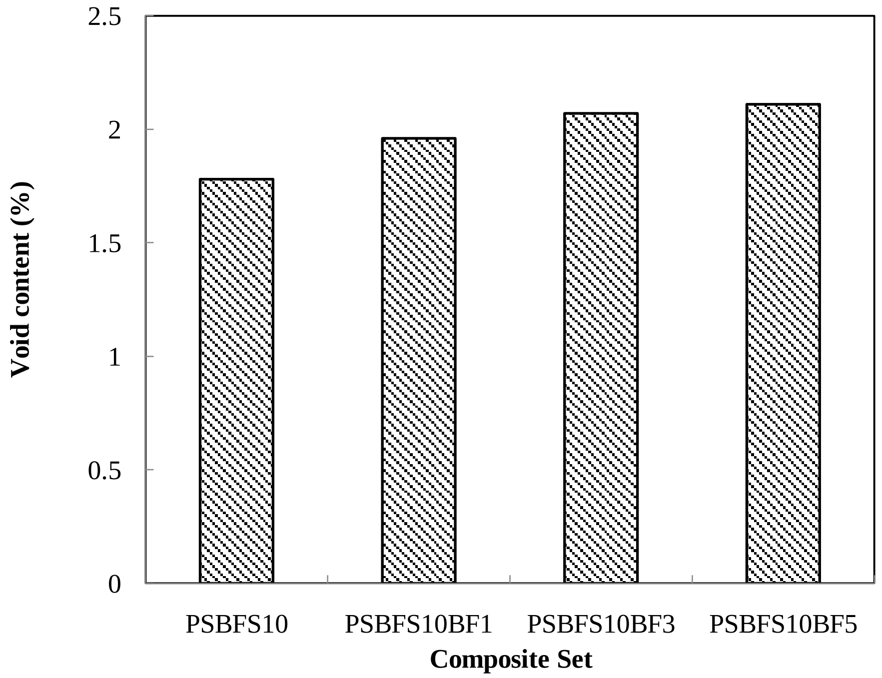

Figure 2 Void content in Polyester/BFS/Banana fibre composites

Further, with the inclusion of banana fibre as a secondary filler, the density of the composite decreases. With the inclusion of 5 wt. % banana fibre, the density decreases to 1.139 g/cm^3. This is a decrement of 1.97 % against polyester/BFS composites. The decreasing trend is obtained for theoretical density as well. The trend is obvious as the density of banana fibre is less than the density of the matrix. The voids content generated within the composites is calculated based on measured and calculated density. From figure 2, it is clear that the void content increases with fibre loading. The void content of 1.78 % is observed for the set PSBFS10 and the void content increases to 2.77 % for the set PSBFS10BF5.

B. ***Water absorption rate***

The variation in water absorption behaviour of polyester-based composites at varied content of BFS and banana fibre along with immersion time is presented in figure 3.

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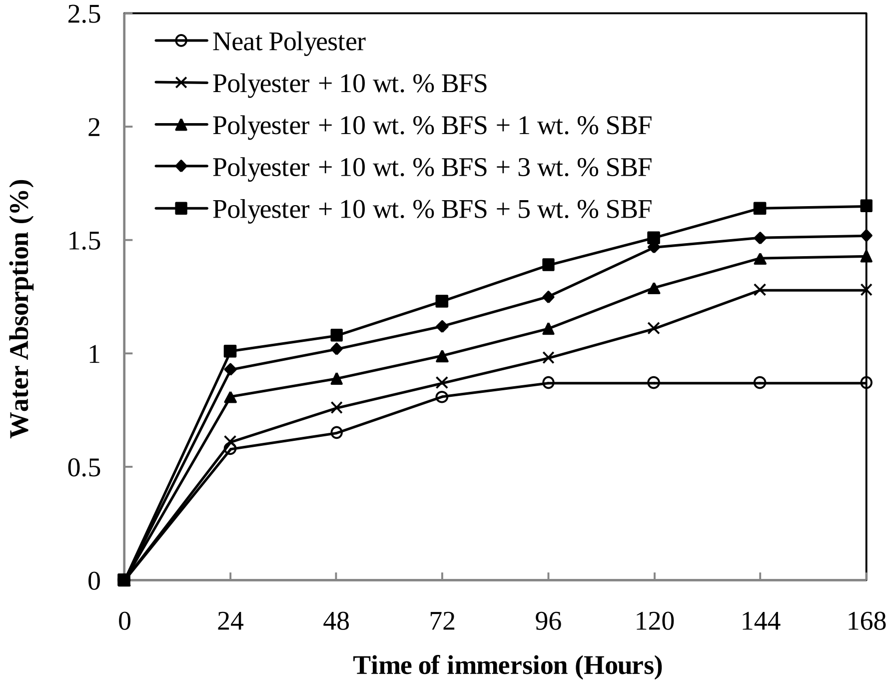

Figure 3 Water absorption behaviour of polyester/BFS/banana fibre hybrid composites as a function of filler content

It is observed that the inclusion of either BFS or banana fibre increases the water absorption rate of the composite material. It is mainly because of the hydrophilic nature of banana fibre and the formation of voids. As the banana fibre content increases, the composite water absorption rate increases. This is mainly because of the hydrophilic nature of the banana fibre. Also, void content increase with filler content and hence water absorption rate increases. It is also seen that the water intake rises with the immersion time initially and later it reached saturation then no further water intake is observed.

C. ***Tensile properties***

The tensile strength of the different sets of composite material under investigation is shown in figure 4. From the graph, it can be seen that the strength of the material increases with the addition of 10 wt. % of BFS. The inclusion of banana fibre improves tensile strength further. With the inclusion of BSF or banana fibre, the strength increases mainly because such filler combinations provide rigidity to the composite material. The tensile strength of the neat polyester is 33.5 MPa which increases to 39.8 MPa for the set EPBFS10 composite. Again, for set EPBFS10BF5 composite, tensile strength increases to 46.2 MPa with an increment of 39.91 % against neat polyester and 16.08 % against PSBFS10 set composite.

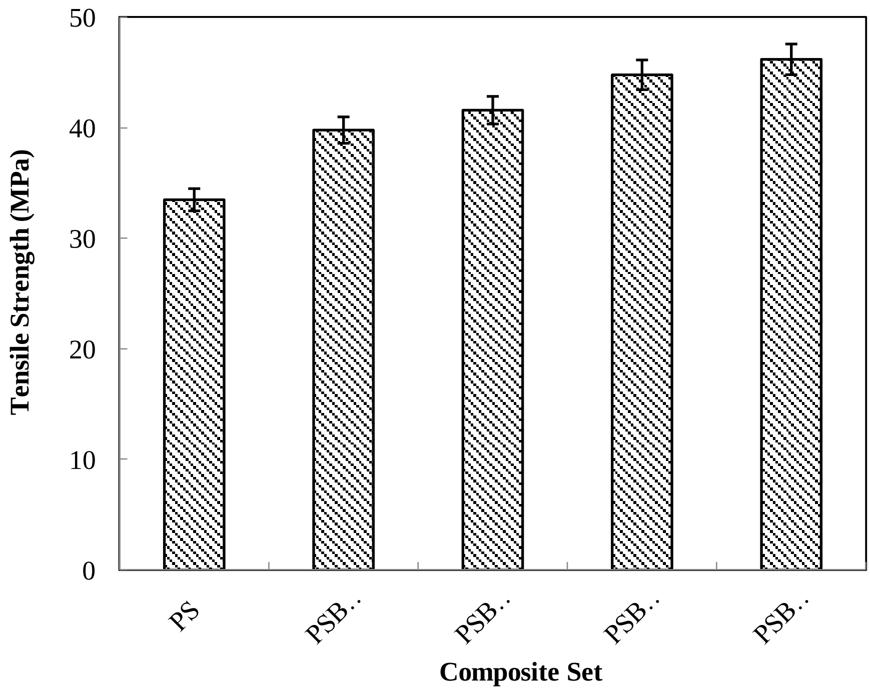

Figure 4 Tensile strength of polyester/BFS/banana fibre hybrid composites

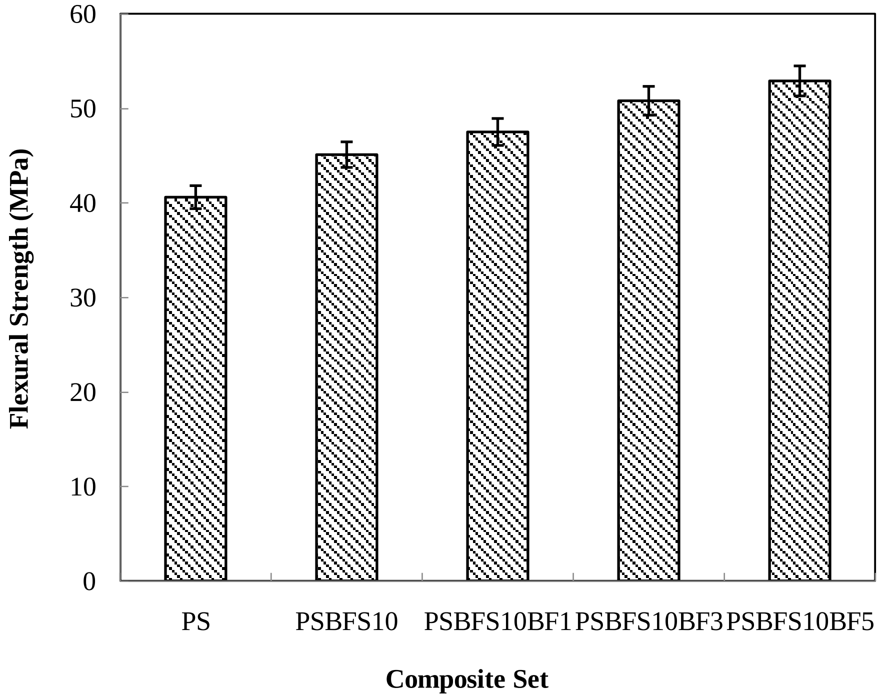

Figure 5 Flexural strength of polyester/BFS/banana fibre hybrid composites

D. ***Flexural properties***

The flexural strength of the polyester-based hybrid composites also follows the same trend as followed by the tensile strength of the composite material. The value obtained is presented in figure 5. The flexural strength of the neat polyester is 40.6 MPa which goes to 45.1 MPa for the set PSBFS10 composite. Again, for set PSBFS10BF5 composite, flexural strength increases to 52.9 MPa with an increment of 30.29 % against neat polyester and 17.29 % against PSBFS10 composite.

E. ***Compressive strength***

The variation in the compressive strength of the different sets of composite material under investigation is given in figure 6. It can be seen that the compressive strength of the material increases with an increase in the content of blast furnace slag and banana fibre.The compressive strength for the set PSBFS10BF5 reached 87.5 MPa. The increment is around 20.19 % over neat polyester and 11.89 % over the polyester filled with 10 wt. % BFS. From the analysis, it is observed that the inclusion of banana fibre further increases the compressive strength of the material, though the rate of increment of compressive is not as high as that took place with the inclusion of BFS.

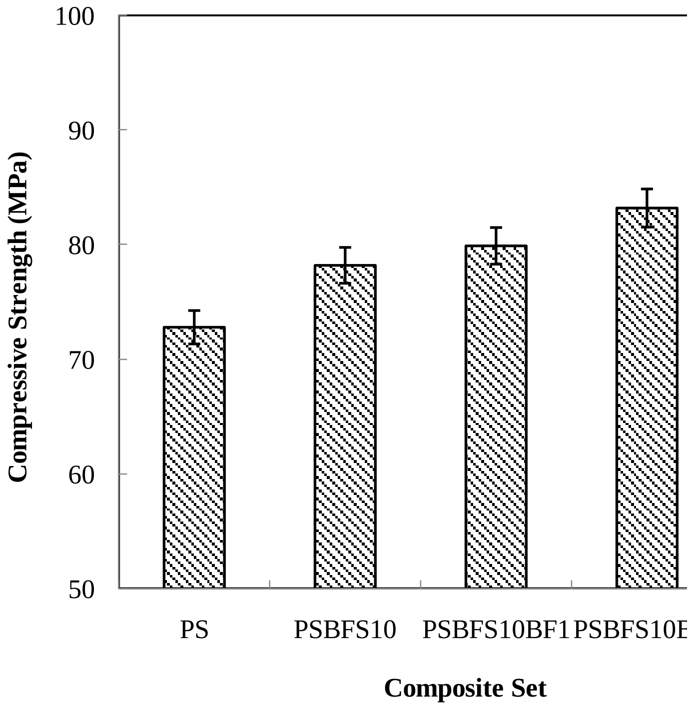

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Figure 6 Compressive strength of polyester/BFS/banana fibre hybrid composites

F. Micro-Hardness

The hardness of the polyester-based hybrid composites under investigation is presented in figure 7.From the figure, it is clear that, with the inclusion of sisal fibre as secondary filler material, the hardness of the composite increases slightly. The Shore-D hardness of neat polyester is 80 and increases to 81.3 with the inclusion of 10 wt. % of BFS. As the banana fibres are reinforced in the polyester composites, the hardness reaches 82.4 with the inclusion of 5 wt. % of banana fibre.It is seen that there is a marginal improvement in the value of hardness over neat polyester as well as polyester/BFS composites with the inclusion of banana fibre.

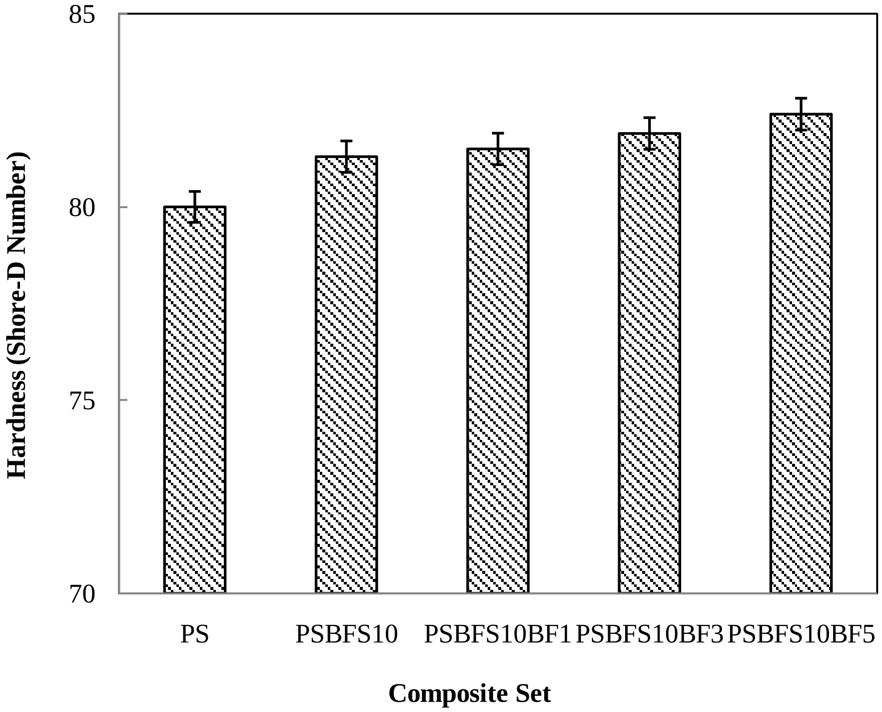

Figure 7 Shore-DHardness of polyester/BFS/banana fibre hybrid composites

For maximum content of 5 wt. % banana fibre in combination with 10 wt. % BFS, the improvement registered is 3 % over neat polyester and 1.35 % over polyester/BFS composites.

IV. CONCLUSIONS

This experimental investigation has led to the following specific conclusions:

1. Blast furnace slag and banana fibre in combination possess ample reinforcing potential to be used as a hybrid filler material in polyester matrices. Successful fabrication of polyester matrix composites reinforced with blast furnace slag and banana fibre is possible by simple hand-lay-up technique.

2. Polyester with 10 wt. % BFS shows better properties in the case of single filler composites and hence 10wt. % of BFS is taken as primary filler and the content of banana fibre is increased till 5 wt. %. With the increase in the content of banana fibre, the theoretical density as well as the measured density of the composite decreases with an increase in the banana fibre content. The maximum void content generated is 2.11 %

3. The water absorption rate also increases with the inclusion of banana fibre as secondary filler material. Further, due to the hydrophilic nature of the banana fibre, its inclusion enhances the water absorption rate of the composite body. The maximum water absorption reported is 1.65 %

4. Under the evaluation of mechanical properties, it is found that the inclusion of banana fibre as a secondary filler improves all the mechanical properties under investigation. The inclusion of banana fibre greatly influences the properties like tensile strength, flexural strength and compressive strength, whereas, the hardness of the material slightly improves by the inclusion of banana fibre.

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