

# Mechanical Properties of Silk and Glass Fiber Reinforced Hybrid Polypropylene Composites

M.R.H. Mazumder, F. Numera, A. Al-Asif and M. Hasan

Department of Materials and Metallurgical Engineering, Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh

**Abstract.** In present research, mechanical properties of silk-glass fiber reinforced hybrid polypropylene composite were evaluated. Composites were prepared using hot press machine at three levels of fiber loading (5, 10 and 15 wt.%). Tensile, flexural, impact and hardness tests were conducted for the characterization of the composites. Tensile strength decreased, whereas flexural strength increased with fiber loading. On the other hand, Young's modulus, flexural modulus and hardness increased up to 10 wt.% fiber loading. Impact strength remained unchanged with fiber loading. Based on fiber loading, 10 wt.% fiber reinforced composites had the optimum set of mechanical properties. For 10 wt.% fiber loaded composite, silk and glass fiber ratio was also varied at 1:1, 3:1 and 1:3. On the basis of fiber loading and ratio, the composite containing 10 wt.% fiber at 1:1 ratio of silk and glass showed the best set of mechanical properties.

**Keywords:** Silk; Glass; Polypropylene; Hybrid composite; Properties

## 1. Introduction

Natural fiber reinforced composites are of high interest in this present day. Due to its environment friendly nature and bio-degradability, it is being incorporated in making composites [1]. Amongst the natural fiber, cellulosic or animal fiber has attracted considerable interest as a reinforcement for polymer. This is due to its properties such as high strength and stiffness, low hardness high impact strength which reduces abrasion. Silk is a natural fiber obtained from the cocoon of silkworm. It has high toughness and better mechanical properties which gives it an advantage over the other animal fibers. Glass fiber, on the other hand, is a synthetic fiber. It has properties such as high strength, stiffness. Fiber glass is lightweight. Because of their excellent property the application of glass fiber is found in different industries [1]. Silk is reactive to light, less chemically resistant and absorbs water. However it is abrasion resistant, has good elasticity and is biodegradable. On the other hand, glass is unaffected by light, does not absorb water, does not naturally degrade and is chemically inert.



However abrasion resistance of glass fiber is less than that of kevlar fiber, thus glass fiber is prone to abrasion [2]. To balance the property of the fibers and overcome their weaker properties, the hybrid composite of glass and silk fiber reinforced polypropylene matrix will have its bulk property enhanced [3]. Hybrid composites are a good combination of natural and synthetic fiber because it gives the composite structural strength which the natural fiber lacks and is environment friendly which is not true for synthetic fibers. Glass and silk fiber are both available in Bangladesh. Polypropylene is a widely used polymer matrix because of its low cost, recyclability and thermal stability [4]. Present research discusses the property enhancement of polypropylene due to addition of glass and silk fiber reinforcements and is emphasized on the mechanical strength of the composite.

## **2. Experimental**

### *2.1 Materials*

In this study, thermoplastic polymer polypropylene (PP), used as matrix material, was collected from the local market in the form of granules. It has a specific gravity of 0.90-0.91, melting temperatures of around 160 °C and crystallinity of 82% [5]. Glass fiber was collected from local market and the silk fiber was collected from a silk industry in Rajshahi, Bangladesh. The die used to prepare the composite was made of aluminium. The die was made by machining aluminium to a desired shape.

### *2.2 Preparation of composites*

Hybrid composites of polypropylene matrix with varying amount of silk and glass fiber were prepared by hot press technique in a 150 x 150 x 10 mm aluminium die. A hydraulic type machine having maximum load of 35 kN and maximum temperature of 300°C was utilized. The fiber loading was varied at 5, 10 and 15 wt% with the ratio of silk to glass of 1:1 and also of silk to glass ratio of 3:1 and 1:3 for 10 wt% fiber loading. The fibers were chopped into approximate length of 3 mm. The required amount of fiber and PP were weighed in a balance. The weighed fiber was placed into the oven at 100°C temperature for at least 1 hour. It was done to make the fiber dry and remove all moisture in order to prevent air bubble in composite. A clean aluminium mold was used and mold releasing agent was sprayed on it uniformly for easy removal of the finished composite. PP granules and fibers were placed into the mold die with the fibers sandwiched between the PP granules layer. This technique improved the uniformity of the fiber within the polymer and increased wettability. Then the mold die along with PP granules and fiber mixtures were placed in hot press machine at 30 kN. The temperature was initially raised to 160°C and held there for 15-20 minutes. The temperature was then raised to 195°C and held there for 5 minutes. The die was cooled to room temperature by the water cooling system. The pressure was released and the composite was withdrawn from the die.

### *2.3 Mechanical testing*

Tensile, flexural, Charpy impact and hardness tests were conducted on the prepared composites. For each test and type of composite, 3 specimens were tested and the average values are reported. Tensile tests were conducted according to ASTM D 638-01 [6] using a Universal Testing Machine situated at the department of Materials and Metallurgical Engineering, Bangladesh University of Engineering and Technology, Bangladesh. The tests were performed at a crosshead speed of 6mm/min. The dimension of the specimen used was 100 mm x 19 mm x 3 mm. Static flexural tests were carried according to ASTM D 790-00 [7] using the same testing machine mentioned above with the same crosshead speed. The dimension of the specimens used was 78 mm x 12.5 mm x 3 mm. The flexural strength and modulus were calculated using the following equations:

$$\text{Flexural strength, } \sigma_f = \frac{3PL}{2bd^2} \quad (1)$$

$$\text{Flexural modulus, } E_f = \frac{mL^3}{4bd^3} \quad (2)$$

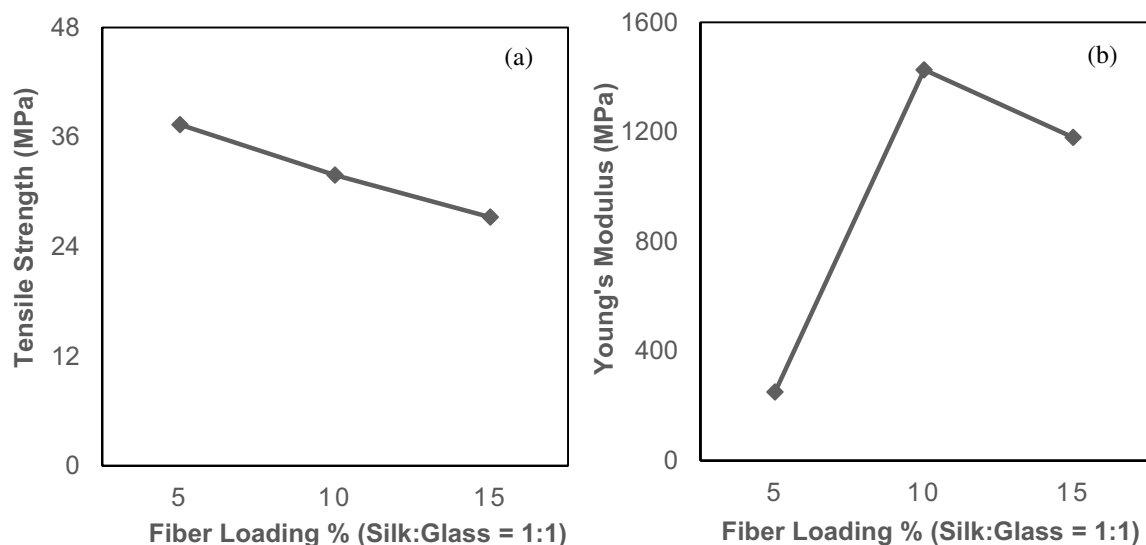
Where P is the maximum applied load, L is the length of support span, m is the slope of the tangent, b and d are the width and thickness of the specimen respectively.

Dynamic Charpy impact tests were conducted according to ASTM D 6110-97 [8] using a Universal Impact Testing Machine. The dimension of the specimens used was 72 mm x 18 mm x 3mm. The hardness of the composite was measured using a Durometer hardness tester in Shore (D) scale.

### 3. Results and Discussion

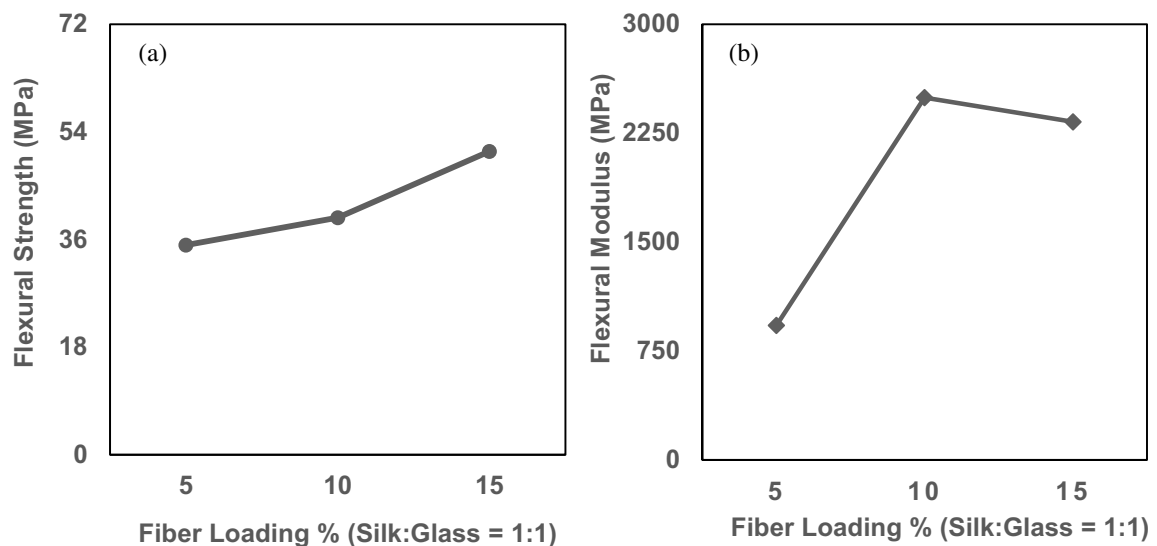
#### 3.1 Effect of fiber loading

**3.1.1 Tensile properties.** Tensile properties of composite samples were measured for each fiber content (5,10 and 15 wt.%) with the help of stress/strain curves. The tensile strength values of raw silk and glass (silk:glass=1:1) fiber reinforced hybrid polypropylene composites at different fiber loading are shown in Figure 1 (a). With the increase in fiber loading, the ultimate tensile strength of the composite decreased. As the amount of fiber added increases, contact between fiber and matrix increases to make the interfacial bonding weaker. As a result, the weak interfacial area between the matrix and fibers increase. Due to this, the ease of failure increased and thus the tensile strength decreased [9]. The same trend was also observed by other researchers [10-13]. Young's modulus values of raw silk and glass (silk:glass=1:1) fiber reinforced hybrid polypropylene composites at different fiber loading are shown in Figure 1 (b). Young's modulus increased up to 10% fiber loading and then decreased when the fiber content was further increased to 15%. Young's modulus increased because incorporation of fibers in matrix creates partially separated micro spaces, which obstruct stress propagation between the fiber and the matrix [12]. As the fiber loading increased, the degree of obstruction increased, which in turn also increased the stiffness [14].



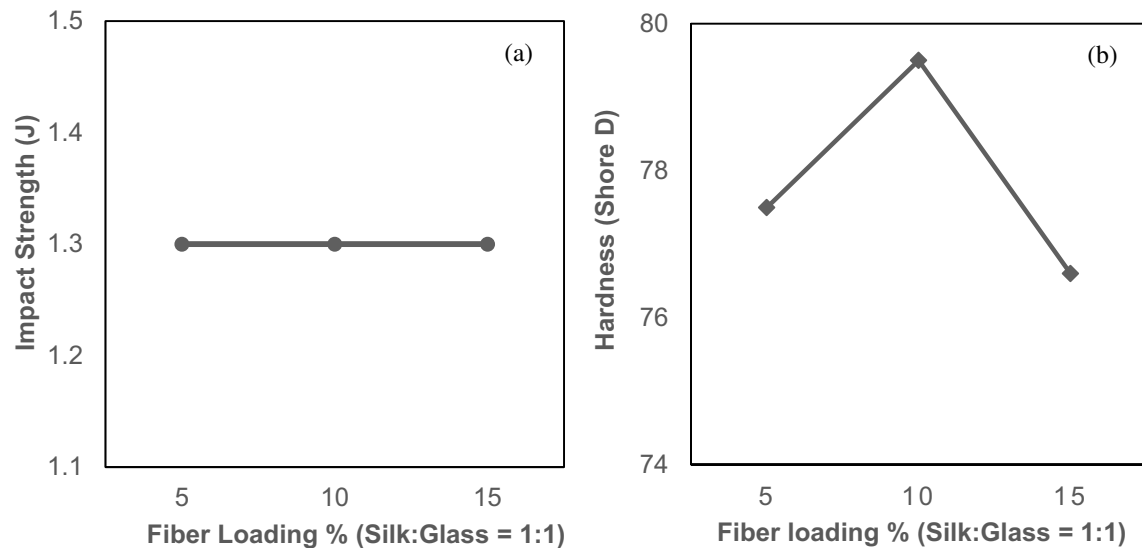
**Figure 1.** Variation of (a) tensile strength and (b) Young's modulus against fiber loading.

**3.1.2 Flexural properties.** Flexural properties were measured for samples of each fiber content (5, 10, 15 wt.%) with the help of stress/strain curves and respective equations. The flexural strength of raw silk and glass fiber reinforced hybrid polypropylene composites at different fiber loading is shown in Figure 2 (a). The flexural strength increased with an increase in fiber loading, which is in agreement with the findings by other researchers [15-17]. Owing to the suitable alignment of the polypropylene chain with the fiber, weak fiber-matrix adhesion might be easily overcome. Therefore, as fiber loading increases [12], the possibility of strong fiber-matrix adhesion increases, which results in an enhanced flexural strength [11]. Flexural modulus values of raw silk and glass (silk:glass= 1:1) fiber hybrid polypropylene composites at different fiber loading are shown in Figure 2 (b). Flexural modulus increased with an increase in fiber loading up to 10%, but decreased slightly at 15% [16, 17]. Since both silk and glass are materials having high modulus, higher fiber concentration demands higher stress for the same deformation [13] and increased fiber-matrix adhesion provides increased stress transfer from the matrix to the fiber. This result can be attributed to the incorporation of rigid glass fiber into the soft PP matrix. As a result, high modulus fiber incorporation into the soft polypropylene matrix increased flexural modulus.



**Figure 2.** Variation of (a) flexural strength and (b) flexural modulus against fiber loading.

**3.1.3 Impact strength.** Impact strength of a material provides information regarding the energy required to break a specimen of given dimensions; the magnitude of which reflects the ability of the material to resist a sudden impact. Variation of Charpy impact strength with fiber loading for raw silk and glass (silk:glass= 1:1) fiber reinforced hybrid composite is shown in Figure 3 (a). As shown in the figure, impact strength of the composites remained unchanged with an increase in fiber loading. The impact strength of the fiber reinforced polymeric composites depend on the nature of the fiber, polymer and fiber-matrix interfacial bonding [18, 19]. Poor interfacial bonding induces micro-spaces at the fiber-matrix interface. The micro-spaces cause micro-cracks when impact occurs, resulting in crack propagation and giving no change in impact strength with increase in fiber loading.

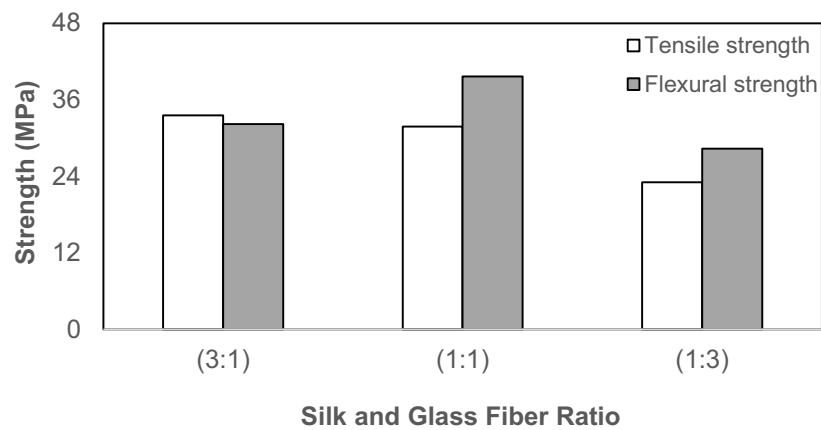


**Figure 3.** Variation of (a) impact strength and (b) hardness against fiber loading.

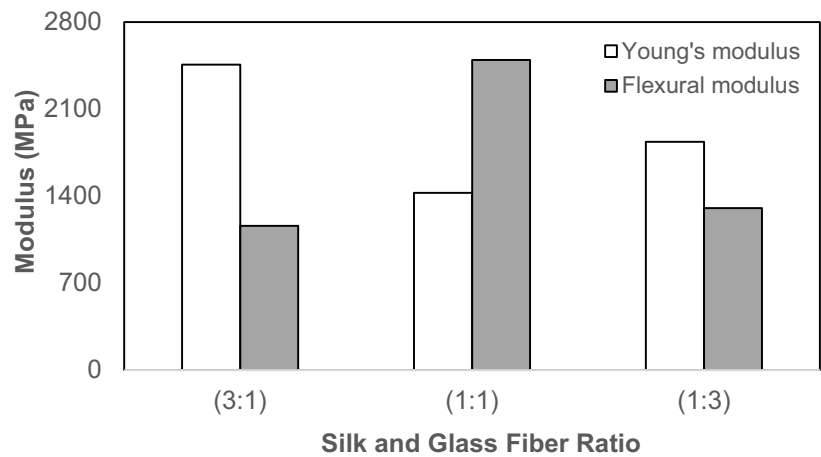
**3.1.4 Hardness values.** Hardness of a composite depends on the distribution of fiber into the matrix [13, 20]. Variation of hardness with fiber loading for raw silk and glass (silk:glass= 1:1) fiber reinforced hybrid composites is shown in Figure 3 (b). Hardness increased up to 10% fiber loading, however it decreased for 15% fiber loading. Hardness increased because incorporation of fiber into the polypropylene matrix reduced the flexibility of the matrix resulting in more rigid composite. With 15% fiber loading, hardness decreased because of the poor dispersion of the fiber into the matrix with more voids between matrix and fiber.

### 3.2 Effect of fiber ratio

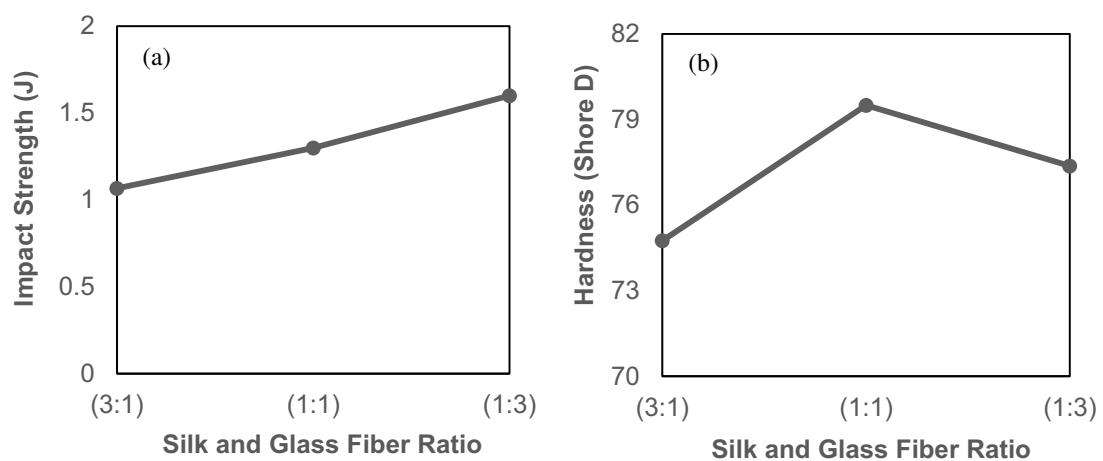
Variation of mechanical properties of the composites reinforced with different ratios of silk and glass fiber are shown in Figures 4-6. Composite with higher weight fraction of glass fiber showed higher impact strength compared to the composite with higher fraction of silk fiber. This is probably due to high strain to failure of the single glass fiber [20]. Strength of glass fiber is higher than that of silk fiber and as a result, glass fiber is capable of absorbing more energy due to impact force. Both tensile strength and Young's modulus increased with increase in silk fiber loading. The chemical composition of the fiber and its internal structure affected tensile strength [21]. With the same fiber loading ratio of 1:1, the flexural strength, flexural modulus and hardness showed the highest value. This is due to the proper adhesion between the fibers and the matrix. Fibers were also uniformly distributed throughout the matrix with the same fiber loading ratio.



**Figure 4.** Variation of tensile and flexural strength at different silk and glass fiber ratio.



**Figure 5.** Variation of tensile and flexural modulus at different silk and glass fiber ratio.



**Figure 6.** Variation of (a) impact strength and (b) hardness at different silk and glass fiber ratio.

#### 4. Conclusion

In present research, silk and glass fiber reinforced hybrid polypropylene composites were prepared using hot press technique at three levels of fiber loading (5, 10 and 15 wt.%). Silk and glass fiber ratio was varied at 1:1, 3:1 and 1:3 for 10 wt% fiber loading. Tensile strength of prepared composites decreased with an increase in fiber loading, whereas Young's modulus increased up to 10% fiber loading. Flexural strength of prepared composites increased with fiber loading, on the other hand flexural modulus increased up to 10% fiber loading. Impact strength remained unchanged but the hardness (Shore D) increased up to 10% fiber loading. Based on the experimental results and analysis, composite containing 10 wt% fiber at 1:1 ratio of silk and glass exhibited the best set of mechanical properties.

#### References

- [1] Ashik K P and Sharma R S 2015 *A review on mechanical properties of natural fiber reinforced hybrid polymer composites*, Journal of Minerals and Materials Characterization and Engineering, Vol. 3, pp. 420-426.
- [2] Fibre Glass Development corporation, <https://www.fibreglast.com/product/the-fundamentals-of-fiberglass>, Date of Access: 16 May 2018.
- [3] John M J, Anandjiwala R D and Thomas S (2014) *Hybrid Composites* (South Africa).
- [4] Haque M M, Islam M N, Hasan M, Islam M S and Islam M S 2010 *Coir fiber reinforced polypropylene composites: physical and mechanical properties*, Advanced Composite Materials, Vol. 19, pp. 191-206.
- [5] Brydson J A 1999 *Plastics Materials* (UK: Butterworth-Heinemann).
- [6] ASTM Standard D 638-01 2002 *Annual Book of ASTM Standard* (USA: ASTM International), Vol. 08.
- [7] ASTM Standard D 790-00 2002 *Annual Book of ASTM Standard* (USA: ASTM International), Vol. 08.
- [8] ASTM Standard D 6110-97 2002 *Annual Book of ASTM Standard* (USA: ASTM International), Vol. 08.
- [9] Rahman M R, Hasan M, Haque M M and Islam M N 2010 *Physico-mechanical properties of jute fiber reinforced polypropylene composites*, Journal of Reinforced Plastics and Composites, Vol. 29(3), pp. 445-453.
- [10] Jamil Md S, Ahmed I and Abdullah I 2006 *Effects of rice husk filler on the mechanical and thermal properties of liquid natural rubber compatibilized high-density polyethylene/natural rubber blends*, Journal of Polymer Research, Vol. 13(4), pp. 315-321.
- [11] Rahman Md R, Haque Md M, Islam Md N and Hasan M 2008 *Improvement of physico-mechanical properties of jute fiber reinforced polypropylene composites by post-treatment*, Composites A, Vol. 39, pp. 1739-1747.
- [12] Yang H S, Kim H J, Son J, Park H J, Lee B J and Hwang T S 2006 *Water absorption behavior and mechanical properties of lignocellulosic filler-polyolefin bio-composites*, Composite Structures, Vol. 72(4), pp. 429-437.
- [13] Rahman M R, Huque M M, Islam M N and Hasan M 2009 *Mechanical properties of polypropylene composites reinforced with chemically treated abaca*, Composites A, Vol. 40, pp. 511-517.
- [14] Mir S S, Nafsin N, Hasan M, Hasan N and Hassan A 2013 *Improvement of physico-mechanical properties of coir-polypropylene biocomposites by fiber chemical treatment*, Materials and Design. Vol. 52, pp. 251-257.
- [15] Rana A K, Mandal A and Bandyopadhyay S 2003 *Short jute fiber reinforced polypropylene composites: effect of compatibiliser, impact modifier and fiber loading*, Composites Science and Technology, Vol. 63(6), pp. 801-806.

- [16] Joseph S, Sreekala M S, Oommen Z, Koshy P and Thomas S 2006 *A comparison of the mechanical properties of phenol formaldehyde composites reinforced with banana fibers and glass fibers*, Composites Science and Technology, Vol. 62(14), pp. 1857-1868.
- [17] Reis J M L and Carneiro E P 2012 *Mechanical characterization of sisal fiber reinforced polymer mortars: Compressive and flexural properties*, Journal of Reinforced Plastics and Composites, Vol. 31(23), pp. 1662-1669.
- [18] Lin J C, Chang L C, Nien M N and Ho H L 2006 *Mechanical behavior of various nanoparticle filled composites at low-velocity impact*, Composite Structures, Vol. 74(1), pp. 30-36.
- [19] Bajpai P K, Singh I and Madaan J 2012 *Comparative studies of mechanical and morphological properties of polylactic acid and polypropylene based natural fiber composites*, Journal of Reinforced Plastics and Composites, Vol. 31(24), pp. 1712-1724.
- [20] Premalal H G B, Ismail H and Baharin A 2002 *Comparison of the mechanical properties of rice husk powder filled polypropylene composites with talc filled polypropylene composites*, Polymer Testing, Vol. 21(7), pp. 833-839.
- [21] Hatta N and Akmar N 2008 *Proc. CUTSE Int. Conf. (Miri, Sarawak, Malaysia)*.

### Acknowledgement

The authors would like to thank Department of Materials and Metallurgical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh for their support during present research.