Materials Physics and Mechanics 16 (2013) 107-117 Received: January 9, 2013

EFFECT OF FIBRE LENGTH AND FIBRE CONTENT ON MECHANICAL PROPERTIES OF SHORT BASALT FIBRE REINFORCED POLYMER MATRIX COMPOSITES

P. Amuthakkannan[1*], V. Manikandan[2], J.T. Winowlin Jappes[3], M. Uthayakumar[2]

[1]Department of Mechanical Engineering, Kalasalingam University, Krishnankoil, India

[2]Veerasamy Chettiar College of Engineering and Technology, Puliangudi, India

[3]Department of Mechanical Engineering, Cape Institute of Technology, Levengipuram, India

*e-mail: pa_kanna@yahoo.co.in.

Abstract. This investigation focuses on the effect of fibre length and fibre content of basalt fibre on mechanical properties of the fabricated composites. Specimen prepared with short basalt fibre as reinforcing materials and polyester resin as a matrix in polymer composite. Based on the availability, different fibre length was taken and fabrication was done with compression moulding machine, keeping the mould closing as constant and increasing the content of fibre in the composites. Specimens were subjected to tensile strength, flexural strength and impact strength test and the failure of the composite was examined with the help of scanning electron microscopy (SEM).

1. Introduction

Due to the necessities of low weight and high strength materials, it is required to find out the suitable substitute with low cost. Short fibres composites are the most commonly used reinforcements to improve mechanical performance of ceramics, metals and polymers. When compared to continuous fibres reinforced composites, short fibres reinforced composites can be easily processed with affordable cost. The most important factors in the short fibres reinforcement are fibre dispersion and fibre aspect ratio.

The homogeneous fibre dispersion is the most important factor to enhance the mechanical properties. In this investigation short fibre is spread manually and its uniformity is checked periodically.

Tiesong et al studied the effect of fibre content on mechanical properties and fracture behavior of short carbon fibre reinforced geopolymeric matrix composites with different volume fractions [1]. Shao et al studied the effect of length and fibre orientation distributions on tensile strength of short fibre reinforced polymers using an analytical method for predicting the tensile strength of short-fiber-reinforced polymers (SFRP). The results showed that the strength of SFRP increased rapidly with the increase of the mean fiber length at small mean fiber lengths. The inclined tensile strength of fibers has a great effect on the strength of composites [2]. According to Junzhi Zhang et al. experimental results show that bending resistances of short – chopped basalt fiber concrete is increased. As a result, it is proved that short- chopped basalt fiber is useful in concrete [3].

Impact mechanical properties of basalt fiber reinforced geopolymeric concrete (BFRGC), including dynamic compressive strength, deformation and energy absorption capacity were studied using a 100-mm-diameter split Hopkinson pressure bar (SHPB) system.

The addition of basalt fiber can significantly improve deformation and energy absorption capacities of geopolymeric concrete (GC), while there is no notable improvement in dynamic compressive strength. In addition, the optimum volume fraction of basalt fiber was presented for BFRGC [4]. Thomason and Vlug studied the influence of fibre length and concentration on the properties of glass-reinforced polypropylene. Composite impact strength increased directly with increasing fibre concentration. For the current fibre/polypropylene combination a fibre length > 8 mm is required [5].

Xinrui Zhang studied the wear and friction properties of the Short basalt fiber (BF) reinforced polyimide (PI) composites were fabricated by means of compression-molding technique. The results revealed that the low incorporation of BFs could improve the tribological behavior of the PI composites remarkably. The friction coefficient and wear rate decreased with increases in the sliding speed and load respectively [6]. Botev et al investigated the mechanical properties of basalt fiber-reinforced polypropylene with different contents of short basalt fibres and mechanical characteristics, for example, stress and strain at yield with increasing of the fiber content [7]. Measurement of fiber length is often performed on photographs of short fibers obtained from burning off or dissolving the matrix. Correction of the measurement of fiber length was carried out and the real value of mean fiber length and the real fiber length distribution were obtained [8]. The geometrical and mechanical properties and chemical composition of different basalt and glass fibers had been investigated. Tensile tests were performed on short basalt fiber made by melt blowing. The SiO_2 and Al_2 O_3 content of basalt fibers showed correlation with tensile properties of fibers [9]. The relationship between properties of basalt Fibre –Wood Plastic Composites and the content of BF were studied, when the wood-plastics composite (WPC) was reinforced by 12 mm and 3 mm short basalt fiber (SBF). The BF-WPC plate can be developed with different properties and cost-effective material by choosing different length and content of basalt Fibre [10]. Composites of polypropylene (PP) reinforced with short glass fibers (SGF) and short carbon fibers (SCF) were prepared with extrusion compounding and injection molding techniques. The tensile properties of these composites were investigated [11]. Bernasconi et al investigated the effect of fibre orientation on the fatigue strength of a short glass fibre reinforced polyamide-6 [12]. Hui et al. studied the influence of fiber length on tribological properties of short carbon fiber (SCF) reinforced epoxy composites were investigated [13]. Nevin et al. studied the effect of fiber length and fiber length distribution on the properties of short carbon-fiber-reinforced-polypropylene composites using extrusion compounding and injection molding techniques with three different fibre lengths and tensile strength and modulus values of the composites increased with the increasing carbon fiber content [14]. Bin et al studied the influence of fibre length and compatibilizer on mechanical properties of long glass fiber and tensile strength and notched impact strength models were applied to interpret the experimental results of the mechanical proper ties [15]. Mechanical properties of the kenaf fibre reinforced composites were investigated as a function fibre loading. The reinforcing effects of kenaf and fibrefrax fibers were evaluated at various fiber loadings - 19, 28, 36, 43, 52, and 62 vol. % [16]. According to Wong et al, the impact strengths of E-glass, coir, oil palm as well as E-glass/coir and E-glass/oil palm hybrid polyester composites were studied. All types of composites were reinforced with fiber volume fractions of 30 %, 40 %, and 50 % and fiber lengths 3, 7, and 10 mm. Results show that impact strength was improves with fiber content and fiber length [17]. From the literature, most of the authors studied the mechanical properties of the short basalt fibre with concrete applications and some fatigue and wear properties. Some authors studied about the mechanical properties of the short fibre with different types of fibres.

In this study to investigate the mechanical properties of short basalt fibre reinforced polymer composites considering different fabricating parameters such as effect of fibre content and fibre length. Mechanical properties of the specimen are conducted as per ASTM standard. The fractured surfaces are studied using scanning electron microscope.

2. Experimental tests

2.1. Materials. Basalt fibre of different length was imported from ASA.TECH, Austria. Unsaturated polyester resin, methyl ethyl ketone peroxides (MEKP) and co-napthenate was purchased from G.V.R. Enterprises, Madurai, India.

2.2. Fabrication of composites. Basalt fibre reinforced polymer matrix composites were fabricated using the compression moulding method and unsaturated polyester resin was used as a matrix. For a proper chemical reaction, cobalt naphthenate and methyl ethyl ketone peroxide were used as accelerator and catalyst respectively. Different length of basalt fibre such as 4 mm, 10 mm, 21 mm and 50 mm of basalt fibre were take for experimentation. These were weighed to determine the corresponding 1:1 amount of unsaturated polyester resin. The polyester resin was cured by incorporating 1 % volume of the methyl ethyl ketone peroxide (MEKP) catalyst. 1 % volume of Cobalt Napthenate (accelerator) was also added to perform effective reaction. A stirrer was used to homogenous the mixture and then, the resin mixture was used to fabricate the basalt fibres polymer by compression moulding technique with uniform moulding pressure for all the composites. The samples were cured for approximately 24 hours at room temperature. Composites sample was fabricated with different fibre length and different fibre percentage. Fibre added gradually in the composite from 10 %, 20 %, 30 %.....90 %, and Table 1 represents the volume fraction of fibre in the composites. The photograph of the short fibre is presented as Fig. 1.

Fig. 1. Short basalt fibre.

Table 1. Volume fraction of fibres in the composites.

SI No	Adding of fibre in the composite, %	Fibre content, wt. %
1	10	21
2	20	32
3	30	43
4	40	55
5	50	64
6	60	66
7	70	67
8	80	68
9	90	71

3. Experimental tests

3.1. Tensile strength. A material can withstand the maximum stress while being stretched or pulled before necking. This test was done with Universal Testing Machine (UTM) according to ASTM standards (D638).

3.2. Flexural strength. The flexure test method measures behavior of materials subjected to simple beam loading. The 3-point bending test is used to find the flexural modulus, flexural strength and strain at break of the Basalt fibre reinforced polymer composites. Flexural test is conducted on Universal Testing machine with cross head speed of 2 mm/min according to ASTM D790-98. The sample dimensions are 127 mm×13 mm×3 mm. The span length of 100 mm is maintained.

3.3. Impact strength. Impact test is used to determine the amount of impact energy that was required to break the specimen. An un-notched Izod Impact test is conducted to study the impact energy according to ASTM D256. The un-notched specimens are kept in a cantilever position, and a pendulum has swung around to break the specimen. The impact energy (J) is calculated using a dial gauge that is fitted on the machine. Five samples were taken for each test, and the results are averaged. The tested specimen is presented in Fig. 2.

Fig. 2. Typical tested specimens.

4. Results and discussion

4.1. Tensile strength

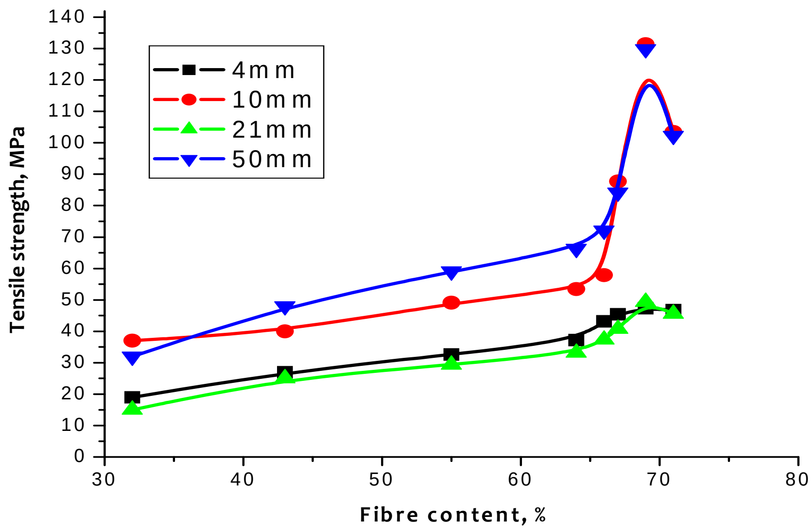


Fig. 3. Tensile strength of short basalt fibre composites.

Figure 3 shows the tensile strength of short basalt fibre with varying fibre length and fibre content. From the figure, it is clear that the addition of basalt fibre improve the tensile strength of composites in 10 mm and 50 mm owing to better tensile strength. The addition of basalt fibre get increased strength by the fibre content of 68 wt %. Length of fibre also influences the tensile strength. But 4 mm and 21 mm length of fibres shows the lowest tensile strength. This is due to may not be producing the strong interfacial bonding between fibre and matrix. However increasing fibre content there is no remarkable improvement in tensile strength. From the Fig. 5c shows the voids due to fibre pull out. The strong interface region can transfer the maximum load from the matrix to fibre surface.

In discontinuous fibre polymer composites the stress along the fibre is not uniform. A definite fibre length is required for the effective transfer of stress between fibre and matrix. From the Fig. 3 it is clearly explained that tensile strength gives a maximum values of 10 mm and 50 mm length of fibres. At lower fibre content this is not enough to impart high strength. The tensile strength shows linear increases from 10 wt.% of fibre content. At a fibre content of 68 wt.% the tensile strength is highest which allowable fibre content. When the stress concentrations at the fibre ends leads to matrix cracking. Shorter fiber lengths will create more fiber ends, which eventually act as stress concentration points where failure often occurs at these sites. This possibly clarifies the reduction of tensile strength [18].

Figure 4 shows the tensile modulus of short basalt fibre composites. The tensile strength and modulus of composites increases with increasing fibre weight percentage up to a certain amount. If the fibre weight ratio decrease the below optimum value, load is not uniformly distributed to more fibres, which are not well bonded with resin and fibre resulting decreases in tensile properties. Further increment in fiber weight ratio has resulted in decreased tensile properties. The failure mechanisms have shows that under tensile loading the failure start at ends of the fibre and propagate along the fibre matrix interface.

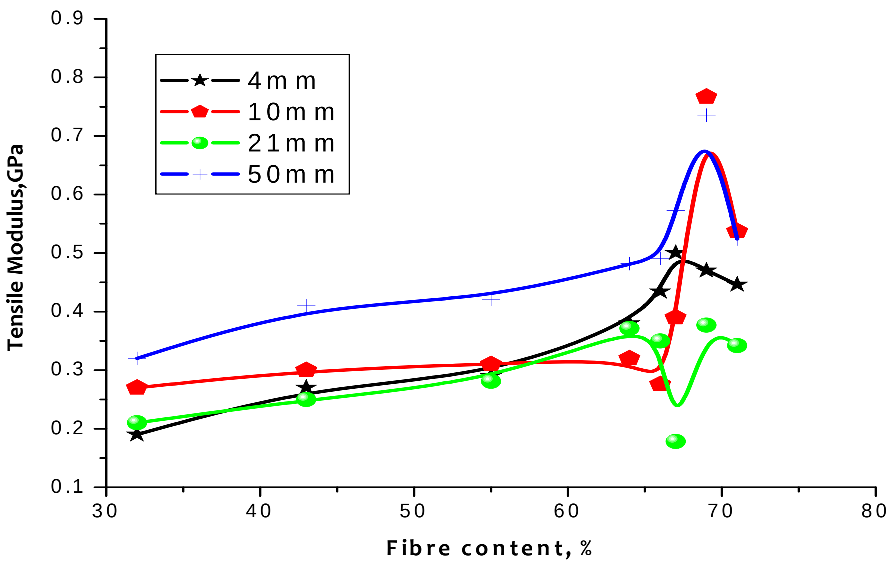
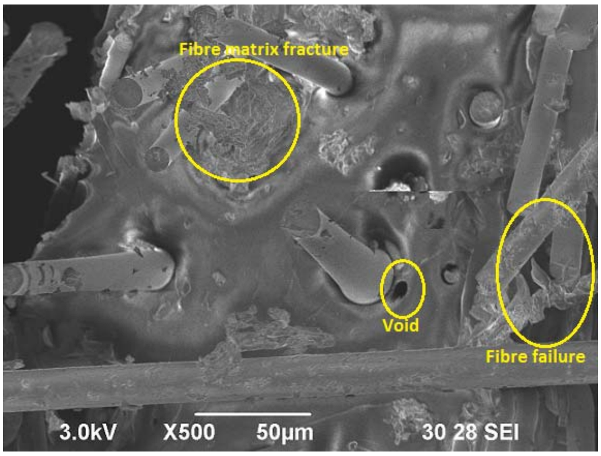
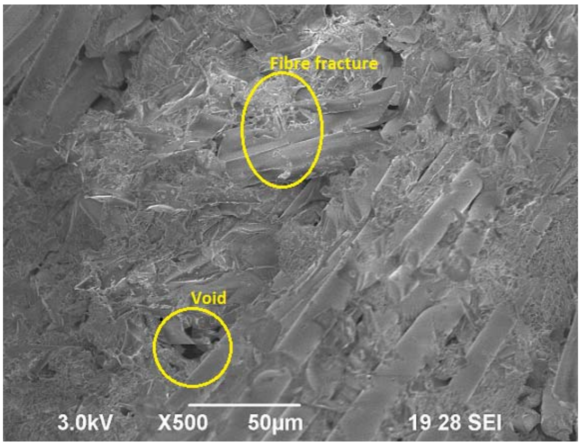


Fig. 4. Tensile modulus of short basalt fibre composites.

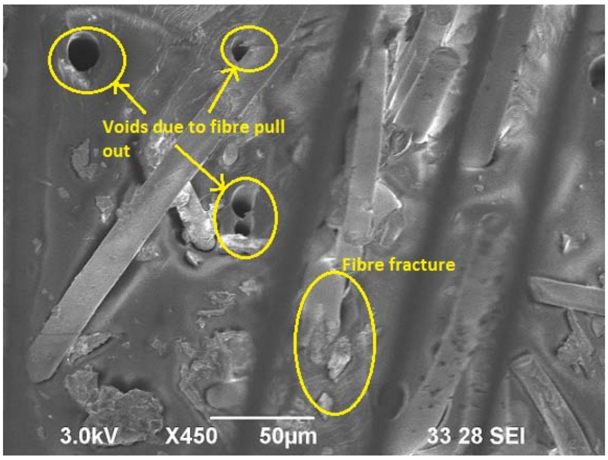
Composites having shorter fibre length (4mm), tensile strengths were decreased compared to 10mm fibre reinforced composites. The reason is that shorter fibre may not be compatible composites because of the improper bonding between the fibres and matrix. Tensile strength was decreased with higher percentage of fibre. In general poor uniform distribution of fibres can be observed for less percentage of fibre. Fiber breakage and fiber pullout and fiber fracture mechanisms can be seen easily. From the SEM photograph, fibre and matrix debonding, fibre fracture, voids due to fibre pull-out are observed as failure modes.



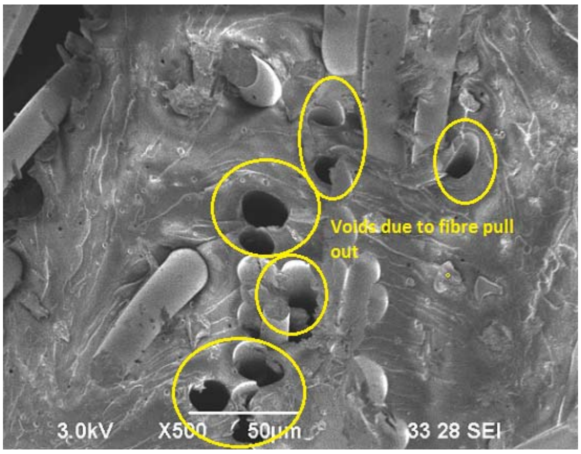
(a)



(b)



(c)



(d)

Fig. 5. SEM image of Tensile strength of basalt fibre composite a) 4 mm fibre length, b) 10 mm fibre length, c) 21 mm fibre length, d) 50 mm fibre length.

4.2. Flexural strength. The flexural properties of short basalt fibre reinforced polyester composites under different fibre content and fibre length are given in Fig. 6 and Fig. 7. Flexural strength and modulus were found to increases significantly as the fibre content increased up to 68 wt.%. Lower flexural strength and modulus were observed for the composites with lower fibre content. For every increasing of fibre content there is an increase of flexural strength. The flexural modulus is higher for 10 mm length fibre but the strength is low compared to other lengths. The flexural strength is found to be maximum when the fibre length is 21 mm and flexural modulus is found to be maximum when the fibre length is 10 mm. The higher length of fibre is capable withstanding higher bending load and lower fibre length of fibre having higher modulus.

Flexural modulus of basalt fibre reinforced polymer composites have been tested with 3 point load. Comparing 4 mm and 10 mm length of fibre, flexural modulus of the 10 mm length of fibre showed better property than 4 mm length fibre. In 64 % of fibre has the highest variation in the flexural strength and in 68 % of fibre which was 56.7 % greater than the 4mm length of fibre. The fibre and matrix interaction is high in the 64 % and 68 % of fibre when

4mm is compared with 10mm length of fibre. Comparison of 10 mm and 21 mm length of fibre, 68 % of fibre has the highest variation in the flexural modulus. Based on 10 mm and 21 mm length, the flexural modulus of 10mm length of fibre was superior to the other length of fibres. 71 % of fibre 21 mm length of fibre was 14 % greater than the 10 mm length of fibre.

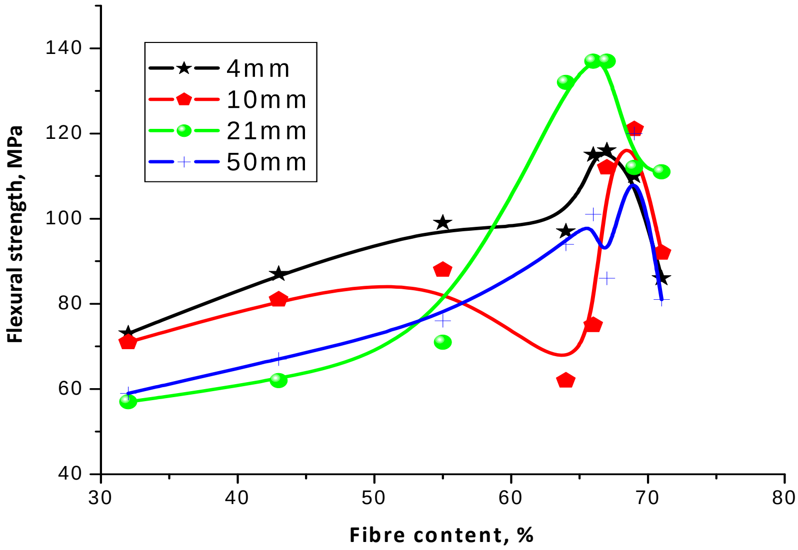


Fig. 6. Flexural strength of basalt short fibre composites.

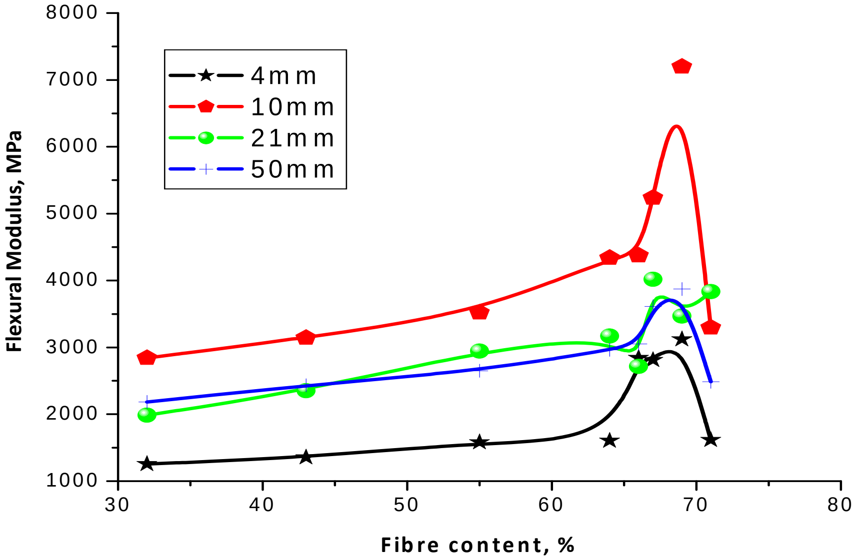


Fig. 7. Flexural modulus of basalt short fibre composites.

Comparing of 21 mm and 50 mm length of fibres, 21 mm length of fibre is dominating in the flexural modulus except 66 % and 68 % of fibre in the composites.

As per the overall observation in the flexural strength of the composite, incorporation of fibre content in the polymer composite influences the properties of the composites [21]. Increasing of fibre content in the composite increased the strength of the composites.

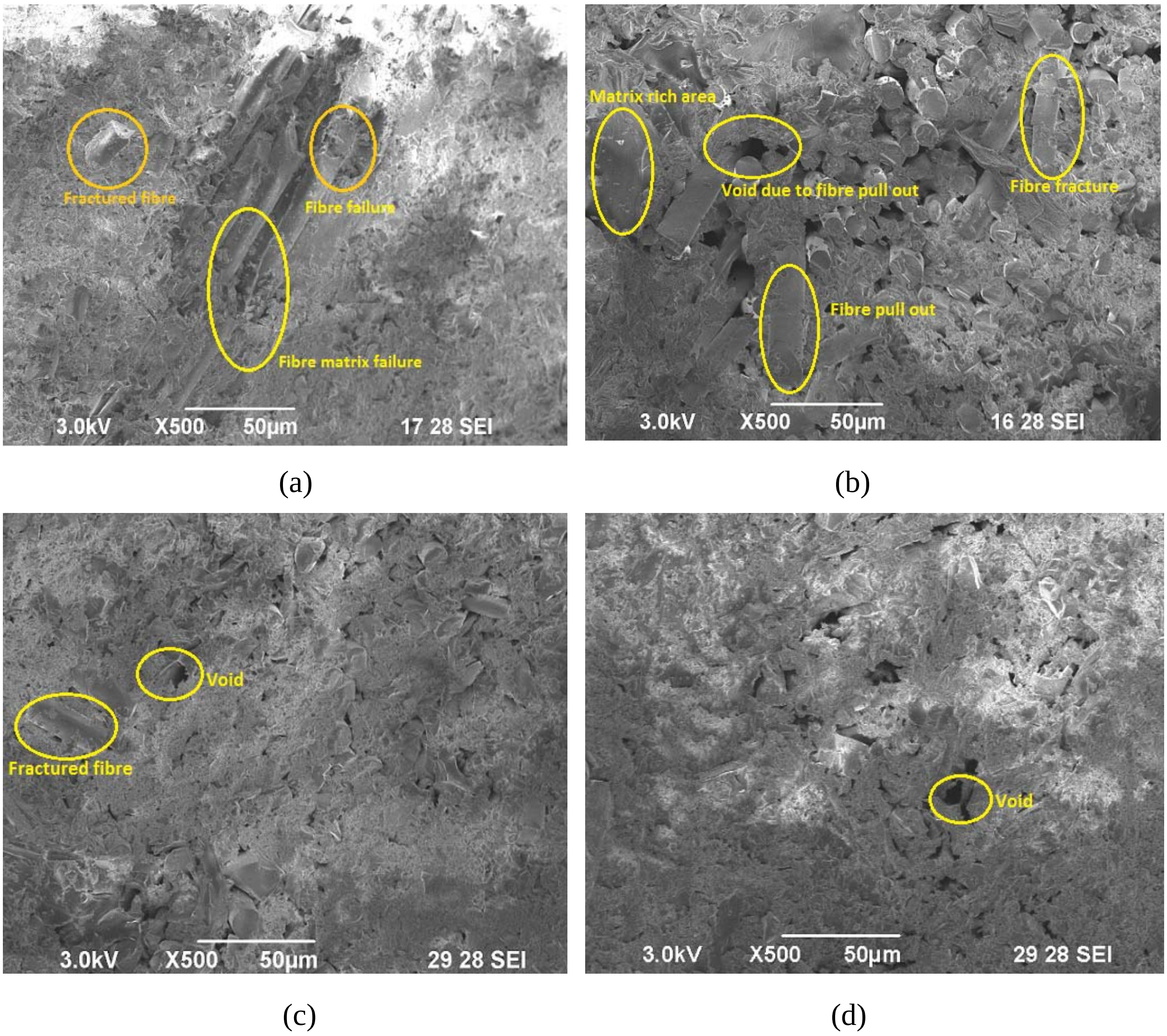


Fig. 8. SEM image of flexural strength of basalt fibre composite a) 4 mm fibre length, b) 10 mm fibre length, c) 21 mm fibre length, d) 50 mm fibre length.

The strong interface between fibre and matrix results in composite with high flexural strength. The failure indicates the separation between fibre and matrix. When the content of reinforced fiber reached above the certain value; these excessive fibers affect the even combination between matrix and fiber. It is evident that reason for the failure of composites is weak bonding as mentioned in the SEM photograph. According to the SEM, fibre pull- out, void, fibre fracture and matrix reach area are predominated in the fracture surfaces.

4.3. Impact strength. Impact strength of a composite is nothing but ability of the material to resist the fracture failure under sudden applied at high speed and is interrelated to the toughness. Impact strength of the short basalt fibre composites were measured with varying fibre content and fibre lengths. Figure 9 shows the effect of fibre content and fibre length on impact strength of the composites. For a given fibre length of 50 mm increased linearly from 45 J/cm^2 to 55 J/cm^2 linearly with increasing fibre content. Other length of fibres are shows lower impact strength. Short basalt fibre may not be effective for the higher energy dissipation.

The gradual increase in impact strength is due to the increases of fibre content and also due to compression pressure which eliminates voids contents in the composites. And length of fibre also contributed to increase the impact strength.

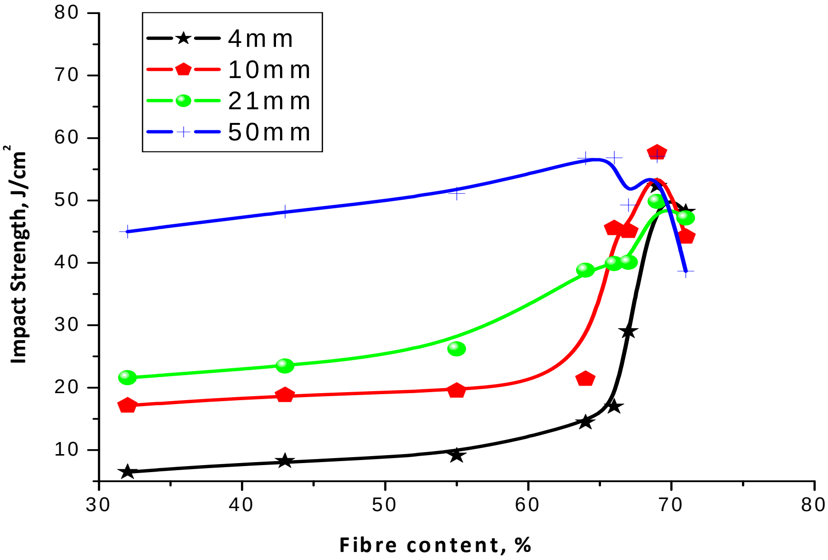


Fig. 9. Impact strength of basalt short fibre composites.

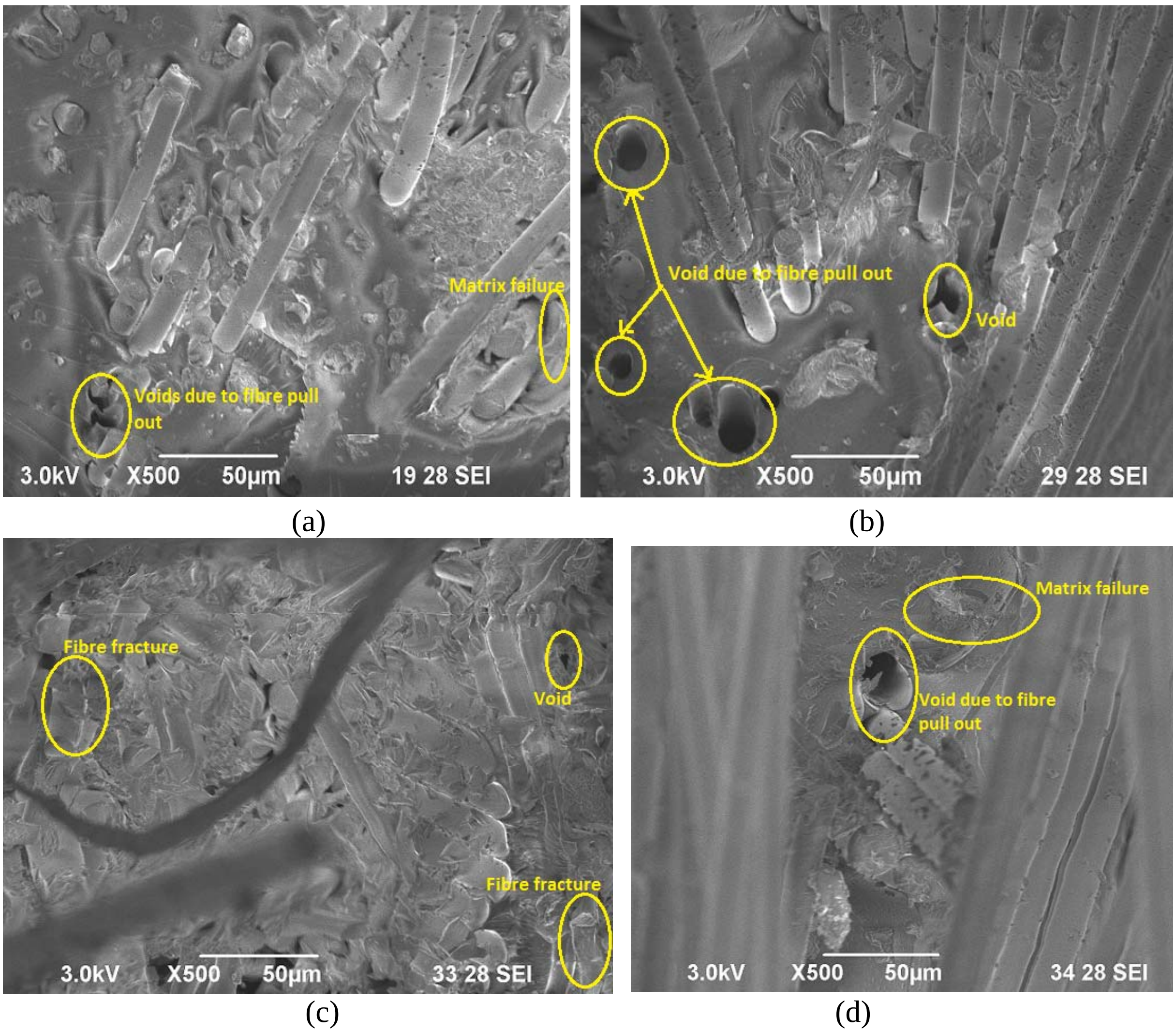


Fig. 10. SEM image of impact strength of basalt fibre composite a) 4 mm fibre length, b) 10 mm fibre length, c) 21 mm fibre length, d) 50 mm fibre length.

Particularly 68 % of fibre shows the better property than others. Impact properties of 10 mm length of fibre were 1 % greater than the 50 mm length of fibre. Due to incorporation of fibre contents in the composite which reduce the voids in the composite.

The fibre plays an importance role in impact strength; they should resist the crack propagation and act as a load transfer medium. Improvement in impact strength of the composites is due to increment in fibre content. The applied stress is transferred effectively due to effective interfacial bonding strength. Fibre length has significantly effect on impact strength to withstand sudden load, when the impact energy exceeds the fibre strength fibre fracture occurs and the fracture transfer thorough out the composites. SEM image showed that the interaction between the short Basalt fibre and polyester matrix. SEM of an impact tested specimens shows the fibre pull-out that is fibre offer resistance to fracture and absorb the sudden load until its fracture.

5. Conclusions

Short Basalt fibre reinforced polymer composites have been investigated with different fibre length and fibre content and the following conclusion were drawn. The characterization of the composites reveals that the fiber length is having a significant effect on the mechanical properties of composites and also fibre content. The optimum fibre weight percentage of 68 % of fibre and optimum length of the fibre of 10 mm were investigated. The tensile strength of the Basalt fibre composites revealed that 68 % of fibre and 10 mm length of fibre exhibits better properties than other lengths of fibre. Flexural strength of composites also shows better properties in 68 % of fibre and 10 mm length of fibre. The length of reinforced basalt fibre play a significant impact on some mechanical properties, Impact strength of basalt fibre reinforced composite of 50 mm length shows the maximum impact energy absorption in all the percentage of fibre.

Acknowledgements

The authors gratefully acknowledge the financial assistance provided by the Department of Science Technology (SERC): SR/S3/ME/0038/2007, GOVERNMENT OF INDIA for this work. The authors also thank the Centre for Composite Material, Department of Mechanical Engineering, Kalasalingam University, Krishnankoil, for completing this work.

References

[1] Tiesong Lin, Dechang Jia, Meirong Wang, Peigang He, Defu Liang // *Bull. Mater. Sci.* **32 (1)** (2009) 77.

[2] Shao-Yun Fu, Bernd Lauke // *Composites Science and Technology* **56** (1996) 1179.

[3] G. Zak, M. Haberer, C.B. Park, B. Benhabib // *Composites Science and Technology* **60** (2000) 1763.

[4] Junzhi Zhang, Huating Liu, Yandong Zhu, Zhaoqi Fu, Jing Zhao // *Advanced Materials Research* **261-263** (2011) 407.

[5] Weimin Li, Jinyu Xu // *Materials Science and Engineering* **505 (1-2)** (2009) 178.

[6] J.L. Thomason, M.A. Vlug // *Composites Part A: Applied Science and Manufacturing* **28** (1997) 277.

[7] Xinrui Zhang, Xianqiang Pei, Qihua Wang // *Journal of Applied Polymer Science* **111** (2009) 2980.

[8] M. Botev, H. Betchev, D. Bikiaris, C. Panayiotou // *Journal of Applied Polymer Science* **74** (1999) 523.

[9] Shao-Yun Fu, Yiu-Wing Mai, Emma Chui-Yee Ching, Robert K.Y. Li // *Composites Part A: Applied Science and Manufacturing* **33** (2002) 1549.

[10] Jinxiang Chen, Sujun Guan, Shunhua Zhang, Jingjing Zheng, Juan Xie, Yun Lu // *Advanced Materials Research* **189-193** (2011) 4043.

[11] S.-Y Fu, B. Lauke, E. Mäder, C.-Y. Yue, X. Hu // *Composites Part A: Applied Science and Manufacturing* **31** (2000) 1117.

[12] A. Bernasconi, P. Davoli, A. Basile, A. Filippi // *International Journal of Fatigue* **29** (2007) 199.

[13] Hui Zhang, Zhong Zhang, Klaus Friedrich // *Composites Science and Technology* **67** (2007) 222.

[14] Nevin Gamze Karsli, Ayse Aytac, Veli Deniz // *Journal of Reinforced Plastics and Composites* **31** (2012) 1053.

[15] Bin Yang, Jinhua Leng, Bobing He, Heng Liu, Yu Zhang, Zhaohua Duan // *Journal of Reinforced Plastics and Composites* **31** (2012) 1103.

[16] Sultan Ozturk // *Journal of Composite Materials* **44** (2010) 19.

[17] K.J. Wong, Umar Nirmal, B.K. Lim // *Journal of Reinforced Plastics and Composites* **29** (2010) 3463.

[18] Y.J. Phua, Z.A. Mohd Ishak, R. Senawi // *Journal of Reinforced Plastics and Composites* **29** (2010) 2592.

[19] P.T. Curtis, M.G. Bader, J.E. Bailey // *Journal of Material Science* **13** (1978) 377.

[20] Laly A. Pothan, Sabu Thomas, N. R. Neelakantan // *Journal of Reinforced Plastics and Composites* **16** (1997) 744.

[21] N. Dayananda Jawali, Siddaramaiah, B. Siddeshwarappa, Joong Hee Lee // *Journal of Reinforced Plastics and Composites* **27** (2008) 313.