Experimental and numerical simulation to predict the Effect of strain rate on tensile response of basalt epoxy woven composite

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Abstract—**The use of sustainable, natural fiber as reinforcement for fabrication of lightweight and low cost composites is increasingly popular in the engineering fields and it is very important to characterize their mechanical properties under different conditions such as varying loading speed. In this present work, the effects of strain rate on the tensile properties of basalt fiber reinforced polymer (BFRP) were investigated. These composites were fabricated hand layup with 12 layer of Basalt fiber Woven Fabric Twill with the ratio of weights of fiber is 50%. Tensile tests of BFRP specimens were conducted at two strain rates 0.1mm/s and 1mm/s using a servo-hydraulic testing system. The tensile strength and elongation increased with increasing strain rate. Moreover, tensile modulus was independent of varying of strain rate. The experiment tensile results and the finite element analysis outcomes for BFRP agree with each other, which validates the numerical results.**

Keywords— Materials composite, basalt, strain rate, loading speed, tensile test, numerical simulation, temperature dependent properties, finite element analysis

I. INTRODUCTION

Nowadays, automotive industries are focusing on developing eco-friendly materials for their components. Basalt fibers have taken an increasing attention for possible replacement of conventional glass fibers [1] because of their advantages such as cost of environmental cost and increased physical and chemical properties.[2] In addition to having non-toxic, non-combustible characteristics, basalt fibers have higher chemical stability and higher tensile strength than those of E-glass fibers in compare to carbon fiber, and their failure strains are bigger [3]. Because of these favorable properties, they can be extensively useful for numbers of application fields, such as automobile industry. The mechanicals properties of most of the polymer and its composites are arte sensitive in nature .for this reason numerous studies have been carried out to study the variation of strength and stiffness of composites at various strain rates. However , most of the researches have concentrated on the behavior of the polymer matrix composites at high strain rates Split Hopkinson Pressure Bar (SHPB) technique is widely used to achieve very high strain rate (>1000s-1)tensile properties [4]. the conventional servo-hydraulic testing machine have been used to achieve low strain rates (<10s-1) are established and few literatures investigated the effects of strain rate in low strain region for basalt/epoxy. Mushtaq et al. investigated the tensile behaviors of the single layer plain woven basalt/epoxy composites under quasi-static and high strain-rate loading. It was found that the tensile behaviors of the basalt/epoxy twill woven composite materials are strain-rate dependent. The tensile modulus and tensile strength increase but the failure strain decreases monotonously with the increasing strain rate [5].

II- MATERIALS AND COMPOSITE PROCESSING

In this study, one laminate is constructed from 12 plies twill woven fabric basalt fiber. The type of epoxy resin used in the matrix material was epoxy and the hardener. The fiber volume ratio in the composite was 2:1. The mechanical properties of fiber and resin applicable for this investigation at room temperature are summarized in table 1.

Material	young's modulus (GPA)	Tensile strength	Fabric weight (g/m2)	Fabric thickness (mm)	Filament dimeter (µm)	Density (g/cm3)	Elongation at Break (%):
fiber basalt	63	571	200	0.28	13	2.8	3.15

Table 1. Physical and mechanical properties of woven basalt and epoxy resin [6]

II-1- Hand Layup Technique

Hand layup is a technique used in the manufacturing process of this research. This technique is a traditional composite processing method, which involves manually positioning the reinforcement mat or woven roving in the open mold, and resin is poured, brushed, or sprayed over onto the glass.

The woven fiber was positioned manually on table and the epoxy resin was brushed over and into the woven basalt fiber (Fig. 1-1). In the preparation of the specimens, twelve fiber basalt plies were used. Plastic were applied to cover the table in order to prevent the epoxy resin from directly touching the surface of table. Fabrication began with fixing the fiber fabric onto the table, followed by preparing the mixture of the epoxy resin and the supplier recommends the hardener. They were left for at least 48 hours to ensure that the epoxy resin is completely dry. In this research, the specimens were exposed to air for two weeks in order to ensure that the curing of the epoxy was complete. Once the epoxy hardened, the specimens were removed for the finishing process (Fig. 1-2). Moreover, the fiber volume of the specimens fell 50 per cent. The final stage of fabrication would be the cutting process (Fig. 1-3). The size of the specimen was estimated by drawing the required lines on the surface of the specimens using a roller and a marker pen. Then, the specimens were cut based on these lines, the test specimens are cut from the sheet to the following size as per ASTM standards (ASTM D3039 [7] by using a saw (Fig. 1-1). The individual specimens were then carefully measured to ensure that they had similar dimensions.

Figure 1: Fabrication process of specimens

II- 2- Mechanical Properties Test

The tensile test is regarded as a basic mechanical testing prerequisite for materials. The test was carried out to determine the ultimate strength, stress-strain relation, and to develop a comprehensive knowledge of basalt/epoxy composite material used in this research. The author used the servo-hydraulic machine (Fig. 2). The machine is connected to a computer to view and interact with the result; it is also supported by software used to calculate the mechanical properties, conduct post analysis, and documentations .The tensile test speed is set at a constant value of 1 mm/ s and 0.1 mm/s up to the fracture stage according to conventional standards.

Figure 2: Setup used for traction test

III- RESULTS AND DISCUSSION

III- 1- TENSILE TEST RESULTS

Figure 3 shows the stress strain curves of BFRP at two different strain rate (0.1/1 mm/s), the stress strain response of BFRP is linearly elastic up to maximum stress point followed by an abrupt failure, the behaviour of BFRP results are extracted from stress-strain curves at two strain rate are summarized in table 2.

	0.1 mm/s	1 mm/s
E (GPa)	3	3
R_m (MPa)	185	228
A(%)	6.5	7.49

Table 2 : Table of experimental results

Figure 3 shows the curve between tensile stress –strain. It is evident from the figure that properties increase with loading rate i.e. from 0.1 mm/s to 1mm/s, the value of tensile stress and the strain at break are also increasing. Its shows the load carrying capacity of the BFRP composite is better at higher loading rate. It is due to the better cohesive bonding between the fibre/matrix interfaces. But the modulus value is found to be unaffected with loading, the Strain at break Vs Loading rate is shown in figure 4 the curves show the displacement and load by time , the tensile test at 1mm/s need just 20 s to achieve failure comparing to lowest strain which need 148s to achieve the failure phenomena explained by better tenacity of BFRP and this quality is very demanded in automotive industry .

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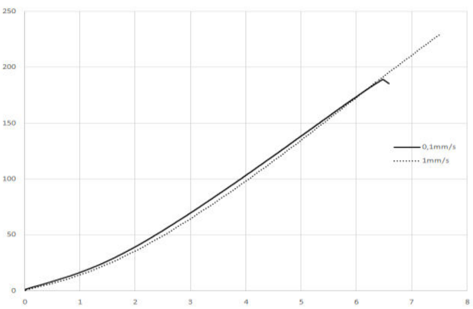


Figure 3: Experimental stress-strain curves for BFRP specimens

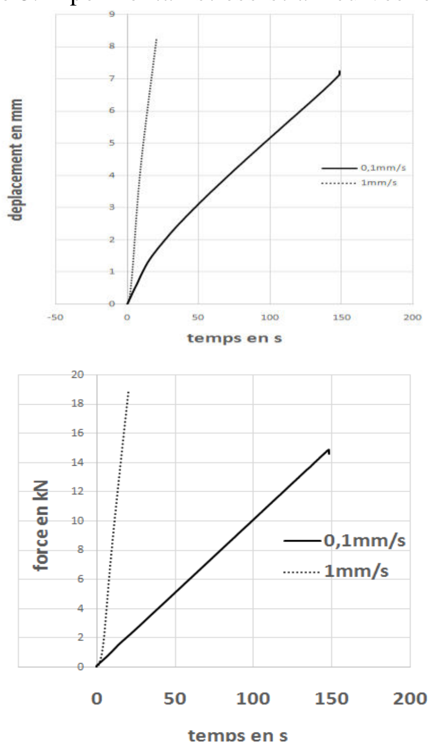


Figure 4: Displacement and load versus of time

III- 2- FAILURE PATTERNS OF BASALT/EPOXY COMPOSITE

Figure 5 shows typical specimens tested in tensile, which presented valid failure mode, classified in accordance with ASTM D3039-0020 (Figure 2) and depicted in Tables 1, 2 and 3. After the tensile tests all specimen were evaluated Some specimens presented fracture near to the tabs as classified in the

ASTM D3039-0020.

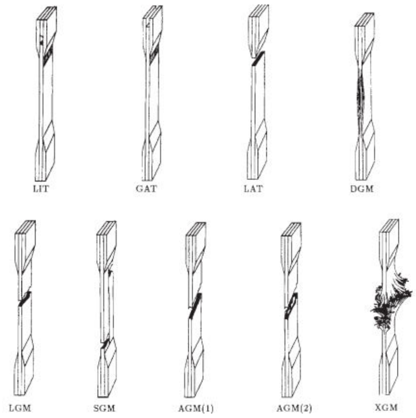


Figure 5: Typical specimens tested in tensile

Figure 6 shows the bulk images of BFRP composite with different failure pattern tested at (a) 0.1mm/s, (b) 1mm/s loading rates. At lower loading rates the initiation of crack generates at the middle portion of the specimens. But at higher loading rates multiple numbers of cracks are generating throughout the samples i.e. at middle portions as

well as at the botom portions

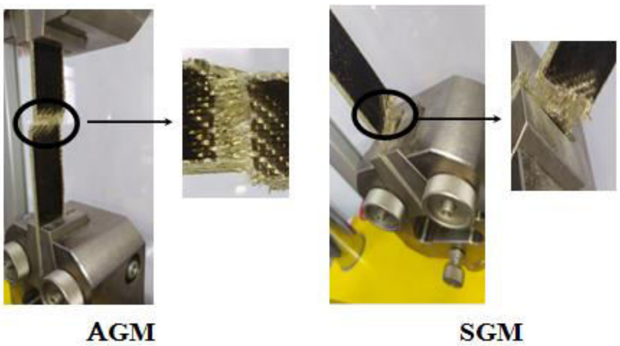


Figure 6: Bulk images of BFRP composite with different failure

III- 3- NUMERICAL ANALYSIS RESULTS USING ABAQUS AND MODEL VALIDATION

3.1. SIMPLIFIED JOHNSON–COOK MODEL

from the stress strain curve the behavior of the BFRP is similar of the brittle material ,we can study numerically this case based on the model of Johnson cook,
The simplified Johnson–Cook model is widely accepted to describe the coupling factors among stress, strain, and strain rate [8,9]. The profile of the stress–strain
curves of BFRP was similar to those of traditional metals with a well-defined Johnson–Cook model. for the sake of simplicity, only isotropic hardening and strain-
rate hardening effects were considered in this study. Therefore, the main difference in this study that we will not take into account the hardening , otherwise we apply the
law on the whole deformation zone unlike what is done for ductile materials where it takes into account the non-linear part only, the dynamic behavior of BFRP can be
expressed as

$$\sigma = (A + B\varepsilon^n)\left(1 + C\ln\dot{\varepsilon}^*\right),$$

where σ is the stress; A is the yield stress; B and n represent the effect of strain hardening,(in this case B=0)
respectively; C is the material constant determined by the specific material, representing the strain rate dependence of the material; ε is the equivalent plastic strain

$$\sigma = A(1 + C \ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}) \quad (1)$$

And from this equation is equivalent of the general strain rate dependence formula

In the damage model, the effect of strain-rate on the nonlinear response of composites is modeled by the strain rate dependent function for the strength values as [10]

$$\{S_{rt}\} = \{S_0\}\left(1 + C \ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)$$

where C is the strain rate constant for strength propertis, {Srt} are the rate dependent strength values; {S0} are the streng th values of {Srt} at the reference strain rate $\dot{\varepsilon}_0$ and $\dot{\varepsilon}$ are the longitudinal, strain rate

ε0 = 0.0004 s−1 on the basis of quasi-static experiments is calculated from the slope of the curve displacement-temps

C can be obtained through the fitting in accordance with Equation (1)

where σ0 represents the yield stress when the strain rate is 0.0004 s−1, and σ1 the stress at the strain rate is 0.0032 s−1

The simplified Johnson–Cook model (Equation (1)) was used to describe the dynamic rate-dependent constitutive behavior of the BFRP. The fitting parameters in the constitutive models in accordance with the experimental data are listed in Table 2 and the constitutive relationship was

$$\frac{\sigma_2(\dot{\varepsilon_1})}{\sigma_0} - 1 = C \ln \frac{\dot{\varepsilon_1}}{\dot{\varepsilon}_0}$$

$$\sigma_2(\dot{\varepsilon_1}) = 228\text{Mpa and } \sigma_0 = 185\text{Mpa donc } c = 0.111$$

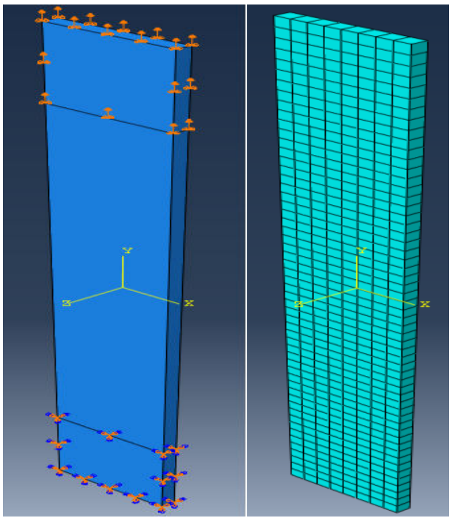
The simplified Johnson–Cook model (Equation (2)) was used to describe the dynamic rate-dependent constitutive behavior of the BFRPs. The fitting parameters in the constitutive models in accordance with the experimental data and the constitutive relationship was obtained as follow:

$$\sigma = 185(1 + 0.111 \ln \frac{\dot{\varepsilon}}{0.0004})$$

3.2. Specimen and FEM Model

To validate the effectiveness of the developed simplified Johnson–Cook model of BFRPs,numerical simulation was conducted using the commercial FEM software ABAQUS 6.13 to simulate the dynamic tensile experiment. A dynamic explicit job was defined based on the above quasi-static parameters and analysis was done. The resultant force and axial displacement was obtained as stress strain curve.

A three-dimensional FEM model was set up to simulate tensile test . of the FEM analysis, an 8-node linear brick with reduced integration and hourglass control (C3D8R) was adopted. The size of all elements was 3 mm. the elemen tsize was 3 mm.,The FEM model had exactly the same size as the tested specimen with setups. Two Cross head were considered as rigid bodies. The following inputs are :Modulus:3Gpa; density :1.58 tonne/mm3, and Poisson ratio:0.3. the Johnson-Cook material parameters were taken corresponding to 0.0004 per second reference strain. And The tensile velocity applied as 1 mm/s.



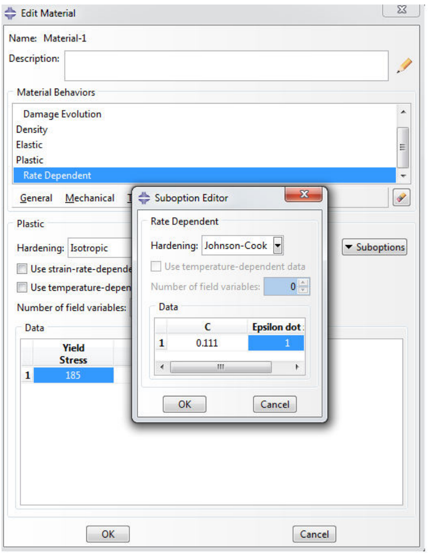


FIGURE 7: SIMULATION OF STRAIN 1 MM/S DYNAMYC (JHONSON COOK)

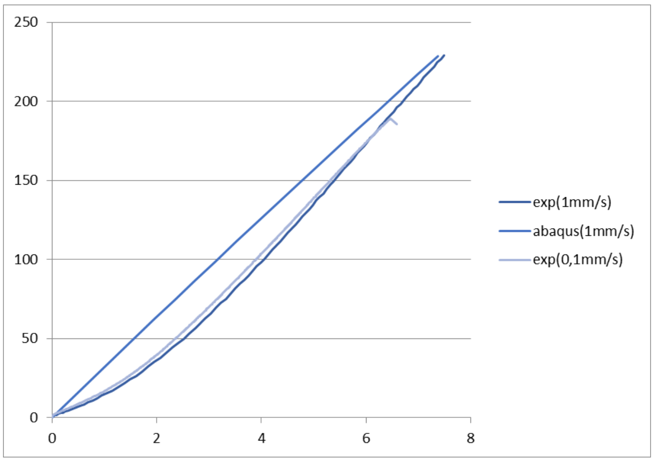


FIGURE 8: NUMERICAL AND EXPERIMENTAL TENSILE TEST RESULTS

CONCLUSION

The effect of loading speed on tensile behavior of BFRP have been experimentally and numerically investigated with two different strain rate 0.1/1 mm/s , from the results of experimental test it can be concluded that the modulus value is found to be unaffected with loading speed moreover the strain at break and ultimate strength are increasing with strain rate , thus the behavior of the numerical response is close to the experimental results for both strain rate .

References

[1] M.Sakthivel and S.Ramesh, " Mechanical Properties of Natural Fibre (Banana, Coir, Sisal)

[2]Polymer Composites", Vol-1, Issue-1, July 2013. Vol-1, Issue-1.

Lopresto V, Leone C, De Iorio I. Mechanical characterisation of basalt fibre reinforced plastic. Composites Part B. 2011; 42(4):717–723. doi:10.1016/j.compositesb.2011.01.030

[3]Y., and Zhu, D. (2015). "Tensile behavior of glass fiber reinforce composite at different strain rates and temperatures." Constr. Build. Mater., 96, 648–656

[4]Sim,J.;Park,C.;Moon,D.Y.Characteristicsofbasaltfiberasastrengtheningmaterialforconcretestructur

[5] Mushtaq, M. (2014). "Tensile behaviors of basalt fiber plain woven/epoxy resin composite under quasi-static and high strain rates."

Donghua Univ., Shanghai, China.

[6] Muhamad Shahirul Mat Jusoh, Carlo Santulli, Mohd Yazid Mohd Yahya, NurIzan Syahriah Hussein and Hariz Ahmad Israr Ahmad (2016)

Effect of Stacking Sequence on the Tensile and Flexural Properties of Glass Fibre Epoxy Composites Hybridized with Basalt, Flax or Jute Fibres.

[7] ASTM D3039M, "Standard test method for tensile properties of polymer matrix composite materials," American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428, vol. 15.03, 1997, USA.

[8] Techniques for Studying Strain Rate Effects inBrittle Materials*B. W. ABBOTT, R. H. CORNISH, and N. A. WEIL, Armour ResearchFoundation, Illinois Institute of Technology, Chicago, Illinois

[9] Hu, D.Y.; Meng, K.P.; Jiang, H.L.; Xu, J.; Liu, R.R. Strain rate dependent constitutive behavior investigation of AerMet 100 steel. Mater. Des. 2015, 87, 759–772. [CrossRef]

[10] Singh, N.K.; Cadoni, E.; Singha, M.K.; Gupta, N.K. Dynamic tensile behavior of multi phase high yield strength steel. Mater. Des. 2011, 32, 5091–5098. [CrossRef]

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