Aging Influence on Charpy Impact Behavior of Basalt Fiber Reinforced Epoxy Composites

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Abstract: Changes in moisture content and temperature can perturb both stiffness and strength and as such the impact resistance of composite structures. In this paper, the pre-notched basalt fibre reinforced epoxy (BFRE) composite specimens are studied under Charpy impact loads in order to investigate the changes in impact energy absorption (fracture toughness) with different kinds of aging conditions. To create three types of aggressive environmental conditions, the specimens were frozen in dried air at T= -18 °C, frozen in Kashan City Potable (KCP) water at T= -18 °C and kept in KCP water at T= 30 °C and the results were compared with the specimen without aging influence (T= 25 °C). Water used for this examination has a high percentage of precipitation (70-80%) which causes high corrosion and consequent decrease in mechanical properties. The outcomes illustrated that the long-term exposure to KCP water (T= 30 °C), dried air (T= -18 °C) and frozen in KCP water (T= -18 °C) were all affected on energy absorption of BFRE composites, however, freezing effect in water was more intense. To study the nature of the failure mechanisms, all failed specimens were inspected by Scanning Electron Microscopy (SEM) photographs.

Keywords: Aging, Basalt Fibres, Epoxy Composites, Fracture Toughness

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1 INTRODUCTION

The influence of liquids or gases on composite materials is undeniably a perplexing process resting on manifold factors such as the essence of the polymer, the constitution and geometry of the reinforcement and the environment changes. All composites experience throughout their life various orders of ubiquitous moisture in the air and a large number of them may contact with water. This is while, increasing hardness of water by adding salt for example, can engender considerable corrosion damage [1]. Theses changes can affect both stiffness and strength of composite structures and subsequently impact resistance [2]. It was shown that threshold kinetic energy is increased significantly when glass fiber-reinforced composites are subjected to long-term exposure to sea water prior to impact [2]. However, peak load during impact and the total energy absorbed are substantially reduced.

Moreover, the effect of moisture absorption and freezing on impact resistance of resin transfer moulded glass/vinyl-ester resin composites was studied. Results were not enough to draw general conclusions [2]. Fernandez-Canteli et al. investigated the dynamic behaviour of three fiber fabric composite laminates by testing notched specimens in an instrumented Charpy machine [3]. They studied the changes in fracture toughness due to impact velocity, crack size and stacking sequence of the specimen with different degrees of aging conditions. They found that dynamic fracture toughness had significant reduction in value under aggressive environmental conditions as function of the aging time, especially at early stages. Besides, the impact velocity exerted no noticeable influence on the magnitude of the dynamic fracture toughness for different ages.

In the recent decade, some basalt fibres reinforced composite materials were studied and compared with glass fibres indicating high potential for basalt fibres to be replaced with glass fibres, the most common reinforcing materials of polymer composites [4]-[5]. Basalt fibres are made from volcanic igneous rock possessing higher tensile strength and modulus of elasticity as well as heat resistance than those of glass fibres [5]. Khalili et al. investigated basalt fibre reinforced epoxy and basalt fibre metal laminate composites under tensile and bending loading conditions [6]. Furthermore, they added micro-glass powders into the epoxy resin of the composite to study their effects on the mechanical behaviours. They also compared mechanical characteristics of glass fibre reinforced epoxy (GFRE) and basalt fibre reinforced epoxy (BFRE) through tensile and bending tests illustrating superior mechanical properties for BFRE.

Wei et al. studied the degradation of basalt fibre and glass fibre reinforced epoxy composites in seawater [7]. The materials were treated with a seawater solution for different periods of time. They showed that tensile and bending strengths encounter a decreasing trend with treating time. In addition, it was found that the anti-seawater corrosion characteristics of the basalt fibre reinforced and glass fibre reinforced composites were almost the same. Besides, they discovered that an effective lowering of the Fe^{2+} content in the basalt fibre could contribute to higher stability for the basalt fibre reinforced composites in the sea water.

Ha et al. studied the damage behaviour of high velocity impact of hybrid basalt woven as one of the high strength, lightweight and flexible materials for producing a shield to protect aircraft against space debris impact and they showed that basalt fibre can be a good choice for this purpose [8]. Wang et al. studied the effect of fibre arrangement in three dimensional (3D) woven hybrid composites by aramid and basalt fibres in epoxy resin [9]. The composites were impact tested at 2 m/s and 3 m/s impact velocities along warp and weft directions. They showed that the interplay hybrid composite had higher ductile indices, lower peak load and higher specific energy absorption in both warp and weft directions than those of the interaply hybrid composition.

Lopresto et al. carried out some mechanical tests on comparable E-glass and basalt fibre reinforced plastic laminates to evaluate the feasibility of substituting basalt fibres for glass fibre composites [10]. The results attained on the two laminates were juxtaposed illustrating excellent function of basalt fibres in terms of impact force and energy, Young's modulus, compressive and bending strength. These promising properties can advocate achievable applications of basalt fibres in areas where glass fibre composites are mostly employed.

Colombo et al. investigated basalt fibres composites through several static and fatigue tests [11]. They compared the results with other composite materials in glass and carbon fibres. Carmisciano et al. performed a comparative investigation on basalt and E-glass woven fabric reinforced composites through flexural and inter-laminar characterization [12]. Woven pattern, the laminates and fibre volume fraction used for specimens were the same. They showed that basalt fibre composites had higher flexural modulus and inter-laminar shear strength in comparison with E-glass ones, however a lower flexural strength and similar electrical properties.

This study is an investigation on the effect of aging influence on Charpy impact behaviour of basalt fibre reinforced epoxy (BFRE). These tests are carried out according to ASTM D 6110 in three different aggressive environmental conditions; the specimens were frozen in dried air at T= -18 °C, frozen in KCP water at T= -18 °C and kept in KCP water at T= 30 °C and the results were compared with the specimen without aging influence (T= 25 °C). Fig. 1 shows the schematic diagram of edgewise specimen where the edgewise specimens contained an edge notch. All specimens are studied by Scanning Electron Microscopy (SEM) in order to examine the fracture phenomenology.

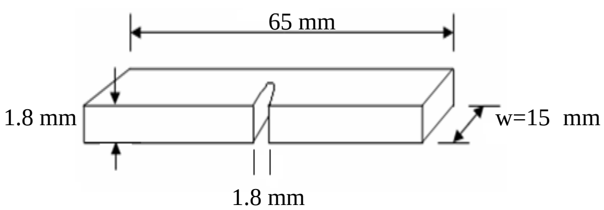


Fig. 1 Schematic diagram of edgewise impact specimen.

2 EXPERIMENTAL PROCEDURES

2.1. Experimental setup

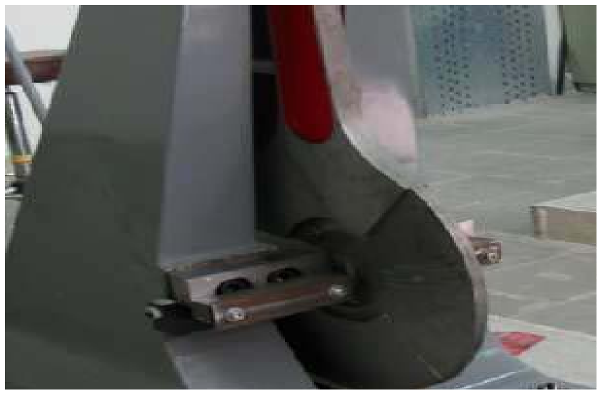
The Charpy impact tests are conducted for both notched and un-notched beams. The experimental setup consists of the specimen, the anvils where the specimen is supported with the fixtures on both sides of the specimen in edgewise tests from jump. The pendulum following a circular trajectory hits the test specimen at the middle span length, transferring the energy to it.
Figs. 2(a) and 2(b), show the Torsee Charpy impact testing machine (Tokyo, MFG. CO., Ltd., Japan) and the fixture used for testing of the specimens. Throughout this investigation, the swing arm length was 750 mm leading to the speed of impact about 5.1 m/s. Energy losses due to the bearing friction and air resistance were neglected, because of their small contribution to the energy balance.
Water used for this examination, has a high percentage of precipitation (70-80 %) which eventuates in high corrosion. Chemical properties of water are shown in Table 1, where TDS and TH are abbreviations for total dissolved solids and total hardness, respectively. PH is a measure of the acidity or basicity of an aqueous solution.

Table 1 Water Ingredient

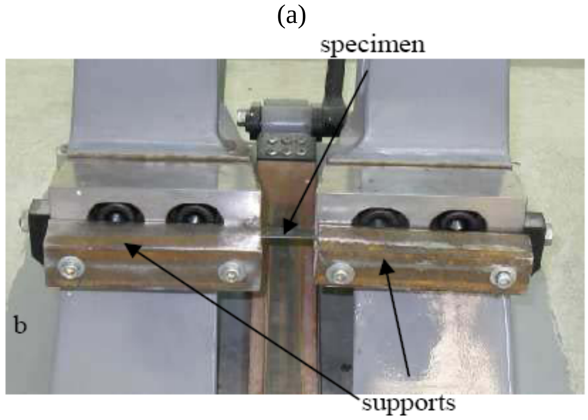
Content (Mg/Lit)	
Calcium	144
Potassium	7.5
Sodium	250
Magnesium	34
Dicarbonate	292
TDS	1396
PH	7.5
TH	504

2.2. Materials, Basalt fibre reinforced epoxy (BFRE)

Unidirectional basalt fibre (Hengdian Group Shanghai Russia & Gold Basalt Fibre Co., Ltd (GBF)) is provided with the following properties: weight = 300 g/m^2, density = 2.7 g/cm^3, tensile strength = 2100 MPa, tensile modulus = 91 GPa, Elongation = 2.6%. To fabricate the composites, the epoxy resin used was ML-506 with the Hardener HA-11, (Mokarrar Engineering Materials Co. Tehran, Iran) which are produced on the basis of epoxy Bisphenol F and Polyamine Hardener with the following physical properties: density = 1.1 g/cm^3, viscosity = 1450 centipoise. The fibre volume fractions for all specimens are 25%. Specimen types and their corresponding codes are shown in Table 2.



(a)



(b)

Fig. 2 Torsee Charpy impact testing machine
(a) base and pendulum of testing machine,
(b) fixtures on both sides of the specimen

Table 2 Specimen types and their corresponding codes

(a) BFRE without aging influence	Code no. 1
(b) BFRE after being kept in water at T=30 °C for 21 days	Code no. 2
(c) BFRE frozen in water at T=-18 °C for 21 days	Code no. 3
(d) BFRE kept in dried air at T=-18 °C for 21 days	Code no. 4

3 RESULTS AND DISCUSSION

The results of impact tests are reported in table 3. After failure of the specimens during impact, the fracture surfaces were studied to understand the nature of failure mechanism. All of the failed pieces and the fracture area were examined by eye inspection and also magnification of 50x as well as SEM photographs.

Table 3 Charpy impact test results on BFREs in different environmental conditions

Specimen	Code 1.	Code 2.	Code 3.	Code 4.
Energy Absorption (KJ/m2)	700	613	412	618

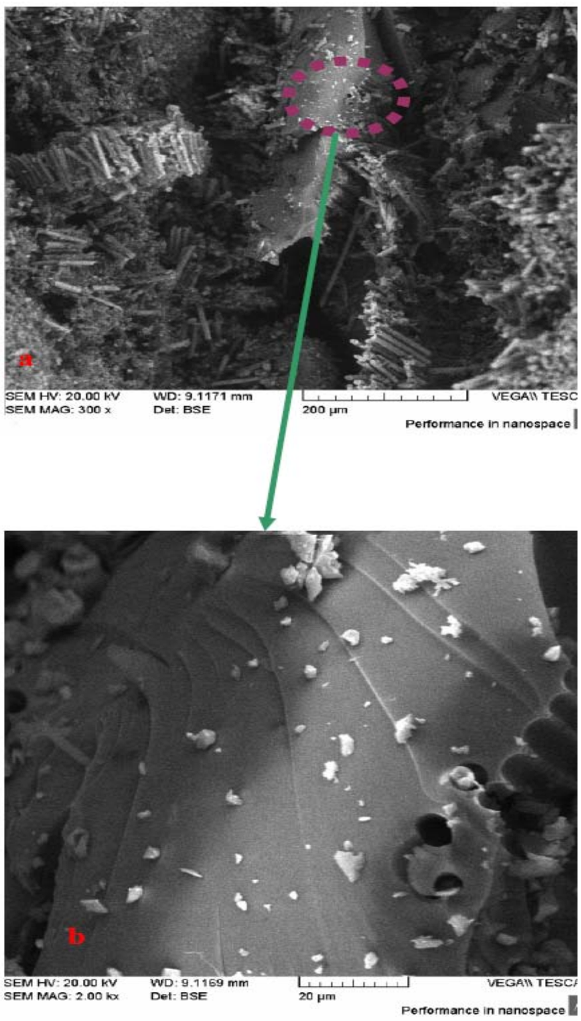


Fig. 3 Fracture surface specimen 4 after impact
a) at 300x.
b) at 2000x.

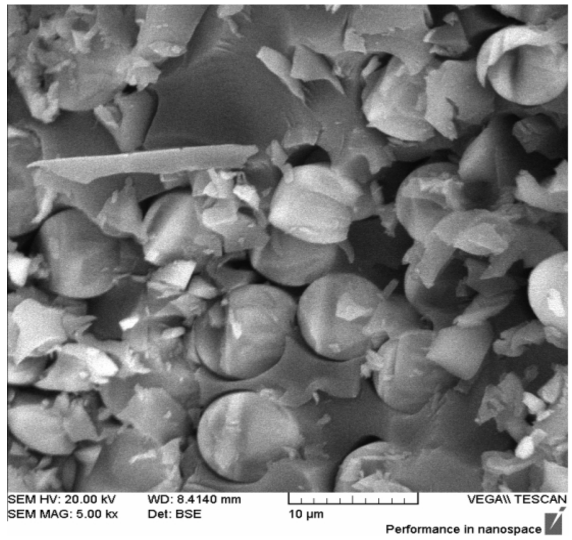


Fig. 4 Specimen 3 after impact test

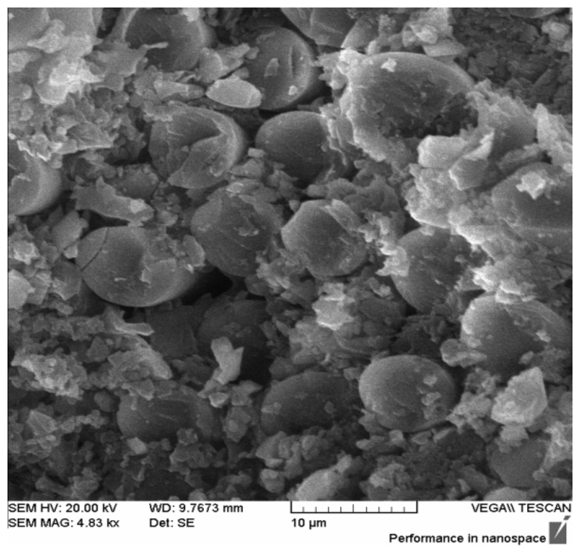


Fig. 5 Specimen 1 after impact test.

Figs. 3(a) and (b), 4 and 5 correspond to the specimens 4, 2 and 1, respectively, close to the initial notch line. Taking into consideration a comparative view on Figs. 3 to 5 and energy absorptions mentioned in table 3, the most important factor on decreasing the energy absorption is reducing the adhesion between fibres and matrix. Black holes around the fibres show lack of adhesive and adhesion and consequently pull-out failure and less impact resistance. It is worth to note that the black holes around the fibres in the specimen kept in the ice for 21 days (specimen no. 3) is more than that of the specimens in dried cold weather (specimen 4) or without aging (specimen no. 1). According to energy absorption by the specimens mentioned in table 3, the frozen water showed the most detrimental effect among the various environments, due to more deleterious effect on adhesion between matrix and fibres. Fibre pull-out, quite brittle matrix failure and high fragmentation of matrix and fibres are conspicuous in all specimens.

4 CONCLUSION

Charpy impact test was used to evaluate the aging influence on impact resistance and failure properties of basalt fibres reinforced epoxy composites by edgewise impact. It was found that energy absorption by BFRE is decreased due to aging influence in aggressive conditions. BFRE frozen in water for 21 days, suffered from the most adverse effect on energy absorption compared with BFRE kept in water at 30 °C and BFRE kept in dried air at T=-18 °C for 21 days. In addition, dried air at T=-18 °C and water at T=30 °C caused approximately the same decline in energy absorption by BFRE.

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