Thermal Shock Cycling Effect on Flexural Properties of Phenolic Based Composites Reinforced By Basalt and Carbon Fibers

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Thermal Shock Cycling Effect on Flexural Properties of Phenolic Based Composites Reinforced By Basalt and Carbon Fibers

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Abstract

In order to evaluate the changes in the flexural properties of three types polymer-matrix composites (phenolic resin reinforced with woven basalt and carbon fibers at a total volume fraction of approximately 35%) affected by transient thermal conditions, mechanical tests were performed to specimens, which have previously been subjected to a certain number of thermal shock cycles. During the thermal shock cycling test performed in the air, there is a coupling effect between matrix oxidation occurring at high temperatures of the cycle, and the matrix cracking due to thermo-mechanical ply stresses induced by the prevented differential expansions of the plies. It is at the interfacial area where the stress concentration develops, due to the differences in the thermal expansion coefficients between the reinforcement and the matrix phase. The reduction of ultimate flexural strength after thermal shock cycling was less than 6% of that initial thermal cycling for composites reinforced with woven basalt fibers. The flexural strength of the composite reinforced carbon fibers was reduced to more than 10% of the initial values.

Keywords: Polymer-matrix composites, Thermal shock cycling, Cross-linking, Post-curing, Basalt fiber, Carbon fiber, Phenolic resin.

1. Introduction

In many applications, polymer matrix composites are subjected to transient thermal conditions. Therefore, it is important to evaluate the thermal shock behavior of polymer matrix composites, to understand the mechanisms of thermal shock failure, and to improve their resistance to thermal shock damage. During thermal shock cycling, both matrix and fibers expand or contract, according to their coefficients of thermal expansion. It appears that one of the most severe problems concerning the survivability of most composites is the bond breakage between their constituents. For example, upon thermal loading of the composite, stresses will develop at the interfaces between various constituents. If these stresses exceed the corresponding bonding strength of the composite, they will result in crack formation. Shin and Kim [1] showed that the flexural strength and stiffness of the graphite/epoxy composites after exposure (80 cycles, +100 ^{o}C to –70 ^{o}C) decreased in exponential proportion to increasing thermal cycles.

Phenolic resin that is used as the matrix in this work is regarded as good engineering material since it is cost effective while it has excellent temperature and fire resistance as well as good mechanical properties. Carbon fibers have excellent flexural strength and modulus, though they are much more expensive than other fibers. As an inorganic fiber, basalt fibers have good strength and modulus as well as superior impact resistance, but much better thermal properties than carbon fiber. Therefore, a

woven hybrid composite of these two fibers will be reasonably priced with reasonable flexural, thermal and impact properties. However, it is not clear how the flexural properties of the hybrid composites will be changed as temperature fluctuations occur.

Very little work has been done to evaluate the thermal shock cycling influence on the flexural behavior of reinforced polymer composites, especially for textile composites. In the present study, the effect of thermal shock cycling on the flexural behavior of carbon, basalt and basalt/carbon hybrid fiber reinforced composites, have been investigated.

2. Materials and fabrication of specimens

Three kinds of specimens were prepared. The first material was a composite consisted of eight plies of carbon fibers (AC220) and a phenolic matrix (Phenlam ® CL2000T). The second material consisted of four plies of basalt fibers (BAS 630) and the above said matrix. The third material consisted of three plies of basalt and three plies of carbon fibers, stacked alternatively. The fiber volume fraction of all composites was 35% approximately. Physical and mechanical properties of the matrix and the fibers are presented in Table 1.

Table 1. Specification of the fibers and the resin.

Specification	Basalt fibers	Carbon fibers	Phenolic resin
Density (g/m^3)	2.70	1.75	1.2
Tensile strength (MPa)	3000	4210	24 - 45
Tensile modulus (GPa)	89	230	4
Elongation at break (%)	3.15	1.5	1 - 2
Thickness (mm)	0.56	0.25	…
Coef. of thermal expansion (10^{-6}/ ºC)	8	-6	20 - 31

2.1. Specimen preparation

Specimens were cut from the plates in the specified dimensions, 115 mm × 25 mm × 2.5 mm according to standard ASTM 790M, using a water jet-cutting machine (Figure 1).

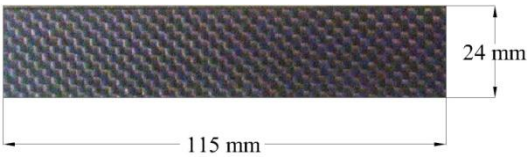

Figure 1: Specimens preparation.

(a) **(b)**

Figure 2: (a) The temperature shock test chamber (b) Aluminum stand with composite specimens.

2.2. Thermal cycling

To investigate the thermal cycling effect, the specimens were put into a temperature shock test chamber (Model TS ^{130}, Weiss Umwelttechnik GmbH, Germany) as shown in Figure 2. Specimens were exposed to –30 ^{o}C for 3 min and then immediately were exposed to +220 ^{o}C for the same period. The thermal cycling was repeated for 5, 10, 15, 20, 25 and 30 cycles.

2.3. Flexural testing

Three point bending tests were performed on a universal testing machine (Santam Co., Iran) according to ASTM D790M, at 4.7 mm/min crosshead speeds as shown in Figure 3.

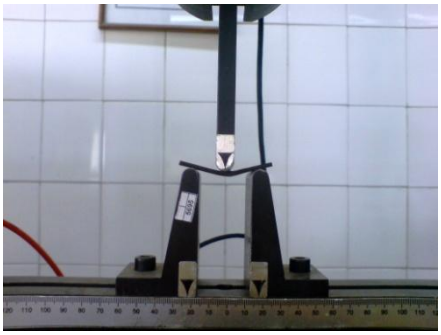

Figure 3:. flexural testing process.

3. Results and discussion

Variations of flexural modulus and strength of composites after exposure to the thermal shock cycling are shown in Table 2 and 3, respectively.

Table 2: Variations of flexural modulus of composites after exposure to the thermal shock cycling.

Composite type	Unexposed	5	10	15	20	25	30
Basalt/phenolic	16.13	16.00	14.68	14.55	14.74	14.86	15.04
Basalt/carbon/phenolic	23.92	23.28	22.13	21.75	21.42	21.03	21.79
Carbon/phenolic	41.84	40.64	38.55	39.52	35.32	35.71	36.04

Table 3: Variations of flexural strength of composites after exposure to the thermal shock cycling.

Composite type	Unexposed	5	10	15	20	25	30
Basalt/phenolic	422.00	420.00	416.21	402.77	404.98	399.51	397.77
Basalt/carbon/phenolic	446.2	444.30	425.66	420.75	425.74	420.24	419.73
Carbon/phenolic	479.13	476.68	443.01	433.43	431.85	427.26	425.76

It is obvious that the carbon/phenolic composites are more capable to damage by thermal shock cycling compared to the basalt/phenolic and basalt/carbon/phenolic composites. The differences between thermal expansion coefficients of the basalt and carbon fibers, and the

polymer matrix, lead to high interfacial strains during a thermal cycling process between +220 ºC and –30 ºC. In this case, a coupling between oxidation and cyclic thermo-mechanical stresses, due to temperature variations can accelerate all the phases of the damage process particularly in the carbon/phenolic composites.

The gradual stability of flexural modulus in basalt fiber reinforced composites implies that some kind of permanent stiffening occurs in the aged material.The overall conclusion drawn here is that there are a number of mechanisms that can be held as responsible for causing a stiffening of the material during the thermal cycling procedure. The most plausible explanation of the stability in flexural stiffness that occurred in the basalt fiber reinforced is a possible post-curing that took place during the thermal cycling procedure. This happened due to a high temperature, which were not severe enough to break the chemical bonds of the polymer [2,3], but in contrast, it contributed to the creation of free radicals to the molecules of phenolic which had not already reacted, and thus, to a further cross-linking [4]. But the weakening effect of thermal shock cycling might dominate over the post-curing hardening effect in the carbon/phenolic composites and thus consequently, it may result in the reduction of flexural properties.

4. Conclusion

In the present work, the effect of thermal shock cycling on the flexural behavior of polymer-matrix composites (phenolic resin reinforced with woven basalt and carbon fibers and hybrid of them) was investigated. In conclusion, the thermal shock cycling results in degradation effects for the thermally conditioned carbon/phenolic composites. The same conditioning causes no extensive weakening response for the basalt/phenolic and basalt/carbon/phenolic composites. The reduction of ultimate flexural strength after thermal shock cycling was less than 6% of that prior to thermal shock cycling for basalt/phenolic and basalt/carbon/phenolic composites. The flexural strength of the composite reinforced carbon fibers was reduced to more than 10% of the initial values. In addition, the reduction of flexural modulus after thermal shock cycling was about 6–9% of that initial thermal shock cycling for basalt/phenolic and basalt/carbon/phenolic composites. The of flexural modulus of the composite reinforced carbon fibers was reduced to more than 13% of the initial value.

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