Study of the influence of thermal shock on interfacial damage in thermosetting matrix aramid fiber composites

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A better fiber/matrix interfacial adhesion/bond will impart better properties such as interlaminar shear strength, delamination resistance, fatigue and corrosion resistance to a polymeric composite. The interface-sensitive properties are weaker in polyaramid-reinforced composites than in their glass or graphite counterparts. Aramid fiber is a generic term for armatic polyamide fibers, which have high specific strength, great cohesiveness and a tendency to form fibrils. They absorb much more energy than brittle fibers and are widely used in aircraft, aerospace and ballistic applications. The interfacial adhesion between the aramid fiber surface and the polymer matrix is of major influence on the response of the composite to stress. The fiber/matrix interfacial behavior is based on mechanical principles with the assumptions made at either the level of fiber/matrix adhesion or using the surface chemistry approach [1]. It is reasonable to assume that the interfacial shear strength is the net result of a number of contribution to the fiber/polymer adhesion. These possibly include chemical bonding, secondary forces of attraction, residual thermal compression forces due to differential shrinkage and also mechanical interlocking between the fiber and matrix [2]. The unique chemistry and morphology of Kevlar aramid fiber is also manifested in its composite behavior. The high radial expansion coefficient of the Kevlar fiber also causes an unfavorable tensile stress state at the interface. The weak interfacial adhesion of Kevlar/polymer makes the composite more sensitive to environmental exposure [3]. This interfacial bonding is further weakened by exposure to active environments [4].

The present study has been carried out to evaluate the comparative mechanical behavior of Kevlar/epoxy and Kevlar/polyester composites with thermal and cryogenic conditionings and combined effects of thermal shock. These aerospace materials frequently experience this kind of severe environmental exposure during their service life. There is still a paucity of experimental data in this area. The test used was a three-point flexural test on a specimen with a small span length, which promotes failure by interlaminer shear. It can be concluded that the results from such tests are useful for the estimation of composite quality [3]. The fiber/matrix interfacial debonding may be reflected in such short beam shear tests.

Kevlar aramid 49 fibers of woven cloth (Scott Bader, UK), epoxy (Gougeon West System, UK, 105 resin and 205 hardener) and polyester (Scott Bader, Crystic 471 PALV and Catalyst Butanox M-50) were used for the experiment. The shear specimens were treated in a thermal shock environment with a 160 °C temperature gradient by two separate routes; for one batch of specimens it was from 80 °C temperature to −80 °C temperature and for the other batch it was in the reversed direction. The first batch of samples were exposed to the 80 °C temperature environment for various times (5,10 and 20 min) and then immediately plunged into the liquid bath at −80 °C temperature for 5 min. The second batch of samples first kept at −80 °C temperature for the same time intervals and then exposed to the 80 °C temperature for 5 min. The three-point bend tests were performed almost instantaneously to avoid any reversible recovery and/or relaxation processes in the composites.

The thermal conditioning at 80 °C for the epoxy system results in further post-curing strengthening. The post-curing effects may be due to further cross-linking in the epoxy matrix and may also introduce more adhesion at the interface [5]. The thermal conditioning may change the chemistry of the fiber/matrix interface in forming an interpenetrating network [6] and also improve the adhesion at the interface either by mechanical interlocking or by a surface chemistry mechanism. The cryogenic conditioning at −80 °C for different times may impart different degrees of shrinkage compressive strength at the interface. This could help in strengthening the adhesion. The effect of thermal shock definitely causes debonding and/or weakening of the interface because of the different thermal coefficients of expansion and/or contraction for the polymer matrix and the Kevlar reinforcement [4]. The combined effects of thermal shock on thermally conditioned specimens and also on cryogenically conditioned Kevlar composites were investigated in each stage of the experiment.

Fig. 1 shows the effect of thermal shock on the shear strength of thermally conditioned Kevlar reinforced composites. This conditioning results in different effects in the Kevlar/epoxy and Kevlar/polyester composites. The improvement of shear strength is noticeable for the epoxy system but there is a reduction in this value for the polyester matrix composites. The strengthening effect may be the result of further cross-linking in the epoxy matrix and it may impart further adhesion at the interface. Several mechanisms may contribute to the fiber/matrix adhesion, i.e. covalent bonding, physical interactions, and mechanical interactions. These post-curing phenomena could dominate over

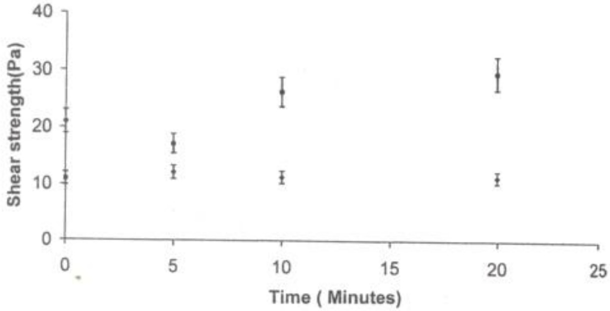

Figure 1 The effect of thermal shock on shear strength of thermally conditioned Kevlar/epoxy (•) and Kevlar/polyester (∙) composites.

the de-adhesion effect of thermal shock. Thus, the improvement in shear strength is reflected for the Kevlar/epoxy composite. But the weakening effect of thermal shock might dominate over the post-curing hardening effect in the Kevlar/polyester system and thus consequently, it may result in the reduction of shear strength.

The variation of shear strength for cryogenically conditioned Kevlar/epoxy and Kevlar/polyester with conditioning times are plotted in Fig. 2. The thermal shock of the 160 °C temperature change over 5 min is performed at each stage of the cryogenic conditioning. The overall nature of the data indicates the decrease of shear strength for both systems. The more phenomenal change is observed at 5 min conditioning time (i.e. 5 min at −80 °C temperature and then at 80 °C for the same time). This could be attributed to the dominating debonding effect of the thermal shock environment over the shrinkage compressive stress for the cryogenic conditioning. Greater conditioning time at the cryogenic temperature might produce greater amounts of such compressive stress. Thus, the loss of shear strength is less noticeable for higher conditioning times.

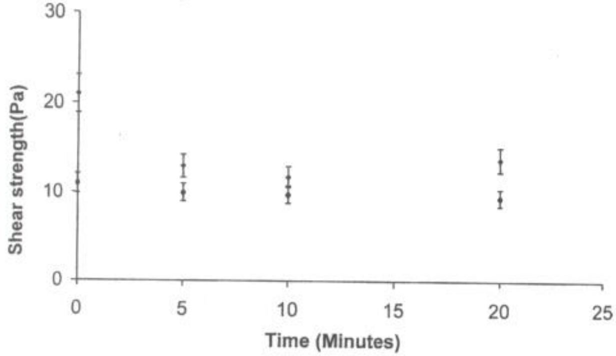

Figure 2 The effect of thermal shock on shear strength of cryogenically conditioned Kevlar/epoxy (•) and Kevlar/polyester (∙) composites.

Thus, in conclusion the debonding effect of thermal shock and strengthening phenomena for thermal and cryogenic conditionings of thermosetting matrix Kevlar fiber composites are shown. The thermal shock results in degradation effects for the thermally conditioned Kevlar/polyester system. The same conditioning causes no weakening response for the Kevlar/epoxy system. The thermal shock manifests similar kinds of debonding effects for cryogenically conditioned specimens Kevlar/epoxy and Kevlar/polyester composites. It is also reasonable to conclude that the polyester matrix is more susceptible to damage by this type of complex environmental exposure compared to the epoxy matrix.

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