# EFFECTS OF THERMAL SHOCK ON MECHANICAL BEHAVIOUR OF KEVLAR FIBRE COMPOSITES

B.C.RAY*, S.T.HASSAN** AND D.W.CLEGG**
** Metallurgical Engineering Dept., R.E.C. Rourkela - 769 008*
***School of Engineering, Sheffield Hallam University, S1 1WB, UK.*

## Abstract

The development of composite technology represents one of the most significant advances in materials science since 1940s. The major advantages of composite materials are their high strength and stiffness, light weight, corrosion resistance, crack and fatigue resistance and design flexibility as compared to metallic materials. Because of the attractive properties, the use of composite materials has been increasing steadily in recent years. Unfortunately, there are disadvantages in composite materials as compared with metals. They include brittleness, vulnerability to stress concentration, inflexibility for localised multidirectional stresses, sensitivity to environmental effects, and poor damage tolerance to impact. These factors must be critically considered in designing a composite system.

The aramid kevlar family of fibres have been accepted as reinforcement for composites and finds wider and newer applications in various industrial and aerospace sectors. The interfacial bond strength between aramid fibres and epoxy resins is normally lower than what is experienced with carbon fibre composites. This weakness with kevlar necessitates investigation and evaluation of the interlaminar shear strength (ILSS) and modulus under some realistic environmental conditions. The present work has been taken up to evaluate the variation of ILSS and modulus values after being given the extreme thermal shock of 160°C thermal gradient. The thermal shock is given in two separate ways, firstly, one series of kevlar/ epoxy and kevlar/polyester short beam shear (SBS) specimens are kept in a oven at 80°C for different time intervals and then immersed in a liquid bath at -80°C temperature. The other experiment is done in reverse way i.e. first kept at -80°C and then exposed to 80°C temperature. The interesting variations of ILSS and modulus values have generated some ideas for assessment in this area. The thermal shock, positive temperature and cryogenic temperature affect the kevlar/epoxy and kevlar/polyester composites in a very complex way. The wide fluctuation in results necessitates further investigation and depth analysis of this interaction. It may be hypothesised that the extreme thermal shock may introduce some decohesion between fibre/matrix interface especially when the gradient is positive in thermal shock.

## Introduction

The development of composite technology represents one of the most significant advances in materials science since the 1940s. The major advantages of composite materials are their high strength and stiffiness., light weight, corrosion resistance, crack and fatigue resistance, and design flexibility as compared to metallic materials. Because of their attractive properties, the use of composite materials has been increasing steadily in recent years. Unfortunately, there are disadvantages of some composite materials as compared with metals. They include brittleness, vulnerability to stress concentration, inflexibility for localised multidirectional stresses, sensitivity to environmental effects, and poor damage tolerance to impact. These factors must be critically considered in designing a composite system.

The fibre-matrix interface is known to play a major role in the mechanical performance of fibre reinforced plastic (FRP) composites. This contribution is mainly related to the ability of the interface to transfer load from matrix to fibre during loading. Present research has found that this stress transfer process affects some quasistatic properties such as strength-toughness ratio. However, the importance of the interface becomes largely predominant in the overall behaviour of the composite when the durability of the materials is considered. Long-term performance and fatigue life are effectively controlled by micromechanical damage processes occurring at the fibre-matrix interface.

The aramid kevlar family of fibres has been well accepted as reinforcement for composites and finds wider and newer applications in various industrial and aerospace components. The interfacial bond strength between aramid fibres and epoxy resins is normally lower than what is experienced with carbon fibre composites. This weakness with kevlar necessiates investigation and evaluation of the interlaminar shear strength (ILSS) and modulus under some realistic environmental conditions. The present work has been taken up to evaluate the variation of ILSS and modulus values after being given the extreme thermal shock of 180°C thermal gradient. The thermal shock is given in two separate ways, firstly, one series of kevlar/epoxy and kevlar/polyester short beam shear (SBS) specimens are kept in an oven at 80°C for different intervals of times and then immediately immersed in a liquid bath at -80°C. The other experiment is done in reverse way i.e., first kept at -80°C and then exposed to 80°C. The interesting variations of ILSS and modulus values have generated some ideas for the assessment in this area.

## Material and fabrication of test samples

a) Materials

Kevlar aramid 49 fibre were used for this work. The fibre is of woven cloth tape, supplied by Scott Bader Company Ltd., UK (Trade name Strand). The matrix resins used are 1) polyester (Scott Bader, Crystic 471 PALV and catalyst Butanox M-50) and 2) epoxy (Gougeon West System Brand, 105 resin and 205 hardener).

b) Fabrication

The kevlar composite plates were fabricated by wet lay-up method, where kevlar fabric is laid over a mould and then catalyzed resins (either polyester or epoxy) are poured and brushed over the reinforcement. The wet composite is rolled, to evenly distribute the resin and to remove air pockets. This sequence is repeated until the desired thickness is obtained. The layered structure is then allowed to harden or cure, which at the molecular level involves chain extension, branching and crosslinking. After curing, the laminate is cut into required size for 3-point bend test by a diamond cutter.

**Experimental Details**

A) Thermal shock experimentation

The SBS specimens made of kevlar/epoxy and kevlar/polyester composites are separately given two types of thermal shock. The -80°C is maintained in a saturated mixture of acetone and solid carbon dioxide. The equilibrium temperature is approximately - 80°C. The temperature of the oven is controlled at 80°C. At a time single sample is conditioned for uniform and quick distribution of target temperature. Each sample is exposed to 80°C for various time intervals (5, 10 and 20 minutes) and then immediately the sample is conditioned at -80°C for 5 minutes. The second category of experiment is done in a reversed fashion, i.e., each sample first conditioned at -80°C liquid bath for various periods (5, 10 and 20 minutes) and then immediately exposed to 80°C for 5 minutes.

B) 3-Point bend test

The 3-point bend test was performed in accordance with BS 2782 method 304B. The approximate dimensions of the samples are: span length-37mm, width-15mm and thickness-3mm. The SBS samples were tested immediately after the specified conditioning. It is assumed that the test temperature and last conditioning temperature are almost same.

The ILSS and modulus are determined as follows,

$$\text{ILSS} = 0.75P/bt$$

$$\text{Modulus} = PL^3/4bdt^3$$

where, P = maximum breaking load, b = width of specimen, d = deflection, t = thickness of specimen and L = span length.

C) Photomicrography

The fractured surfaces of kevlar composites were examined under the stereomicroscope (Olympus), which is attached with colour video printer. This study is taken up to observe the crack propagation modes, adhesion and decohesion behaviour.

**Results and Discussion**

A) Kevlar/Epoxy composites

The ILSS values are measured from the 3-point test data and plotted against exposure/immersion time to specified temperature. Fig.1 refers to conditioning at 80°C for 5, 10 and 20 minutes exposure and immediately immersed in liquid at −80°C for 5 minutes. The plotted curve indicates that there is a over-all improvement in ILSS values with increasing exposure time. This may be attributed to post-curing hardening effect on matrix epoxy resulting in improved interlaminar strength. The more exposure time at 80°C results in further cross-linking and more polymerization which in turn improves the strength and stiffness of epoxy.

Fig.2 shows ILSS values against immersion time at -80°C. As the specimens are first immersed in liquid bath at -80°C and then exposed to 80°C for 5 minutes, the effect is unlike the previous one. It is noticeable that there is degradation trend of ILSS values with increasing immersion time. It can be assumed that the effect of cryogenic temperature and the positive temperature gradient thermal shock (i.e., -80°C to 80°C) promotes microcracks and/or decohesion at interface which in turn degrades interlaminar strength. The thermal shock may develop the tensile non-mechanical stresses which may, to an extent, unlock the fibre/matrix adhesion, and subsequent reduction in ILSS values.

Fig.3 and Fig.4 correspond to the shear modulus against exposure times. Fig.3 reveals that the modulus values reduce maximum at 5 minutes thermal shock, i.e., specimens exposed to 80°C for 5 minutes and then immersed at -80°C for 5 minutes. It is observed that modulus values start increasing with the exposure times. The increased values in modulus with more exposure time may be because of more hardening effect. And this effect is not totally nullified by cryogenic environment. But the hardening effect at 5 minutes exposure at 80°C is fully degraded because of cryogenic temperature.

Fig.4 shows the reversed trend compared to Fig.3. The most interesting data is at 5 minutes. The sharp increase in modulus at 5 minutes drops with increasing exposure time at -80°C. The rise at 5 minutes is due to post-curing effect. But with increasing immersion time at -80°C has damaged the specimen permanently which is not being restored because of following condition at 80°C.

B) Kevlar/Polyester composites

Fig.5 shows the variation of ILSS values with different exposure times at 80°C and then followed by immersing the SBS specimens at -80°C for 5 minutes. The curve indicates that there is an over-all degradation in ILSS values but most noticeable at 5 minutes. The nature of curve may lead to the conception that the thermal shock affects adversely the ILSS values. The 10 and 20 minutes conditioning results in improved hardening effect because of further cross-linking and setting of molecules. But maximum thermal shock at 5 minutes results most noticeable damage to the specimen because, small degree of hardening effect is being damaged by thermal shock and cryogenic temperature.

Fig.6 corresponds to the different immersion time at -80°C temperature versus ILSS values. Here the trend shows a reduction in ILSS except at 20 minutes where it starts improving. This improvement may be because of more exposure time at -80°C leads to the development of compressive stresses which may be locking the fibre/polyester interface.

Fig.7 and 8 are plotted for the modulus versus exposure/immersion times. Fig.7 shows that except at 5 minutes, the over-all nature of the curve reveals that the thermal shock improves the modulus values. This is because of more post-curing time available. But a little hardening at 5 minutes has reverse damage effect under cryogenic environment. Fig.8 reveals the degradation in modulus values throughout immersion periods. The positive temperature gradient thermal shock develops tensile residual stresses, which may damage the interface region.

C) Comparative study

Kevlar/epoxy and kevlar/polyester composites specimens are given same thermal shock. Fig.9 shows the variation of ILSS values for both composites with different exposure times at 80°C temperature. The two systems are responding in opposite way to the thermal shock. The epoxy based composites get improved but polyester based get worse. This opposite response may be attributed to the chemistry at the fibre/matrix interface. It necessiates further investigation to draw further conclusion.

Fig.10 corresponds to the variations of ILSS values with different immersion times at -80°C. Here it is observed that for both the systems, the effect of the thermal shock imparts damaging results. The exceptional point at 20 minutes may lead to assume that the more immersion time at -80°C bath develops high amount of compressive stresses which subsequently improves the adhesion chemistry at the interface.

Fig.11 and Fig.12 are drawn to observe the variations of shear modulus with exposure/immersion times for both types of thermal shock. Fig.11, shows there is an over-all improvement or tendency to achieve improved modulus values with increased exposure times except at 5 minutes of interval. But for the reversed thermal shock (Fig.12), the two systems behave in different modes. The epoxy system gets improved but polyester one gets worse. It may be hypothesised that stronger bond exists in epoxy/kevlar system. This bond is less deteriorated because of tensile thermal stress. This stress may be predominating over the weak bond between kevlar and polyester resin.

## Conclusions

The thermal shock, positive temperature and cryogenic temperature, affect the kevlar/epoxy and kevlar/polyester composites in a very complex way. The wide fluctuation in results necessitates further investigation and in depth analysis of this interaction. It may be hypothesised that the extreme thermal shock may introduce some decohesion between fibre/matrix interface especially when the gradient is positive in thermal shock. The 80°C conditioning imparts post-curing hardening effects and it may be concluded that cryogenic temperature has damaging effects. When the composites are conditioned at 80°C, further polymerization and cross-linking occurs especially with epoxy resin and which in turn improves the over-all strength and stiffness of the system.

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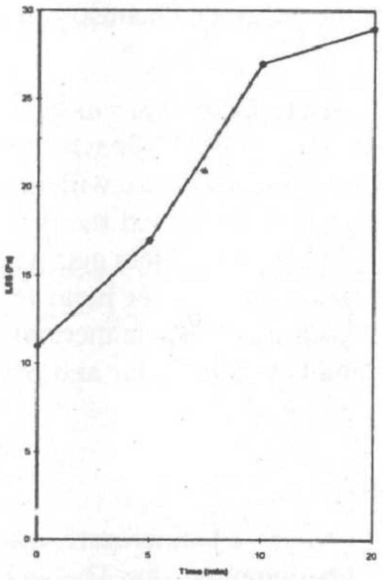

Fig.1- Effect of temperature and thermal shock on ILSS values of Kevlar/Epoxy composites.

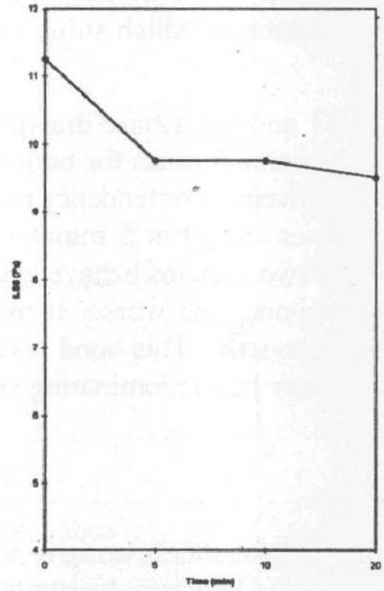

Fig.2 - Effect of cryogenic temperature and thermal shock on ILSS values of Kevlar/ Epoxy composites.

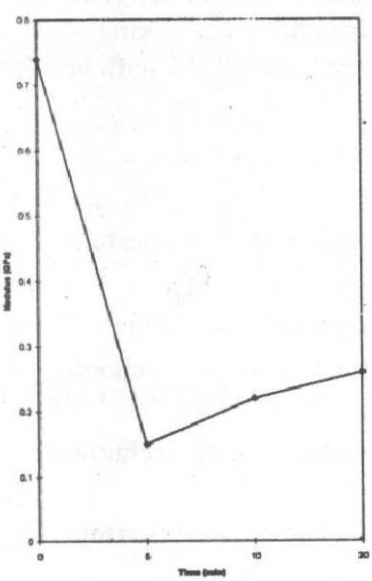

Fig.3- Effect of temperature and thermal shock on modulus values of Kevlar/Epoxy composites.

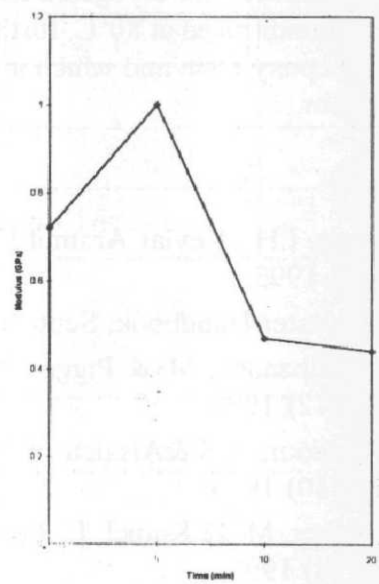

Fig.4 - Effect of cryogenic temperature and thermal shock on modulus values of Kevlar/ Epoxy composites.

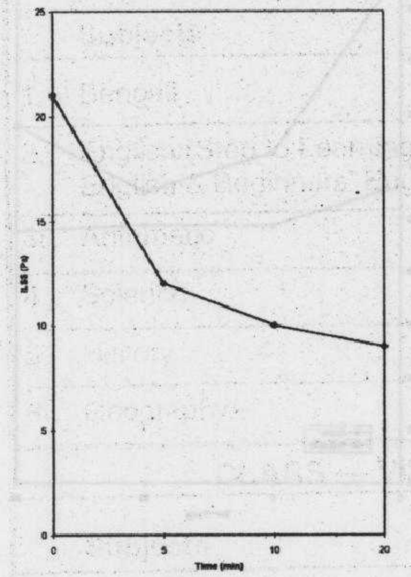


Fig.5 - Effect of temperature and thermal shock on ILSS values of Kevlar/Polyester composites.

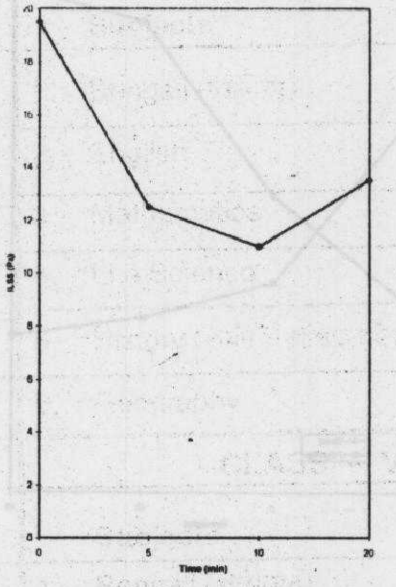


Fig.6 - Effect of cryogenic temperature and thermal shock on ILSS values of Kevlar/Polyester composites.

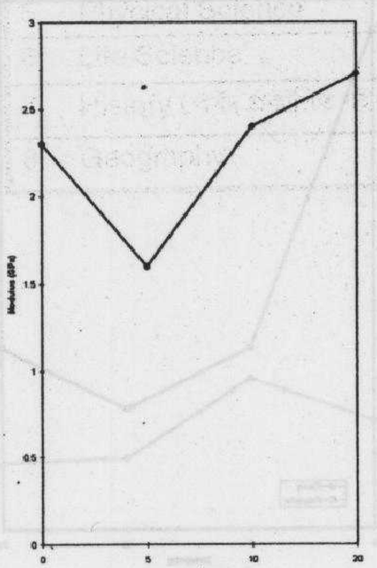


Fig.7- Effect of temperature and thermal shock on modulus values of Kevlar/Polyester composites.

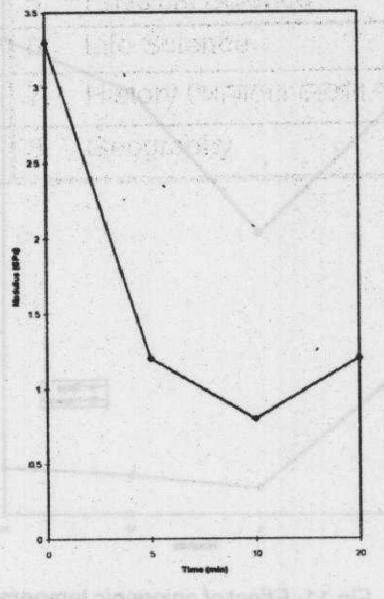


Fig.8 - Effect of cryogenic temperature and thermal shock on modulus values of Kevlar/Polyester composites.

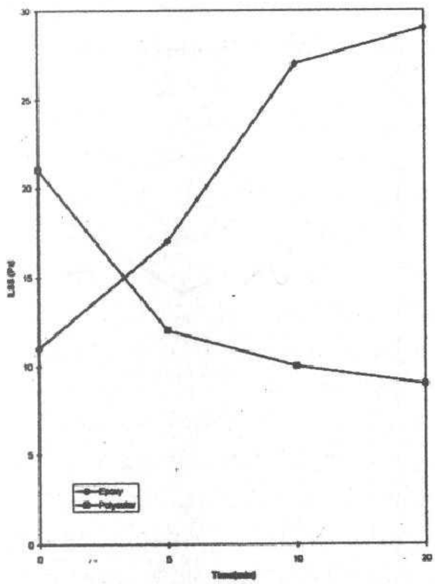


Fig.9 - Effect of temperature and thermal shock on ILSS for Kevlar/epoxy and kevlar/ polyester composites.

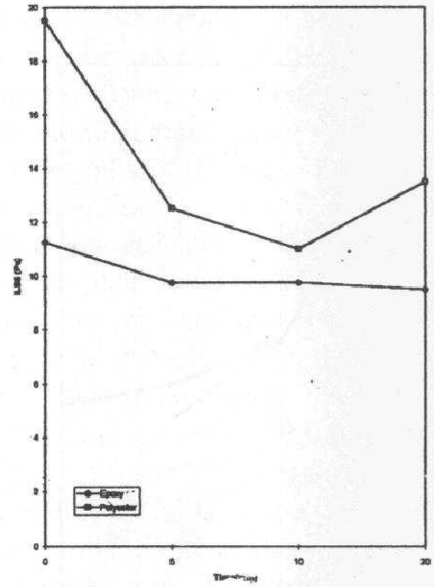


Fig.10 - Effect of cryogenic temperature and thermal shock on ILSS for Kevlar/Epoxy and Kevlar/Polyester composites.

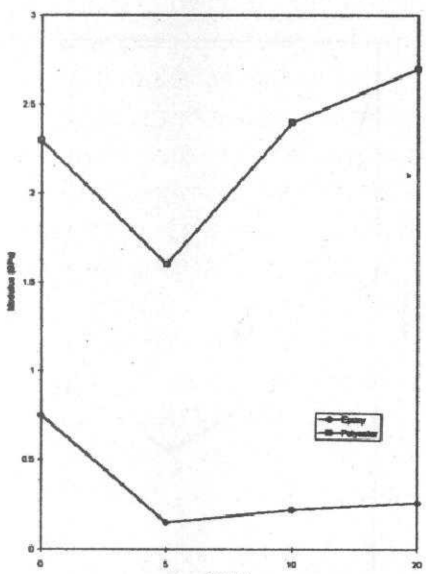


Fig.11- Effect of cryogenic temperature and thermal shock on modulus for Kevlar/Epoxy and Kevlar/Polyester composites.

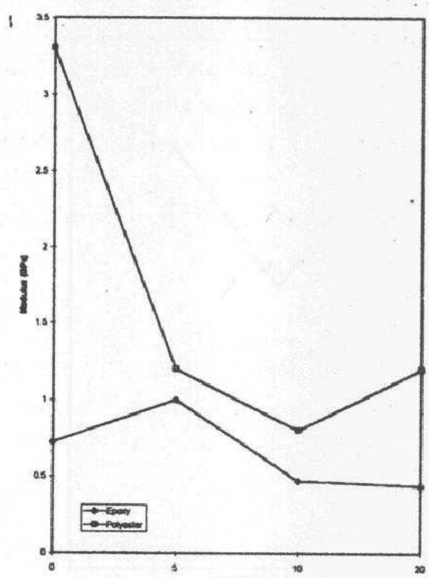


Fig.12 - Effect of cryogenic temperature and thermal shock on modulus for Kevlar/Epoxy and Kevlar/Polyester composites.

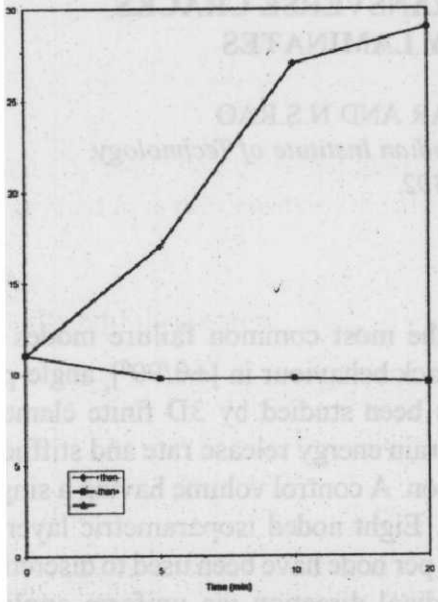

Fig.13 - Effect of thermal shock on ILSS for Kevlar/epoxy composites.

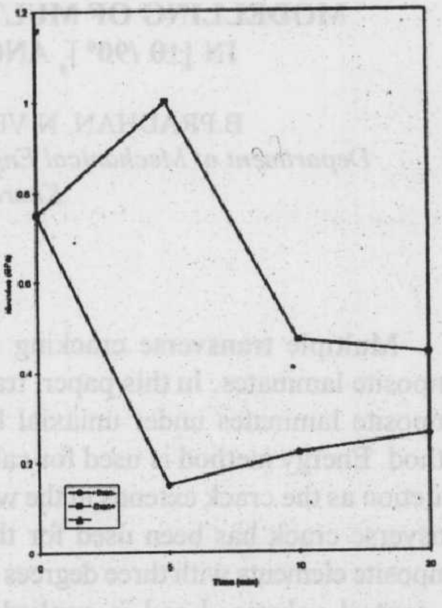

Fig.14 - Effect of thermal shock on modulus for Kevlar/Epoxy composites.

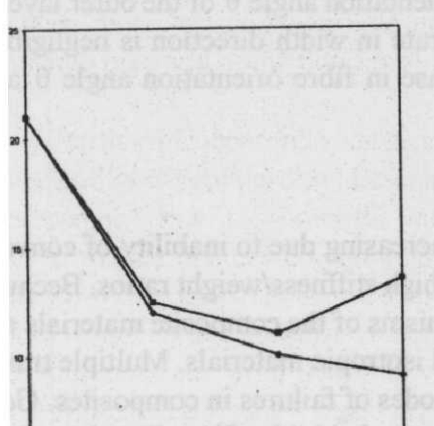

Fig.15- Effect of thermal shock on ILSS for Kevlar/Polyester composites.

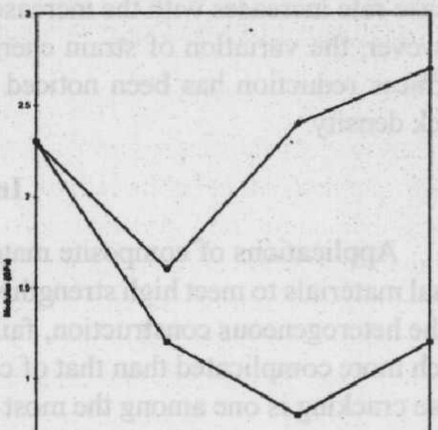

Fig.16 - Effect of thermal shock on modulus for Kevlar/Polyester composites.