DEVELOP HIGH TEMPERATURE GLASS FIBRE/PEKK PREPREG

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Keywords: Poly-ether-ketone-ketone, High temperature high performance thermoplastic composites, Quasi-static perforation.

ABSTRACT

There is a large potential for high temperature high performance (HTHP) thermoplastic composites for aerospace applications to satisfy the design requirements of the next generation of fuselage, especially the large size supersonic aircraft where the material has to withstand temperatures between – 65 °C to 400 °C. In this project, woven S-glass fibre (GF) Poly-ether-ketone-ketone (PEKK) thermoplastic prepreg materials were manufactured via a dry powder prepregging method. The resulting composite panels were evaluated by conducting a series of quasi-static tensile and perforation tests as well as optical microscope technique in order to optimize the concentration of PEKK resin (wt.%). The results have shown that the optimum weight percentage in terms of the maximum contact force, energy absorption and tensile strength corresponding to a PEKK weight fraction of 40 %, when such the fraction is varied at 30, 40 and 50%.

1 INTRODUCTION

Reinforced composites made with thermoplastics as matrix materials in conjunction with Glass fibre (GF), Carbon fibre (CF), Natural fibres (NF) have been seen as a steadily growing market, especially their increasing use in aerospace, automotive and renewable energy sectors. These materials offer substantial advantages over thermosetting matrices, such as improved fracture toughness, fire/smoke resistance, high hot/wet stability, recyclability and ability to be processed rapidly due to no need of long curing cycles. Thermoplastic prepregs can be stored in any ambient environment with infinite shelf life unless they contain solvent which may limit their shelf life. There is a large potential for high temperature high performance (HTHP) thermoplastic composites for aerospace applications to satisfy the design requirements of the next generation of fuselage, especially the large size supersonic aircraft where the material has to withstand temperatures between – 65 °C to 300 °C. It is expected that the multi-functional HTHP prepregs will offer a great potential in aerospace and automotive applications either used alone or integrated with alloys for FMLs [1-3]. The development of multi-functional thermoplastic matrix based on aromatic polymer has an ability to address all the limitations of thermoset composites. The use of matrix materials, such as Poly-ether-ether-ketone (PEEK) and Poly-ether-ketone-ketone (PEKK), have demonstrated excellent mechanical barrier, exceptional impact resistance, vibration damping and thermal properties at high temperatures, especially when reinforced with high performance fibres [4]. Some studies have been carried out on these materials. The effect of low velocity impact on CF/PEEK crossply laminates and CF/PPS was conducted by Wang and Khanh [5] and Vieille et al. [6]. Ghasemi and Parvizi [7] investigated the compression after impact (CAI) to evaluate the damage tolerance and impact performance of woven CF based on PEEK and PPS fabricated by film stacking method. They found that the impact performance of the panels was affected by the impact energy. Davim and Cardoso [8] performed experiments on CF/PEEK and GF/PEEK with the same fibre content, which showed that CF/PEEK presented the best tribological behaviour. Also, Mazur et al. [9] investigated the effect of accelerated aging on compression and shear properties of CF/PEKK manufacturing by hot compression moulding. It can be seen from the review that data of plain S-glass fibre reinforced poly-ether-ketone-ketone is limited and there is no previous work has been done to evaluate its properties under various test conditions. Therefore, the primary aim of the proposed project is to investigate the fundamental science/technology related to novel GF/PEKK composites and to provide experimental data for numerical modelling validation and further for assisting design prepreg materials.

2 EXPERIMENTAL PROCEDURE

The composite material investigated in this research project was based on a plain woven S-glass fibre fabric from East Coast (UK) and a poly-ether-ketone-ketone (PEKK) matrix (KEPSTAN 6003PL) from ARKEMA (France). The prepregs of PEKK resin and woven s-glass fibre are made via a dry powder prepregging technique in which the resin powder of PEKK is deposited onto the woven S-glass fibres. In this technique, the woven glass fibre was coated with a temporary binder (adhesive) on both sides. The function of using the adhesive is to hold the powder of PEKK onto fibre. The glass fibre with suspended powder was placed between two moulds (300 mm X 300 mm) before inserting the hot press at 330 ^{o}C. A high temperature release agent (Frekote) was used between the mould and the prepreg to ensure easy removal after the consolidation. The processing cycles in terms of holding time and pressure to make these prepregs were 10 min and 6 bar, respectively. After that, the composite laminates were manufactured by stacking a number of (0.125 mm thick) plies in a mould .The resulting stack was then heated to a temperature of 330 ^{o}C at a heating rate of 5 ^{o}C per minute. The laminates with dimensions (125 X 125 mm) were cured under a pressure of 3 bars for 30 minutes prior to cooling at rate of 2 ^{o}C/ minute as shown in Figure 1. After cooling, the pressure was released and the laminates were removed from the mould and inspected for defects. Prior to the mechanical testing, specimens have been sectioned and polished under an optical microscope to study the microstructure and the distribution of the PEKK powder within of the panels.

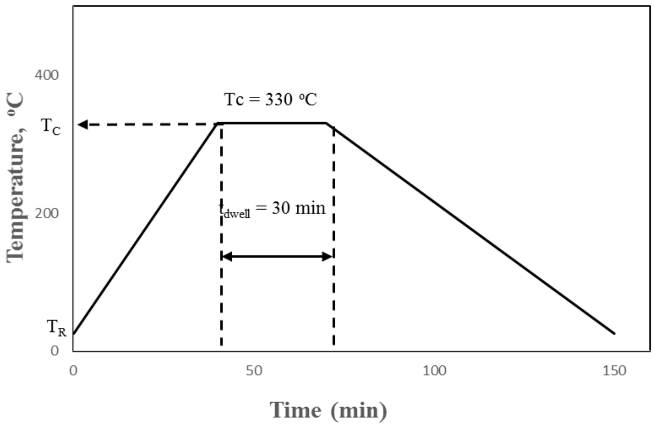

Figure 1: Curing process curve of GF/PEKK

2.1 TENSILE TESTS

For determining the tensile properties of GF/PEKK, coupons were cut from plates according to ASTM D3039/D3039M – 14[10] recommendation. Static tensile was conducted using the Instron 3369 testing machine. An extensometer with 25 mm gauge length (GL) was attached to the coupon in the middle to measure strain. The dimensions of the tensile specimen are outlined in Figure 2. Tests were undertaken at a constant crosshead speed of 0.5 mm per minute.

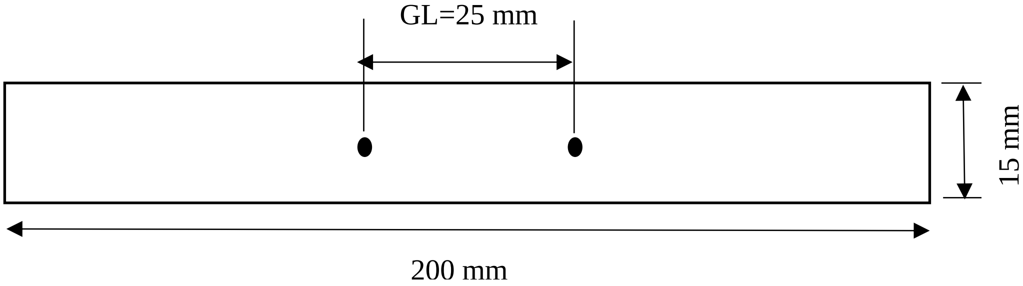

Figure 2: The geometry of tensile specimen for composite material

3.1 QUASI-STATIC PERFORATION TESTS

A series of quasi-static perforation tests were carried out on the GF/PEKK panels. Specimens were clamped in a frame of square steel with a 72 mm X 72 mm internal cavity. Then, the specimens were tested using an Instron 4505 testing machine with the maximum loading capacity of 50 kN. Crosshead displacement rate of 1 mm/minute was employed and the load-displacement curve was recorded during each test. The test machine is controlled using INSTRON Series IX Software which is also used for capturing data. The static test setup is shown by Figure 3.

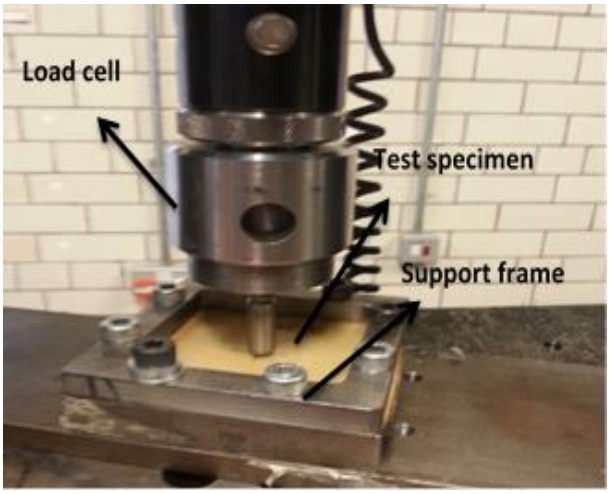

Figure 3: The perforation test setup

4 RESULTS AND DISCUSSION

The quasi-static perforation tests were performed on four ply GF/PEKK panels placed on the steel support with internal rectangular of 72 mm X 72 mm with different PEKK powder concentrations (30 wt. %, 35 wt. %, 40 wt. %, 45 wt. % and 50 wt. %) in order to optimize the proportion of PEKK resin (wt. %). Figure 4 illustrates the load-displacement traces obtained in quasi-static perforation for GF/PEKK laminates with different PEKK concentrations. It is can be observed from the figure that all samples show similar trend which is non-linear behaviour for small deflections. The curve then reaches to the maximum value; hence, large area under the curve is obtained as a result of rapid increase in deflection. It can also be seen from the figure that the maximum force increases with PEKK weight fraction increment and the highest value was obtained by using 40 wt. % of PEKK whilst the lowest value was with 30 wt.%. Figure 5 shows the energy absorption results obtained from the contact force – displacement .It can be seen from the figure that the total energy of GF/PEKK increases with PEKK percentage increment up to 40 wt. % of PEKK, and there is no significant effect on the energy absorption after this value. Figure 6 shows the micrographs of the virgin and damaged panels with the above PEKK percentages. An examination of the micrographs indicate that 30 wt. % of PEKK was not enough to give good coating between the resin and the fibre where as good coating has been achieved using 40 wt.% PEKK panels. Moreover, the examination of the fracture zone after quasi-static perforation tests of these panels showed that more voids are created on the centre of 30 Wt.% PEKK, and these voids work as weak points between the resin and the fibre resulting lower impact force and energy comparing with other concentration panels.

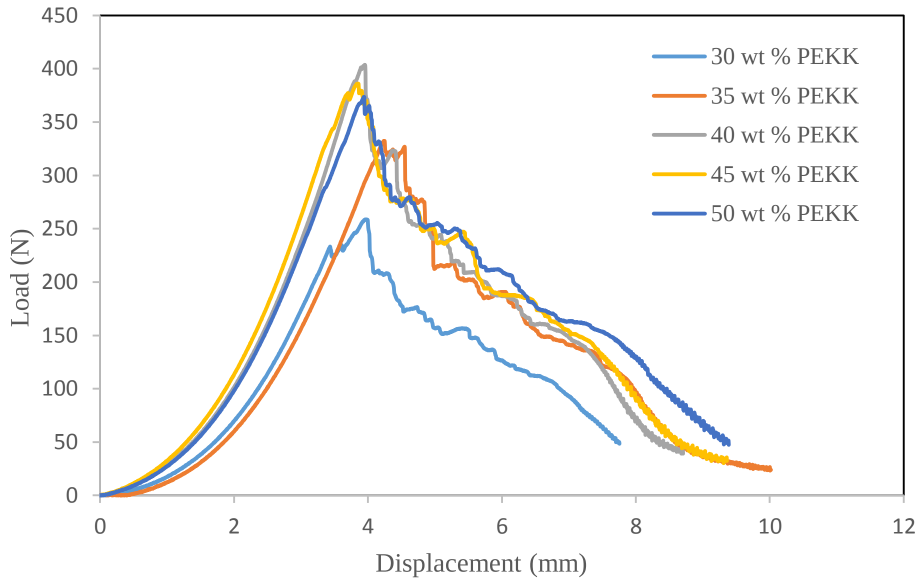

Figure 4: load-displacement traces following quasi-static perforation tests on GF/PEKK (4-ply) panels with different PEKK concentration.

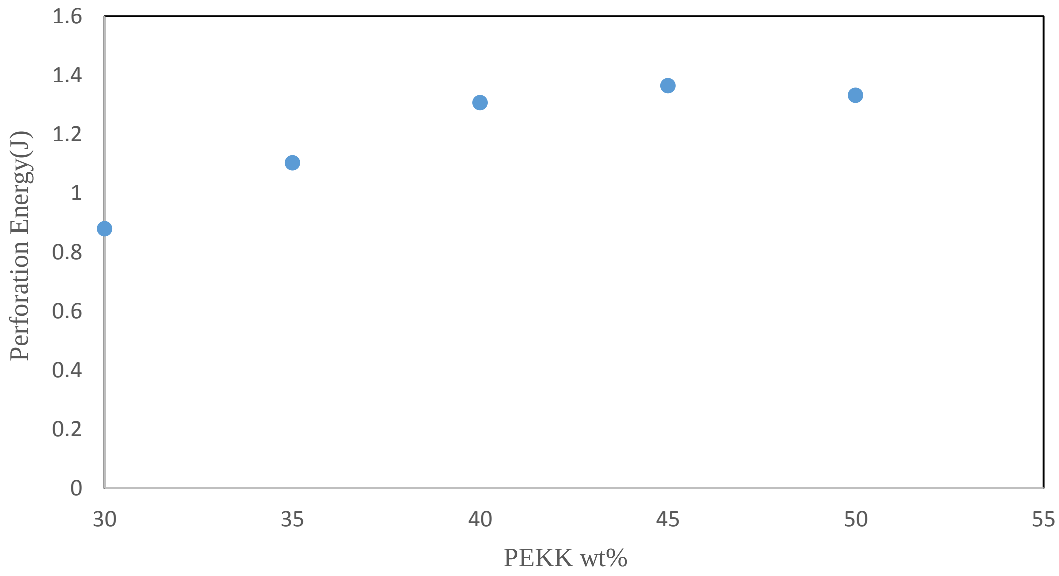

Figure 5: Perforation energies of GF/PEKK with various PEKK weight percent under quasi-static perforation tests.

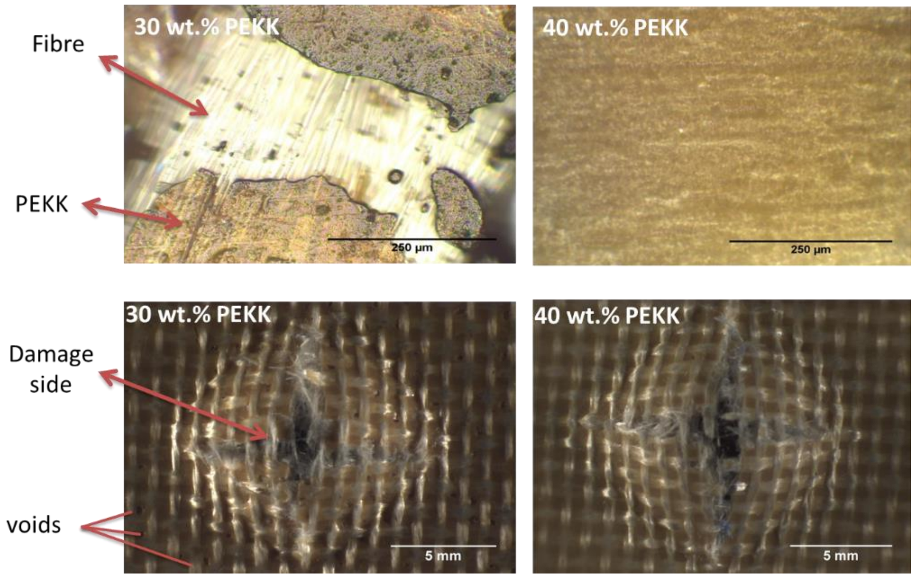

Figure 6: Micrographs of 30 wt. % and 40 wt. % PEKK (undamaged and damaged panels)

Further investigations have been done on these panels to analyse its behaviour under the tensile tests. Figure 7 shows the typical stress-strain traces of GF/PEKK with different PEKK weight percent (30, 35, 40, 45 and 50 wt. %).As expected, the maximum tensile properties increase as the weight percent of PEKK is increased, and the highest values were obtained by using 40 wt. % of PEKK. This may be related to the good bonding between the resin and the fibre. The relationship between the tensile strength values for different sample thicknesses (4, 8, 12, and 16) ply is illustrated in Figure 8. From the figure, it is clear that the tensile strength of GF/PEKK panels are not affected by the sample thickness. It is interesting to note that good bonding between S- glass fibre and the PEKK resin has been obtained even by using thin panel about 0.5 mm thickness. An optical characterization of these panels were performed in order to study the bonding between the resin and the fibre. Figure 9 shows micrographs of GF/PEKK (40/60 wt. %) at different ply numbers (4, 8, 12 and 16). It can be seen from the images that the glass fibre are covered by PEKK resin uniformly for all panel thicknesses. In other words, good bonding between the glass fibre and the PEKK resin was obtained.

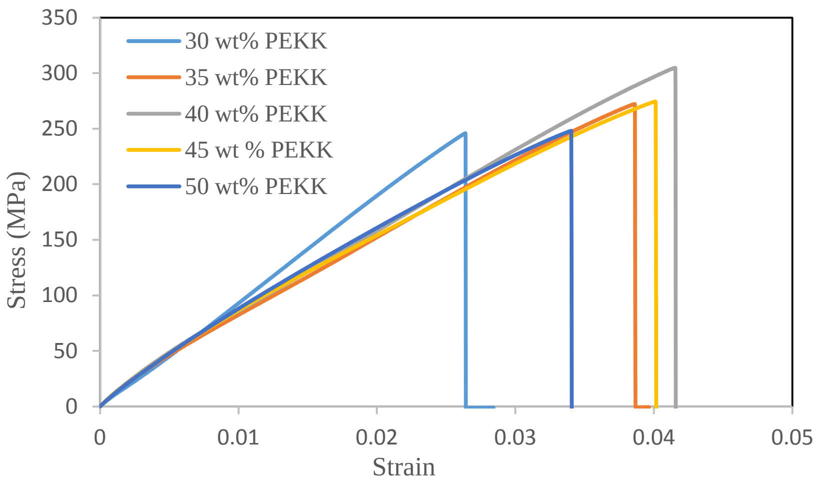

Figure 7: Stress-strain traces of GF/PEKK with different PEKK weight percent.

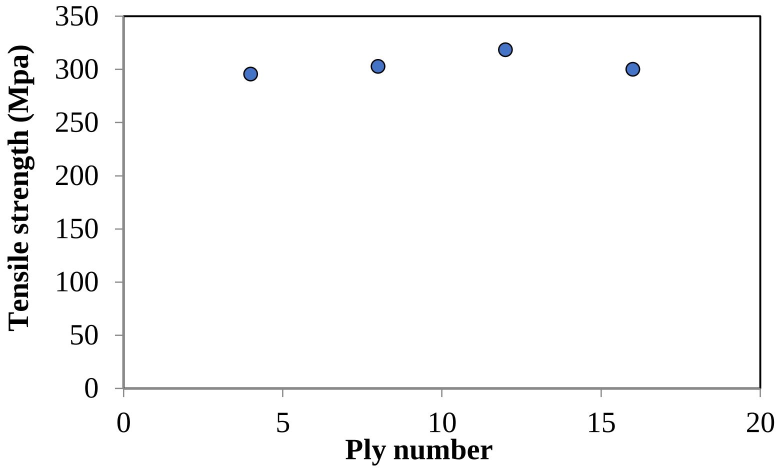

Figure 8: Tensile strength versus ply number of GF/PEKK.

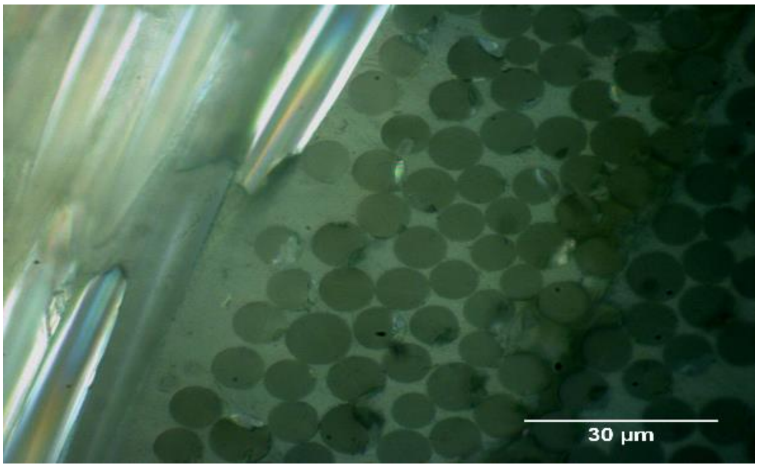

Figure 9: Micrograph of 4 ply GF/PEKK at high magnification (1000x).

5 CONCLUSIONS

Mechanical properties of multi-functional high temperature thermoplastic composites of S-glass fibre reinforced Poly-Ether-Ketone-Ketone (PEKK) have been investigated. Dry power prepregging technique has been employed to make the prepregs of GF/PEKK. The powder distribution and the wettability between the fibre and the resin is highlighted by using polished sections of the laminates. The results have shown that the maximum perforation force and tensile strength corresponding to a PEKK weight fraction of 40 %, when such the fraction is varied at 30, 40 and 50%. The results have also shown that the maximum perforation energy of the prepreg is corresponding to 40 % PEKK weight ratio. The results of tensile tests have shown that the tensile strength of GF/PEKK panels are not affected by the sample thickness.

ACKNOWLEDGEMENT

The authors would like to thank the higher committee for Education Development (HCED) in Iraq for supporting this work.

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