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Short communication

Geometric parameters and chemical corrosion effects on bearing strength of polyphenylenesulphide (PPS) composites

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Abstract

The pin-bearing strength of polymer composites has been the focus of a significant research effort. In bolted composite structures, the presence of bolt holes induces high stress concentrations, which are hence recognized to be a source of damage developed during loading. In this study we aim to investigate the bearing performance of random oriented short fibre reinforced polyphenylenesulphide (PPS) composites which are widely used in various engineering applications. Both geometric parameters and chemical corrosion effects on the bearing performance of the material were investigated. It is concluded that the load bearing performance of the materials strictly depends on the geometric parameters of the joints. Chemical corrosion was also found an important environmental factor which was affecting the load bearing performance remarkably.

1. Introduction

Because of their high specific stiffness, high specific strength, high damping and a low coefficient of thermal expansion the fibre reinforced composites are still used widely in structural applications such as aircraft, spacecraft and automotive industry. These applications usually require the joining of composites either to other composites or to metals such as steel and aluminium by bolted joints. In bolted composite structures, the presence of bolt holes induces high stress concentrations, which are hence recognized to be a source of damage developed during fatigue loading [1].

A common method used to determine the strength of mechanically fastened joints is through pin loading, where the bolt is replaced by a pin. The pin-bearing strength of polymer composites has been the focus of a significant research effort. Joints present potential problem regions to the designers due to stress concentrations, and therefore, the strength of such a structure is dependent on the strength of its joints. The strength and failure modes of mechanically fastened joints have been shown to be significantly effected by relations between geometrical parameters such as the pin diameter, D, width of the specimen, W, and edge distance, E [2].

It is well known that, depending on joint geometry, a pin loaded composite can exhibit different failure modes. In general, when the ratio W/D is lower than a critical value, a net-tension failure is precipitated; a low E/D ratio results in shear-out or cleavage; finally, only when both W/D and E/D are sufficiently high, poor bearing failure is induced [3].

The effect of environmental conditions has also been investigated by other researchers. Because the properties of polymer matrix materials in fibre reinforced composites are sensitive to variations in temperature and moisture, the mechanical behaviour around joints laminates becomes more complicated under different environmental conditions [4].

Polyphenylenesulphide (PPS) is a semicrystalline material. It offers an excellent balance of properties, including high temperature resistance, chemical resistance, dimensional stability and electrical characteristics. PPS must be filled with fibres and fillers to overcome its inherent brittleness. Because of its low viscosity, PPS can be molded with high loading of fillers and reinforcements. These fillers and

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reinforcements will make a difference in the strength, surface properties, dimensional stability, electrical properties and overall cost. PPS composites are being employed increasingly especially in aerospace and automotive industry.

In literature generally studies were done in order to investigate the bearing performances of continuous fibre composites. There are limited works about discontinuous fibres. This why, we aim to investigate the bearing performance of random oriented short fibre reinforced PPS composites which are widely used in various engineering applications. Both geometric parameters and chemical corrosion effects on the bearing performance of the material were investigated.

2. Experimental

Random oriented short glass fibre reinforced (40% w/w) PPS and random oriented short glass fibre and calcium carbonate particle reinforced ($40 + 25 = 65\%$ w/w) PPS composite materials used in this study. Materials were kindly supplied from Ticona-Germany as 80×80 mm plaques with thickness of 2 mm. The load bearing experiment have been carried out according to the ASTM D953 standards in Instron 4411 universal testing device, which has 5 kN loading capacity. As suggested in ASTM D953 standard, tension speed was performed as 1 mm/min [5]. To make easy to follow, experimental specimens were coded as F and F/P type. "F" represents random oriented short glass fibre reinforced (40% w/w) PPS composite materials and "F/P" represents random oriented short glass fibre and calcium carbonate particle reinforced ($40 + 25 = 65\%$ w/w) PPS composite materials.

Fig. 1 schematically illustrates testing fixture and the geometrical parameters of tested samples. The main geometric parameters used in pin connected joint researches are: pin diameter "D", width of the composite plaque "W", the smaller length from the center of the hole to the edge, which is perpendicular to the applied load direction of the material "E", the ratios E/D and W/D.

In order to investigate the chemical corrosion effect on bearing performance of PPS composites, samples were immersed in two different corrosive environments. One of these environments was 10% HNO_3 solution, and the other one was saturated NaCl solution. Solutions were prepared by using triple distilled water. Samples were immersed into the corrosive environments for three months (90 days) and than tested.

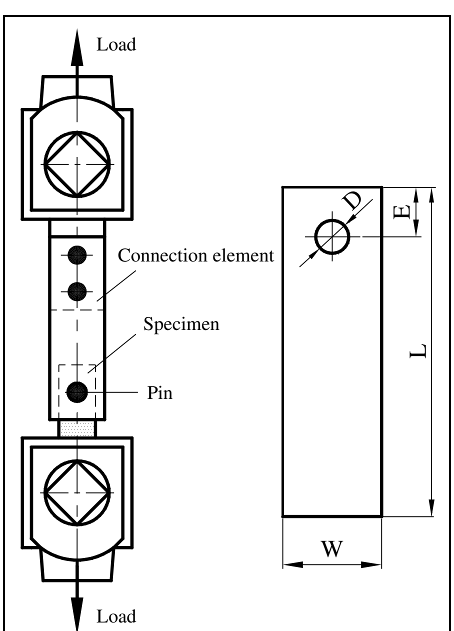

Fig. 1. Testing fixture and geometry of the specimen.

Table 1
Dimensions and ratios for the tested samples

L (mm)	W (mm)	D (mm)	Ratio of W/D	Ratio of E/D
80	20, 30, 40	5, 10	2, 3, 4, 6, 8	1, 2, 3, 4, 5, 6

The specimens for each material has different geometric parameters. W/D ratio was set constant as 2, 3, 4, 6 and 8; E/D ratio was changed as 1, 2, 3, 4, 5 and 6. In this study three types of samples with 20, 30 and 40 mm of width were tested. The specimens were loaded by steel pin with diameters of 5 and 10 mm. Pin deformations was neglected. The specimen dimensions are provided in Table 1.

The appearance of the net-tension failure is catastrophic, immediate and without warning. Therefore, the designers have to choose optimal W/D and E/D ratios to avoid such catastrophic and immediate failure at structural elements. The definition of net-tension type failure is

$$\sigma_{nt} = \frac{P}{(W - D)t} \tag{1}$$

where σ_{nt}, P, W, D and t represent net-tension strength, maximum load, specimen width, pin diameter and specimen thickness, respectively.

3. Results and discussion

In tension type failure, propagation direction of the crack was perpendicular to the direction of the applied load. Load values were rapidly drop to zero in a short time after reached its maximum. It is clear that sudden drop in load after small displacement means unexpected failure type with an unadequately energy absorbing. The slope of the curve in elastic region is higher for original (uncorroded) sample compared to corroded samples as seen in Fig. 2. The slopes of corroded samples (in 10% HNO_3 and saturated NaCl solutions) are approximately the same. Also the samples immersed in 10% HNO_3 solution gives the highest bearing load. There was a remarkable difference in absorbed energies of the samples during the experiments. Also Fig. 2 implies the corrosive environment/absorbed energy differences between corroded samples. The samples

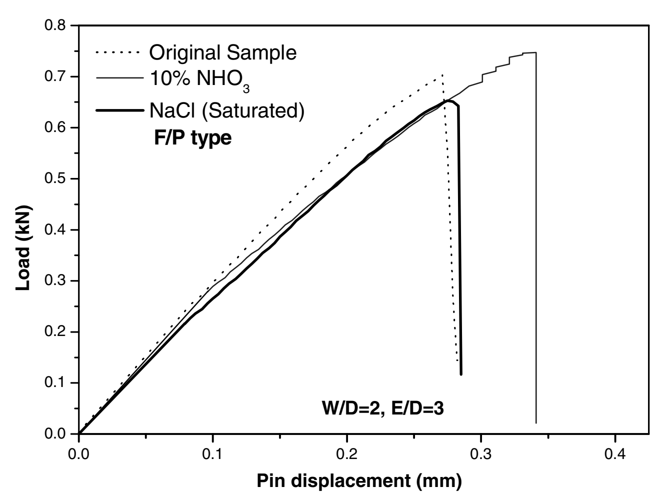

Fig. 2. Load–pin displacement curves of F/P type composite plaques.

immersed in 10% HNO_3 solution absorbing higher energy until catastrophic failure compared to original and immersed samples NaCl (saturated). It is possible to say that materials became more ductile in 10% HNO_3 solution.

Figs. 2 and 3 illustrate load–pin displacement curves of F/P and F type specimens failed in net-tension type failure mode. The load–pin displacement curve for these specimens illustrates an approximately linear load displacement relation prior to catastrophic failure.

As seen in Figs. 2 and 3 there is a smooth difference between F and F/P type material. As a result of particle reinforcement mechanical properties of the material are remarkably changed. During the bearing tests slightly higher slopes was observed at F/P type materials. On the other hand higher bearing loads was observed at F type materials. Tension type failure was observed for every parameter. In uncorroded F/P type materials failure was happens after 0.28 mm of pin displacement, on the other hand in F type materials failure was happens after 0.4 mm. After chemical corrosion of 90 days there was a remarkable changes in mechanical properties was observed. Most remarkable changes were observed in slopes. As a result of corrosion lower slopes were observed in both F and F/P type materials. Decrease in slope was higher as a result of chemical corrosion in F type materials. Also pin displacements up to fracture were higher for corroded samples.

Load bearing capacities of pin loaded samples are shown in Figs. 4 and 5. In order to find the optimum geometry for these composite plaques, E/D and W/D ratios are systematically changed during the experiments. As stated before net-tension failure type was obtained for all geometric parameters. Maximum load was achieved at ratio of E/D was 6 for F/P and F type composites.

The load bearing characteristics of the short fibre reinforced composite was found very interesting. In many cases, unidirectional fibre reinforced composite materials reported with higher bearing loads at E/D ratios between 2 and 4 for given W/D ratio. Dissimilar to continuous fibre reinforced materials we investigated that bearing loads were increased with the E/D ratios. Bearing loads approximately increases proportional with E/D ratios for given W/D ratio. Slightly higher bearing loads were investigated at samples immersed in HNO_3 solution and lower bearing loads were investigated at samples in saturated NaCl solution compared to uncorroded materials.

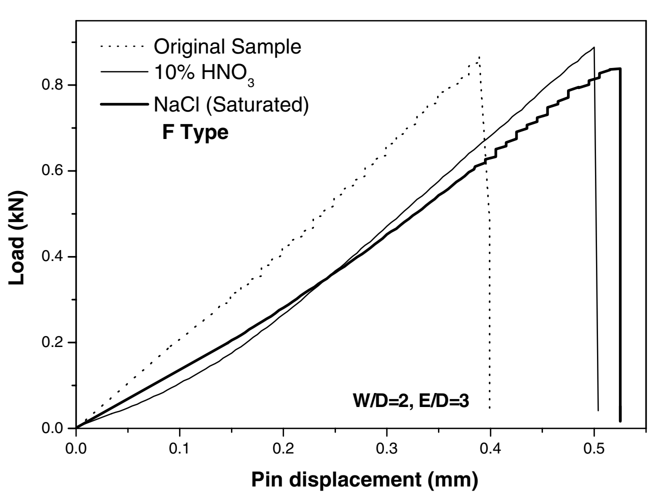

Fig. 3. Load–pin displacement curves of F type composite plaques.

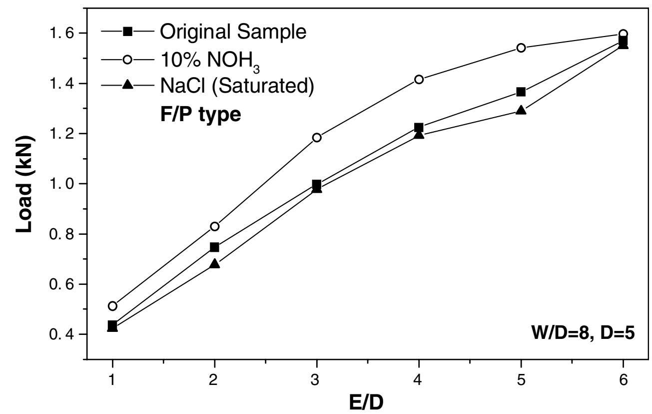

Fig. 4. Load bearing performances of F/P type composites.

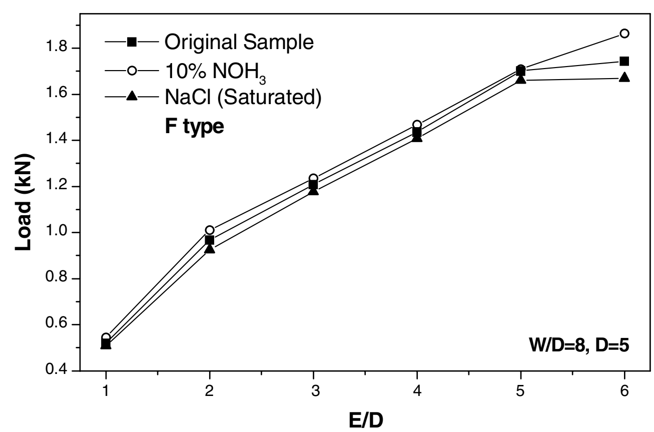

Fig. 5. Load bearing performances of F type composites.

The macrographs of the failure types of the tested specimens are shown in Fig. 6. Fig. 6-a and b represents the tension failure for F type 10% HNO_3 immersed samples.

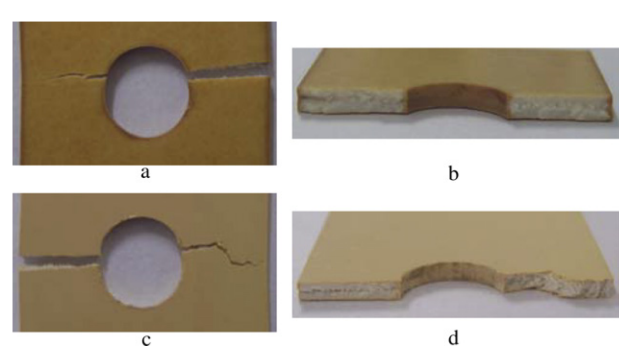

Fig. 6. Macrographs of the composite samples after pin loading experiments failing by net-tension failure mode (a,b) F type 10% HNO_3 immersed sample: $E/D = 3$, $W/D = 2$, $D = 10$ and (c,d) F/P type 10% HNO_3 immersed sample: $E/D = 3$, $W/D = 2$, $D = 10$.

Fig. 6-c and d represents the tension failure for F/P type 10% HNO_3 immersed samples.

4. Conclusions

In this study we investigated the different load bearing characteristics in short fibre reinforced PPS composites compared to continuous fibre reinforced composites. Additional to the short fibres, particle reinforcement effects on load bearing performance were presented. Also the effect of chemical corrosion on mechanical properties of the short fibre reinforced PPS composites was investigated.

It is concluded that the load bearing performance of the materials strictly depends on the geometric parameters of the joints. Microstructure of the materials affects the performance of the joints. Chemical corrosion was also found an important environmental factor which was affecting the load bearing performance remarkably.

Results were presented briefly in this study. We aim to investigate the chemical corrosion effects on bearing performance in longer periods and investigate the effects of chemical corrosion in molecular scale in future studies.

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