Characterisation of graphene modified carbon fibre reinforced poly-ether-ether-ketone (PEEK) substrates and examination of the mechanical enhancements

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1. Nanomaterial fillers in thermoplastic composites

Thermoplastic composite (TPC) materials are used extensively in high performance aerospace and automobile applications. TPC's can be reformed at high temperatures allowing ease of manufacturing and a high potential for re-use [1].

Graphene is material consisting of a two-dimensional lattice array of carbon atoms. This material is characterised by its exceptional thermal and electrical conductivity as well as its high strength [2, 3]. Recent advancements in manufacturing large quantities of graphene using methods which are low-cost and pose minimal environmental impacts has seen the viability of utilizing graphene for material reinforcement increase.

Carbon fibre reinforced poly-ether-ether-ketone (PEEK) is a particular TPC which is already used in aerospace applications. Sheets, termed substrates, of this material can be manufactured into laminar composites using quick and efficient technologies. If graphene can be deposited between these sheets during manufacturing, there is great potential to strengthen these high performance composites. This could reduce weight in aircrafts and automobiles, leading to economic benefits.

2. Aims of the Investigation

- Develop a coating and characterisation technique for a water based graphene dispersions onto carbon fibre PEEK thermoplastic substrates.
- Evaluate the relative strength of graphene reinforced carbon fibre PEEK composites.

3. Method

- Exfoliate graphene in water

Graphene was extracted in an aqueous solution using methods described previously [4]. Solutions yielded concentrations of graphene in water ranging between 1.62 g/L and 2.49 g/L.

- Improve the wettability of carbon PEEK

The surface of carbon PEEK was modified by plasma treated using water vapour. The surface level wettability enhancements are shown for a liquid droplet on carbon PEEK in figure 1 below.

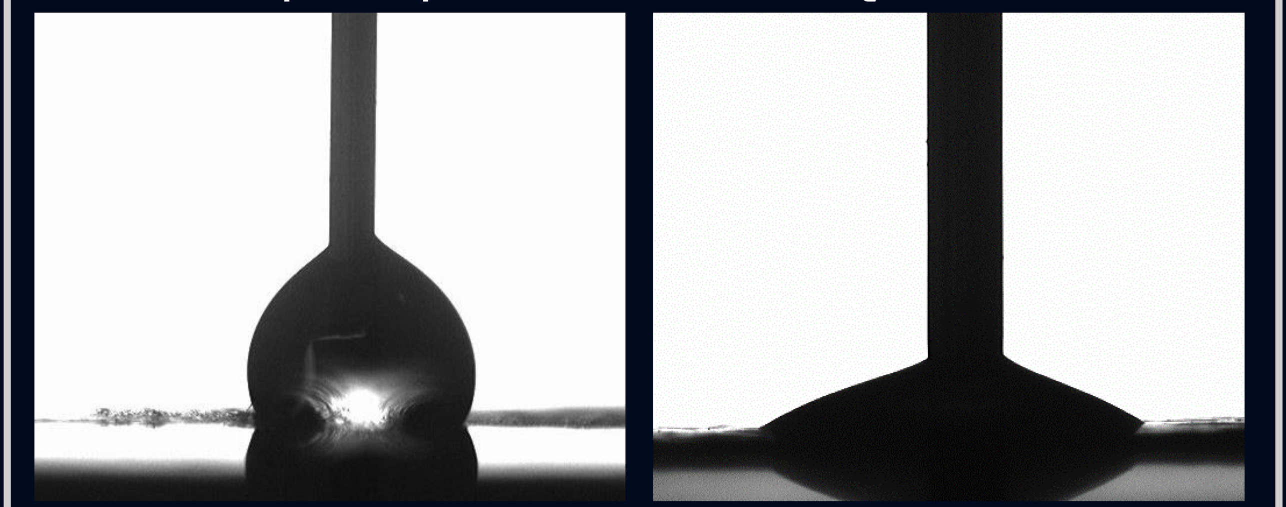

Figure 1 (left) drop profile of water on untreated carbon PEEK, and (right) drop profile of water on plasma treated carbon PEEK

- Coat graphene onto PEEK and characterise coating

Graphene was spray coated onto the surface of plasma treated carbon PEEK. The presence of graphene on the surface was then verified using Atomic Force Microscopy (AFM).

- Manufacture and mechanically test laminates

Graphene coated carbon PEEK laminates were manufactured under a heat press. These laminates were 20 ply thick. The short beam shear (SBS) strength of resulting laminates was evaluated using a universal testing machine.

4. Plasma coating facilitates successful graphene coating onto carbon PEEK

Below is a selection of AFM images of carbon PEEK. The surface topography of a region within one of these images has been analysed in figures C and D.

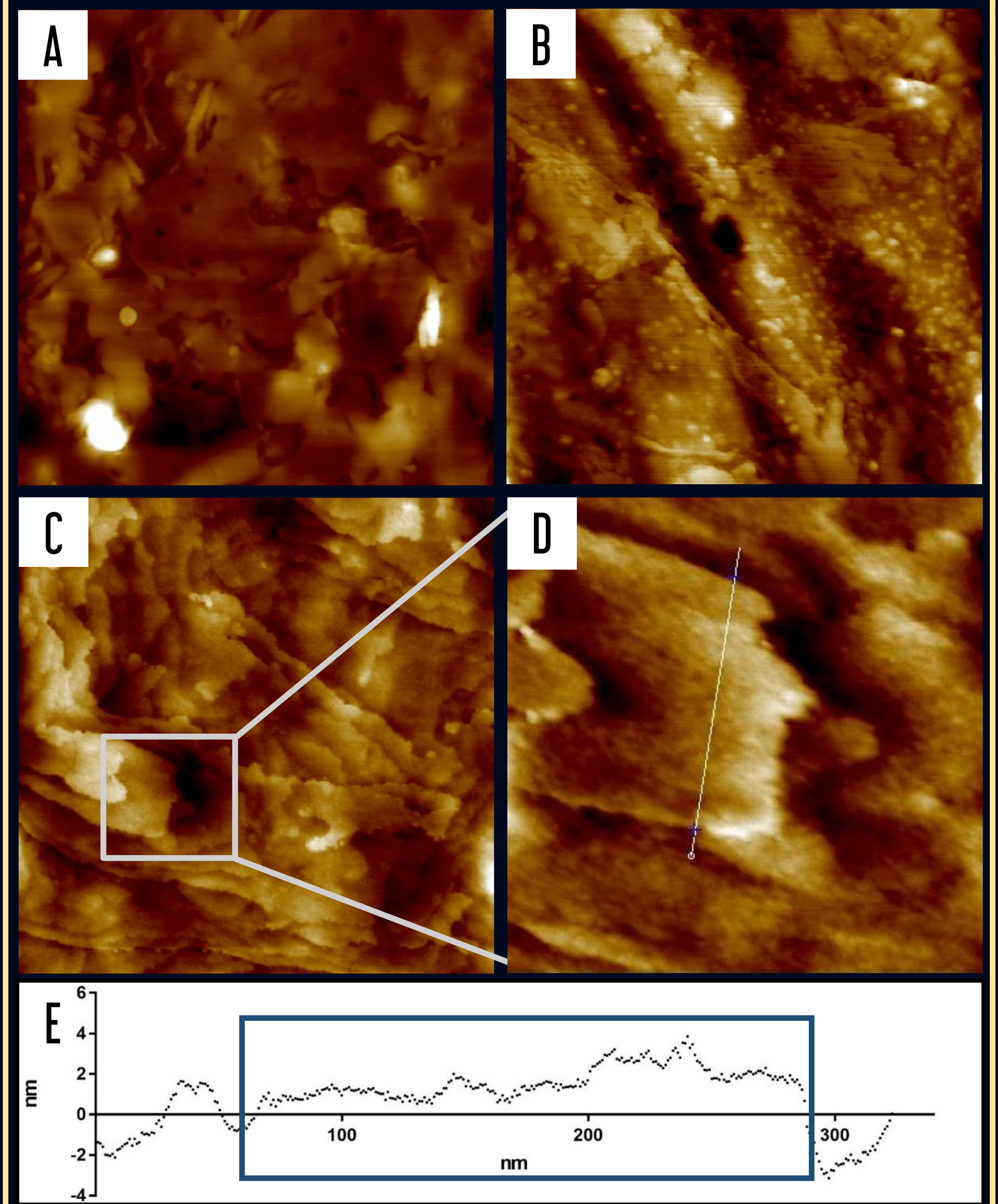

Figure 2 All AFM images are of carbon PEEK. (A) untreated (B) plasma coated (C) graphene coated. Images A-C taken with a scan size of 1 μm. (D) is graphene coated with a scan size of 500 nm. (E) is a topographical plot of image (D)

Distinct surface level changes are evident between figures 2A-C. 2C shows stacked flakes which form a uniform coating. Analysing a region within figure 2C, shown as a height profile in 2E, with lateral dimensions in the range of 200-250 nm and a height between 1-4 nm, these are graphene flakes [5].

5. Graphene filler improved the mechanical properties of carbon PEEK

Plots of the maximum loads supported before failure for a reference and graphene reinforced carbon PEEK laminate are shown below in figure 3. Maximum supported load is the maximum point on each graph.

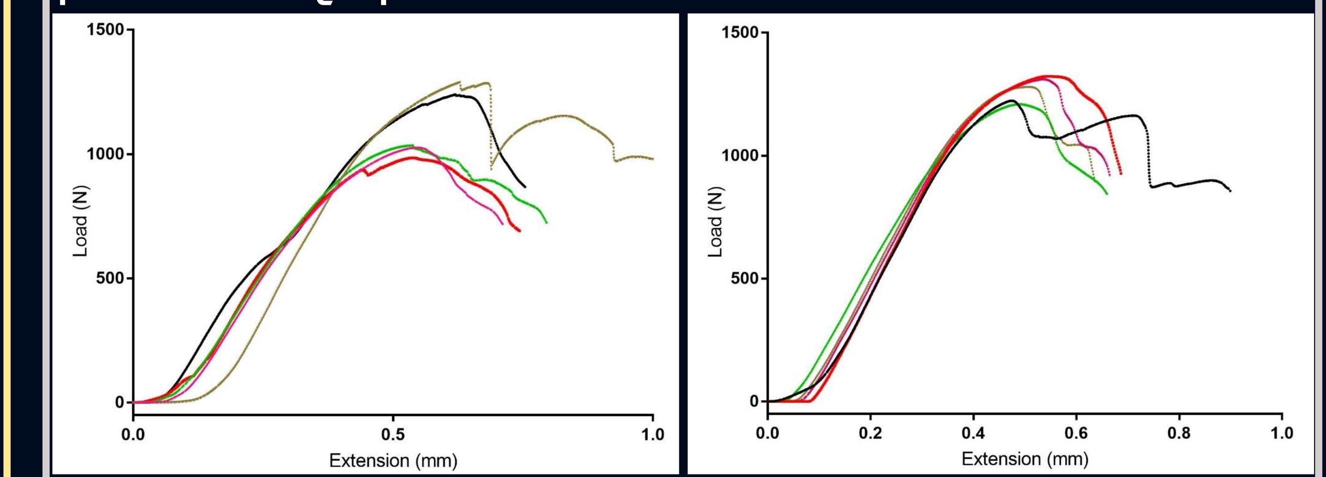

Figure 3: The maximum shear stress developed in five different samples of a carbon PEEK laminate (left) and a graphene reinforced carbon PEEK laminate (right). Also shown below each figure is the average SBS strength for each of the different samples.

Sample	σ(MPa)	E(MPa)
Reference	75.35 ± 10.26	10177.70 ± 784.55
Graphene reinforced	86.50 ± 3.45	11599.91 ± 474.81

- The graphene reinforced composite exhibited a higher average SBS strength, elastic modulus and lower associated uncertainty when compared with the reference laminate.
- Low value of uncertainty for the graphene laminate indicates that the graphene has been uniformly dispersed throughout the laminate.
- The increase in strength is likely due to the fact that the graphene filler has formed a nanocomposite in the interlaminar region of the composite. The high elastic modulus and surface area to volume ratio of graphene have been enhanced within this reinforcement.
- Uneven resin flow during production is the most likely explanation for the high uncertainty associated with the SBS strength of the reference sample.
- Observable failure showed delamination in the mid plane of the composite. This validates correct shear strength testing.

6. Conclusions and future work

- An industrially scalable method for coating graphene dispersion onto carbon PEEK has been developed within this research.
- Graphene coated carbon PEEK manufactured into laminates using a heat press exhibited improved mechanical properties, resulting from strength enhancements within the interlaminar region of the composite.
- Future work directions include analysis of the failure regions within the laminates through scanning electron microscopy an investigations into the thermal and electrical enhancements resulting from the graphene filler.

References

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