DEVELOPING THE NEXT GENERATION OF SINGLE POLYMER/CARBON FIBRE HYBRID COMPOSITE MATERIALS FOR AUTOMOTIVE USE - HIVOCOMP

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Abstract

In this paper we present some recent results on new single polymer/carbon fibre hybrid composites. These are based on Nylon 6 (PA6) and were developed under the European FP7 HIVOCOMP project, which is funded under the topic NMP-2009-2.5-1 "Light high-performance composites" of the 7th Framework Programme for Research and Technological Development. Two different strategies have been trialled for hybridisation, termed intralayer and interlayer. In the intralayer hybridisation, highly stretched PA6 tapes are co-woven with PA6/T700 carbon fibre prepreg tapes and then processed using the Leeds hot compaction process. In the interlayer technique, layers of PA6/T700 prepreg are directly bonded to sheets of single polymer PA6 composite. Adding the carbon fibre was found to always give a significant improvement in stiffness and strength at strains below the failure strain of the carbon fibre (~2%). For the intralayer (co-woven) hybridisation strategy, samples were found to be brittle in tension, that is once the carbon fibres broke, the samples as a whole broke. In bending, however, this was not the case, with the hybrid samples remaining load bearing up to a high failure strain even after the breakage of the carbon fibres. For the interlayer hybridisation, an alternative strategy was adopted, where the prepreg tapes were located on the exterior of the SRP PA6 sheets. In tensile testing this combination was found to behave in parallel, so that the composites showed ductile behaviour even after the breakage of the carbon fibres.

1 Introduction

The ideal objective for any composite designer is to have available a material that combines high stiffness/ strength with high toughness/extensibility. In general, however, these two types of behaviour are mutually exclusive. Traditional carbon fibre composites deliver exceptional stiffness and strength but can often have a limited extensibility and poor damage tolerance especially at lower operating temperatures (vehicles need to maintain their integrity and crash performance at -40°C). On the other hand, the development of single polymer composites over the last 20 years has seen the emergence of a new material that is light weight and has exceptional toughness even at low temperatures.

The goal of the new FP7 project, HIVOCOMP, is to combine the best attributes of these two material types by creating a self-reinforced, single polymer/carbon fibre hybrid. This new generation of composite will combine high stiffness carbon fibres, together with oriented PA6 elements, to produce the hybrid composite. The aim is to combine the properties of a self reinforced nylon sheet (PA6), that is lightweight, has outstanding impact performance and strength and can be produced in high-volume processes, with those of existing carbon fibre reinforced composites, which have outstanding stiffness but low toughness (especially thermosets). The goal is to develop a material that satisfies automotive design requirements.

While the concept of combining a high stiffness, but brittle, fibre with a ductile polymeric fibre with a much larger strain to failure is not new, the production of hybridised self reinforced polymer composites is very much a new research area. All of these studies (for example the work at the University of Leuven [1, 2]) have looked at combining discrete layers of a prepreg composite and a self reinforced polymer (SRP) sheet. While there are a number of published methods for producing self reinforced polymer composites (for example film stacking, powder impregnation and bicomponent tapes), the one used for this research is that developed, and patented, at the University of Leeds and is termed hot compaction [3-5]. The underlying principle is to take assemblies of oriented polymer fibres or tapes, and expose them to a critical temperature, while held under pressure, such that a thin skin on the surface of each oriented element is *'selectively melted'*. On subsequent fast cooling, the melted material recrystallizes to form the matrix phase of a self reinforced polymer composite, with the remaining fraction of the original oriented phase acting as the reinforcement. The virtues of this technique are that the matrix phase is produced around each fibre, negating the need for infiltration, and that molecular continuity is achieved between the two components of the final composite. Research has shown this to work with a wide range of oriented thermoplastic fibres and tapes including polyethylene [6], polypropylene [7] polyester [8] and nylon 6.6 [9].

In this paper we will present some results on hybridised self reinforced PA6/carbon fibre composites, Two different strategies have been trialled for hybridisation, termed intralayer and interlayer hybridisation. In the intralayer hybridisation, highly stretched PA6 tapes are co-woven with PA&/T700 carbon fibre prepreg tapes, to produce a cloth which is then processed using the hot compaction technique. In the interlayer technique, the T700/PA6 prepreg tapes were simply laminated together with sheets of self reinforced PA6. Variables to be reported on include the effect of the volume fraction of the carbon fibres, the compaction conditions (particularly the compaction temperature) and the weave style.

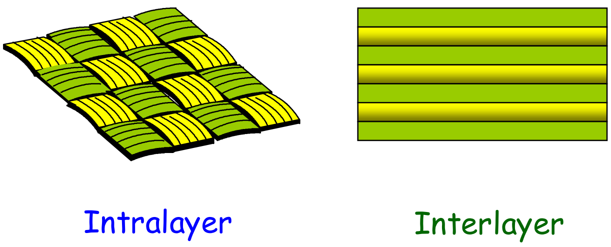

Figure 1: Hybridisation strategies

2 Composites Preparation

Continuous carbon fibre (type T700) reinforced PA prepreg tapes were obtained from *SOFICAR* with a carbon fibre volume fraction of ~50%. The tapes were 3.2mm wide and 0.28mm thick. Oriented PA6 tapes were produced at Leeds using a purpose built draw frame (Figure 2A). Experiments showed that the best properties for the drawn tape were from by a two stage drawing procedure. For the first draw, the ratio was 7:1 at a temperature of 120°C, followed by a subsequent draw of 2:1 at 140°C: the overall draw ratio was therefore 14:1.

Fig 2a: The Leeds draw frame

Fig 2b: Tape drawing in progress

2.1 Intralayer: The two tapes (highly drawn PA6 and T700 carbon/PA6 prepreg) were woven on a hand loom to produce cloth (Figure 3a). For the pure PA6, both the warp and weft were from the PA6 drawn tapes (Figure 3a). For the hybrid co-woven cloth, the PA6 drawn tapes formed the warp and the T700/PA6 tapes the weft (Figure 4b). The cloths produced were around 200mm wide and 800mm long.

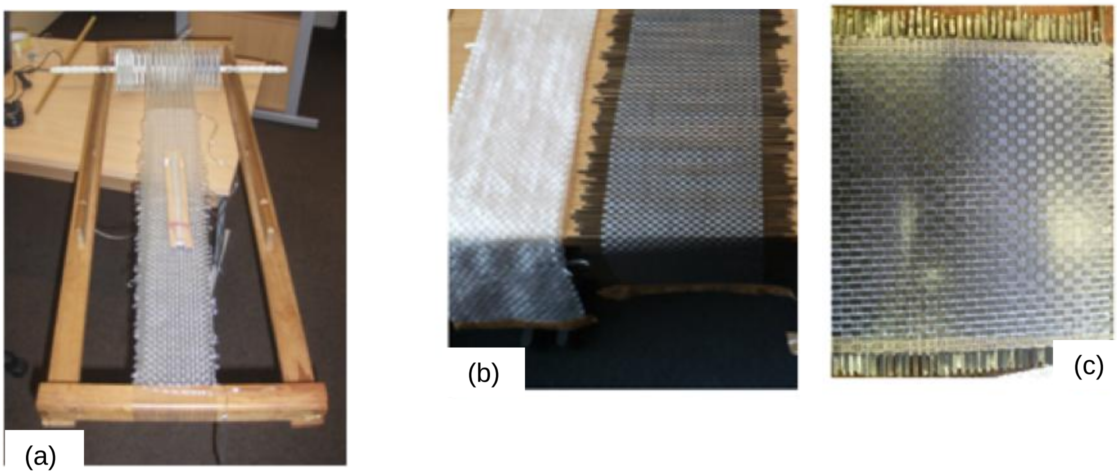

Figure 3. Details of the weaving of the hybrid and a manufactured sample

Finally, the cloths were made into hybrid samples using the hot compaction process. The optimum compaction temperature was found to be 202 ± 1 °C. For these tests, the carbon fibre tapes were arranged in one direction (the subsequent testing direction). By using different amounts of the two cloths, a range of carbon fibre volume fractions were obtained (from 0 to 30%). A typical compacted sample, with a carbon fibre volume fraction of 8%, is shown in Figure 3c.

2.2 Interlayer: For the interlayer samples, lengths of the PA6/T700 prepeg tapes were laminated on the outside of a pure PA6 hot compacted sheet using a cyanoacrylate adhesive.

3. RESULTS

3.1 Tensile tests – Intralayer

As described above, in the first series of tests the composites were made with the carbon fibres all laid in the same (testing) direction. They were then interleaved with layers of pure PA6 woven cloth to change the fibre volume fraction. These latter samples can be considered to be a mixture of intra and interlayer hybridisation. Figure 4 shows the results of tensile tests (ASTM D638) and the various lay-ups.

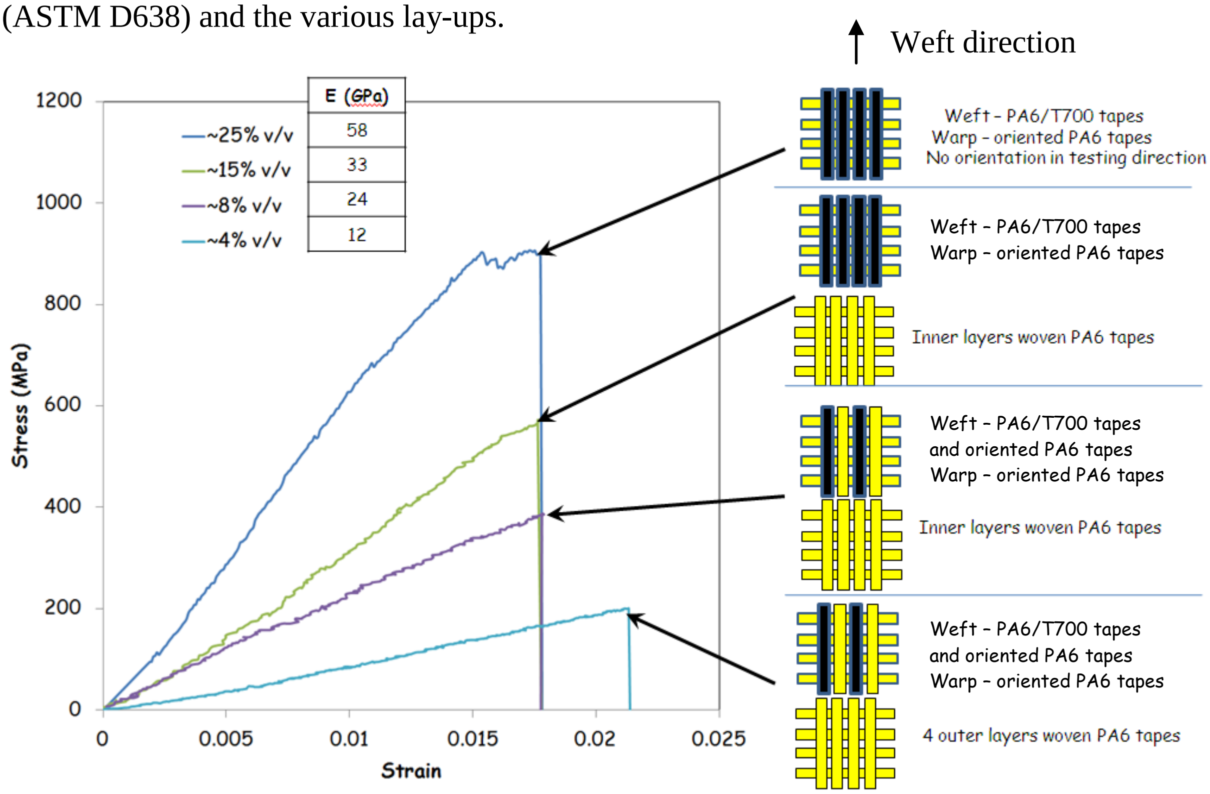

Figure 4: tensile tests on intralayer hybrids

All the samples tested, even at the lowest carbon fibre volume fraction of 4%, showed brittle failure, that is catastrophic failure of the sample once the carbon fibres break. This is very different behaviour to a 100% PA6 SRP composite sheet, which shows a much lower modulus but a strain to failure of 10%.

Figure 5 on the right shows a comparison between a 100% PA6 SRP sheet and a hybrid UD sample with 8% carbon fibre (the purple curve on Figure 4.

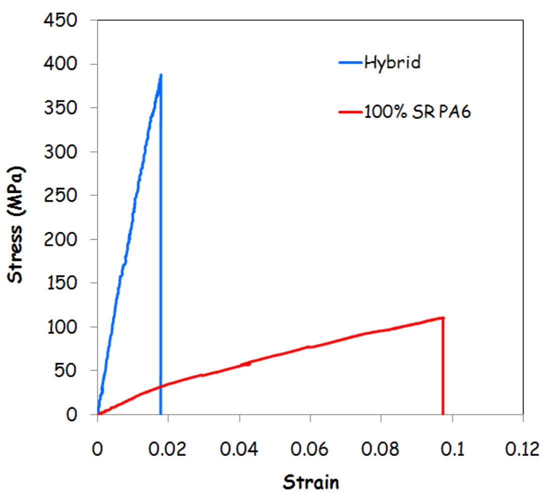

Fig 5: A comparison of the tensile properties of a 100% PA6 SRP sample (red curve) and an 8% carbon fibre/PA6 hybrid (blue curve).

For the next set of experiments, the carbon fibre prepreg tape was cut in half and then co-woven with the oriented PA6 tapes. This had the effect of reducing the amount of carbon fibre at any location by a half, while retaining the same overall fibre volume fraction. It is seen that samples tested in tension with this configuration, showed some load bearing capability after the carbon fibres were broken. This suggests that separating the carbon fibres could mediate the shock effect of the carbon fibres breaking and releasing their stored energy.

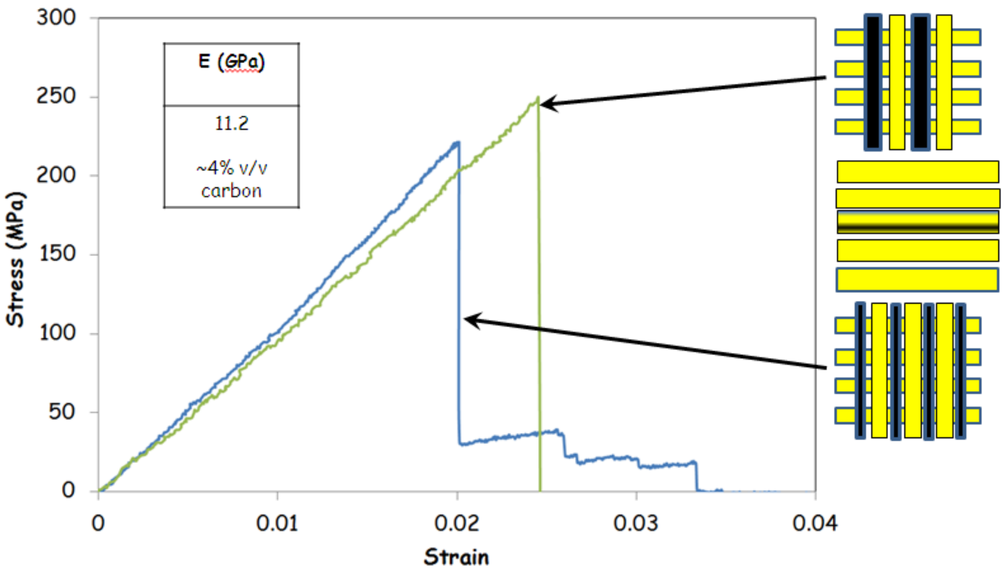

Fig 6: The effect of the width of the reinforcing prepreg tapes on the hybrid performance.

3.2 Tensile tests – Interlayer

For the first interlayer tests, samples were made by placing the prepreg tape on the outside of the SRP PA6 woven layers and then using the hot compaction technique as above. These samples all showed brittle failure similar to that described in the previous section for the Intralayer samples. A second set of tests were carried out, but this time laminating the prepreg tapes to the outside of the SRP PA6 sheet.

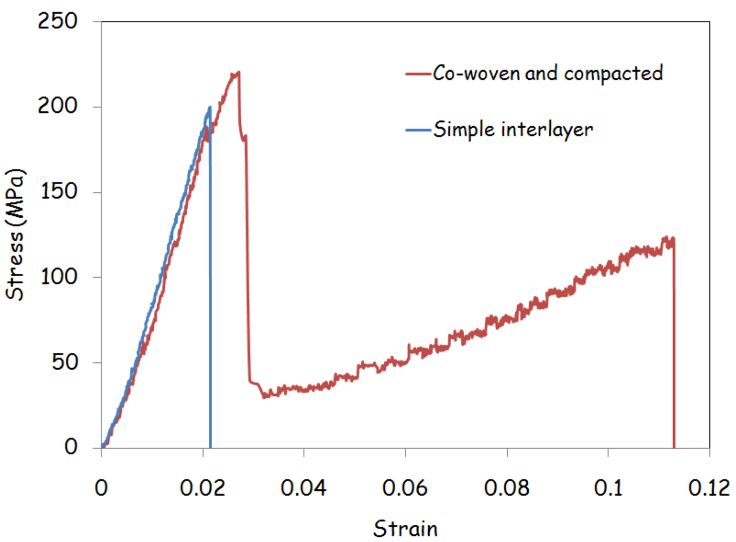

Fig 7: A comparison of the tensile properties of a co-woven sample (blue) and a simple interlayer sample (red curve - 4% carbon for this comparison).

The results in Figure 7 show that for this simple laminate, the carbon fibres can break without damaging the SRP PA6 sheet, which then proceeds to carry load until over 10% failure strain. In this configuration, the two components effectively behave in parallel, with the resulting hybrid combining the best aspects of the two components. A stiffness of 11GPa, a strength of 230MPa and a failure strain of 11%.

3.3 Bending tests – Intralayer

Bending tests were also carried out on the intralayer (co-woven) samples under ASTM D790. Interestingly, the co-woven nylon hybrids were found to be ductile in flexure, compared to their brittle behaviour in tension. It was seen that the sheets retained their load carrying capacity even after the carbon fibre broke. Figure 8b shows a typical comparison of a tension test and a flexure test on the same hybrid intralayer sample. The flexural modulus was measured to be lower in flexure (as the carbon is located towards the centre of the sample), but remained intact once the carbon layer had fractured.

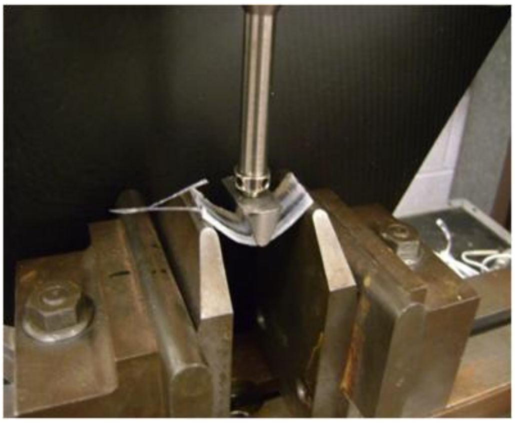

Figure 8a: Details of flexure testing of the co-woven hybrids

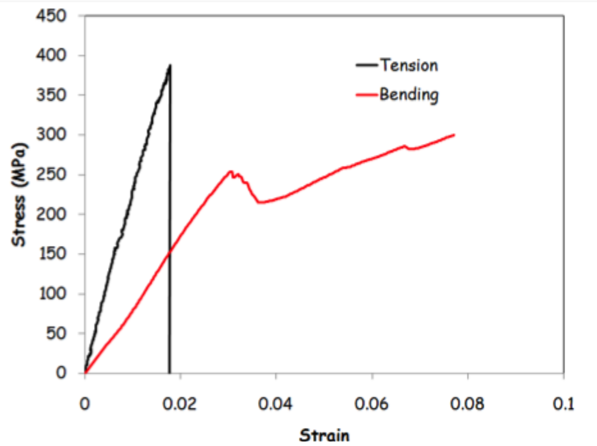

Fig 8b: A comparison of the tensile and bending properties of a hybrid sample.

Figure 9 summarises the tensile and bending properties of the intralayer hybrids compared to the pure SRP PA6 sheet. In both cases, the hybrid sample has a much improved stiffness and strength. Whereas in tension, the sample breaks once the carbon fibres break, in bending this does not occur, and the sample is not seriously damaged when the carbon fibre fraction breaks.

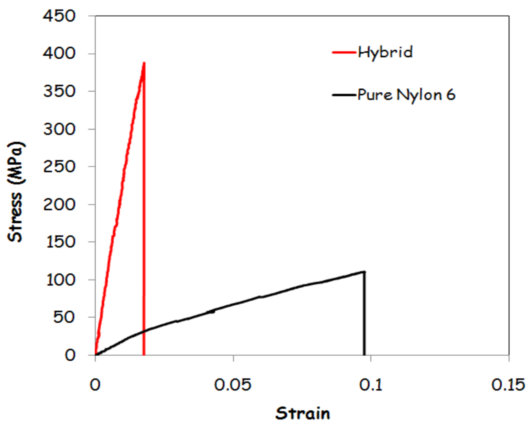

Fig 9a: A comparison of the tensile properties of a pure PA6 sheet (black) and a hybrid sample (red curve).

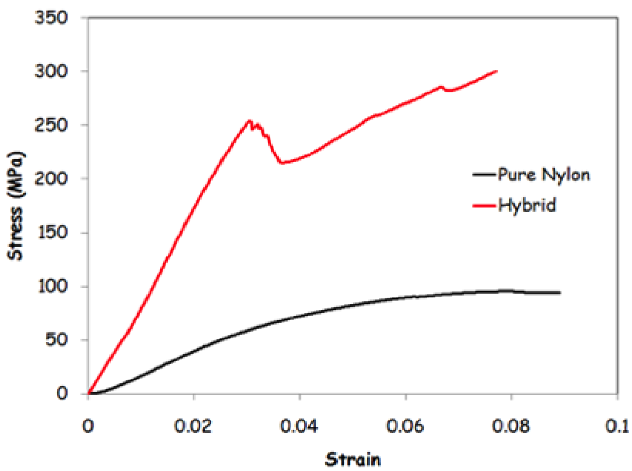

Fig 9b: A comparison of the bending properties of a pure PA6 SRP sheet (black curve) and a hybrid sample (red curve).

4. Conclusions

In this study we have investigated the behaviour of self reinforced PA6 polymer/carbon fibre hybrids. Adding the carbon fibre always leads to a significant improvement in stiffness and strength at strains below the failure strain of the carbon fibre (~2%). For the intralayer (co-woven) hybridisation strategy, samples were found to be brittle, that is once the carbon fibres broke, the samples as a whole broke. In bending, however, this was not the case, with the hybrid samples remaining load bearing up to a high failure strain even after the breakage of the carbon fibres. For an alternative hybridisation strategy, the prepreg tapes were located on the exterior of the SRP PA6 sheets. Here it was found that the components behaved in parallel in tension, resulting in ductile behaviour even after the breakage of the carbon fibres.

5. Acknowledgements

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6. References

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