PROCESSING OF CHARACTERISATION OF CARBON FIBRE REINFORCED PEEK WITH DISCONTINUOUS ARCHITECTURE

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Keywords: thermoplastics composites, discontinuous fibres, randomly oriented strands, PEEK, carbon fibre

Abstract

Current applications of composite materials have been focussing on the use in thin shells and continuous profiles, commonly being manufactured on the approach of a layered structure. The aim of this work was to evaluate the eligibility of a process based on compression moulded thermoplastic chopped tapes as a candidate to replace complex CNC machined metal parts for load introduction elements in aircrafts. Due to their discontinuous character, such materials are subject to scale effects, which are discussed in detail and interpreted in respect to the combination of failure modes leading to fracture.

1. Introduction

The reduction of greenhouse gas emissions [1] has fostered the quest for mass reduction in transportation. While novel aircraft such as the Airbus 350XWB or the Boeing 787 already show a large amount of carbon fibre reinforced polymers (CFRP), their application is typically limited to thin walled structures such as shells or profiles, which can be represented as a layered structure, while load introduction elements are typically metallic. For aerospace applications however, complex metallic load introduction elements have several drawbacks depending on the candidate metals that are commonly used - Aluminium, Steel and Titanium - hereafter summarized: (i) when integrated within aircrafts in combination with CFRP airframes, aluminium parts have to be mounted with several cost-intensive precautions against galvanic corrosion [2], (ii) The use of steel adds an increasing weight penalty, (iii) whilst the use of titanium results in higher material and production costs.

The use of CFRP for complex load introduction was studied by Toray industries in the 90s [3] and describes how strips pieces (further referred as chips) constructed of chopped thermoplastics pre impregnated unidirectional (UD) fibres (as tapes) can be distributed in plane parallel to the surface cavity of a tool, heated up and consolidated under pressure. The length of the chip is defined to be long enough to obtain mechanical properties similar to those of a quasi-isotropic laminate, whilst being short enough to maintain the advantage of a good fit in the tool. Lee, Harper [4, 5] and Ionita [6] have studied the mechanical behavior of such reinforcement architecture, however with a thermoset matrix as opposed to a thermoplastic polymer, Feraboli [7, 8] used chopped UD prepreg with an aerospace equivalent fibre volume content higher than 50%, whereas Harper [4, 5] and Ionita [6] have used dry chopped tows and later infused the matrix [9] with a thermoset matrix resulting in a fibre volume content less than 50%. These studies served as benchmark to compare the results for thermoplastics matrix CFRP materials from this work.

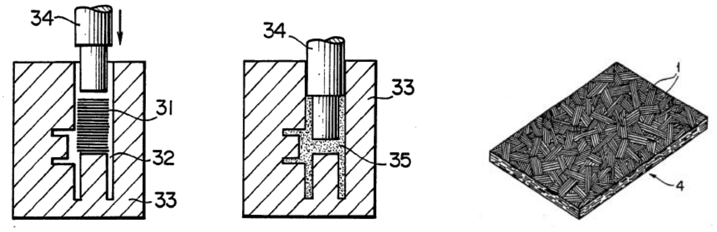


Figure 1 Pictures the Toray patent outlining the moulding process and the discontinuous and random orientation aspect of the finishes part [3].

2. Materials and methods

In the present work, UD tapes (supplied by Suprem SA, Switzerland) consisting of 55 % in volume from AS4 carbon fibres (from Hexcel, US) embedded within PEEK-150 (from Victrex, UK) with width of 6 mm and a thickness of 0.16 mm were slit down to 3 mm and cut transversally to different lengths to obtain chips . A pre-dosed gravimetric quantity of chips is then distributed into the mould cavity. The tool is closed using a vertical hydraulic press and put under cavity pressure of 75 bar at 360°C. After cooling, the produced part is finally ejected from the tool.

Five plates, having dimensions of 200 mm by 350 mm, with a nominal thickness of 3 mm, were produced with different chip lengths. These were 10, 20, 30, 75 and 150 millimetres Polished cross sections and tensile coupons were cut out from the plates using a water cooled disc saw to avoid smearing of the PEEK matrix due to the generated heat. The tensile coupons, having a free length of 150 mm by 25 mm were cut from the central area of the plate to avoid orientation effects from the mould cavity. Tensile tests were conducted on the cut coupons from the produced sample plates with the different compositions of chip size with a universal testing machine at a load rate of 1mm/min and using a 100 mm gage extensometer to measure strain.

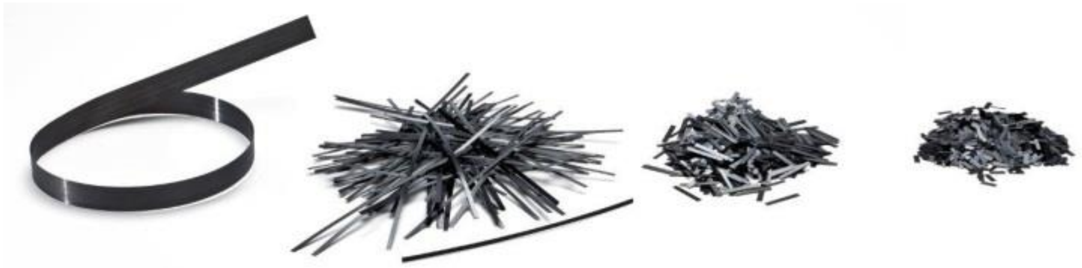


Figure 2 From left to right: unidirectional tape, chips with length 150 mm, 30 mm and 10 mm.

3. Results

The general trend of the data in Figure 3 shows that the mean tensile stiffness increases with chip length. The 10 mm chip was found to have approximately seven intermediate failure events prior to the ultimate failure. After each intermediate failure event, a decrease of the stiffness was noted. Through the progressive failure of the composite, quasi-plasticity of the material was observed. The 20 mm and 30 mm chip lengths were found to have approximately two to three failure events during the tensile tests. Finally, samples produced with 75 mm and 150 mm chip materials displayed a typical linear elastic behaviour until ultimate failure.

The ultimate tensile strength is shown in Figure 4 as a function of chip length. The general trend in the data shows that the ultimate tensile strength increases with chip length. For the samples produced with a 150 mm chip length, all the samples have presented end tab failure, and hence are only included for completeness.

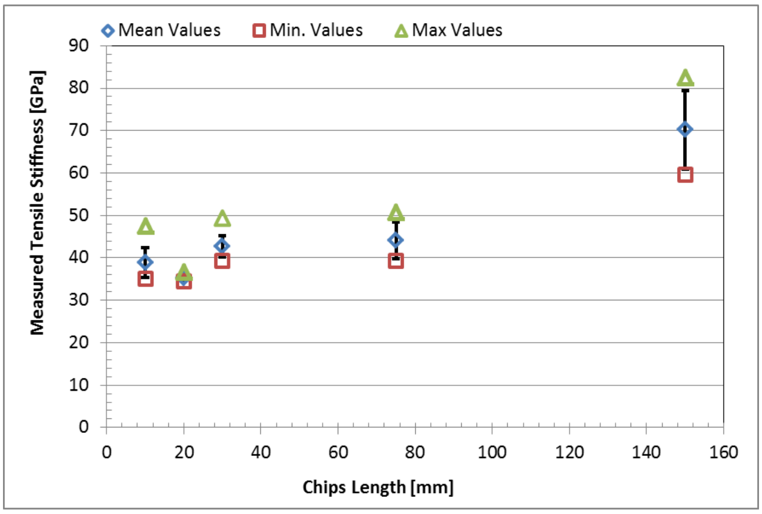


Figure 3 Tensile stiffness as a function of chips length

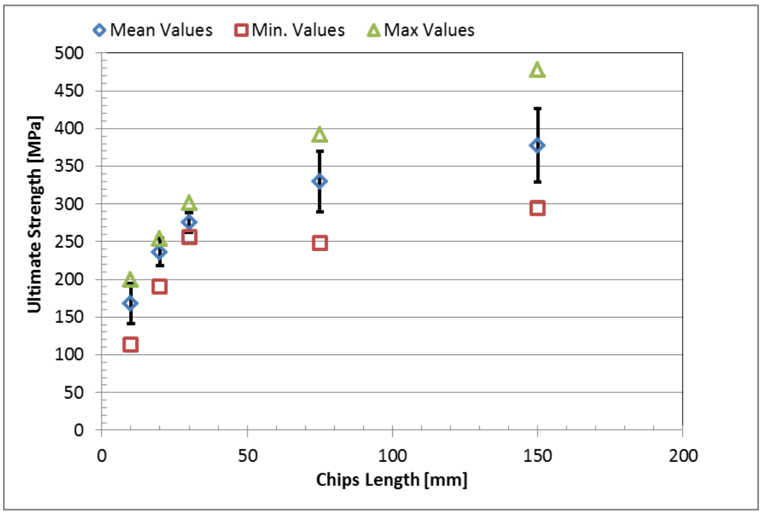


Figure 4 Ultimate strength as a function of chip length

4. Conclusions

The measured mean tensile stiffness may be compared to the results obtained by Feraboli [10] on epoxy based materials as shown in Figure 5. Both experimental studies provide good correlation as would be expected for such a fibre dominant property i.e. similar fibre volume contents and manufacturing processes have been implemented with a matrix material of comparable stiffness. The standard deviation in the mean for each chip length were smaller than those obtained by Feraboli [10]. This can be explained through the test set-up and size effects [11, 12]: The 100 mm extended gauge extensometer used in the present study is less sensitive to local heterogeneities of the material as the 25.4 mm gauge extensometer used by Feraboli [10]. Ionita and Harper [6, 11] also encourage the use of longer gauges to measure the tensile stiffness over the longest possible distance. The thickness, respectively the average number of chips over the thickness of the tested samples has a major influence on the spread of the measured tensile stiffness [6, 10]. Feraboli, by varying the thickness of samples from 2.3 mm to 5.9 mm measured in the mean tensile stiffness Coefficients of Variation (CoV) being reduced from 20 % to 4 %. The samples in this study have a nominal thickness of 3 mm, compared to a nominal thickness of 2 mm. Moreover, a better dispersion may be achieved due to a greater degree of homogenization by a reduction in chip’s cross section dimensions to 0.16 mm thick and 3 mm wide compared to 0.2 mm thick and 8.4 mm wide as previously studied by Feraboli [10].

The ultimate tensile strength was also compared, as shown in Figure 7 as a function of chip length. It can however that the CF/PEEK specimen form this work always yield a higher strength compared to Feraboli's CF/epoxy data.. Pictures from the fractures surface shown in Figure 6 suggests that several mechanisms, as shown in Table 1, contribute simultaneously to the fracture. The intra-chips failure modes are similar to what can be found in the literature concerning the failure modes for continuous fibre reinforced laminates. Whereas the mode *1-a* is mainly to be seen for chips oriented along the longitudinal direction of a tensile tested sample, the mode *1-c* is similarly specific to chips oriented transversally. The mode *1-b* corresponds to all the other chips mainly submitted to a shear deformation with an off-axis orientation. The inter-chip failure mode also matrix driven we could also call chip pull-out, as an analogy to the fibre pull-out. The failure modes *1-b* and *2a* are the most frequent failure modes observed and are matrix dominated.

Based on the hypothesis that the failure of discontinuous materials is matrix dominated, Taketa [13] working on discontinuous oriented UD materials could increase the exhibited tensile strength by 20% by toughening his samples and the epoxy matrix with thermoplastic interlaminar layers. Maekawa [14] has compared longitudinal and transverse properties of UD laminates constituted of AS4 fibres with several types of PEEK and epoxy matrices. The latter were produced using an epoxy matrix with a T_g at 120°C, the other samples having a PEEK matrix. Table 2 shows how UD laminates with PEEK matrix are showing better longitudinal and transverse properties. A direct analogy with the Intra-chip failure modes *1-a* and *1-b* speaks in favour of the PEEK matrix. For shear-properties no direct comparison could be found to make a direct comparison between a PEEK and an epoxy matrix. Carlsson [15] has shown how the Mode II interlaminar fracture toughness for UD laminates is superior with PEEK matrix as with epoxy, this time with the epoxy type CYCOM 982/24 from Cytec. An analogy with the Inter-chip failure modes *2-a* speaks again in favour of PEEK matrix. It is likely, that the increased fracture toughness of the PEEK matrix is partially responsible of this strength increase, compared to Feraboli's data measured with an epoxy matrix.

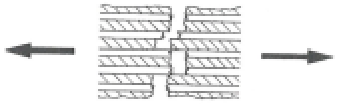
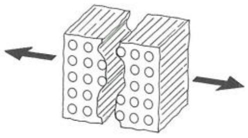
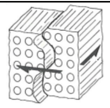
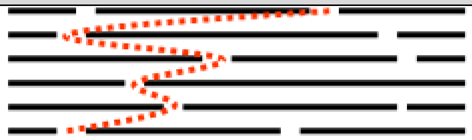
Intra-Chip Failure		
Mode 1-a	Longitudinal fibre failure	
Mode 1-b	Transverse Matrix Failure	
Mode 1-c	Shear Matrix Failure	
Inter-Chip-Failure		
Mode 2-a	Matrix Failure	

Table 1 Failure mode in chopped tapes materials (in parts taken from [16], modified)

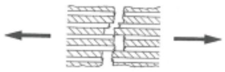
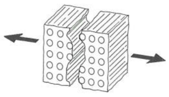
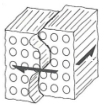
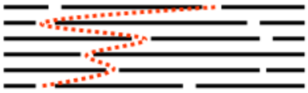
Intra-Chip Failure				
Mode 1-a 	Ref. Maekawa	AS4 Epoxy (T_g120°C)	APC2-AS4 PEEK	Normalised Epoxy/PEEK
	σ_{1t} MPA	2132.6	2253.1	**94%**
	ϵ_{1t} %	1.39	1.55	**89%**
Mode 1-b 	Ref. Maekawa	AS4 Epoxy (T_g120°C)	APC2-AS4 PEEK	Normalised Epoxy/PEEK
	σ_{2t} Mpa	63.4	91.4	**69%**
	ϵ_{2t} %	0.70	1.15	**61%**
Mode 1-c 	Epoxy/PEEK –			
Inter-Chip-Failure				
Mode 2-a 	Ref. Carlsson	AS4 CYCOM 982.24 Epoxy	APC2-AS4 PEEK	Normalised Epoxy/PEEK
	G_{IIC} kJ/m^2	0.77	1.93	**39%**

Table 2 Review of Literature concerning comparison of PEEK and epoxy matrices in UD laminates, data from Maekawa et al. and Carlsson et al. [14, 15]

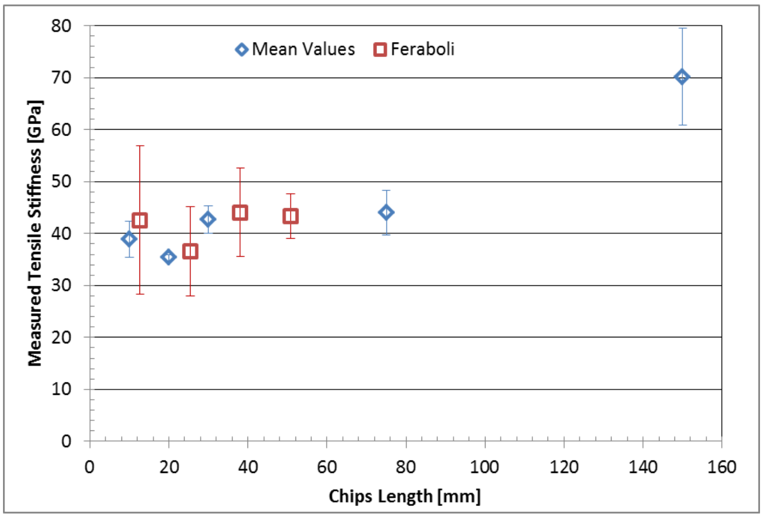


Figure 5 Tensile stiffness with different chips length in comparison to reference [10].

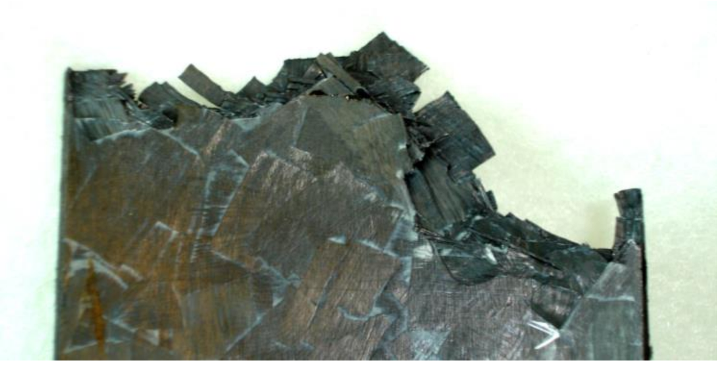


Figure 6 Fractures sample with 10mm chips length, showing intra and inter-chip failure

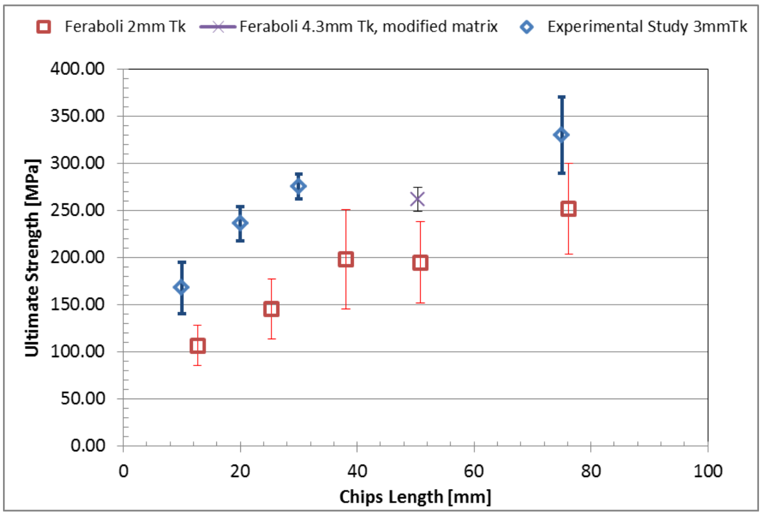


Figure 7 Ultimate with different chips length in comparison to reference [10].

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