SIZE EFFECTS IN RECYCLED THERMOPLASTIC CFRP FROM ELECTRODYNAMIC FRAGMENTATION

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Abstract

Thermoplastic carbon fibre reinforced polymers (CFRP) have a potential for recycling by re-melting the polymeric matrix. The authors choose a novel approach to separate thermoplastic CFRPs into fragments using high voltage pulses through a method known as electrodynamic fragmentation (EDF). The method was applied to a rotorcraft door hinge which was compression moulded from unidirectional chopped tapes of 20 mm length (PEEK/AS4 55 Vol%). The specimens made with chopped tapes were subsequently dissociated in a high voltage fragmentation lab unit. The ultimate load of the door hinges made with recycled thermoplastic composites were comparable to the ones made from virgin chopped tapes with a reduction of 17% of the maximal strength [1]. It was observed that smaller fragments considerably reduce the statistical variations of strength while lowering the mean value to a limited extend only.

1. Introduction

Currently over 2000 aircrafts are in graveyards and over 5000 commercial airliners will be withdrawn from service in the next 20 years. The increase of disposal costs and the end-of-life (EoL) regulations push the manufacturers towards more efficient solutions for the EoL of their aircrafts. In addition, the new aircraft generation contains more than 50wt% of high performance composite materials which increases their fuel efficiency and comfort, but also brings new challenges concerning their recycling compared to traditional metallic structures.

For thermoset CFRP considerable effort is being made to recover the carbon fibres [2] by removing the thermoset polymer by means of mainly thermal pyrolysis processes [3]. The recovery rate is thus limited to less than 50 percentage in volume (vol%), and the resulting recovered carbon fibres are often short in length with reduced quality and mechanical properties which consequently limit their applications and their economic value. Even if new methods are being developed with the aims of reducing the energy consumption of CFRP recycling, a direct re-use of the recycled material to produce new parts is still not possible. In contrast to CFRPs with a thermoset matrix, thermoplastic composites have better perspective of recyclability with theoretical recovery rates up to 100%. Indeed thermoplastic polymers can be re-manufactured through reversible thermal processes while the curing process of thermoset polymers is considered as non-reversible. The thermoplastic CFRP parts have to be grinded down to small fragments prior reprocessing. While fragmenting aerospace CFRPs, the main problem comes from the high content of carbon fibres which dramatically damaged the shredder blades [4]. Furthermore, important amounts of harmful carbon powder are produced. Given that no solution was proposed in the industry to grind down efficiently high performance thermoplastic

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CFRPs, the authors choose a novel approach to separate TPC into its constituents without tool wear using high voltage pulses through a technology known as electrodynamic fragmentation (EDF).

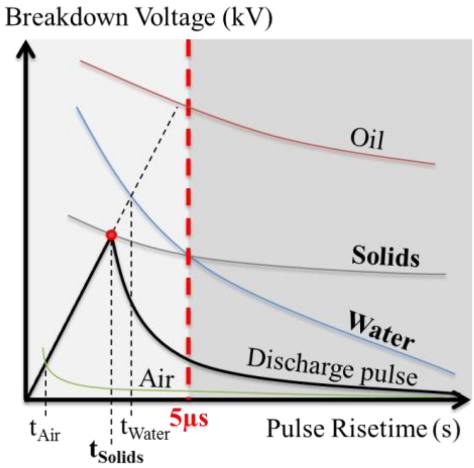

Figure 1. Breakdown voltage as a function of the pulse rising time. Solids have breakdown voltages lower than water below rising time of 5µs.

Electrodynamical fragmentation was first used in the early 60's by The Tomsk Polytechnic University in Russia [5]. The main application of this method was initially to disintegrate rocks in the mining industry in order to extract crystals and precious stones without aggressive and polluting chemical procedures, by applying electrical discharge through the specimen. The material is placed in water between two electrodes and high voltages between 50 and 200kV are applied. The voltage must be higher than the actual breakdown voltage of the material to be fragmented, but lower than the surrounding medium (usually water). This is achieved by reducing the pulse rise time below 5 µs for solid material in water using a Marx generator as described in the Figure 1. The electrical discharge brings a high energy (10 to 100 J/cm) creating a plasma channel in the solid. This strong energy induces temperatures and pressures up to 10'000°C and 10^4 MPa which create pressure waves exceeding the strength of most materials and leading to the cracking of the weakest materials surrounding the plasma channel. The best fragmentation results are obtained with brittle and heterogeneous materials. The electrical discharges are also attracted toward inclusions with higher permittivity and then follow its boundary, separating it from the rest. Furthermore, stress concentration mainly from material inhomogeneities and internal boundaries also attract the discharges. The separation of polymer materials is more challenging especially with those having high fracture toughness.

The aim of this work was to demonstrate the applicability of EDF to thermoplastic CFRP, with particular interest in understanding the effect of fragment size on the mechanical properties.

2. Materials and Methods

The thermoplastic matrix selected in this study was a polyether-ether-ketone (PEEK) from VICTREX®. The CFRP was supplied in unidirectional directional (UD) 55 vol% AS4 high modulus carbon fibres (Hexcel) pre-impregnated and chopped into 20 mm long “chips” by SUPREM AG, Switzerland. These chopped tapes where compression moulded using a non-isothermal process. The raw material was dropped into the tool cavity and then pressed using a vertical hydraulic press (Schwabenthan 200T, Germany) with 20 tons clamping force and heated up at 360°C. The parts were finally cooled at a rate of 20°C/min and ejected from the cavity. The authors [6] already performed a complete study investigating the influence of the process parameters, the size and type of material used. The weight of the CFRP door-hinge was only 22 g, compared to 134 g of the initial door hinge made of steel representing a weight reduction of 83%.

Figure 2. Compression molded door hinge demonstrator used for this study, the part on the laft is made from chopped tapes, tha part on the right is made from recycled fragments

The EDF equipment was a lab-scaled unit, Selfrag Lab manufactured by Selfrag AG, Switzerland. The fragmentation was operated in a 3 to 4 litres water closed vessel. For a single door hinge, 6 cycles of 100 pulses each with an applied discharge voltage of 180kV at a frequency of 5Hz were sufficient. Between each cycles the content of the vessel was filtered using at first a metallic sieving grid having a mesh interspace of 4mm, fragments passing through were separated, whereas the rest was returned for further fragmentation. Finally the smallest fragments and the carbon powder generated were separated with a sieving grid having 1mm interspaces and a filter with mesh around 15µm. The recovered fragments were subjected to the same compression moulding cycle with identical processing condition as used before to make a door hinge composed of 100% of recycled material.

The door hinges were subjected to a static load up to failure, fractography was carried out via scanning electron microscopy.

3. Results and discussion

The ultimate failure load, shown in Table 1, of the door hinges made with recycled thermoplastic composites were comparable to the ones made with virgin chopped tapes with a reduction of only 17% of the maximal strength. The decrease of mechanical properties is attributed to two reasons: the fragments coming from fragmentation process are shorter than the original ones, and the discharge led to a localized pyrolysis of the polymer at the surface of the fragments, similar to observations made in lighting strike experiments on CFRP [7]. This results in a decrease of adhesion between fragments in the final part.

Table 1. Mechanical properties of composite door hinges

Specimen (door hinge)Type	*Fibre length (mm)*	*Ultimate Load* (kN)	*Standard deviation (kN)*
20mm chopped tapes	20	4.15	± 0.94
Recycled fragments	< 20	3.46	± 0.29

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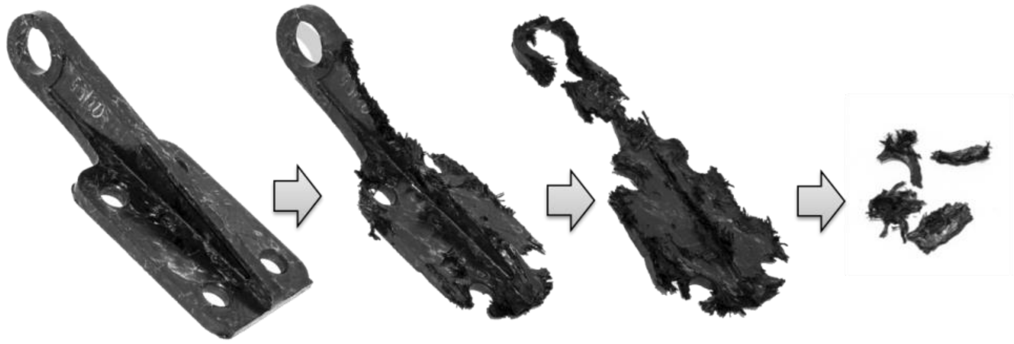

Figure 3. Evidence of fragmentation with increasing number of pulses

5. Conclusion

In this report, the recycling feasibility of high contents carbon fibre reinforced thermoplastic parts is demonstrated without the typical tool wear known from shredders. Door hinges were successfully produced with 100% of recycled materials using the same compression moulding unit as for the original hinges and without any post processing applied on the fragments between the recycling and the re-processing and with a reduction of only 17% of the mechanical performance compared to novel chopped tapes door hinges. After fracture analysis, it has been clearly demonstrated that this reduction of mechanical performance came from smaller fragments and from a partial reduction of polymer coverage on the fragment surface due to thermal pyrolysis reducing the fibre/matrix adhesion and load transfers [1]. It was observed that smaller fragments have a positive effect on the the statistical variations of strength while lowering the mean value to a limited extend only.

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