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Preliminary Study of CFRP Manufacturing Offcuts with Ssecondary Resin Impregnation via Hand Lay Up

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Abstract- Carbon fibre reinforced polymer (CFRP) composites have been extensively used because of their excellent performance and lightweight. Due to its widespread use, manufacturing scrap and end-of-life prepregs is constantly generated. Investigation into the potential of CFRP reclamation by second impregnation process via hand lay-up was performed. It is focusing on the effects of number of layers (2, 4, 6 and 8 layers) to the physical and mechanical properties of laminated secondary impregnated Carbon Fibre Prepreg/Epoxy (i-CFPE) composites. It was then compared with laminated Carbon Fibre Prepreg composites without second impregnation (w-CFP). Samples were tested under tension, flexural and impact. Mechanical properties of i-CFPE increased with the increase of laminates layer in the composites. Furthermore, i-CFPE laminated composites showed better performances if compared to the w-CFP.

Keywords: composite recycling, CFRP, impregnation, hand lay-up

I. INTRODUCTION

Carbon fibre has seen exponential growth in usage in a wide array of application. With the advent of regulatory directives such as The End-of-Life Vehicle Directive (Directive 2000/53/EC) and EU Directive on Landfill of Waste (Directive 99/31/EC), proper waste management of carbon fibre are currently being studied extensively[1].

A more economical approach of recycling CFRP is to through mechanical recycling such as cutting and shredding CFRP and using it as reinforcements or fillers for later applications[2, 3]. The challenge of using the CFRP wastes for other value added applications worthy of its own expensive source value are now leading researchers for carbon fibre extraction[4, 5].

Carbon fibres could come from various sources. Whether cured or uncured, most of the recent studies is trying to extract as pure as possible the carbon fibres [1, 6, 7]. Removing unwanted fillers, reinforcements and additives could in future promise a whole new range as well as reinforcing current applications for recycled carbon fibres.

This paper introduces initial results of recycling manufacturing offcuts of carbon fibre prepregs from a local composite manufacturing company by hand lay up with epoxy resin and its mechanical properties.

II. METHODOLOGY

Manufacturing offcuts of carbon fibre prepregs were collected from a local composite manufacturing company and still had up to 90 hours of preimpregnated resin outlife (Fig. 1). The company's name and trade name of the carbon fibre prepregs could not be disclosed due to sensitivity of its operations and the material's export license.

Afterwards the carbon fibre prepregs were then cut into approximately 2' by 2' (600mm x 600mm) sheets. Due to limited supply of manufacturing offcuts, 20 sheets were reserved to be laid up with commercially available epoxy resin while 10 sheets were hot pressed without adding any resin. The first 20 sheets were sorted for 2, 4, 6 and 8 layers and later hand lay up with epoxy resin. Vacuum bagging was later applied on different layers to ensure removal of entrapped air and removing excess resin. The second 10 sheets were sorted into 4 and 6 layers, later hot pressed using a Gotech (GT 7014-A) compression moulding machine for 5 minutes at 180°C.

Tensile testing was performed in accordance with the ASTM D3039, with 6 samples for each set of layered composites. For testing, a universal testing machine with constant cross-speed of 2mm/min was used. The tensile strength, percent elongation and modulus of elasticity were calculated in accordance to ASTM D3039.

Flexural testing were carried out in accordance to ASTM D790 (3-point loading) using six specimens (80 × 10 × 4 mm) for each set of layered composites. The tests were performed on the Universal Testing Machine at a constant cross-speed of 2.5 mm/min.

Fig. 4. Carbon Fibre Prepreg Manufacturing Offcuts

Water absorption was done in accordance to ASTM D570-98. Samples for measuring water absorption were prepared in the form of bar with dimensions of 76.2mm x 25.4mm x thickness of layered composites (W x L x t). The samples were immersed in distilled water maintained at a temperature in the container. The water absorption determination was based on Equation 1:

$$\%wf = [(Ww - Wc) / Wc] \times 100 \quad (1)$$

Scanning electron microscope was done on each of the samples to study the morphology.

III. RESULTS AND DISCUSSIONS

Fig. 2 shows the tensile strength of all tested laminates. From the result, it can be seen that i-CFPE showed higher tensile strength as compared to w-CFP. This supports the argument that the resin acts to distribute an applied load uniformly to the reinforcing fibers [8, 9]. Furthermore, with increasing fibers, the specific strength of the composite is also increased [10]. Comparing properties of the same layer of composite, the addition of resin have contributed to increasing the tensile strength of the laminate. For 2 layers, the tensile strength value is 23.44 MPa with secondary resin impregnation when compared to 17.46 MPa of the same layer without secondary resin impregnation. This translates to 11.72MPa per layer. Comparing with its stated tensile strength of 50 MPa according to its product specification sheet [3, 11], one layer of recycled manufacturing offcuts could only produce up to 20% of its initial tensile property which is a reduction of 80% tensile strength. This is further reduction than expected from literature, which put the use of recyclates to reduce the mechanical properties of 50% when compared to virgin material [12]. A good interfacial bonding between fibre and matrix has been discussed as important to contributing the composite's mechanical property [13]. Recyclates tend to absorb more resin [7, 8], therefore further reducing its specific strength. However, the advantage is that these carbon recyclates have lower density than other type of fillers such as calcium carbonate or glass.

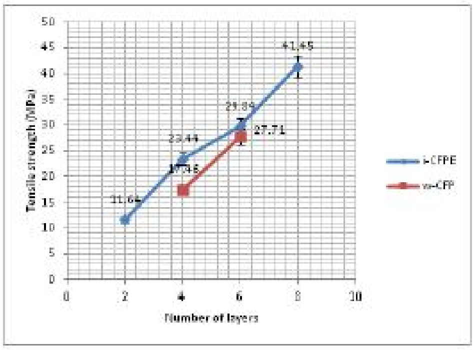


Fig. 2. Tensile strength of i-CFPE and w-CFP laminated composite at different number of layer.

Fig. 3 shows the flexural strength result for i-CFPE and w-CFP laminated composite. The flexural strength result of the i-CFPE laminated composite decreased with fibre contents and it was significantly higher than corresponding to without second impregnated carbon fibre prepreg obtained in experiment. This is due to increasing layer, stiffness of the samples increased but what interesting to note was that the difference of value between secondary impregnation i-CFPE with without secondary impregnation w-CFP. The same 2 layers of i-CFPE could only produce 119.83 MPa, only 42% of the corresponding 2 layers of w-CFP of 282.02 MPa. This is in agreement with literature [7, 8, 14]. Lowering the amount of resin and visible voids improves the flexural property [14].

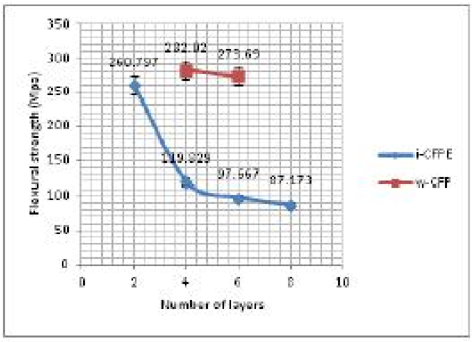


Fig. 3. Flexural strength of i-CFPE and w-CFP at different number of layer.

The plot of Charpy impact strength in Fig. 4 for i-CFPE and w-CFP laminated composite had shown the increasing trend of impact strength with different number of layers. From the Table 1, the Charpy impact strength was found be increasing with increasing number of layers. Fibres addition helps with impact energy absorption [15, 16].

The fibres can also give rise to high strength due to following mechanisms of dissipation of energy. Fibres may pull out of the matrix and dissipate the energy by mechanical friction [15]. From the study, it clearly shows that the impact strength increase as fibre content increasing. This statement was strongly supported [17] which found that, the higher amount of fibre provides high adsorption surface energies for the formation of the spot of failure sites, which later requires comparatively less energy to initiate a crack.

Table 1. Charpy impact properties of i-CFPE and w-CFP laminated composite.

Number of layer		Impact Strength, J/mm^2
With Second impregnation Carbon fibre/Epoxy laminated composite (i-CFPE)	2 layer	116913
	4 layer	146552
	6 layer	175377
	8 layer	178748
Without Second impregnation Carbon fibre/Epoxy laminated composite (w-CFP)	4 layer	114333
	6 layer	148686

Water absorption curve was illustrated in Fig. 5 where the percentage of water absorption was plotted against time for all samples. The plotted graphs showed maximum amount of water absorption in the first day of exposure to the all samples. Then, it slightly decreased with time reaching a certain value at saturation point where no more water was absorbed and the composites water content remained constant. This may due to the ability of epoxy resin to limit the absorption of water flow into the carbon fibre/epoxy laminated composite (i-CFPE) since the epoxy resin matrix has a water-resistance nature. This is one of the reason epoxy resins are the most widely used resins in high performance composite structures these days. According to Choi et al. (2000) [11], the absorbed water molecules in polymer composite materials are known to have significant effects on their physical and chemical properties of matrix as well as on their final performance of composite structures especially in their long term utilization.

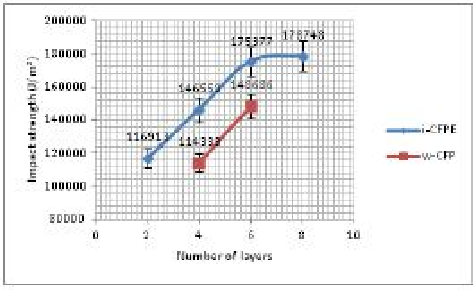


Fig. 4. Impact strength of i-CFPE and w-CFP at different number of layer.

The morphology of the i-CFPE and w-CFP laminated composite were observed under SEM to investigate the interfacial bonding and the interaction between the epoxy resins with the fibres. Micrographs in Fig. 6 (a, b) showed comparison of the fractured surface of the i-CFPE and w-CFP laminated composite. From the figure, it clearly shows the i-CFPE surface was fully and better covered by epoxy resin which further indicates presence of strong interfacial adhesion and good wettability between the fibre and matrix compared to w-CFP. These interactions tend to lower the interfacial tension between the matrix and its fibres making i-CFPE more compatible.

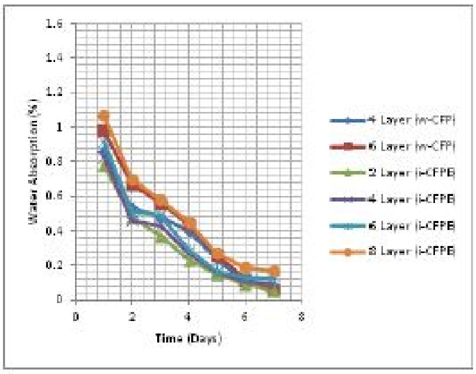
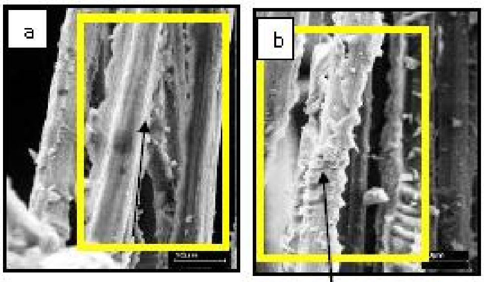


Fig. 5. Water absorption characteristic of i-CFPE and w-CFP at different number of layer within 7 days of immersion.

As conformed by tensile test results which indicating improvement in tensile strength of i-CFPE compared to w-CFP (Fig. 2), this morphological condition revealed formed of good initial strength to the matrix used. Besides that, it can clearly be seen the morphology of the laminate composites of both has rough surface. This further proved the phenomena of brittle fracture of fibre and matrix. Thus the overall morphology for both i-

CFPE and w-CFP sample indicates the brittle fracture behaviour.

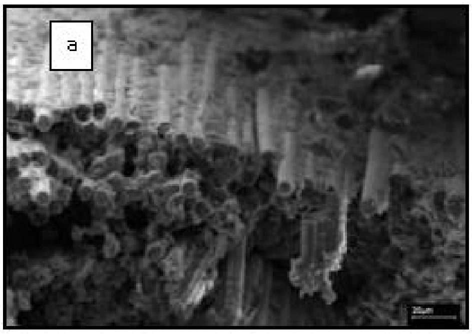


Indication of poor wettability between matrix and fibre

Indication of good wettability between matrix and fibre

Fig. 6. SEM micrograph of fractured surface of the (a) 4 layer w-CFP and (b) 4 layer i-CFPE laminated composite sample indicating fibre and epoxy resin wettability.

It is generally agreed that the pull-out work of fibres or several cracks provides the main source of toughness or energy absorption capacity of carbon fibre laminate composites. The energy absorption capability of a composite is attributed through two basic mechanisms which material deformation and the formation of new surfaces by cracking. The material deformation occurs first. If the energy supplied is large enough, a crack may initiate and propagate, thus actuating the second energy-absorbing mechanism. Fibre pull-out and fibre breakage are example of this energy absorption mechanism. The fibre pull-out process involves, first, a debonding action which provides an alternative path for the crack to follow and second the formation of a new surface at the fibre-matrix interface. Moreover, the fibre deformation and compliance during pull-out contributes directly to the total deformation of the composite. These types of mechanism can be seen in Fig. 7(a-c).



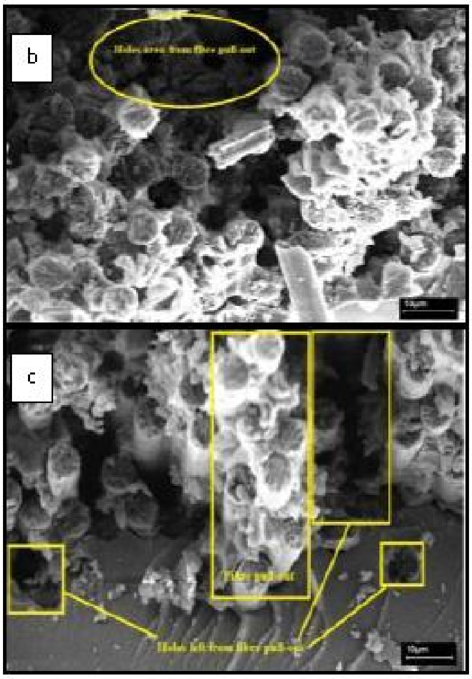


Fig. 7. a) Fibres breakage and homogenous stage of fibre fracture b) Surface topography of a typical brittle composite fracture c) Fibres pull-out from the matrix presenting holes on the fracture surface.

IV. CONCLUSIONS

In this study, mechanical properties particularly for tensile, flexural and impact properties of with second impregnation (i-CFPE) and without second imprengnation (w-CFP) laminated composites are described. On the basis of the experimental evidence, the conclusions are as follows: tensile and impact test of laminated composites with second impregnation have showed improvement compared to without second impregnation. Both results favoured an increased values as increasing number of layers and this behaviour is attributed to the compatabiliy of fibre-matrix bonding and interfacial anchorage. In flexural test, the results showed decreasing with increasing number of layers may due to weak bonding interface between the laminated composite plies and difficulty for the matrix to penetrate the hole of fibre when the fibre was almost cured. The percentage of water absorption was decreasing with increasing number of layers. According to scanning electron microscopy observation it is verified that presence of good wettability within carbon fibre and epoxy resin.

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