MECHANICAL PROPERTIES OF WET-LAID NONWOVEN MAT RECLAIMED CARBON FIBRE IN POLYMER COMPOSITE

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ABSTRACT: Reclaimed carbon fiber (rCF) has been produced on an industrial scale, especially nonwoven mat form. The nonwoven mat, however, required a large amount of waste and the process parameter as opposed to the lab-scale production. In this project, the nonwoven mat rCF in the lab-scale was prepared using a wet-laid method adapted from the papermaking technique before the physical properties of the mats been measured and observed via drapability and optical microscopy, respectively. The rCF mat was impregnated and molded with epoxy to produce composite at different plies of mats using a vacuum infusion process. Their mechanical properties were examined under flexural and impact tests. The scanning electron microscope used to elucidate and validate the morphological properties of the composite. Result data showed that the composite with higher rCF ply content have higher flexural and impact strength, with the maximum being a flexural strength of 51.26 MPa and impact strength of approximately 20.41 kJ/mm^2 with 3 plies nonwoven rCF mat. Morphological obtained from the failure mode showed a behavior of debonding and pulling out mode indicated a correlation impregnation between the rCF mat and epoxy. Hence, these findings conclude the fundamental of fabrication rCF mat in lab-scale showed there was a significant variation in mechanical properties at different plies and considered as a potential for alternative materials in composite applications.

KEYWORDS: *Reclaimed Carbon Fibre; Nonwoven Mat; Wet-Laid; Flexural Behaviour; Fractography*

1.0 INTRODUCTION

Synthetic waste material has been commercialized a variety of form reinforcement in polymer composite since the waste industrial increased especially waste carbon fibre [1]. Most of the waste carbon fibre is from cut-offs pre-pregs during the kitting process and end-life pre-pregs [2]. These pre-pregs have been recycled and processed using several methods including pyrolysis to convert it into reclaimed carbon fibre for secondary applications. The secondary applications such as non-structure automotive parts were also can be characterized by their overall performance by a selection of shape reinforcement.

The manufacturing of reclaimed carbon fibre (rCF) has been increased due to the awareness in the green environment [2]; economical, promising in strength properties, corrosion resistance as well as the adaptability as reinforcement in composite fabrication [3]. Moreover, the usage of rCF as reinforcement in the polymer matrix has attracted researchers to study on the mechanical properties for the automotive industry [4-6]. The automotive parts mostly require a suitable shape of reinforcement. Nonwoven mat consisting of short and randomly oriented fibres were selected because of the ease in production. However, the non-homogeneity of the fibres especially for the rCFs which have random sizes and low-density-packing is a commonly perceived problem since the rCF processed is in chopped [2]. In order to incorporate chopped reclaimed fibres into specific processing, the wet-laid process was introduced to ensure the fibres segregated into a homogeneous form suitable for handling in a composite environment. The reason for applying the wet-lay process is to distribute the fibres is as to simplify the fabrication route and economical.

The previous study done on the natural fibre [5-6] had shown that reinforcement produced from this method reduced the irregularities of the preform by averaging the irregularities between the layers and produced fewer voids composites. However, as a ply form, the wet-lay mat was fragile which contributed to a lack of processability. Besides, there is still a lack of information on optimization on layers to produce more uniform reinforcement and easy to conform onto the tooling surface during manufacturing as well as regarding increasing fibre content, controlled fibre damaged during processing and application external forces during the wet-laid [7]. A few of literatures concerning the development reinforcement from rCF in the lab-scale process as much as for natural fibre or combination of hybrid rCF [8-10]. This is due to the reinforcement produced from rCF that has been developed on a commercial scale to meet high demands from industries. Moreover, lack of optimization of feasibility between the properties in terms of the distribution of fibre, thickness, fibre volume fraction and parameter of the process involved as in [1] still need to be measured. Thus, the present study is focused on the investigation of rCF reinforcement prepared in lab-scale in polymer matric (rCFRP) and comparison of the performance with virgin carbon fibre composite (vCFRP) is supported by morphology behavior after tested using flexural and impact test.

2.0 METHODOLOGY

The nonwoven reclaimed carbon fibre (rCF) mat was fabricated by a wet-laid method adapted from the papermaking technique using the waste from the industry. The waste industry mainly from uncured prepregs carbon fbre that has been reclaimed via the thermal pyrolysis process. The rCF was chopped into a short fibre of 2 mm with a diameter of approximately 6-8μm. The chopped fibres were introduced with 68% of nitric acid and heated at 115°C for 40 minutes to unsized the rCF. Afterward, the rCF was cleaned under ethanol, rinsed with distilled water, filtered before dried in the drying oven at a temperature of 50°C for 30 minutes. rCFs of 2.4 g in weight were dispersed in 1 liter of solution which contains distilled water and polyvinyl alcohol (PVA) as binder agent before drained and filtered onto the net with the dimension of length, width and thickness are 120 mm, 60 mm, and 3 mm, respectively. The nonwoven mats were taken out and dried in the drying oven at room temperature for 24 hr. The physical observation of drapability, density, and distribution of rCF was recorded. The mat was undergone a drapability testing through Equation (1) of the drape coefficient between the rCF with chemical treatment and virgin carbon fibre [11].

$$DC\% = \frac{w_2}{w_1} \times 100 \tag{1}$$

where DC is a drape coefficient; W_1 is a weight of the mats of the drape shadow and W_2 is a weight of the area of the full annular ring.

The rCF non-woven mats were impregnated with epoxy (Sigma-Aldrich) to produce reclaimed carbon fibre reinforced polymer (rCFRP) composite using a vacuum bagging process (Model Vacmobile 20/2). This sample was compared to vCFRP (virgin carbon fibre) as listed in Table 1. Each of the plies was weighted for approximately 10wt% to get a thickness of 2 mm. Three samples of rCFRPs and vCFRPs for each group of plies were subjected to mechanical tests under three-point bending (Shimadzu 3300 Series) and impact test (Impact Tester QC-639C). The flexural and impact analyses were conducted according to ASTM Standard D 790 and ISO Standard 180, respectively. The samples tested from the flexural and impact tests were sputtered with gold for fractography observation. All the samples were observed at a magnification of 100 X, 300 X and 500 X under the scanning electron microscope (Model: EVO 50 Carl Zeiss SMT) to correlate the inclusion of nonwoven mat prepared in lab-scale with the performance of the composite.

Table 1: Number of ply for each sample of rCFRP

Code	Ply	
rCFRP	2 plies	3 plies
vCFRP	2 plies	3 plies

3.0 RESULTS AND DISCUSSION

3.1 Physical Properties of Nonwowen Mat

The drapability of samples was tested after dried in the oven. Drape coefficient referring to the weight of the mat of the drape shadow which denoted as a percentage and it reflects the level of stiffness with the drape coefficient increased [11]. The treated reclaimed carbon fibre (rCF) shows a lower drape coefficient as opposed to the virgin carbon fibre (vCF) to be 0.59 and 3.75, respectively. This may be caused by the selection of the amount concentration of PVA which can usually be suppressed due to the viscosity PVA slightly higher for this rCF wt% used. Moreover, the flow rCF in the solution during wet-laid was not smooth ascribed to agglomeration fibres and manual controlled which attributes irregularity in distribution of thickness rCF deposited on to the mesh screen. Figures 1(a) and 1(b) illustrate the conditions of rCF as 'fluffy' and mat after the dried by visual inspection.

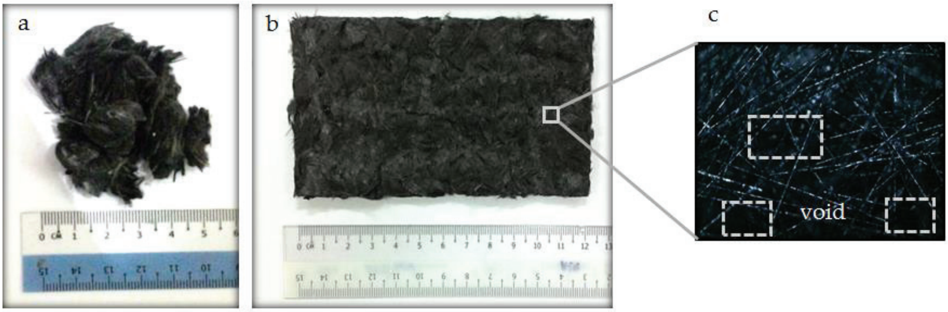

Figure 1: The rCF nonwoven mat after wet-laid process of (a) fluffy rCF, (b) nonwoven mat and (c) micrograph of rCF distribution via optical microscopy

It can be seen in Figure 1(c) the distribution of rCFs was observed via optical microscope appearing rCFs processed using the system of wet-laid had dispersed loosely. Moreover, the void has appeared in few areas and visible porous were observed as well as the rCF distribution was weak which similar to relevant literature [6, 10]. The rCFs were deposited manually without external forces to ensure the rCF well dispersed. Work by Yu et al. [5] has shown that the frictional force was applied to aid the fibre mats held together without using a binder.

3.2 Mechanical Properties of Reclaimed Carbon Fibre Reinforced Polymer (rCFRP)

Flexural strength and flexural modulus were presented in Table 2. Overall, the number of plies increased, the ability of the composite to withstand the load was increased as ascribed by the stiffness of the plies. The stiffness shown by flexural modulus exhibited slightly different between the rCFRP and vCFRP approximately 18% for 2 plies and 3 plies. It deduced that the inclusion of the CF regardless of the condition of fibre, the role fibre remain acts as a load carrier in the composite [7].

Table 2: Flexural properties of rCFRP and vCFRP

Sample	2 plies		3 plies	
	vCFRP	rCFRP	vCFRP	rCFRP
Flexural Modulus (MPa)	2.13	2.58	95.54	119.21
Standard deviation	0.16	0.09	0.73	0.72
Flexural Strength (MPa)	11.08	6.66	51.59	51.26
Standard deviation	0.16	0.09	0.73	0.72

In contrast, the comparison flexural strength between rCFRP and virgin carbon fibre reinforced polymer (vCFRP) as a function of rCF ply was displayed in Figure 2. It was found that the highest average was vCFRP for 2 plies and 3 plies with 11.08 MPa and 51.59 MPa, respectively. The differences were represented by 24.9 %. This similar trend also seen in sample 3 plies of vCF applied in epoxy and contributed the strength accumulated to 0.3%. These results were lower as compared to the [10] where the value of the differences volume % significantly change the flexural behavior. This can be explained by the fact that the preparation of the sample composite for rCFRP and vCFRP confront a challenge due to the flowability of the resin during the vacuum infusion process (Figure 3). The arrow showed the flow of the resin was not smooth because of the consistency of epoxy used was too viscous. This has caused the rCF and vCF were not well impregnated and can be attributed to that the resistances of the resin to consolidated uniformly. The results for the notched Izod impact test are given in Figure 4. The results revealed that vCFRP has a high impact strength than rCFRP. The sample rCFRP with 2 plies gave the impact strength of 10.87 kJ/mm² while vCFRP slightly higher with 13.16 kJ/mm².

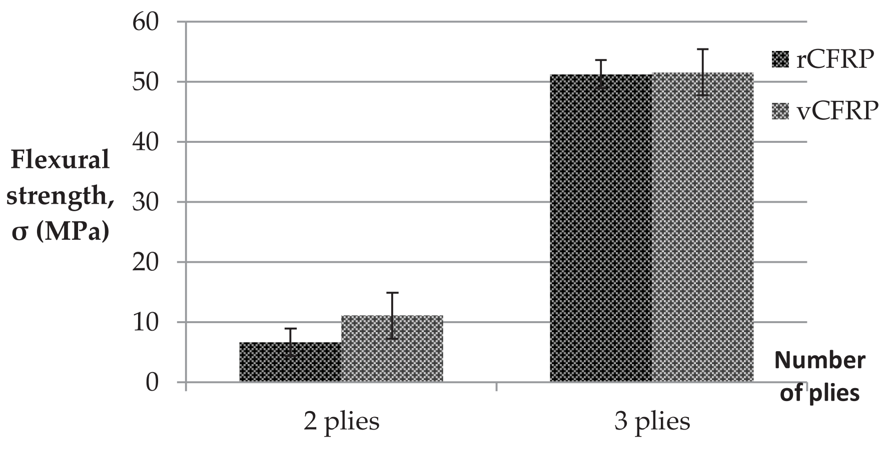

Figure 2: Flexural strength for sample rCFRP and vCFRP

Meanwhile, the vCFRP that consists of 3 plies contributed impact strength of 28.57 kJ/mm² and rCFRP with the same plies had 20.41 kJ/mm² which deduced that the vCFRP have the ability to absorb more forces compared to the rCFRP. Moreover, the number of plies that represent the content of carbon fibre was expected to improve the ability composite to absorb more energy as well as toughness before failure. This finding was supported by Rahmani et al. [12] showed with the different number of laminates and fibre orientation influence the impact behavior of composites. Figure 4 fibre orientation influence the impact behavior of composites. Figure 4 also displays an example of certain features at the fractured area of rCFRP and vCFRP observed by the naked eye. This indicates that these composites break at contrary stresses which represented in the dotted line. The features propagation of crack was seen along the center of the composite. Moreover, the failure path shows rCF fail randomly within the epoxy (Figure 4). Moreover, the rCF alignment plays a crucial role where Figure 1(c) shows that the fibres were not uniformly distributed and as compared to their commercial counterpart, vCF which expected well distributed. Tse et al. [10] recommended that the poor in consolidation fibre caused the void which directly influences the final performance composites.

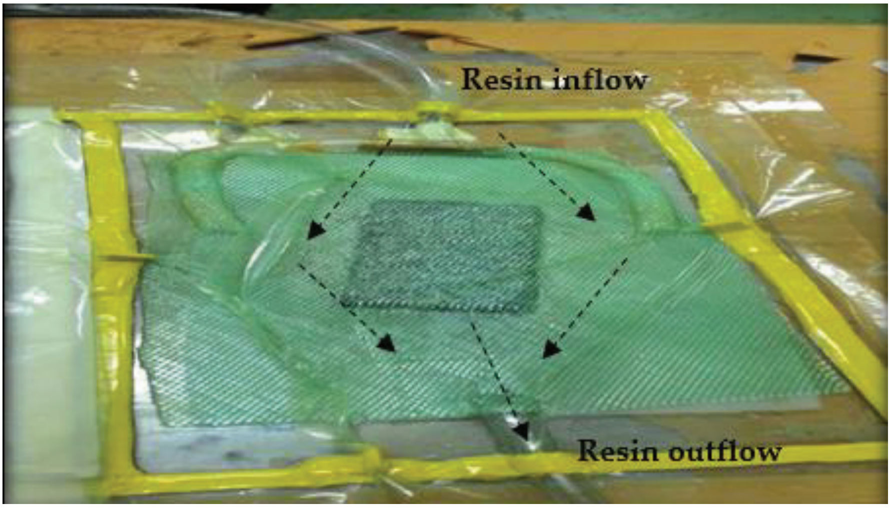

Figure 3: The flowability of resin from inlet to outlet of vacuum infusion process

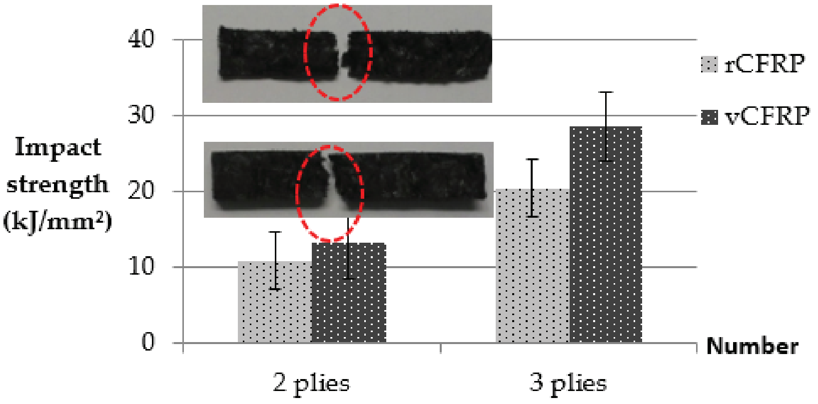

Figure 4: Izod impact strength of rCFRP and vCFRP for different ply with features of fracture after tested

3.3 Fractography Analysis of rCFRP and vCFRP

The composite prepared from vacuum infusion showed were debonding behavior and fibre pull-out. Many pores are randomly formed one place to another place. The microstructure of nonwoven mat composite changed depends on the plies and testing. Figures 5 (a) and (b) show the flexural behavior reflects low value where the presence of void and surface porosity induce the propagation of crack which identified as a peak point of stresses. The fibre breakage and fibre pull-out were clearly observed which is similar findings from Tse et al. [10], the rCF fibres were not fully coated with matrix and debonding within area crack and revealed that the adhesion rCF onto the matrix was not good.

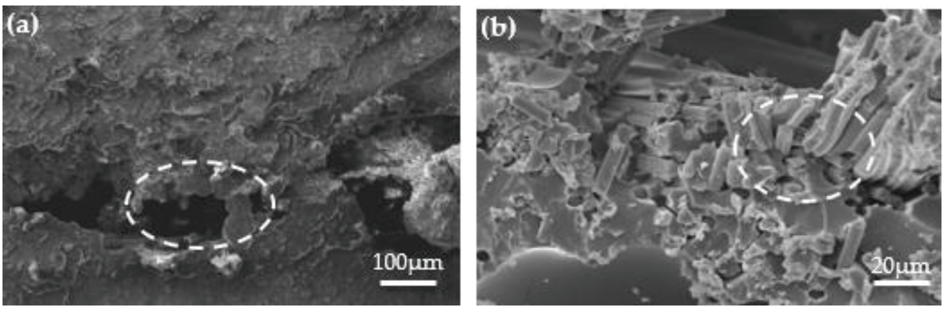

Figure 5: (a) The propagation of crack and (b) rCF breakage

As the plies increased, the high load was applied and crack propagated throughout the matrix (Figure 6(a)). This contributed to the value of average strength greater than the sample with 2 plies. The differences in value can be correlated with interface strength was weak. Moreover, the load absorbed by the matrix to the fibres was not smooth. Therefore, an early failure was expected to be initiated and caused flexural strength decreased [10]. Figure 6(b) represents epoxy is not fully consolidated the rCF which causes the impact properties to decrease. As the impact imposed onto the sample directly area lack of epoxy, trigger the initial failure where fibre breakage was visible. A study by Tse et al. [10] found that once the fibres were not aligned in the direction it can expedite the failure.

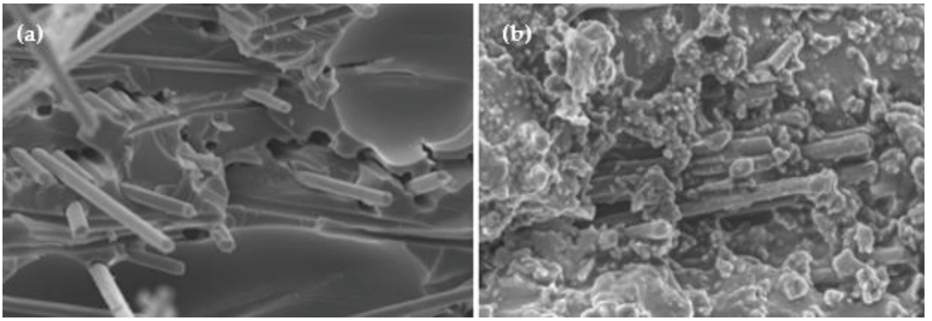

Figure 6: (a) The fibres pull-out and breakage while (b) rCF appeared when not fully coated by epoxy

The 3 plies rCF were laminated and showed the fibre pull-out and certain area with breakage of rCF (Figures 7 (a)-(b)). Crack was propagating across the cross section of the sample at high impact load. The number of plies and the alignment of fibre alignment have contributed to this failure mode which supported by Rahmani et al. [12], summarized that these two factors significantly affect the impact behavior of composites.

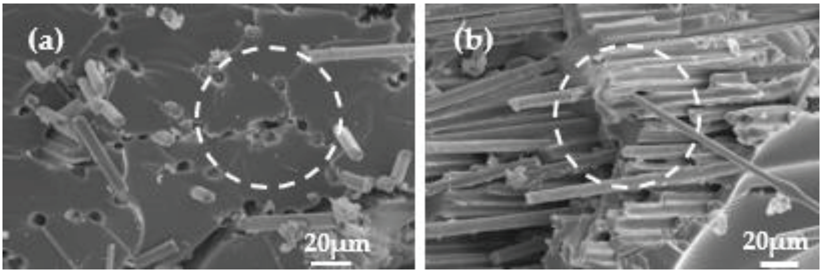

Figure 7: (a) The failure mode of fibre pull-out and (b) rCF breakage

4.0 CONCLUSION

The nonwoven rCF mat and composite were successfully characterized using drapability, optical microscopy and SEM as well as measured via flexural and impact tests. This study showed that different plies of rCF generate significantly different values in physical-mechanical properties. The nonwoven mat prepared via wet-laid was strongly correlated with the flexural behavior and microstructure where SEM observation exhibited that the nonwoven mat from rCF had fibre pull-out and with the present of debonding behavior. Moreover, these results encourage further investigation into the application of nonwoven rCF mat secondary structure materials.

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