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NOTCH-SENSITIVITY OF HYBRID RECYCLED CARBON FIBER COMPOSITES

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ABSTRACT

Recycled carbon fiber (rCF) holds significant promise for reducing both production waste and costs associated with its manufacturing, which is characterized by high energy intensity. However, its full potential remains untapped due to limited understanding of its mechanical behavior, particularly concerning stress concentration factors in notched recycled carbon fiber-reinforced polymer. This study is dedicated to investigating the mechanical properties of r-CFRP and characterizing the tensile behavior of notched composites. Additionally, it explores new functionalities of r-CF and introduces a methodology for correlating strain fields obtained from digital image correlation (DIC) with stress concentration factors (SCF). DIC was chosen as the strain field measurement technique for its enhanced accuracy and speed compared to conventional methods such as strain gauges. The analysis revealed that hybrid rCF/glass fiber composite has higher strength retention compared to glass fiber composite when 5.95 mm notch was applied. This result underscores the potential of rCF as a material to produce notch-insensitive hybrid composites, making them suitable for various applications in the aerospace industry.

KEYWORD

Recycled Carbon Fiber, Stress Concentration Factor, Digital Image Correlation

INTRODUCTION

Composite materials have revolutionized the aerospace industry, offering an enticing blend of lightweight properties, exceptional strength, and resistance to corrosion (Nagaraju et al., 2023) One of the distinguishing characteristics of modern aerospace design is the extensive use of mechanical fasteners, such as rivets and screws, to join various structural elements. While these fasteners provide the necessary connectivity, they often introduce stress concentrations around their attachment points which can lead to premature failure (Gao et al., 2017). Hence, investigating the behavior of composites in the presence of notches is a crucial endeavor.

In the pursuit of aerospace excellence, we delve into the advantages offered by composite materials like recycled carbon fiber (rCF) and glass composites. Many studies have been carried out to investigate the mechanical behaviors of rCF, as reported by Omar et al. (2021) and Patchen et al. (2022). Most of these studies highlighted the capability of rCF to maintain good mechanical properties in composites and provide benefits in terms of weight reduction and sustainability, making them suitable for various applications. Nevertheless, there are limited studies related to the notch sensitivity of rCF reported in the open literature. Glass composites, on the other hand, offer excellent tensile properties and versatility, making them ideal candidates for various aerospace applications (Sanjay & Yogesha, 2017).

In this study, we hybridize glass fiber composite with rCF and utilise Digital Image Correlation (DIC) as a cutting-edge tool is examined to investigate the effects of open hole on composite materials. The use of DIC allows us to precisely track and analyze the full-field deformation and strain fields within the materials under load including the deformation of notched composite specimens (Khechai et al., 2018; Sun et al., 2020).

MATERIAL AND METHODOLOGY

A unidirectional (UD) glass fiber/epoxy composite laminate and a hybrid non-woven rCF/UD glass fiber/epoxy composite laminate are manufactured using vacuum infusion process. 6 test specimens were cut from the glass fiber composite plate and 6 test specimens from the hybrid rCF/glass fiber composite plate with dimensions following ASTM D3039 (International & indexed by mero, n.d.) as shown in Table 1. The glass fiber used is UD with areal weight 200 gsm, the recycled carbon fiber used is non-woven IM56D with areal weight 89 gsm and the resin used is a biodegradable IB2 Epoxy Infusion Bio Resin.

Table 1: Configurations of the test specimens

Material	Dimension (L x W)	Thickness	Stacking sequence
Unidirectional glass fiber	250 x 25 mm	1.66 mm	$[G]_4$
Non-woven rCF/glass fiber	250 x 25 mm	1.45 mm	[G/rCF/G]

The test specimens were sprayed with matte white paint as the background followed by black speckles. Stereo DIC system was set-up as shown in Figure 1. The displacement rate of the test was fixed at 1 mm/min and the DIC images were acquired at 2 Hz and each case was repeated three times. The DIC data was analysed using correlation software provided by MatchID to obtain the strain of the deformed specimen. The strength retention (%) was calculated using Equation 1.

$$Strength\ retention = \frac{\sigma_{OHT}}{\sigma_{UNT}} \times 100 \quad (1)$$

where σ_{UNT} is unnotched strength and σ_{OHT} is open hole tensile strength.

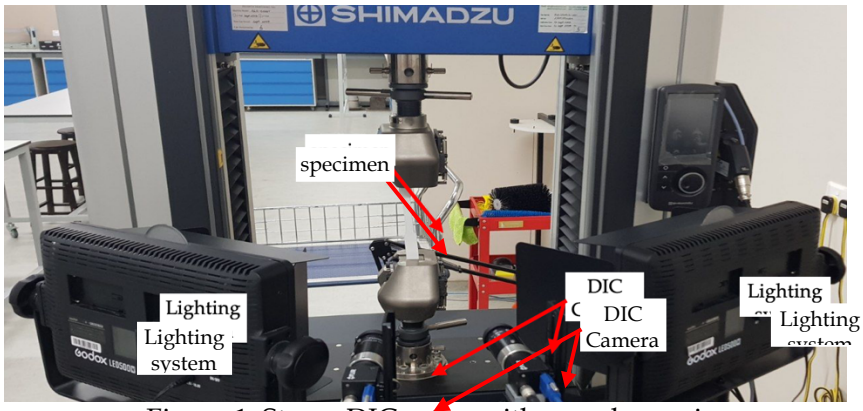


Figure 1: Stereo DIC setup with sample specimen

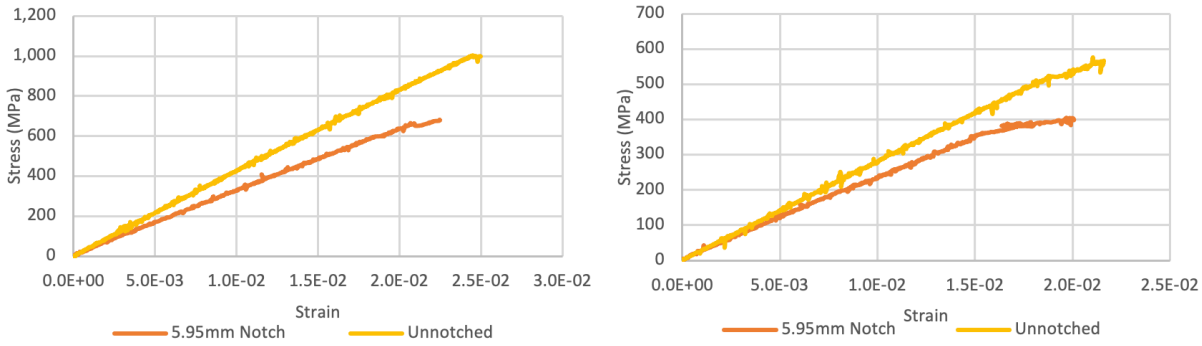
RESULT AND DISCUSSION

Figure 2 shows the stress-strain curves for unnotched and 5.95 mm diameter open-holed specimens of glass fibre composite and hybrid rCF/glass fibre composite. The strain for open-holed specimen was taken as the average strain across the width on both sides of the hole. Unnotched glass fiber composite specimens exhibited a maximum strain of 0.02496 and reached a maximum stress of 1004.02 MPa, showcasing the material's high ultimate tensile strength. In contrast, unnotched hybrid specimens displayed a similar maximum strain of 0.02162 and a maximum stress of 566.73 Mpa, which was 43.6% reduction from pristine glass specimen due to the replacement of two glass layers with a recycled carbon fiber layer.

The 5.95mm notched on the glass fibre composite reduced the maximum stress by 32% due to high stress concentration caused by the notch. Compared to the hybrid specimen, the maximum stress was only reduced 17.3%, indicating that the presence of rCF can reduce the stress concentration on a notched specimen. This is supported by 71.30% strength retention of the hybrid specimen which was higher compared to 67.85% strength retention of glass specimen, when

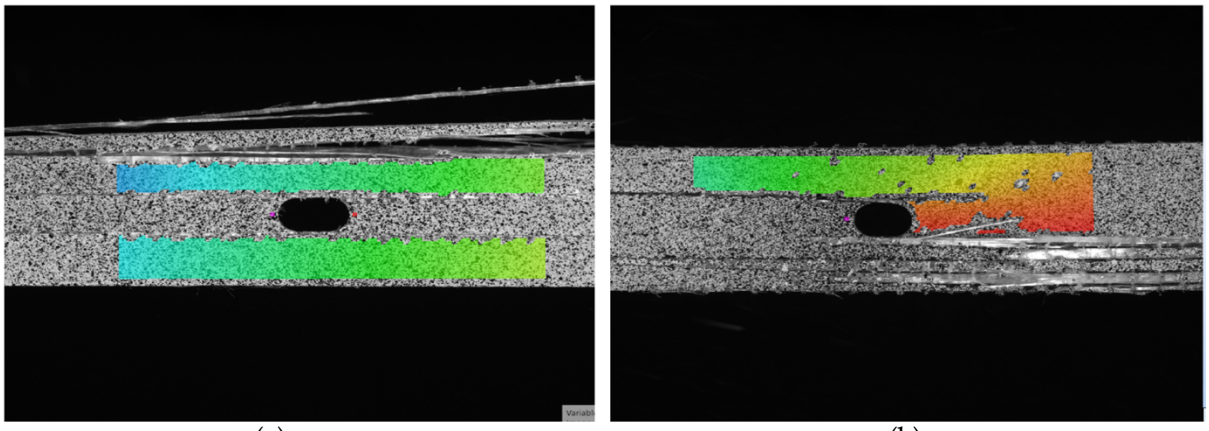
calculated from Equation 1. According to Khan et al., hybrid composite has lower notch sensitivity due to the progressive damage modes of different materials, which delays the final failure of the specimen (Khan et al., 2023). However, from DIC analysis, only intralaminar crack failure was able to be identified on both materials as shown in Figure 3.

The relationship between strength retention and diameter-over-width ratio based on Pilkey's equation was plotted in Figure 4 (Pilkey, 2005). From the graph, the hybrid composite falls closer into the category of notch-insensitive material for both notch sizes compared to the glass fiber composite. This positioning implies that the glass fibre composite's response to notches is more noticeable. It retains a notable degree of strength, yet it exhibits a greater sensitivity to notch-induced stress concentration compared to the hybrid composite.



(a) (b)

Figure 2: Stress-strain curves for (a) glass composite, (b) hybrid composite



(a) (b)

Figure 3: Failure captured by on 5.95 mm notched (a) glass composite, (b) hybrid composite

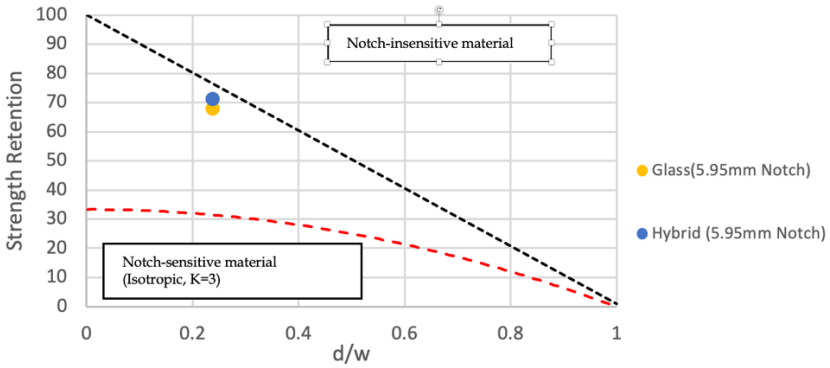


Figure 4: Relationship between strength retention and diameter-over-width ratio

CONCLUSION

In this study, the stress concentration factor of notched GFRP, rCF and hybrid composite subjected to tensile test has been discussed. The results shows that GFRP has the best performance, where it has the highest tensile strength. However, it is proven that when rCF is interleaved with GFRP, the r-CFRP was able to blunt the stress concentration around the hole of the hybrid composite, making it more insensitive to notch as compared to GFRP. Besides that, the methodology of applying digital image correlation in obtaining the strain field and stress concentration factor has also been developed for notched composite. In conclusion, rCF has shown its potential in its application to toughen the open-hole structure of composite as it able to relieve the stress concentration around the hole. This study has proven that carbon fibre is worth to recycle and the potential of applying rCF in different industries especially in manufacturing is possible.

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