Enhancing The Mechanical Properties of Chopped Basalt Composites by Incorporating of Multiwall Carbon Nanotubes

Aidah Jumahat, Ilya Izyan Shahrul Azhar, Napisah Sapiai, Noor Farizza Romli and Mohamad Aizat Aminuldin

Abstract*: This study aims to develop and determine mechanical properties chopped basalt fibre reinforced composites (CBFRP) modified with multiwall carbon nanotubes (CNT). Chopped basalt composite modified with CNT was fabricated using a combination of mechanical stirring and hand layup process. Three different weight percentages of CNT i.e. 0.5, 1, 1.5wt. % were filled into epoxy resin before mixing with chopped basalt fiber. The mechanical performance namely tensile properties and fracture toughness behaviour of the fabricated chopped basalt composites was assessed using Universal Testing Machine in accordance to ASTM standard D368 and D695, respectively. The results showed that the incorporation of CNT enhanced tensile and fracture toughness properties of the CBFRP composites. However, a higher amount of CNT (1.5wt%) incorporated into the CBFRP caused reduction in tensile strength, tensile modulus and G_{ic} by 4.40%, 2.46% and 30.36 %, respectively, as compared to those of 1.0CNT-CBFRP.

Index Terms*: Basalt fibre, Carbon Nanotube, Tensile Properties, Fracture Toughness.

I. INTRODUCTION

Fiber reinforced polymer (FRP) is a composite material made by combining two or more different constituent materials. FRP composites consist of plastic polymer resin and strong reinforcing fibers. The FRP composites are classified by fiber length which is long fiber (continuous) or short fiber (discontinuous). Short FRP composites have lower strength and modulus than continuous FRP composites [1][2]. Although the strength of short fiber composite are lower than long fiber, the possibility to obtain similar or comparable mechanical and physical properties like those made of continuous fiber can be made by tailoring the random orientation of fibers and adding toughening agents or fillers into the resin[1]. Moreover, short fiber composite is easy to process with affordable cost compare to the one of continuous fiber [3].

Among the fibers that can be used as reinforcement in FRP composites, basalt fiber represents the most remarkable properties such as good mechanical strength, low moisture absorption, high corrosion resistance, high chemical resistance, and high thermal stability with extended operating temperature range of −200 ° C to 600 °C and good adhesion bonding with resins [4]–[7]. Basalt fibres also had comparable and better mechanical and physical properties as compared to glass fibre, making it able to replace the usage of synthetic fibres. However, some weaknesses had occurred when epoxy resin is used as a matrix in basalt fibre reinforced composites. The epoxy resin possesses brittle properties attribute to its high cross-linked, limiting its application as fibre composite [5][8].

To overcome the brittleness, fibre composites could be modified with nanofillers into matrix resin such as nanoalumina, nanosilica, nanoclay, carbon nanotubes and graphene. Carbon nanotubes (CNT) are known as the strongest materials compare to other types of second-phase modifiers. CNT exhibits good mechanical, thermal and electrical properties like high flexibility, low density, strong interfacial interactions and good stress transfer properties. Several studies were conducted and proved that CNT has the capability to reduce the 'brittle nature' of the polymer matrix in FRP composites [8]–[22]. Behera et al. [1] had evaluated the tensile behaviour of three-phase glass/epoxy laminate embedded with MWCNTs. The results showed that the tensile strength increased with increasing amount of MWCNT up to 1 wt%. The 1 wt. % of MWCNT doping enhanced the tensile strength by 105.26 % as compared to unmodified glass/epoxy laminate. This enhancement occurred due to the existence of MWCNTs, which delay the crack initiation and crack propagation under the tensile stress. However, the 1.5 wt% of MWCNT doping was reported to decrease the tensile properties due to agglomeration phenomena that occurred during the doping process [9]. Yaghoobi and Fereidoon [2] used 0 to 2 wt. % of MWCNT in the fabrication of PP/kenaf/PP-g-MA/MWCNT nano-biocomposites.

Revised Manuscript Received on October 30, 2019.

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The results showed that the tensile strength, flexural strength and notched impact strength were enhanced about 13.8%, 15.6%, and 11.4%, respectively, as MWCNT content was increased to 1 wt%. However, lower tensile, flexural and impact properties were recorded when the comoosites were modified with 1.5 and 2.0 wt% MWCNT. As supported by SEM images, the agglomeration of MWCNT becomes more intense with higher content of MCWNT. The agglomeration of MWCNT takes place due to Van-der-Waals forces between the MWCNT, thus developed highly inhomogeneous of PP/kenaf/PP-g- MA/MWCNT nano-biocomposites [23].

All the research as mentioned above, indicated that there is a good possibility for enhancement of mechanical properties of FRP via the incorporation of CNT into the polymer matrix. Therefore, the current study has investigated the influence of multi-wall carbon nanotubes (CNT) on the tensile and fracture toughness properties of chopped basalt fibre reinforced epoxy composite (CBFRP). The CNT was incorporated in the epoxy matrix with three different wt.% 0.5, 1.0 and 1.5 wt%) using mechanical stirrer before mixing with chopped basalt fibre. The CNT-CBFRP composites were subjected to tensile and fracture toughness test.

II. EXPERIMENTAL PROCEDURE

A. Materials

In this study, multiwall carbon nanotube (CNT), basalt fibre and epoxy were used to produce CNT-CBFRP composites. The chopped basalt fibres with a length of 3 to 5 mm were supplied by Innovative Pultrusion Sdn. Bhd. The epoxy, namely Miracast 1517 A/B were purchased from Miracon (M) Sdn.Bhd. While the CNT was purchased from CNanoTechnology (Beijing) Ltd. Three different wt.% of CNT were modified with epoxy resin, which is 0.5 wt. %, 1.0 wt. % and 1.5 wt. %. The modified CNT was mixed with chopped basalt to produce CNT-CBFRP composites and coded as 0.5CNT-CBFRP, 1.0CNT-CBFRP and 1.5CNT-CBFRP according to the percentage of CNT used. The epoxy resin and hardener were mixed with a ratio of 100:30 as recommended by the supplier.

B. Fabrication of MWCNT-CBFRP composites

The MWCNT with three different weight percentage i.e. 0.5 wt. %, 1.0 wt. % and 1.5 wt. % was homogenously mixed with epoxy resin using mechanical stirrer about 30 to 40 minutes. The MWCNT-epoxy mixtures were then impregnated with 10wt. % of chopped basalt fibre. The mixtures were then poured into silicon mold of 200mm x 36mm x 3mm for tensile test, 80mm x 10mm x 5mm for fracture toughness and 10 mm x 10mm diameter for compression test. The mixtures were left for 24 hours at room temperature for curing process. Fig. 1 shows the flow of the MWCNT-CBFRP composites fabrication process.

Fig. 1. Fabrication process of MWCNT-CBFRP composites

C. Characterization

Tensile Test

The tensile test was conducted according to ASTM D368. The specimens were prepared with a dimension of 200mm x 36mm x 3mm. The 100kN INSTRON 3382 Universal Testing Machine was used to record the applied load and corresponding extension of the specimen. The loading rate for the tensile test was 1mm/1min. At least five specimens of each MWCNT-CBFRP composites were tested to determine the tensile properties i.e tensile modulus, tensile strength and tensile strain. Tensile stress (σ)is defined as the tensile force (F) per unit area (A) of the original cross-section within the gauge length as follows equation 1.

$$\sigma(MPa) = \frac{F}{A} \tag{1}$$

Tensile strain (ε) is an increased length (L_0) per unit original length (L_0) of the gauge as in Equation 2.

$$\varepsilon(\%) = \frac{\Delta L_0}{L_0} \tag{2}$$

While tensile modulus (E) is the ratio of the tensile stress and tensile strain. Which was calculated from Equation 3.

$$E(GPa) = \frac{\sigma}{\varepsilon} \tag{3}$$

Fracture Toughness Test

The fracture toughness test was conducted according to ASTM D5045. The specimens size of 5 mm x 10 mm x 80 mm, with 4.5 mm initial crack length across the specimen were prepared and tested using 100kN INSTRON 3382 Universal Testing Machine with cross head speed of 1mm/min. From the data obtained, the graph of force (F) versus Displacement (s) were plotted and the value of critical stress intensity factor, K_{ic} and critical energy release rate, G_{ic} were calculated using Equations 4 and 5:

$$K_{ic}(Pa.\sqrt{m}) = f(a/w)\frac{F_Q}{h\sqrt{w}} \tag{4}$$

$$G_{ic}(J/m^2) = \frac{W_B}{h \times w \times \emptyset(a/w)} \tag{5}$$

where f(a⁄w) is a calibration factor, F_Q is a Maximum Load, a is an Original Crack initiation, w is a width of specimen, h is a thickness of specimen, W_B is an energy to break, Ø(a⁄(w)) is a calibration factor and a is an original crack initiation.

III. RESULT AND DISCUSSION

A. Tensile Properties

Table-I and Fig. 2 indicate the tensile properties of CBFRP containing different percentage of CNT. The results show that the tensile properties of CBFRP had increased with inclusion of CNT in the epoxy matrix. The CBFRP specimen incorporated with 1.0 wt% of CNT (1.0CNT-CBFRP) exhibit highest tensile strength and tensile modulus as compared to those contained 0.5 and 1.5 wt% of CNT (0.5CNT-CBFRP and 1.5CNT-CBFRP). The tensile strength and tensile modulus of the 1.0CNT-CBFRP composite were recorded about 32.12±5.56 MPa and 2.85±0.79 GPa, which increased by 17.40 % and 82.70% in reference with CBFRP without CNT, respectively. The tensile strength and tensile modulus of 0.5CNT-CBFRP marked 29.56±3.79MPa and 2.25±0.46GPa, which increased by 8.04% and 44.23% as compared to those without CNT, respectively. However, when 1.5 wt% of CNT was incorperated, the tensile properties increased 12.24% for tensile strength and 78.20% for tensile modulus corresponding to the control one but decreased 4.40% and 2.46% as compared to 1.0CNT-CBFRP. It is concluded that the CBFRP incorporated with CNT indeed increased the tensile properties of the resulted composites. However, the higher amount of CNT deteriorated the tensile properties of the CBFRP composites. The higher content of CNT leads to higher viscosity forming the agglomerated regions and inhomogeneous dispersion of CNT inside the epoxy resin. As a consequent, the agglomerated regions and the inhomogeneity act as stress concentrator weaken mechanical properties of the composites. There are also reported by many researchers that the agglomerated regions and poor dispersion of CNT are the main reason in reducing the mechanical properties of modified-composites. A similar finding was also reported by Yaghoobi and Fereidoon [23] and Behera et al.[9], which indicated that the composites modified with 1.0 wt% of CNT demonstrate optimum enhancement in mechanical properties. The higher amount of CNT in a polymer matrix, which is up to 1.5 % and above caused the agglomeration of MWCNT due to Van-der-Waals forces between the MWCNT, which act as weak point when subjected to load result in low mechanical performance of the composites.

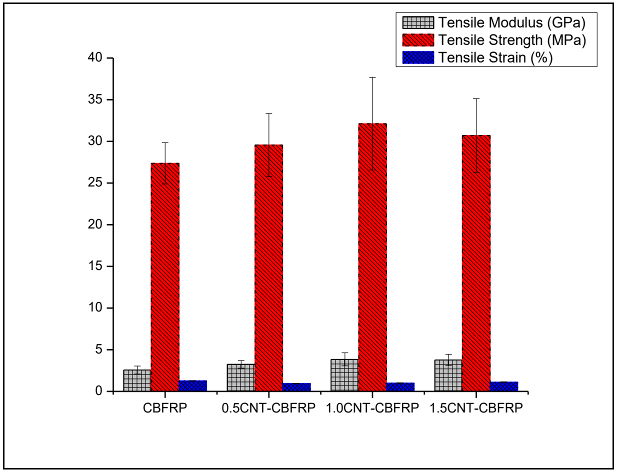

Fig. 2. Effect of the CNT incorporating on the tensile modulus, tensile strength and tensile strain of CNT-CBFRP composites

Table-I: Tensile properties of CNT-CBFRP composites

Tensile Properties	CBFRP	0.5CNT - CBFRP	1.0CNT - CBFRP	1.5CNT - CBFRP
Tensile Modulus (Gpa)	1.56 ±0.48	2.25 ±0.46	2.85 ±0.79	2.78 ±0.68
Tensile Strength (MPa)	27.3 ±2.48	29.56 ±3.79	32.12 ± 5.56	30.71 ± 4.42
Tensile Strain (%)	1.28 ±0.02	0.95 ± 0.03	1.01 ± 0.04	1.11 ± 0.06

B. Fracture Toughness Properties

Fig. 3 presents the load-displacement curve for CNT-CBFRP composites. The curves show that the displacement gradually increases as the force applied is higher until the maximum load is reacheed, which indicates brittle failure behaviour of the CNT-CBFRP composites. The incorporating of CNT up to 1.5% enhanced the fracture toughness properties as well as G_{ic} and K_{ic}. The 1.0CNT-CBFRP composites attained highest fracture toughness properties as compared to other CNT-CBFRP composites. The 1.0CNT- CBFRP recorded 103.67±8.31N for maximum load, 1.90±0.15 MPa.√ m for K_{ic} and 1181.05±111.65 Jm^{-2} for G_{ic}, which increased by 62.54% of maximum load, 62.39% of K_{ic} and 44.36% of G_{ic} corresponding to the control CBFRP composite. The similar trend of the tensile properties was found, which the inclusion of high amount of CNT (1.5CNT- CBFRP) did not enhance the fracture toughness properties in reference to 1.0CNT- CBFRP. The G_{ic} of 1.5CNT- CBFRP decreased by 30.36 % as compared to 1.0CNT- CBFRP. This spectacle is ascribed to the high content of the CNT, same reason as discussed for that of tensile behaviour. Table-II shows the summary of the fracture toughness properties of the 0.5CNT- CBFRP, 1.0CNT-CBFRP and 1.5CNT- CBFRP.

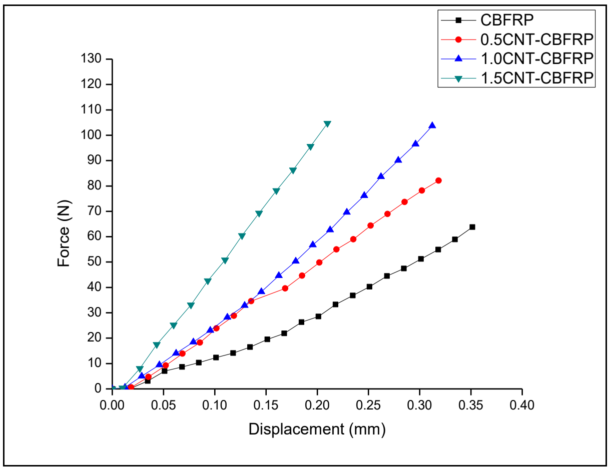

Fig. 3. Force-Displacement curves of CNT-CBFRP composites

Table-II: Fracture toughness properties of CNT-CBFRP composites

Fracture Toughness Properties	CBFRP	0.5CNT-CBFRP	1.0CNT-CBFRP	1.5CNT-CBFRP
Maximum Load F_Q (N)	63.78 ±13.52	82.13 ±12.20	103.67 ±8.31	102.69 ±6.87
Critical stress intensity factor, Kic $\left(MPa.\sqrt{m}\right)$	1.17 ±0.24	1.50 ±1.43	1.90 ±0.15	1.90 ±0.13
Critical energy release rate, Gic $\left(J/m^2\right)$	818.13 ±96.46	954.69 ±78.17	1181.05 ±111.65	822.51 ±195.25

IV. CONCLUSIONS

This paper presents the experimental study on the tensile and fracture toughness properties of the CNT-CBFRP composites. The effect of the CNT modified in CBFRP composites was investigated. The results showed that inclusion of CNT enhanced the properties of the CNT-CBFRP composites. However, when higher amount of CNT was incorporated, the tensile and fracture toughness properties of CNT-CBFRP decreased. The tensile strength, tensile modulus and G_{ic} of 1.5CNT-CBFRP decreased by 4.40%, 2.46% and 30.36 % as compared those of to 1.0CNT-CBFRP. The primary reason for the reduction of tensile and fracture toughness is attributed formation of to agglomerated regions and inhomogeneous dispersion of CNT in epoxy matrix. The good dispersion of CNT should be fully deliberated to achieved remarkable mechanical properties for the resulted composites.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Universiti Teknologi MARA (UiTM), Ministry of Education Malaysia and Institute of Graduate Studies (IPSIS) for the financial supports. The research is performed at the Faculty of Mechanical Engineering, UiTM, Malaysia under the support of Fundamental Research Grant Scheme (FRGS) no: 600-IRMI/FRGS 5/3 (336/2019).

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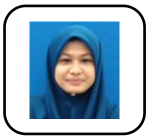

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Mohamad Aizat bin Aminuldin completed his Bachelor Degree (Hons) in Mechanical Engineering from Universiti Teknologi MARA (UiTM) in 2018. His main research of interest is in fibres reinforced composites. His final year project involved investigation on fracture toughness behavior of basalt, kenaf, glass and carbon fibres reinforcd polymer composites with addition of nanofillers (carbon nanotubes and nanoclay)