Quasi-Static Indentation Behavior of Nanoclay-Chopped Carbon Fibres Composites

Aidah Jumahat, Adila Nalisa Mohd Roslan, Napisah Sapiai, Husna Zaemah Ramlan

Abstract*: This paper presents the Quasi Static Indentation (QSI) behavior of the chopped carbon fibre composites with three different loadings of nanoclay. The composites, which are Carbon fibre (CF), 1wt% Nanoclay–Carbon Fibre (1NC-CF), 3wt% Nanoclay–Carbon Fibre (3NC-CF) and 5wt% Nanoclay–Carbon Fibre (5NC-CF) were prepared using hand lay-up method. The nanoclay was dispersed using a three roll milling machine. The 10wt% of chopped carbon fibres with 3-5 mm length were used in fabricating these composites. The QSI test was conducted using Universal Testing Machine according to the ASTM D6264. The damage section was examined using optical microscopy. The results show that the energy absorbed was increased with addition of nanoclay up to 81.42 %, 137.69 % and 202.95 % for 1NC-CF, 3NC-CF and 5NC-CF composites, respectively. It was concluded that the addition of the nanoclay enhanced the QSI of chopped carbon fibres composites.

***Index Terms*: Quasi Static Indentation, Nanoclay, Chopped Carbon fibres**

I. INTRODUCTION

Carbon fiber reinforced polymer composites (CFRP) are widely being used in many applications such as in automotive, aerospace and building construction due to high specific properties such as high stiffness and strength, light weight and good fatigue properties [1]–[5]. Despite these advantages, the CFRP are prone to impact and indent from the loading of vehicles, flood, bird strikes and storm. These impacts and indents are then lead to huge damage and drop the performance of the composites. Besides, when use of the epoxy as matrix resin, it also reveals several drawbacks include reducing the mechanical strength due to high crosslinking density that makes the composite system brittle. To cope with these problems, the carbon fiber composites are toughened by the inclusion of nanofillers. There are a few types of nanofillers such as nanosilica, nanoclay, carbon nanotube. Among them, nanoclay is a most valuable type of nanofillers due to abundant in nature, low-cost, high strength, high modulus value and easy to process. Several researchers had studied the effect of the nanoclay inclusion into matrix resin, in which the results showed that the addition of nanoclay increased the mechanical performance of the polymer and composite systems [6]–[12].

The quasi-static indentation (QSI) tests provide the information of materials behaviour, damage structure and interfaces that occur during the indentation at constant cross-head speed. The damage growth is recognized by a constant punch displacement until the perforation of the samples complete. Throughout the indentation process, there are three sections identified in the load-displacement curve as illustrated in Fig. 1. Section 1 shows the load increases initially causing elastic bending to occur as represented by the linear graph. The increasing of the indentation force leads to matrix cracking and delamination of samples. In Section 2, severe delamination and fibre breakage occurred during penetration, hence reduce the load-carrying capacity. Finally, in section 3, perforation and friction between sample and indenter occurred until the sample is fully penetrated [13]. Saravanakumar and Arumugam [14] stated that the damage behaviour of the polymer composites was quite similar to low-velocity impact (LVI) when they were subjected to quasi-static indentation (QSI).

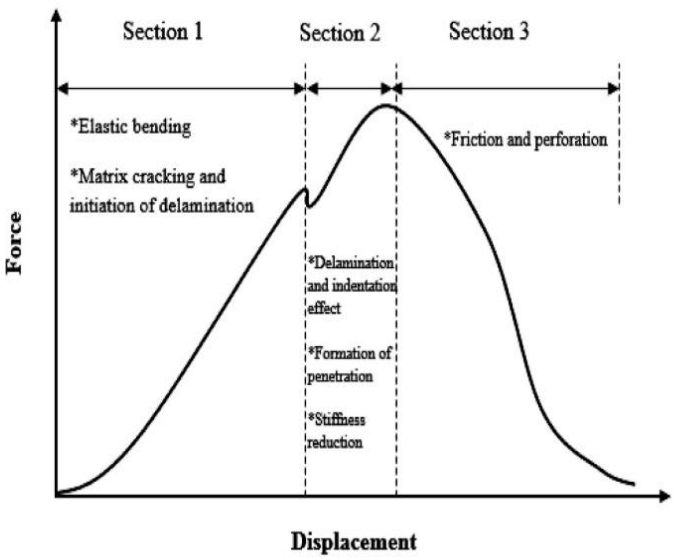

Fig. 1. Schematic diagram of force-displacement curve for typical quasi-static indentation test on composites plates [13]

Based on the previous studies, the quasi-static indentation properties of advanced nano-filled chopped fiber reinforced composite have not yet been fully discovered. In the current study, the effect of nanoclay filler on energy absorption, indentation deformation, depth

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of penetration and surface damage of epoxy polymer and chopped FRP composites during quasi-indentation test was studied.

II. MATERIALS AND PROCEDURES

A. Materials

Carbon fibre, epoxy and nanoclay were used in producing nanomodified CRRP composites. The carbon fibres were chopped using crusher machine in order to get a length of 3 to 5 mm. The epoxy and hardener namely Miracast 1517 A/B were purchased from Miracon (M) Sdn. Bhd. while nanoclay was purchased from Sigma Aldrich. Three different weight percentages of nanoclay were used (1, 3 and 5 wt. %) to fabricate the nanomodified CFRP. The epoxy resin was mixed with a hardener with a ratio of 100:30, as recommended by the manufacturer.

B. Fabrication of Composites

Fiber reinforced polymer composites specimens were manufactured by mechanical stirring and hand layup process. The nanoclay with three different wt.%, which are 1 , 3 and 5 wt.%, was first mixed with epoxy resin using a three roll milling machine for 30-40 minutes before the hardener was added. The epoxy nanomodified resin was impregnated with 10wt. % of chopped carbon fibre. The mixtures were then poured into silicon mold with 100mm length x 100mm width and average thickness of 4mm. The Polytetrafluoroethylene (PTFE) film was placed onto the top of the mold and the aluminium plate was also used to overlap the samples. The composite mixture was left for curing processes at room temperature. The release agent was sprayed in mold surfaces to facilitate the removal of the nanoclay-toughened chopped carbon fibres composites samples.

C. Quasi-Static Indentation Test (QSI)

The quasi-static indentation test on fibre reinforced polymer filled with nanofiller was conducted in accordance with ASTM D6264. The nanoclay-toughened chopped carbon fibres composite samples with the size of 100mm x 100mm x 4mm length were prepared and tested using Universal Testing Machine (UTM). The 13mm of indenter size and 1.25 mm/min of cross head speed was applied during testing. The force applied constantly until the indenter fully penetrates into the specimen. The special design of rig was used to support and hold the specimen position into static condition. A force versus displacement graph was plotted and total energy absorption was calculated based on the area under graph. The energy absorbed by the specimen due to the quasi-static test was calculated using Equations (1) to (3).

$$E(\delta) = \int_{\delta_o}^{\delta} F(\delta)\, d\delta \qquad (1)$$

where:

E is a energy at displacement (N-m), δ is a indenter displacement during the test (m), δ_o is a indenter displacement at initial specimen (m) and F is a measured contact force at indenter displacement (N)

$$E_{max} = E(\delta) = \int_{\delta_o}^{\delta_{max}} F(\delta)\, d\delta \qquad (2)$$

where:

δ_{max} is a maximum indenter displacement (m)

$$E_a = E(\delta_f) = \int_{\delta_o}^{\delta} F(\delta)\, d\delta \qquad (3)$$

Where:

δ_f is a indenter displacement at the end of the unloading cycle (m).

After the impact test, the damage samples were observed and evaluated under digital camera.

III. RESULTS AND DISCUSSION

Fig. 2 shows a force-displacement curves represent CF, 1NC-CF, 3NC-CF and 5NC-CF composites, while Table-I presents the QSI properties such as maximum load, displacement at maximum load and energy absorb for these four series of composites. The force-displacement curves for all the composite systems display a similar trend in term of indentation response. Initially, the load increases linearly until the first load drop. In this phase, the composite experienced elastic bending until the composite break (matrix cracking and delamination). The second section, which right after the first load dropped, the damage of the composite continued resulted in reduction of stiffness. The multiple load drops were observed due to fibre ruptures until the maximum load was reached. The last section shows the complete perforation and penetration of indenter to the composite samples. The similar finding was also reported by Bulut and Erklig [13][15]. The energy absorbed (E) was obtained from area under graph of force-displacement. As tabulated in Table I, the addition of the nanoclay shows the greater the energy absorbed was greater by 81.42 %, 137.69 % and 202.95 % for 1NC-CF, 3NC-CF and 5NC-CF composites, respectively corresponding to those of CF samples. As expected, the distribution of energy absorbed and indentation force increased with higher amount of nanoclay added. This remarkable increment deduced that the addition of nanoclay play an important role in the enhancement of QSI properties of the composite. The optical images visualize the damaged area for CF, 1NC-CF, 3NC-CF and 5NC-CF composites as illustrated in Table II. From the images observed, the size of penetration holes were measured. As compared to those with and without the nanoclay content, the holes size seem to reduce from 23 mm for CF composite to 11 mm, 15 mm and 14 mm for 1NC-CF, 3NC-CF and 5NC-CF composites, respectively. From the enlarge view of the hole penetration as illustrated in Table-II, the CF and 1NC-CF composite exibit that both composites experienced brittle failure. However, the hole penetration of 3NC-CF and 5NC-CF composites demonstrate ductile failure, ascribe to chirping postponement during penetration and restraining the penetration load as the result of nanoclay inclusion. It is also noted that, the 1wt. % of the nanoclay is too low amount to alter the CF composite behaviour. The higher addition of the nanoclay which is 3 wt. % and 5 wt. % nanoclay may suffice to toughen the epoxy matrix of CF composites. It was reported by several researchers that addition of nanoclay in FRP composites enhanced the mechanical properties such as, tensile and flexural behaviour, fracture toughness properties, impact properties, compressive behaviour and wear properties [6], [16]–[19].

Table -I : Maximum load (F_{max}), displacement and energy absorbed for CF, 1NC-CF, 3NC-CF and 5NC-CF composites

Samples	F_{max} (N)	Displacement (mm)	Energy Absorbed (J)
CF	474	4.23	26.85
1NC-CF	1265	3.74	48.71
3NC-CF	1772	3.98	63.82
5NC-CF	2101	4.17	81.34

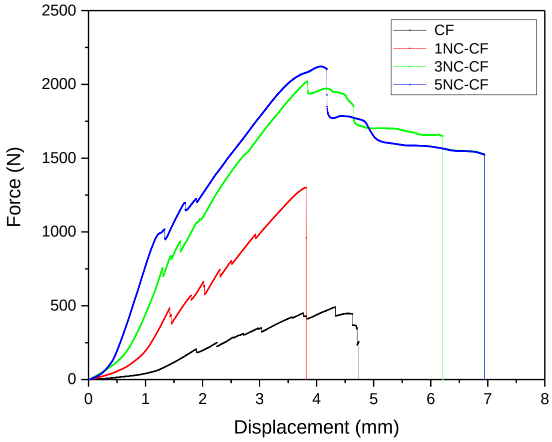


Fig. 2. Typical force - displacement curves for CF, 1NC-CF, 3NC-CF and 5NC-CF composites tested under QSI force.

Table-II: Observed damages modes of CF, 1NC-CF, 3NC-CF and 5NC-CF composites under QSI force

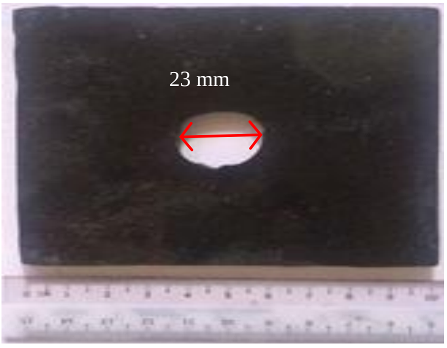
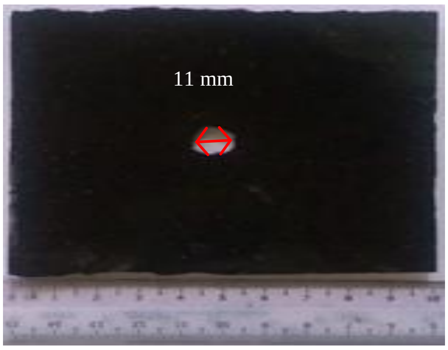
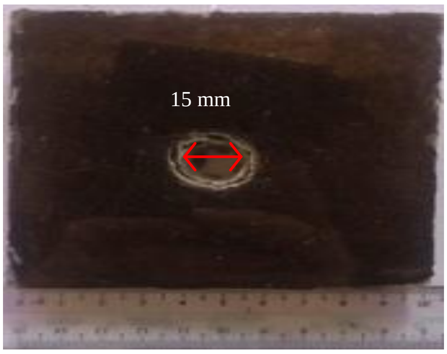
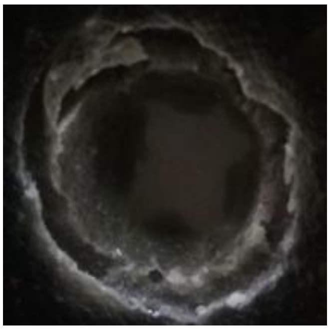
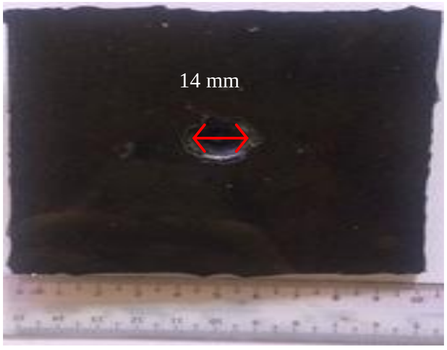
Samples	Overall view	Top view	Bottom view
CF			
1NC-CF			

Table-II: Obsrved damages modes of CF, 1NC-CF, 3NC-CF and 5NC-CF composites under QSI force (*Continued*)

Samples	Overall view	Top view	Bottom view
3NC-CF			
5NC-CF			

IV. CONCLUSIONS

The QSI behavior of nanoclay filled chopped-CF composites was investigated. The force against displacement shows that the curves can be divided into three sections. The first section, as the indentation force was applied, the chopped- CF composites showed elastic behavior. In section two, composites samples experienced matrix cracking and fibre breakage due to several load drops until the maximum load was reached. The third section demonstrated the composite samples had gone through complete perforation and penetration of indenter. The energy absorbed and indentation force increased with the increasing of nanoclay amount recorded 81.42 %, 137.69 % and 202.95 % for 1NC-CF, 3NC-CF and 5NC-CF composites, respectively. It is concluded that the addition of nanoclay enhanced the resistance against the indentation force of the CF composites.

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Dr. Aidah Jumahat has a PhD degree in Mechanical Engineering from the University of Sheffield United Kingdom, a MSc (Mechanical Engineering) degree and a B.Eng. (Hons.) Mechanical and Materials Engineering degree from the Universiti Kebangsaan Malaysia. She joined the Faculty of Mechanical Engineering UiTM as a lecturer in 2001. Currently, she is an Associate Professor at the Faculty of Mechanical Engineering and the Director at Community of Research Frontier Materials and Industrial Application (CoRe FMIA) Institute of Research Management and Innovation (IRMI) Universiti Teknologi MARA Shah Alam Selangor Malaysia. Dr. A Jumahat has been lecturing on Composite Materials, Finite Element Method, Mechanics of Materials, Manufacturing Processes, Product Design and Advanced Materials, which happens to be her areas of research interest. She has published more than 100 technical papers in journals and conference proceedings locally and internationally in these research areas. She is an esteemed member of the panel of judges for the International Invention, Innovation & Technology Exhibition (ITEX) since 2012 and an executive member of several professional bodies

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Husna Zaemah binti Ramlan completed her Bachelor Degree (Hons) in Mechanical Engineering from Universiti Teknologi MARA (UiTM) in 2018. Her main research of interest is in fibre reinforced composites. Her final year project involved investigation on the quasi static indentation of chopped basalt, kenaf, glass and carbon fibres reinforced polymer composites incorporating carbon nanotubes and nanoclay.