International Journal of Engineering & Technology, 7 (4.18) (2018) 51-54

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Effect of Silica Nanoparticles on Quasi-Static Indentation and Impact Properties of Glass Fibre Reinforced Epoxy Polymer Composites

Nurul Emi Nor Ain Mohammad, Aidah Jumahat*, Anthony Arthur

Faculty of Mechanical Engineering, UniversitiTeknologi MARA, 40450 Shah Alam,Selangor, Malaysia
**Corresponding author E-mail: aidahjumahat@salam.uitm.edu.my.*

Abstract

The present study aims to investigate the effect of the silica nanoparticles on the quasi-static indentation and impact properties of glass fiber reinforced polymer (GFRP) composite laminates. The unmodified and modified GFRP composite laminates were fabricated using vacuum bagging method. The epoxy resin was modified with three different silica nanoparticles weight percentages; 5 wt.%, 10 wt.% and 15 wt.%. Quasi static indentation tests were conducted using Instron Universal Testing Machine in accordance to ASTM D7136. Drop weight impact tests were performed using Instron Dynatup 8250 Impact Tester under low energy level (50 J) in accordance to ASTM D6264. The failure mode and damage mechanisms involved during both tests were characterized by observing the indented surfaces and impacted area using an optical microscope. The 15 wt % silica nanoparticle modified GFRP composite laminates showed the highest energy absorb and maximum load when compared to unmodified GFRP composite laminates.

Keywords: *Glass Fiber Reinforced Polymer, Impact Properties, Quasi Static Indentation, Silica nanoparticles.*

1. Introduction

Fiber reinforced polymer (FRP) composites are extensively being used in various applications such as aerospace, marine and railway industries. Glass fiber reinforced polymer (GFRP) is one type of FRP composite materials that has been employed in the design of aircraft and automobile parts, windmill blades, sportequipments and in structural use for concrete components and reinforcements. This is due to its excellent characteristics such as high corrosion resistance, high strength, high stiffness, lightweight, high impact resistance and anticipated long-term durability [1-3]. The addition of reinforcement fiber leads to a better mechanical properties of polymer. Fibers acts as the principle load bearing while matrix acts as a load transfer medium when applied in specific application and loading condition. Epoxy resin has mainly been used as a matrix for fiber reinforced composites because cured epoxies have excellent mechanical properties, good adhesive properties and high chemical resistance [4].

It is well known that the mechanical properties of fiber reinforced polymer composites are influenced by the adhesive strength and wettability of the fiber and matrix. However, the epoxy resins exhibit low load carrying capability, brittleness, rigid in nature and poor resistance to crack propagation. This could be solved by embedding nanofillers into the epoxy resin [5],[6]. Shaari et.al [7] investigated the effect of fabrication method and influence of micronsized alumina filler on the impact properties. From the result obtained, the presence of alumina fillers enhanced the impact energy absorption of GFRP composite. Sharma et.al [8] reported that even 5wt% nanoclay embedded in the glass fiber reinforced polymer composite improved the flexural and tensile strength. Other researches include Manjunath et. al [9] that investigated the presence of alumina, silica and alumina trihydrade as a filler into GFRP. They found that the impact strength for nanofillers filled GFRP increased around 28% compared to the unfilled GFRP.

Jaganathan et al. [10] found that the fatigue life of nanosilica-GFRP composite was four times higher than that neat GFRP composite. They concluded that the presence of silica nanoparticles in the epoxy matrix of GFRP reduced the matrix cracking and also retared the crack growth rate in the composite leading to enhanced fatigue life [10]. In work conducted by Megahed et al. [11], the effect of incorporation of silica and carbon particulates nanofillers into epoxy reinforced glass fiber was studied. The result showed an improvement in tensile, impact and fatigue life with addition of nanoparticles contents as compared to the neat GFRP.Mehmet Bulut and Ahmad Erklig [12] studied the quasi-static indentation effects on laminated hybrid composite laminates and found a strong correlation between interlaminate fracture toughness and impact resistance of hybrid composite laminates. The failure mechanism in hybrid samples were significantly affected by the stacking sequence of the three different types of fibers such as kevlar, carbon and glass fiber.

This study focuses on the development of nanosilica modified glass fibre reinforced polymer (GFRP) composite laminates. Drop weight impact and quasi-static indentation testswere conducted in order to investigate the effect of nanosilica on damage resistance of GFRP composite laminates. The fracture mechanisms involved during the tests were observed and identified using an optical microscope.

2. Materials and Method

2.1. Materials

The materials used to fabricate thecomposite laminates were epoxy resin (Miracast 1517 A/B) from Miracon Sdn.Bhd, Malaysia, woven type glass fibres (CWR200) supplied by Vistec Technology Sdn.Bhd, Malaysia and nanosilica(Nanopox F400) purchased from Nanoresins AG,Germany. Table 1 shows the properties of fibre glass used in this study.

Table 1: Glass fibre properties

Weave pattern	Twill (2x2)
Area density (g/m2)	200
Thickness	0.2
Count (rows per in.)	15 x 15

2.2. Mixing of Silica Nanocomposite Resin

In order to prepare a series of nanocomposites with 5, 10 and 15 wt% nanosilica content, the epoxy resin was mechanically mixed with nanosilica for 60 minutes at 400 rpm using the mechanical stirrer. After that, the mixture was degassed in a vacuum chamber to remove the entrapped air for 15-20 minutes.

2.3. Fabrication of Unmodified and Modified GFRP Composite Laminates

Vacuum bagging method was applied to prepare the unmodified and nanomodified GFRP composite laminates. An aluminum plate was set as the base plate and the PTFE film plastic was put on the plate to easily removed the laminates once it is completely cured. Then,the nanomodified resin was poured into the plate and spread evenly. A layer of woven glass fiber was then laid onto the nanomodified resin system. Both steps were repeated until the 4 mm thickness was achieved. Finally,the perforatedrelease film was put on top of the laminate followed by the absorption fabric. Vacuum bagging film was placed on the laminate and pressed firmly against the sealant tape to provide an enclosed vacuum area. The laminates were degassed for about 60 minutes. Once completed, the GFRP laminates were cured at room temperature for 24 hours. Finally, the specimens were cut from the same laminated panels with the dimensions of 50 mm x 50 mm.

2.4. Quasi-Static Indentation Test

The quasi-static indentation test was conducted in accordance to ASTM standard D6264. In the quasi–static indentation test, the total energies were calculated from the area underthe load-displacement curve. After the test, the permanent indentation depth of the specimens was measured and the damage area was identified using optical microscope. Quasi-static indentation test was performed in order to identify the mechanical properties of GFRP composites when exposedtoa low static of 5 mm/min velocity. A flat square composite panel was subjected to a concentrated load by slowly compressing the 10 mm diameter indenter into the specimen surface and the indentation force was applied continuously until the final failure which is the penetration of the specimen. The quasi-static contact force as function of indenter displacement and time data was recorded.

2.5. Drop Weight Impact Test

The low velocity impact test were performed at room temperature based on ASTM D7136 standard using Instron Dynatup 8250 Drop Weight Impact Tester. A hemispherical impactor with a diameter 10mm and mass of 6.0 kg was used at constant height of 85 cm, resulting in kinetic energy of 50 Joule for each test. Fig. 1a shows the Dynatup Drop Impact test machine and Fig.1 bshows the Universal Testing Machine for quasi static indentation test used in this study.

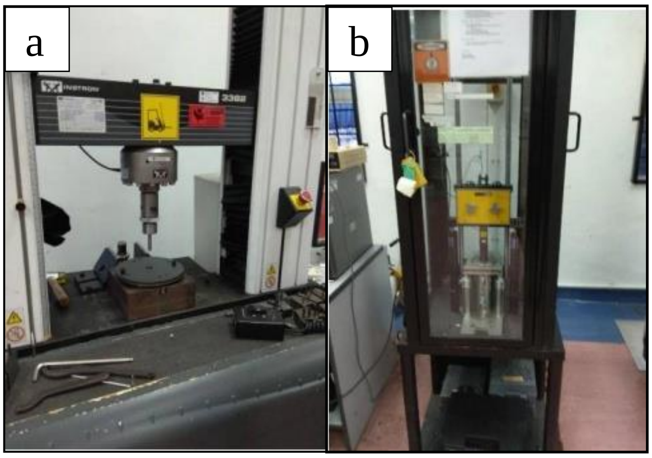

Fig. 1: (a) Universal Testing Machine and (b) Dynatup Drop Impact Test

3. Results and Discussion

This study focuses on the impact response and the quasi-static indentation of GFRP composites that were modified with three different weight percentages of nanosilica (5wt. %, 10wt. % and 15wt. %). Impact energy of 50 J was used for the impact response evaluation.

3.1. Drop Weight Impact Test

Impact test was performed to measure the response of a material to dynamic loading. From the result shown in Fig. 2, the addition of 15wt. % of nanosilica into the GFRP increased the energy absorption of unmodified GFRP by 17 %. The peak force also increased from 3315 N for composite without nanosilica to 3443 N for 5wt. % of addition of nanosilica in epoxy. The peak force is further increased to 3524 N for 10wt % and 3594 N for 15wt.% nanosilica, respectively.Glass fiber is known as high impact resistance materials. Impact resistance for GFRP composites was enhanced by the addition of nanosilica and 15wt % nanosilica system shows the best impact resistance. From this findings, it is demonstrated that the presence of nanosilica improved the ductility and promoted higher plastic hardening behavior after yielding of the epoxy without reducing its strain to failure.

3.1.1. Force- Displacement Curves

From the results obtained in Fig. 3, 15wt % nanomodified system showed the highest impact load (3594.351N) compared to other systems. To compare with unmodified system, 5wt%, 10wt% and 15wt% nanomodified system improved their impact load by 3.5%, 6.3% and 8.4% respectively. Higher deflection was recorded at around 70mm due to the addition of nanosilica. Thus, it can be concluded that the presence of nanosilica in the GFRP composites helps to prolong the deflection. Due to the large displacements, nanosilicaalso progressively increase the stiffness of GFRP composites. According to Jaganathan [10], the presence of silica nanoparticles into the epoxy matrix of GFRP reduced the matrix cracking and also retarded the crack growth rate in the composite leading to enhanced fatigue life.

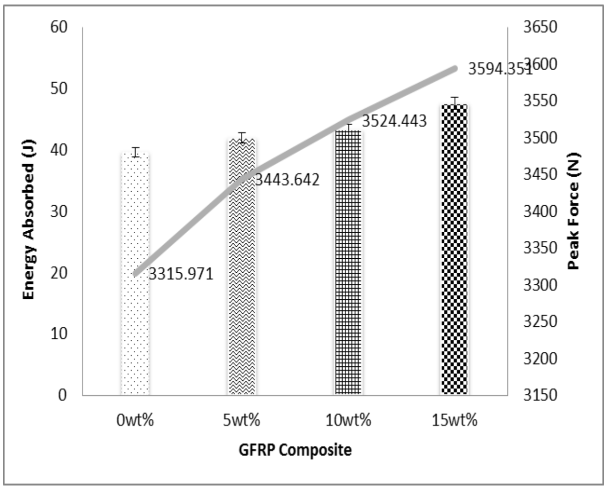

Fig. 2: The effect of weight percentage of nanosilica filler on energy absorbed and peak force of GFRP composite laminate

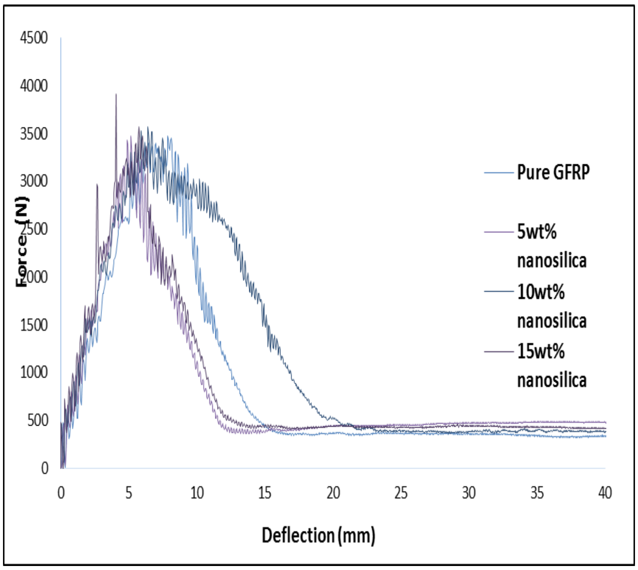

Fig. 3: Force-displacement curves for unmodified and nanomodified GFRP

3.4. Quasi Static Indentation Test

Fig. 4 shows the energy absorbed and the load for different sample of GFRP for quasi-static indentation. The energy absorbs and force of nanosilica modified epoxy system showed that the energy absorbs of the composite increased with additional of nanosilicacontent. Energy absorbs of unmodified system is 2.44 J with the peak force of 1.964 kN. The energy absorbs increased up to 13.4% for addition of 15wt.% nanosilica. The peak force increased to 2.767kN for 15wt.% nanosilica.

Fig. 5 illustrated the load- displacement characteristics of unmodified and nanomodified GFRP. The absorbed energy (E) denoted by the area under the load-displacement curve was obtained directly from the machine. All curves showed similar trend in terms of indentation responses. There are three sections for typical quasi-static indentation test where section A involves the elastic bending, matrix cracking and initiation of delamination of the GFRP composite laminates. Section B involves the delamination and indentation effect, formation of penetration and reduction of stiffness. In the last section C, the perforation and friction completed the composite laminates indentation behaviour.

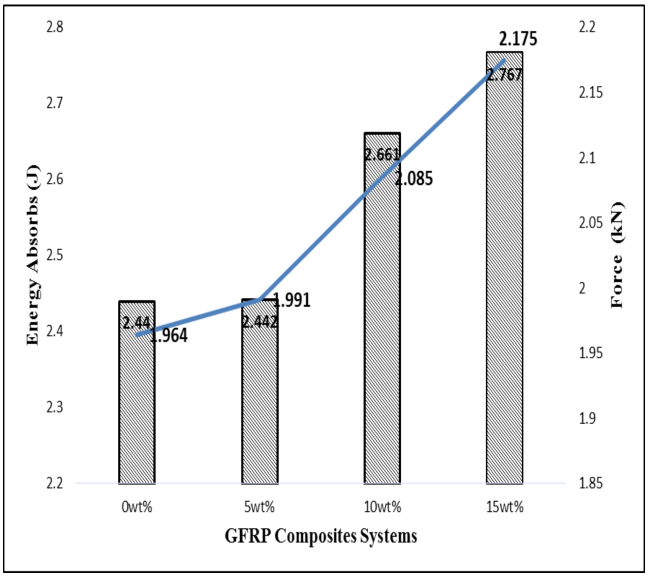

Fig. 4: Energy absorbed and load for different sample of GFRP for Quasi Static Indentation

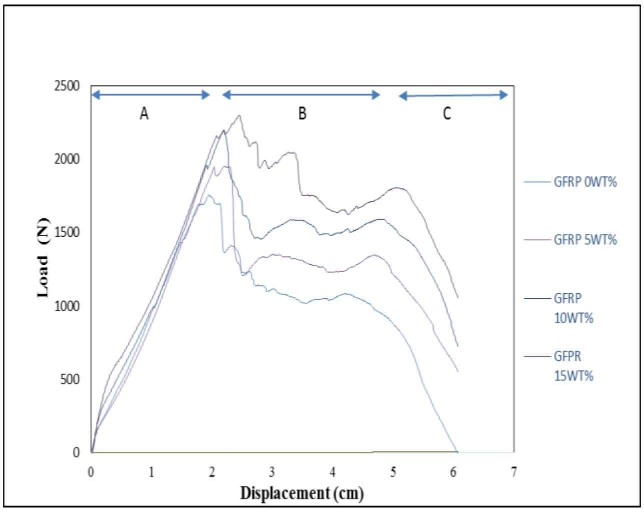

Fig. 5: Load-displacement curves for unmodified and nanomodified GFRP under quasi static indentation

3.5. Micrograph Observations

The impact and indentation damage were observed under the optical microscope for unmodified and nanomodified GFRP composite laminates. Fig. 6 presents the damage for both drop impact test (Fig. 6a and 6b) and quasi-static test (Fig. 6c and 6d). It can be seen that the damageswere observed only at the impacted or indented area. The impact and indentation loads caused the fiber breakage, matrix cracking and ply delamination fracture mechanisms, as shown in Fig. 6. The damage area was reduced with the addition of nanosilica into the GFRP composites as shown in Fig. 6b and 6d under the impact load and indention load, respectively. A smaller fractured area was observed when the GFRP composites were tested under indention tests (refer Fig. 6c and 6d) when compared to a sudden load under impact test as shown in Fig. 6a and 6b.

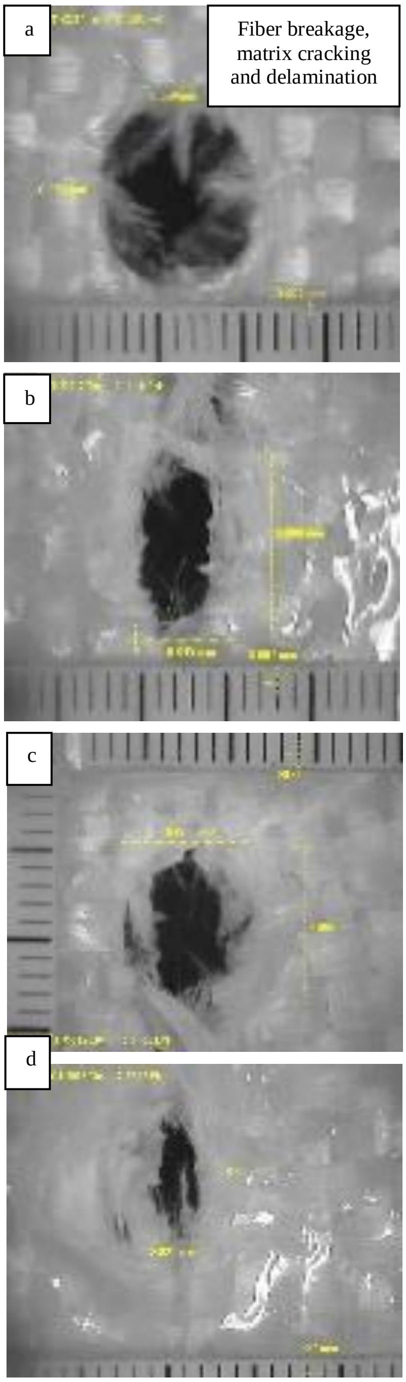

Fig. 6: Damage patterns of GFRP composites laminates under drop impact test (a) unmodified GFRP (b) modified GFRP,and under Quasi static indentation test (c) unmodified GFRP and (d) modified GFRP

4. Conclusion

The indentation and impact behavior of unmodified and nanomodified GFRP composite laminates were investigated. The damage chracteristics in the GFRP composites structure were determined by observing the fracture surfaces of the specimens using optical microscope. According to the results, the following conclusions can be deducted from the present study:

- The addition of nanosilica into the epoxy polymer significantly affects the indentation and impact response (force and absorbed energy) when compared to unmodified composite.
- Indentation and impacted area around the indenter resulted in a significant reduction in load bearing capacity. The failure mechanisms involved were fiber breakage, delamination and matrix cracking.
- Unmodified GFRP composite laminates showed a poor indentation and impact resistance which could be improved by the addition of silica nanofiller.

Acknowledgement

The authors would like to thank the Institute of Research Management and Innovation (IRMI), UniversitiTeknologi MARA (UiTM), Institute of Graduate Studies (IPSIS) UiTM and Ministry of Education Malaysia for the financial support. This research work was performed at the Faculty of Mechanical Engineering, UiTM Shah Alam Selangor Malaysia under the support of BESTARI research grant no. 600-IRMI/DANA 5/3/BESTARI(0006/2016).

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