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Research paper

Review on low velocity impact of nanocomposite in addition of nanoclays

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Abstract

Many exciting new materials that generated with novel properties with rapidly growing field as nanocomposites. Hybrid materials such as polymer nanocomposites has at least one dimension in the nanometer range are made of dispersed inorganic filler in an organic polymer matrix. When a small amount of filler is used, the macroscopic properties of the polymer will strongly modified. Furthermore, the nanofillers will has a greater aspect ratio. Therefore, nanocomposites usually have better properties such as higher mechanical properties and thermal stability compared to neat polymers. Aerospace, automotive, electronics, and biotechnology industries offered the new technology and business opportunities by applications of nanocomposites due to its environmentally friendly properties. The results of an experimental presents the low velocity impact made on different composite with an addition of nanofillers. A drop weight testing machine are used to evaluate composites behaviour with different nanoclay content. In conclusion from this review, nanoclay loading with 3% shows the best properties among the other loading with least damage area and lowest absorbed energy.

Keywords: *low velocity impact; nanocomposites; nanofiller; nanoclay.*

1. Introduction

Many engineering applications are widely using composite structures due to their unique properties that are suitable to replace the traditional metals. Extensive use of composites in industries such as aerospace and military has increased with improved mechanical properties such as high composite strength to weight ratio, fatigue and wear resistance, and also formability of complex shapes [1-2]. In the meantime, the consideration of nanoscale particles utilization been taken recently. The synergistic combination of functional fillers with the highly processed polymer affects the composite systems, which can offer various functionalities that enlarge their application area [3-4]. Over the past decades, studies on few types of nanocomposites have been carried out by the researchers since nanoclay/epoxy nanocomposites manufacturing in 1993 [5] and carbon nanotubes in 1991 [6]. Several unique properties of the nanocomposites including high elastic modulus [7-8], high tensile strength [9], thermal resistance, flame retardancy, high fracture toughness [10], dimensional stability and optical properties [11], and water resistance [12] can be increased by adding small amount of nanofillers.

There is a big potential for the fibre-reinforced polymers known as high-quality materials in electrical and high-tech, along with military applications. On the other hand, the applications are still limited to smaller parts made of reinforced plastics such as the bridge deck, reinforcement bars, girders, handrails or staying cables for fibre-reinforced plastics [13-19]. Extensive improvements have been found with advantages added of lightweight, high strength to weight ratio, improved dimensional stabilities and also excellent weathering stabilities in mechanical behaviours of the fibres reinforcement upon polymeric matrix [20].

2. Nanocomposites materials

The improvement in material properties has attracted great attention of polymer nanocomposites in industry and academics compared to conventional micro or virgin polymer and macro composites [21-24]. Desired mechanical properties of conventional composites can be achieved by high content (>10%) of the inorganic fillers. The density of the product increased by high filler levels, which then causes the deterioration in properties between the filler and the organic material through interfacial incompatibility. In addition, as the filler content increases, the processability will also decreases. In comparison, a small amount of layered silicate (65%) can improved the thermomechanical properties of nanocomposites.

Outstanding mechanical properties of polymer nanocomposites are known with very small addition (65 wt%) of nano particles comparable to its strength improvement, higher modulus elasticity [21-23], barrier resistance [24], retardancy of flame [25-26], and others due to the huge surface area between nano filler and polymer matrix interaction. Clays had been paid special attention in the field of nanocomposites among the various nanofillers. Nanoparticles have been widely used in polymer matrix composites as reinforcements because their convenient properties compared to corresponding microfillers, including ease of processing and advanced materials improvement at 1-5% volume fractions [27].

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3. Preparation of low velocity impact sample and testing

A new method has been reported that nanoparticles or tri block-copolymers addition into the thermoset matrix can avoid the delamination with good toughness of polymer matrix. Type of damage as in Figure 1 can be prevented by using a tough matrix since the delamination is initiated by the bridging of matrix cracks and the extension. Impact applications often use the composite materials [28]. Fibre breach, delamination and matrix cracking can be caused by the low velocity impact as the matrix cracks initiate the damage has been an evidence for new study. A reversed pine tree has characterized by damage such as ply boundaries delamination and matrix cracks [29]. High contact stresses will initiate the matrix cracks on the surface of the specimen, especially for the stiffer specimens. A pine tree damage propagation through the other plies from the top surface to the bottom one [30].

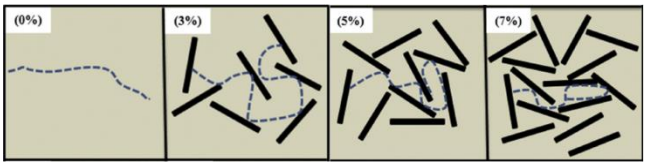


Fig. 1: Theoretical picture of more delimited crack propagation with increasing the weight percentage of nanoclay: a) 0 wt%, b) 3 wt%, c) 5 wt%, and d) 7 wt% (the crack growth path shows by dotted lines while the black rectangles shows the nanoclays [65]

Nanoclay utilization as the filler in polymers has attracted many researchers' extensive attention due to thermal, dynamic, the advanced static, flame retardant and gas barrier properties of the resulting composites [31-32]. Highest energy absorbed and highest emerging energy have been shown by composites with 3 wt% clay compared to 0 and 5 wt% according to findings by Iqbal *et al.* [33]. The least damage area is shown with 3 wt% clay distinguished while the impact energy increased by the increasing damage. The damage initiation and propagation inside the fibre based nanocomposites excited by addition of nanoclay with higher damage areas has been found by Aymerich *et al.* [34] and Esfahani *et al.* [35]. Substantial effects on the load bearing properties and damage resistance have been found when the fibre reinforced epoxy clay nanocomposites undergoes the low velocity impact tests. A possible reason for this behaviour is also schematically illustrated in Figure 1.

Anbusagar used sonicator mixer to produce nano-modified polyester resin. Using the sonicator, polyester and nanoclay were mixed for 30 minutes for every polymer matrices group and added curing agent with a suitable amount and mixed for an extra 5 min. For hand lay-up processing, the air bubble must be removed after the mixing process by allowing the nano-dispersed pre-polymer to rest awhile [36]. Table 1 shows the list of different processing method of composites with different nanoclay type. The typical processing methods as listed in Table 1 are to disperse the clay layers in epoxy matrix via sonicator mixer [36], ultrasound sonication, mechanical stirring [37-38,42], high shear mixing [39-40,42,64], ball milling [41] and high speed agitation [58]. Even though exfoliated morphology is produced, Zunjarro *et al.* [38] have reported that better mechanical properties are yielded via high-speed shear mixing compared to ultra-sonication.

Referring to Table 1, three roll mills were found by Yasmin *et al.* [39] that high levels of exfoliation and dispersion of clay particles was achieved the efficient way for epoxy clay nanocomposites processed within a short period of time. Increasing of clay concentration was found by increased of nanocomposites modulus. Chen *et al.* [42] use the combination of high shear mixing and ultrasonication to prepare the silicate epoxy nanocomposite layered by a fully exfoliated in the presence of acetone. Process of epoxy-DDS-clay nanocomposites were reportedly showing dramatic increase in fracture toughness by using high-pressure mixing method compared to direct mixing method [43]. Ngo *et al.* [44] had studied the effect of speed, temperature and time at the pre-mixing step epoxy resin with clay during the exfoliation and dispersion on intercalation. The intercalation/exfoliation of nanoclay during the curing step gives the positive effect even though the intercalation of organoclay at the pre-mixing step does not show any significant effect on above premixing parameter.

Table 1: Different processing method of composites

Processing method	Composites		Reference
	Filler	Resin	
Sonicator mixer	Nanoclay	Polyester	36
Ultrasound sonication and mechanical stirring	Nanoclay	Epoxy	37
	MMT clay	Epoxy	38
Three roll mill and high shear mxing	Cloisite 30 B clay	Epoxy	39
High shear mixing	Organoclay and unmodified clays	Epoxy	40
	Nanoclay		64
Ball milling	MMT clay	Epoxy	41
High shear mixing and ultrasonication	Silicate nanoclay (MMT)	Epoxy	42
High pressure mixing	Clay	Epoxidized soybean oil	43
Sonicator, magnetic stirring and three roll shear mixer	MWCNT and nanoclay	Epoxy	66
High speed agitation	Nanoclay and graphene	Epoxy	58

4. Result and discussion: Low velocity impact

Several researchers' findings of nanoclay addition in their composites tabulated in Table 2. Different finding with different fibre and resin used along with different nanoclay loading. Some findings have found the nanoclay best loading with 3% support with Iqbal *et al.* [33], Aymerich *et al.* [44] and Esfahani *et al.* [45]. Anbusagar *et al.* [46] stated that nanoclay addition by 2% and 4% has resulted in increased load in impact graph of load vs. time represented in Figure 2. Meanwhile, Ahmad *et al.* [64] found that 1.5% of nanoclay showed the lowest absorbed energy, which explained the uniformly distributed dispersion of nanoclay with epoxy.

Table 2: Different findings for nanoclay content

Author	Fibre	Finding
Iqbal *et al.* [33]	Carbon fibre	3 wt% clay show the highest emerging energy and highest energy absorbed showed by composites with compared to 0 and 5 wt%
Aymerich *et al.* [44] and Esfahani *et al.* [45]	Epoxy	3 wt% clay distinguished the least damage area while the damage increasing along with impact energy increased.
Reis *et al.* [51]	Epoxy	Nanoclay promoted the best performance, lower displacements, higher impact loads in terms of maximum residual tensile strength and elastic recuperation
Anbusagar *et al.* [46]	Glass fibre / polyester	The addition of nanoclay by 2 and 4 wt%, results in the increase in peak load.
Ahmad *et al.* [64]	Glass fibre / epoxy	Samples with clay loading of 1.5 wt% showed the lowest absorbed energy that related to the uniform dispersion of nanoclay.

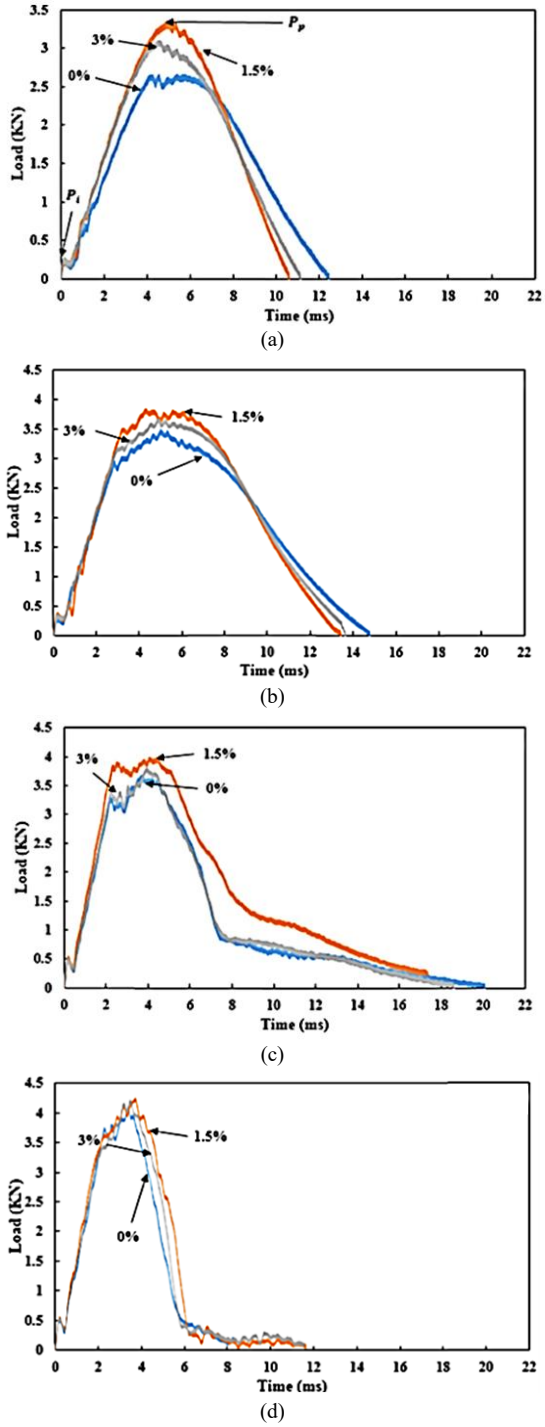


Fig. 2: Load vs time curves of samples impacted with (a) 10 J (b) 20 J (c) 35 J and (d) 50 J [45]

Based on Figure 2, the load vs. time response of the composites as illustrated by Ahmad (2017) when the different clay loading was subjected to drop weight impact. The first material damage such as matrix cracking or interface failure identified by the first sudden drop in the load-time curve, which is presented usually at/or near the back face of composites known as incipient load, Pi [45]. The first sudden load is also a sign of failure in the composites of fibre-matrix interface or the internal delamination beginning [63]. As shown in Fig. 2(a), the performance of clay loading sample of 1.5 wt% has higher values compared to that of 3.0 and 0.0 wt% which apparent in peak loads of these composites. This impact resistance can be improved by the nanoclay addition since the variation on clay loading of the samples only. Based on Fig. 2d, impact energy of 50J shows no recovery that indicated complete penetration after the sharp drop in the graph. Higher damage [46] in Fig. 2(a) to Fig. 2(c) shows the increasing in duration of impact until it decreases in impact period at Fig. 2(d). This is due to consequence of higher impact energy acting as higher impulse, causing substantially greater localized damage [47]. Baseline composite with similar impact responses has been reported by several researchers [48]. The rapid vibration causes the impactor and the composite body to excite and the oscillation occurs within the force time profile [49, 50]. Improved contact force 29% has resulted from the addition of nanoclay with 3wt% in the epoxy resin as shown by Reis *et al.* [51]. Nanoclay promotes the best performance, lower displacements, higher impact loads in terms of maximum residual tensile strength and elastic recuperation according to the studies of Reis *et al.* [59-61].

Flexural stiffness known as force-displacement regime in Figure 3(a) and Figure 3(b) is shown in the impact force vs penetration displacement for neat and nanoclay composite systems. The displacement of 10 wt% NC-reinforced composite panel is the minimum while the displacement of the baseline panel is the maximum. The average displacement reduction is ~17%. Thiagarajan stated that the most effective filler is nanoclay among his studies of the nanofillers. The packing density of the epoxy matrix is increased by the fine nanoclay suggested by his observation, which is effective in the impact resistance application [53]. Fig. 3(b) depicts the curves of the force displacement slop, which represents the comparison to the stiffness. During the impact process, the impact composites bending stiffness is presented by the slope [54]. The increase in composite panel stiffness is resulted from the nanoclay addition. The samples' stiffness has changed with damage initiation and growth provided by the curves [62]. Flexibility and brittleness has increased while elastic deformation reduced with the nanoclay addition due to reduction of the displacement.

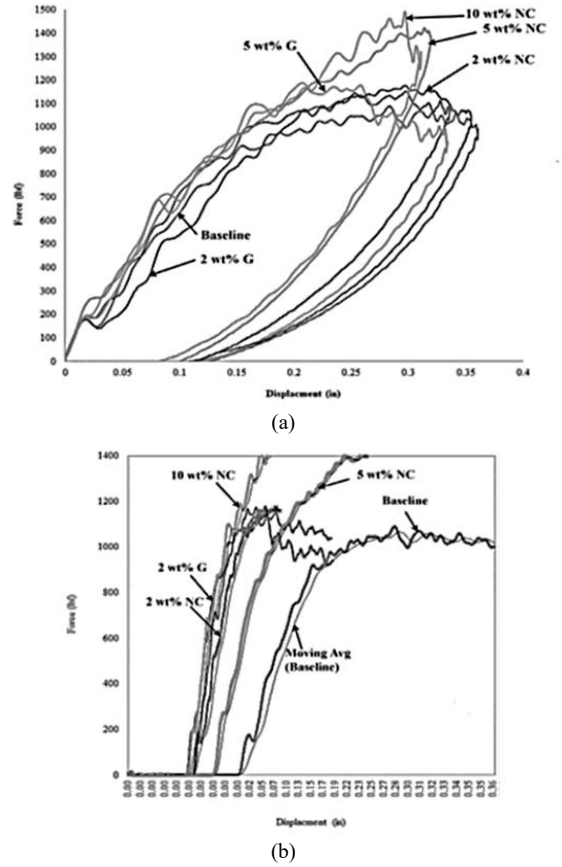


Fig. 3: Graph of nanoclay loaded composite panels: a) impact force vs. displacement, and b) profile of moving average and slope of force displacement profile [52]

Figure 4 shows an illustration of the impact energy with time for four different energy level. As depicted in Figure 4(a) and Figure 4(b), the energy absorbed by the composites will never equal with the impact energy until it reaches the threshold for penetration.

Figure 4(c) and Figure 4(d) show the specimen absorbed the energy since the start of the flat-line to the end of impact event. The impact energy of 35J in Fig. 4(c) shows that the 1.5 wt% sample still has some finite amount of elastic energy available and absorbed less energy. That is means the sample still can absorb more energy since the sample has higher energy gap of 1.5 wt% before complete failure occurs as shown in Fig. 4(d). The situation is the same when the samples have higher damage resistance and also slightly higher of energy gap at 50 J impact energy the clay [55]. Damage will be created when the excess energy is consumed and attribute the energy consumer by energy absorbed since no plastic deformation in composite materials category [56]. The delamination resistance increases with the addition of nanoclay by the increasing of interlaminar shear strength and delamination is the most dominant energy absorption mechanism in impact scenario according to Iqbal [33] and Alomari [34].

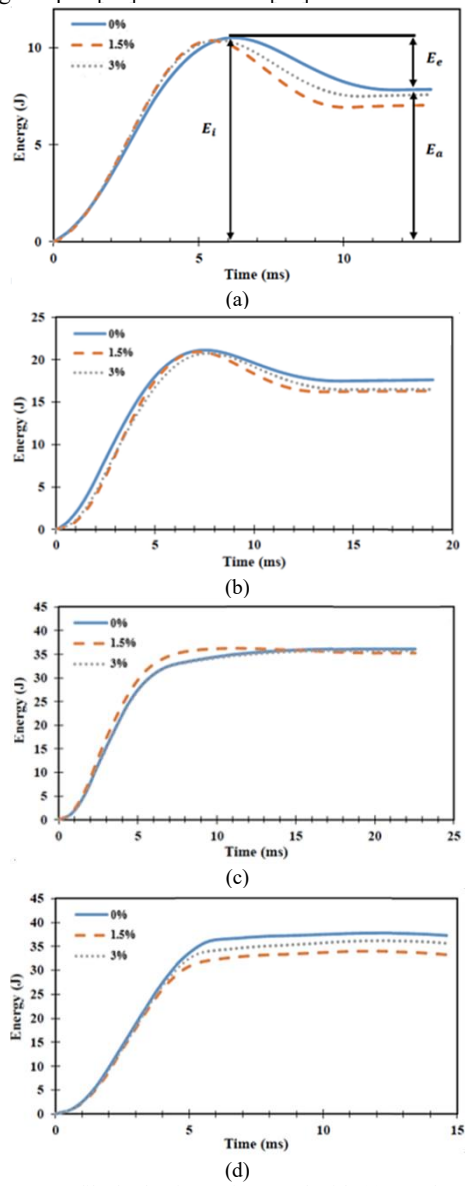


Fig. 4: Energy profile for laminates impacted with (a) 10J (b) 20J (c) 35 J and (d) 50J [55]

The energy-time response for baseline and nano-filled composites is presented in Figure 5 at 32J impact energy. From the width of the peak along the baseline, the average impactor contact time is measured by individual impact energy profile. This value shows the tolerance with the elastic modulus of an individual composite panel. The higher nanoclay content up to 10wt% is discovered to be the lowest with the maximum baseline composites. Eslam also reported the same results [57]. The elastic modulus is raised with the nanoclay content shows a decrease in contact time. The energy profile starts to fluctuate at the end of the contact time and overlapped with the energy absorbed. After the impact, the residual energy and the impact are different between it. Figure 6 shows the absorbed energies for different composites and the energy absorption capability added up by nanoclay content. The impact resistance of composites increases with the nanoclay addition. Highest impact load is obtained with the 10% of nanoclay content in epoxy composite, which is 26% more than the baseline while most of the energy improved with 24%.

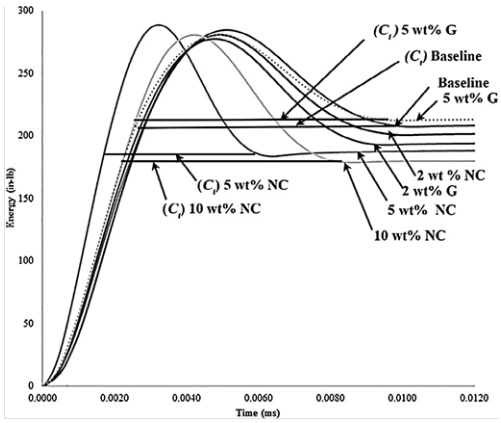


Fig. 5: Energy vs time response of baseline and nano-filled composites [52]

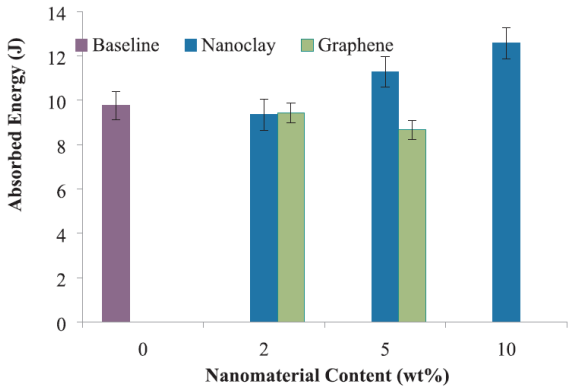


Fig. 6: Absorbed energy of baseline, and nanoclay loaded composite panels at 32 J impact energy [52]

5. Conclusion

The effect of nanoclay/epoxy on the low velocity impact has been studied in this paper. Data of nanoclay/epoxy on the low velocity impact has been presented in graphs of impact load-time, force-time, force-displacement, energy-time and velocity-time response. Nanoclay has been discovered by many researchers and has been proven to result in the best performance in terms of penetration threshold and elastic convalescence. The impact behaviour of the composites has been improved by nanoclay based on this study. Nanoclay with 3% loading shows the best performance compared to other nanoclay loadings. It also shows the least damage area is obtained with 3% nanoclay content. This is because of the barrier property of nanoclay platelets that reduces the damage area to a smaller region. Furthermore, the energy absorption capacity is also increased with the addition of nanoclay during low energy impact tests.

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