Impact response of Napier fibre reinforced nanomodified epoxy composites

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Abstract. The effects of nanoclay filler content on the impact properties of Napier fibre reinforced epoxy composites were investigated. The natural fibre based composites were fabricated using either untreated or 5% alkali-treated Napier fibre along with nanomodified epoxy resin which consists of various nanoclay filler contents which were 0, 3, 5 and 10 wt%. The composites were manufactured using cold compression moulding process. Morphological analysis was then conducted to further analyse the fractured specimens following the impact test. The maximum impact properties were recorded by the treated Napier fibre reinforced nanomodified epoxy with 3 wt% of nanoclay filler content. The SEM image of the Napier fibre reinforced nanomodified epoxy composites at the optimal nanofiller content also exhibited excellent interfacial adhesion between the epoxy matrix and the fibre reinforcement.

Keywords: Composites; nanoclay; alkali treatment; impact properties; natural fibre

1. Introduction
The development of natural fibre based polymer composites can be enhanced by means of fibres modification through chemical treatment or by incorporating interfacial additives within the polymer matrix [1]. This is important since many problems always occur at the interface between the hydrophilic natural fibres and the hydrophobic matrix polymer due to the incompatibility issues [2]. Commonly used chemical treatment is alkalinisation by using Sodium Hydroxide (NaOH) solution, which can reduce fibres' moisture absorption property and improve fibre-matrix interfacial adhesion characteristic. On the other hand, manipulation of desired properties on the matrix polymer can be achieved by adding a small percentage of nanofiller particles such as nanoclay and carbon nanotube (CNT). This most recent and advanced approach has been successfully proven in ameliorating the polymer matrix properties. It has been established that the introduction of nanoscale particles below than 10 wt% effectively modified the matrix epoxy with enhanced mechanical, morphological, thermal and electrical properties, comparing to traditional composites [3]. Therefore in this study, an investigation was implemented to analyse the effect of hybridisation between nanoclay filler particles and natural Napier fibre reinforced epoxy composites through an impact test analysis. Different amounts of nanoclay filler content were incorporated within the composites starting from 0 wt% then, 3, 5 and 10 wt% in order to determine the optimal value. Raw and 5% alkali-treated Napier fibres were also used in this experiment to differentiate their results towards the impact properties. By thoroughly elucidating the impact of properties of the cost-effective and environmental friendly of Napier fibre reinforced nanomodified epoxy composites, this study is profoundly expected to produce supportive manifestation for future development or application.
2. Materials and methods

2.1. Materials
The fabricated composites in this investigation consisted of Napier fibre, nanoclay filler additive and polymer epoxy. The Napier grass stems were supplied by a local farmer from Beseri, Perlis, Malaysia. Napier fibres were extracted from the internodes of the stem through a process called water retting [4–6]. During the water retting, the stems were fully immersed in water for almost a month before the extraction of the fibres was manually done. Some of the extracted Napier fibres were then treated with the alkali solution in order to prepare the treated fibres. The treated Napier fibres were formulated based on previous studies [7,8]. Hence, alkali solution with the optimal of 5% concentration was applied towards the natural fibres to remove the impurities and improve their surface. Next, the nanoclay filler used to modify the polymer epoxy is Montmorillonite type, which was supplied by the Sigma Aldrich Corporation. The surface of the supplied MMT clay has been modified with 25-30 wt% of trimethyl stearyl ammonium, making the nanofiller scale particles more compatible with the polymer epoxy. Lastly, the polymer epoxy employed in the development of the composites was obtained from Smooth-On Inc. Company.

2.2. Composites fabrication
In preparing the composites for the impact test, a mould was specially designed to produce laminates of size 300 mm × 300 mm with the thickness of 5 mm. A thin layer of mould releasing agent was first applied to the whole surface of the mould several times. The weighted unidirectional Napier fibres were then arranged into the form of a mat in accordance with the size of the mould and placed into it. The process continues by mixing the weighted nanoclay filler particles into the required weight of the epoxy resin. Once the nanomodified epoxy was readily prepared, the hardener was then added into the mixture to form a completed polymer matrix system which then evenly poured into the mould containing the fibres mat. Then, the mould was closed before completely pressed by the compression machine. Finally, a series of rectangular plates, containing untreated and alkali-treated Napier fibres with 0, 3, 5 and 10 wt% nanoclay content were obtained for impact characterisation.

2.3. Impact test
Specimens in the form of rectangular shape with dimensions of 55 mm × 10 mm × 5 mm were cut from the produced composite plates using the 4000 Dremel cutter tool as preparation of the Charpy impact test. A ‘v’ notch was then made on every test specimen. This test was performed on the 50 J Charpy Impact Tester and conducted in accordance with the ASTM D6110 standard [9]. The energy absorbed and the impact strength of the composites are properties that were obtained and analysed from this impact test.

2.4. Morphological observation
In conducting an in-depth investigation of the fractured modes of the specimens following the impact test, therefore it was conducted using a Hitachi TM-3000 scanning electron microscope (SEM). In order to do the observation, small pieces from the fractured area of the composite specimens were firstly cut out as preparation in performing the SEM analysis. Then, they were uniformly coated using platinum prior to the scanning process.

3. Results and discussion
The results from the impact test were then summarised in the graph below. Figure 1 shows the energy absorbed and the impact strength of the test composites against nanoclay content. Clearly, from the graph, the energy absorbed and the impact strength was substantially displayed by the composites incorporated with 3 wt% of nanoclay content. Results show that 9.19 and 12.64 J of energy absorbed was revealed by the untreated and treated composite, respectively. Therefore, approximately 74 and 69% increment achieved by the untreated and treated composite respectively compared to when both of them were in the unfilled state. While the impact strength at the optimal nanoclay content obtained by the untreated and treated composites were 29.46 and 43.14 kJ/m², respectively. This means 59%
improvement stated by the untreated composite and close to 72% enhancement by the treated composite if compared to their similar composites when they were at 0 wt% of filler content. These were due to the development of the polymer composites from the hybridisation of natural fibre and nano-sized filler particles which reduced voids and improved their mechanical properties compared to the traditional natural fibre reinforced composites [10].

Still, increasing the nanoclay filler beyond the optimal value had resulted in an inconvenient situation where the impact properties of the developed composites abruptly dropped. The cause for the drop in both the energy absorbed and the impact strength of the composites can be attributed to the increment in the nanoclay loading. Introducing higher concentration of nanoclay filler content during fabrication of the composites yielded in the formation of agglomerated nanofiller particles, causing high-stress concentration zones where could act as the internal flaw within the composites [10,11]. This situation could lead to the embrittlement of the composites, weak interfacial interaction and improper adhesion between the nanofiller and the matrix. Hence, incorporating a higher amount of nanoclay fillers during the development of composites would prevent the nanofiller from functioning effectively. In fact, it reduced the energy absorption capability and impact strength of the developed composites.

Though, it can be seen from the figure that the alkali-treated fibre had a significant influence over the untreated fibre on increasing the energy absorbed from the impact test. This was due to the enhancement in the fibre-matrix interrelation. Indeed, at 0 wt% of nanoclay content, the treated fibre reinforced epoxy composite exhibited higher energy absorbed which was 7.49 J compared to the untreated composite at the same nanoclay content, 5.29 J which close to 42% improvement. Similar observation goes to the impact strength of the developed composites. The treated composites revealed higher impact strength at all nanoclay contents if compared to the untreated composites. From the results obtained, it can be suggested that the untreated composites had more inadequate fibre-matrix interfacial bonding as compared to the treated one. Unlike the treated fibres, raw fibres consist of hemicellulose, wax, oil, lignin and impurities that degenerated the interrelation between them and the epoxy polymer. The situation became worse due to the hydrophilic nature of the natural Napier fibres reduced the degree of compatibility between them and the hydrophobic epoxy polymer, which subsequently deteriorated the strength of the composites.

![Figure 1](image_url). Impact properties of the developed composites against various nanoclay contents.
4. Fractured surface morphology

The effect of different nanoclay content can be observed by the dispersion of the nanoscale particles through the SEM analysis, as shown in Figure 2 below. Unfilled composites exhibited a smooth surface with the presence of void as shown in Figure 2 (a), indicating a brittle behaviour and poor resistance to impact force, thereby resulted in low impact strength of the developed composites [13]. Composites with 3 wt% of filler content, however, showed rough surface and reduced void as depicted in Figure 2 (b), implying better mechanical properties. This observation was in accordance with previously reported work [10]. The morphology of the composites with the optimal nanofiller content also demonstrated fibre bending and damaged end fibre, which reflected more impact energy consumed in order to break the composites. On the other hand, composites incorporated with 5 and 10 wt% of nanoclay content displayed relatively rougher surface and unevenly agglomerated nanoclay particles as can be observed in Figure 2 (c) and (d). More bubbles and voids were also observed in both of the developed composites due to the higher viscosity of the epoxy-clay mixture during their fabrication process, suggesting poor fracture resistance. In addition, pull out traces indicated the embrittlement of the composites owing to the higher concentration of nanoclay content.

5. Conclusion

The effects of various nanoclay content on the impact properties of untreated and 5% alkali-treated Napier fibre reinforced composites were investigated. The highest energy absorbed and impact strength of the developed composites was recorded when they were introduced with 3 wt% of nanoclay content. This was due to the homogenous dispersion of the nanoclay filler particles which successfully functioned in improving the impact resistance of the composites. Beyond the optimal content, however, observing the reduction of the impact properties of the composites. Treated composites yield the greatest performance in this investigation due to the better interrelation between the fibre and the epoxy matrix.

Figure 2. Fractured surface morphology of the developed composites.
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