Technical Article 2

Utilization of Natural Fiber Towards Structural Applications Under Dynamic Loading Through Multi-Walled Carbon Nanotube (MWCNT) Enhanced Polymer Nanocomposite

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Abstract

Recently the sustainable manufacturing concept is emphasized to maximize the development and benefits without depletion of the resources. Natural fiber reinforced polymer composite (NFRPC) has the potential to replace non-ecofriendly material due to its wide availability, low cost and light weight. However, its mechanical properties under various strain rate, especially at low range of strain rate are still vague. From studies, NFRPC underwent fracture from crack initiation and propagation at crack tip due to its viscoelasticity at low strain rate. Therefore, this research investigated the insight on low strain rate behavior of NFRPC particularly for Oil Palm Empty Fruit Bunch (OPEFB) fiber-epoxy composite under dynamic loading condition and its possible enhancement by MWCNT (Multi-Walled Carbon Nanotube) utilizing Weibull analysis. In the low strain rate range of 0.0005 s^{-1}, 0.005 s^{-1} and 0.05 s^{-1}, it was observed that 5 wt% of filler loading with the largest 39.5 % tensile strength improvement confirmed the better interaction and tress transfer capability by palm oil fiber in composite. Interestingly, 0.1 wt% MWCNT enhancement had the highest 14.8 % tensile strength improvement but decreased after 0.1 wt% due to filler agglomeration. Weibull modulus and Weibull scale parameter acted as strain rate sensitivity evaluator and MWCNT-NFRPC was found more sensitive in terms of fracture probability and characteristic strength than NFRPC without MWCNT. Such MWCNT enhanced NFRPC composite would pave the way towards structural application under dynamic loading exposed to low strain rate condition.

Introduction

Recently, the sustainable manufacturing concept is emphasized to maximize the development and benefits without depletion of the resources. Challenges of reducing the emission of carbon dioxide throughout the whole life cycle of a product can be overcome by using sustainable materials [1]. Sustainable material is made up of renewable resources and it has the potential to replace some non-ecofriendly materials. Application of sustainable materials such as natural fiber in polymer composites, particularly biodegradable NFRPC is widely explored instead of synthetic fiber due to its ecofriendly properties, light weight and low cost. Interestingly, oil palm as being major agricultural plant in purpose of deriving palm oil from the mesocarp of fruits is widely available in Malaysia where this is an enormous source of natural fiber. Hence, it is one of the potential fibers to be used in reinforcing polymer especially due to excellent strength-to-weight ratio [2]. However, its mechanical performance is depending on its strain rate sensitivity due to viscoelasticity properties. High strain rate which is ranging from 200 to 10^5 s^{-1} means short time deformation. Meanwhile, long deformation time for low strain rate is below $0.1s^{-1}$ [3]. From previous studies, tensile strength of NFRPC at low strain rate is lower than that at high strain rate at which it experiences crack initiation and propagation at crack tip and resulting in lower fracture toughness [4]. Composite at high strain rate does not have sufficient time to form defect and hence, high energy is required to break it. Whereas strain rate will deform elastically and internal defects will form easily which promotes the crack propagation. However, there is limited research on the low strain rate behavior of NFRPC under dynamic loading. One of the ways to understand such behavior is through Weibull modulus and scale parameter in Weibull analysis which is a good strain rate sensitivity evaluator to measure its strain rate sensitivity in terms of failure consistency and characteristic strength. Interestingly, MWCNT has the potential in enhancing NFRPC due to its high aspect ratio nano-sized filler which can improve adhesion and interfacial bonding, thus, increasing its fracture toughness. Therefore, this research gives an insight on low strain rate behavior of NFRPC particularly for palm oil EFB fiber-epoxy composite and its possible enhancement by MWCNT utilizing Weibull analysis.

Investigation Procedure

Experiments were conducted with 5 wt% of palm oil EFB fiber-epoxy composite testing under ASTM D638 tensile test with low strain rate in the range of 0.0005 s^{-1}, 0.005 s^{-1} and 0.05 s^{-1}, respectively. The detailed method was reported in authors' previous research [5]. Morphology evolutions from these experiments were studied using SEM.

Discussion on Characteristic Strength with Strain Rate

In the low strain rate range of 0.0005 s^{-1}, 0.005 s^{-1} and 0.05 s^{-1}, it was observed that 5 wt% of filler loading with the largest 39.5 % tensile strength improvement confirmed the better interaction and stress transfer capability by palm oil fiber in composite. It is strain rate sensitive as the tensile strength decrease when strain rate decreases. Increment of Young's modulus with filler loading is because improvement of crystallinity and stiffness of the composite due to higher moduli by crystallites [6]. Lowest Weibull modulus of 15.45 at quasi-static indicated inconsistent failure probability. Characteristic strength, which was represented by Weibull scale parameter was improved by 11.63 % when strain rate increased from 0.0005 s^{-1} to 0.05 s^{-1} as shown in ***Figure 1***. This was because non-conventional NFRPC which is majorly anisotropy and heterogenous leads to random-distributed defects and uneven stress distribution. Among 0.05, 0.1 and 0.15 wt% of MWCNT enhancement on 5 wt% fiber composite, 0.1 wt% MWCNT achieved the largest (14.8%) tensile strength improvement on composite. It gave better adhesion towards fiber-matrix interaction which increased the fracture resistance for crack propagation. However, tensile strength dropped after 0.1 wt% because agglomeration of filler acted as stress concentration which eased the crack propagation. Insignificant Young's modulus change might be due to short length of carbon nanotubes at which it was unable be in contact with many polymer chains [7]. As shown in ***Figure 1***, it had slightly steeper slope or higher characteristic strength improvement of 12.72 % which depicted that its strength was more strain rate sensitive at quasi-static. This was due to excellent adhesion within fiber-matrix-MWCNT which results in effective stress transfer from matrix to fiber.

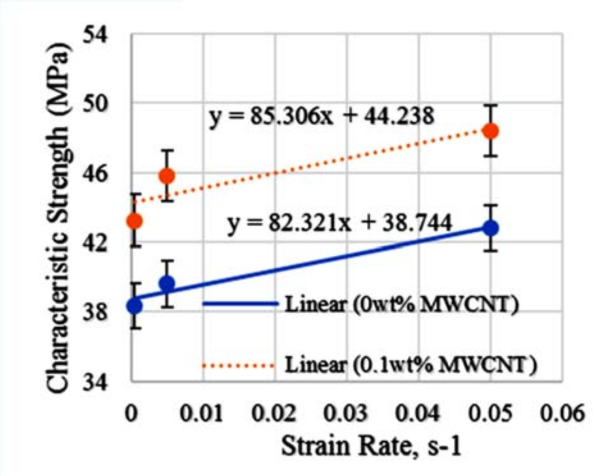

Figure 1: *Characteristics Characteristic strength of palm oil EFB fiber-epoxy composite with and without MWCNT enhancement*

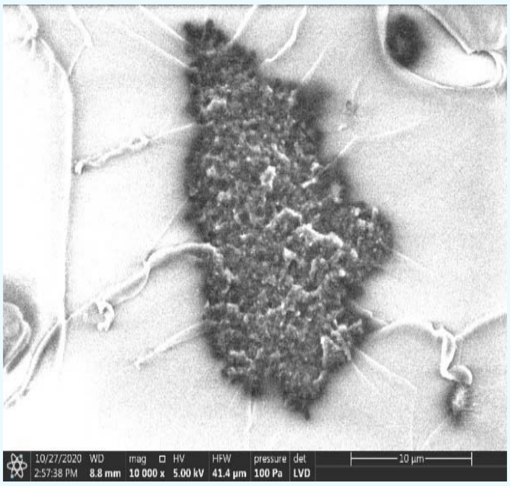

Figure 2*: SEM Micrograph of MWCNTs agglomeration site on 0.15wt.% MWCNTs composite fracture surface*

Figure 2 shows one of the agglomeration sites microstructure in 0.15% MWCNTs reinforced OPEFB (Oil Palm Empty Fruit Bunch) composite in SEM micrograph. Due to the non-homogeneously distribution of MWCNTs, the stress will concentrate at the agglomerated point and cause uneven stress distribution within the composite [8]. This leads to poor tensile performance of 0.15 % MWCNTs/OPEFB composite under various strain rates.

Conclusion

In a conclusion, it is revealed that the 5 wt% filler loading with 0.1 wt% MWCNT has performed with the effective mechanical properties. Interestingly, MWCNT enhanced composite was more strain rate sensitive in terms of fracture probability and characteristics strength due to its better adhesion towards filler-matrix interaction within composite.

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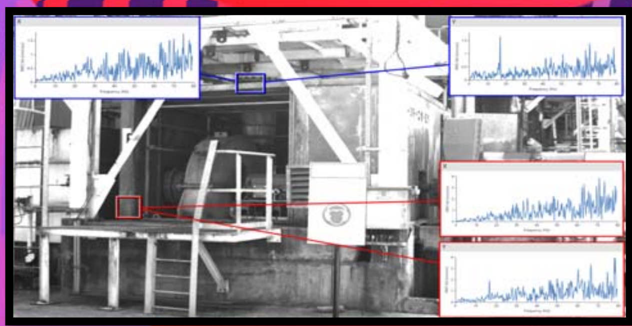
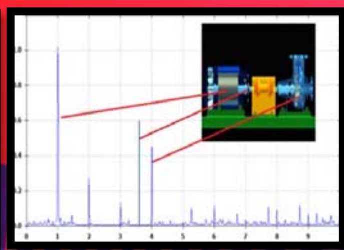
HIGHLIGHTS

- Advanced Vibration Troubleshooting on A Rotating Equipment.
- Application of FTIR Structural Analysis for Dried Coating Failure Investigation in Oil & Gas Industry.
- Utilization of Natural Fiber Towards Structural Applications Under Dynamic Loading Through MWCNT Enhanced Polymer Nanocomposite.





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