

UV radiation effect towards mechanical properties of Natural Fibre Reinforced Composite material: A Review

Shahrudin Mahzan^{1,*}, Muhamad Fitri² and M. Zaleha³

^{1,2,3} Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja 86400 Batu Pahat, Johor, Malaysia

Email: sharudin@uthm.edu.my or gd140052@siswa.uthm.edu.my

Abstract. The use of natural fibres as reinforcement material have become common in human applications. Many of them are used in composite materials especially in the polymer matrix composites. The use of natural fibres as reinforcement also provide alternative solution of usage instead of being a waste materials. In some applications, these natural reinforced polymer composites were used as the outer layer, making them exposed to ultra violet exposure, hence prone to UV radiation. This paper reviews the effect of UV radiation towards the mechanical properties of natural fibre reinforced polymer matrix composite material. The effect of chemical treatment towards the natural fibre is also investigated. One of the important features that was critically explored was the degradation of the composite materials. The influence of UV radiation on the degradation rate involve several parameters such as wavelength, intensity and exposure time. This review highlights the influence of these parameters in order to provide better solution for polymer matrix composite's development.

1. Introduction

Polymer materials have been extensively used in many applications ranging from automotive parts, furniture, housewares and many others. There are various forms of polymer materials such as plastics, rubber and fibres [1-3]. In some applications, pure polymer was used. Nonetheless, the advancement in composite materials have seen polymers are used as matrices of composite material. There are many research works have been conducted in exploring the polymer fibre as matrix reinforcement in composite materials. Two types of polymer fibres have been used namely the natural fibres and the synthetic fibres. The conventional fibres for reinforcement of polymer matrix composites usually use glass fibre, carbon and organic fibre (such as aramid) [1].

Recent years have seen the utilization of natural fibres as reinforcement in composite materials. The choice of kenaf, oil palm, jute, banana and many other natural fibres have been introduced to the polymeric matrix composite materials [4-7]. Besides reducing the cost (i.e. cost of synthetic fibres are comparatively expensive), the natural fibres offer environment safe and recycling benefits. For an example, for a 1 hectare of oil palm plantation, an oil palm industry produced about 55 tons dry matters in the form of fibrous biomass annually [8-9]. This fibrous biomass consists of lignocellulosic fibre which was extracted from trunk, fruit mesocarps and empty fruit bunch (EFB). EFB contributes about 73% of waste of which 1.1 tons of EFB has to be disposed annually from oil palm industry [10]. Instead of being unused waste, this EFB was subsequently recycled and exploited to be a potential natural fibre, hence turning it from waste to wealth as well as environment safe.



Polymers have unique responses to mechanical loads. The properties of polymer (mechanical, electrical and optical) are time dependent, and cannot be treated mathematically by the laws of either solid or fluids [11]. One of the polymers that are usually used is polypropylene (PP). Polypropylene is the simplest chemical polymer which is classified as thermoplastic. Polypropylenes are tough, flexible and water repellent but having low strength. Polypropylene pipe preferably used for potable water which some of them used above ground [12] and exposed to sunlight. It is also used for electrical insulation, cold water pipes, containers and packing sheets [12]. Although polypropylene is very similar to high density polyethylene (HDPE), it has comparatively lower density (0.9 g/cm^3) and a higher softening point enable to withstand to boiling water and much steam sterilizing operation. Polypropylene has been used at large in transportation, particularly in automotive and battery cases. It has secured of about 90% in this market as a result of the drive in automotive industry to reduce weight and cost. In addition to being lightweight, polypropylene is also provides outstanding resistance to creep and fatigue, high temperature rigidity, impact strength and resistance to corrosion. In general, 30% of polypropylene are used as fibre products, 15% as housewares and toys, 15% for automotive parts and 5% for appliance parts 1 [13].

There are three types of fibres dominated as reinforcement, e.g. fiberglass, carbon or graphite fibres, and organic fibres (the most important is generally called aramid). The choice of which fibre were used in particular applications depend on its cost and performance. Fiberglass is rather expensive fibre, carbon fibre is the stiffest of the three major fibres and aramid fibres are the toughest [1]. Natural fibres are exploited as replacement of conventional fibre such as glass, aramid and carbon, due to its low cost and their properties. The properties of natural fibres are fairly good mechanical properties, high specific strength, and non-abrasive, eco-friendly and biodegradability characteristics [14]. Table 1 shows the properties of selected natural fibres and man-made fibres.

Table 1 Properties of selected natural and manmade fibres [14]

Fibre	Density (g/cm^3)	Elongation (%)	Tensile Strength (MPa)	Elastic Modulus (GPa)
Jute	1.3	1.5-1.8	393-773	26.5
Flax	1.5	2.7-3.2	500-1500	27.6
Hemp	1.47	2-4'	600	70
Kenaf	1.45	1.6	930	53
Ramie	N/A	3.6-3.8	400-938	61.4-128
Sisal	1.5	2.0-2.5	511-635	9.4-22
Coir	1.2	30	593	4.0-6.0
Softwood Kraft pulp	1.5	4.4	1000	40
E-glass	2.5	0.5	2000-3500	70
S-glass	2.5	2.8	4570	86
Aramid (std)	1.4	3.3-3.7	3000-3150	63.0-67.0
Carbon (Std. PAN-based)	1.4	1.4-1.8	4000	230-240

Most of natural fibres are used as reinforcement of polymer in a polymer matrix composite material which is designed to achieve combination properties that will be better than properties of fibre itself or properties of the polymer. Compared to fibreglass, natural fibres are cost saving and reduce in density. However, the disadvantages of using natural fibres as reinforcement of polymer composites include the incompatibility between fibres and polymer matrices, poor moisture resistance, inferior fire resistance, tendency to form aggregates during processing, limited processing temperatures, lower durability, variation in quality and price, and difficulty in using established manufacturing process [15]. The fibre reinforced composites efficiency also depends on the manufacturing process that able to transfer stress from the matrix to fibre [7]. The fibre–matrix adhesion in composite can be improved

by doing some treatment to the fibre. The fibre treatment can be chemical treatment by using Methanol [16], or NaOH and acid [17], or hot water and NaOH [18], or NaOH and Anthraquinone solution [19], or hot water, NaOH and Ultrasonic [20]. Therefore some processes needed to overcome these drawbacks have incurred additional cost and needed to be optimised [15].

The addition of natural fibres into some of polymer is expected not only to increase the properties of the composite material, but also to retain the degradation rate. Natural fibre reinforced polymer composites which are used for outdoor environment are prone to be degraded with influence of various factors such as moisture, temperature, microorganism activities and ultraviolet radiation [15]. Natural fibre composites which are used outdoor with direct sunlight are subjected to radiation and thus break the covalent bonds in organic polymer causing colour fading, weight loss, surface roughening, mechanical property deterioration and embrittlement with more reduction in wetter condition [15]. However, it was observed that different reinforcement materials produced different surface responses under UV accelerated degradation conditions [21].

Polymer degradation is a change in the properties of a polymer or polymer based product under the influence of one or more environmental factor such as heat, light or chemical. The changes in the properties can be the changes of tensile strength, discoloration or change of shape [22]. Ultraviolet (UV) radiation is one of environmental factors that cause the polymer degraded. Ultraviolet light or ultraviolet radiation is an invisible electromagnetic radiation of the same nature as visible light, but having higher energies and shorter wavelengths [23]. Conventionally, there are three regions categorised of UV radiation band based on the wavelength, e.g. UV-A for wavelength 315 – 400 nm, UV-B for wavelength 280 – 315 nm, and UV-C for wavelength 100 – 280 nm. UV-C rays are totally absorbed by the atmospheric ozone. Only UV-A and about 10% of UV-B reached the surface of the earth [23]. Quantities of UV radiation are expressed using radiometric terminology as shown in Table 2 [24]. Radiant energy and radiant flux are the terms relating to the radiation passing through space. Radiant intensity and radiance are the terms relating to sources of radiation. Irradiance is the term which is commonly used for photobiology and radiant exposure is strictly the time integral of the irradiance, but sometimes expressed as exposure dose.

Table 2 Radiometric term and unit [24]

Terminology	Unit	Symbol
Wavelength	nm	λ
Radiant Energy	J	Q
Radiant Flux	W	Φ
Radiant Intensity	W sr ⁻¹	I
Radiance	W m ⁻² sR ⁻¹	L
Irradiance	W m ⁻²	E
Radiant exposure	Jm ⁻²	H

Fig. 1 presented a schematic diagram of the degradation of natural fibre/polymer composite due to UV exposure [15]. The polymer, which absorbs the ultraviolet radiation, modifies the chemical structure, providing molecular chain scission and/or crosslinking [15]. All scales of polymer dimension, including the monomer unit, the chain (crosslinking or chain scission), and the morphology (breakdown of tie molecules and crystal) are changed due to photo-degradation. Due to the degradation of fibres and matrix after weathering periods, the polymer composite lost its tensile strength [15]. Therefore, it is necessary to highlight some of the research evolution of UV radiation effects towards composite material and open further areas of study related to UV degradation towards properties of polymer matrix composites.

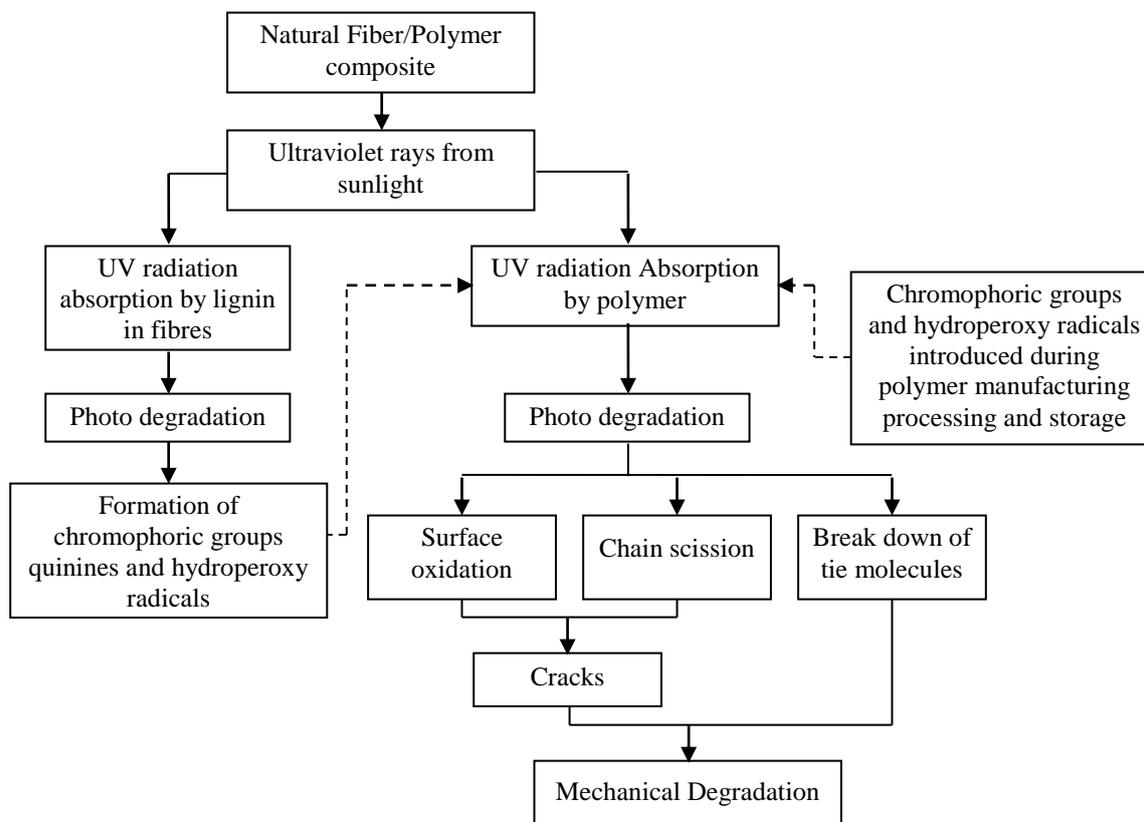


Figure 1. The schematic diagram representing the mechanical degradation processes due to UV exposure [15].

2. Previous Research

2.1 The radiation exposure and its effect

Nowadays, there are so many applications of polymer matrix composite materials which are UV exposed, including the sporting goods, aircraft components, automotive parts, consumer goods and many other applications [1, 25 – 28]. A polymer material may be degraded by chemical changes due to reaction with component in the environment. Basically most pure organic synthetic polymers (polypropylene, polyvinyl chloride, and polystyrene) do not absorb wavelengths longer than 300nm owing to their ideal structure, and hence should not be affected by sunlight [15]. However, polymer is also undergone the photo-oxidation, the oxidation which is induced by light. The following statement briefly introduced on the oxidation process. Polymer reacts so slowly with oxygen at normal temperature, thus the oxidation is only become apparent after a long time. But if UV light irradiates the polymer at the same condition for 12 days, the strong band in the spectrum are appeared. In this case, the polymer free radicals are formed by the synergetic action of factors like electromagnetic radiation and thermal energy on the oxidation. This condition is observed to occur in Polypropylene, Polystyrene and also natural rubber [15].

The effect of UV radiation and associated elevated temperature on mechanical performance of steel / CFRP (Carbon Fibre reinforced Polymer) double strap joints have been investigated. Epoxy adhesive samples were fabricated by pouring two parts of Araldite 420 epoxy into the mould. These adhesives are suitable for bonding both steel and polymeric composite [29]. The wet lay-up method was used for preparing the CFRP specimen. According to the Australian natural weather condition

[28], the total outdoor UV dose for a year in Australia ranges from 250MJ/m² to 385 MJ/m². This data were used to simulate outdoor the UV exposure. Radiation power was measured as 340 nm following the standard practice according to ASTM G155. The result shows that the ultimate strain in tension of the epoxy adhesive specimens (Araldite 420) has decreased under UV exposure and associated temperature. UV exposure for 372 x 2h does not influence the tensile elastic modulus and tensile strength of Carbon fibre and CFRP. The effective bond length of steel / CFRP adhesively bonded joints has increased with the duration of UV exposure [29].

2.2 Weather condition effects of degradation

The effect of weather condition on degradation has been investigated on jute / phenolic composites [15]. It shows that for 2 years UV exposure on jute / phenolic composites has decreased the tensile strength of about 50%. It is also observed that resin cracking, bulging, fibrillation and black spots have existed on the composites. An exposure to natural weather for 9 months on palm fibre / polypropylene also has showed that the composite experienced only a little drop in its strength as compared to pure polypropylene which experienced 50% strength reduction. Moreover, it was also found that increment in exposure time has decreased the fibre strength [15]. It can be assumed that the tensile strength and modulus have decreased due to embrittlement of the matrix [15]. Similar characteristics were observed for sisal reinforced polypropylene composites [15]. After 3 months of UV radiation exposure, it shows that the tensile strength was inversely behaved to the fibre loading. For a neat PP, the tensile strength was decreased by 92.5%. When 10% sisal fibre loading was introduced to the composite, the strength has reduced to 58%. For fibre loading of 20% and 30%, the tensile strength of composites has decreased to 37% and 23%, respectively.

It shows that by adding polypropylene into the composite materials help to alleviate crack propagation to some extent. The extent of retention in tensile properties has increased with the increased in fibre loading [15]. The accelerated weather conditions testing are preferred in investigating weather exposure as this method reduced the duration required for UV exposure. However, accelerated weather test did not exactly correlate to what happen in real condition due to the irregularity of the cycle, duration, intensity and exposure condition [15].

2.3 Fibre Treatment

The fibre treatment is conducted in order to improve the adhesion between the fibres and the matrices. There are several of fibre treatments available such as alkali treatment [30] and fibre coating [31]. For instance, fibre treatment may consist of mercerization, latex coating, γ radiation treatment, silane treatment, acetylation treatment, or peroxide treatment. Effect of fibre treatments on both morphological and single fibre tensile strength of oil palm empty fruit bunches (OPEFB) has been evaluated [18]. The result showed that alkali treatment on OPEFB fibre enhanced the tensile strength and thermal stability of the fibre samples. The effect of oil palm shell (OPS) powder on the mechanical performance and thermal stability of polyester composite has been investigated [16]. The influence of washing OPS powder in methanol to remove surface impurities was investigated with tensile and flexural strengths. The result showed that the composite tensile and the flexural strength generally increased with decreasing powder size with the strength of the composite containing 75 – 150 μ m powder being similar to that of the pure matrix. However, the tensile and flexural moduli of the composite were found to be essentially independent to powder size. Thermogravimetry analysis (TGA) in flowing oxygen indicated that the addition of OPS powder shifted the thermal degradation peak of the bio composite from 370 °C to 480 °C.

The effect of fibre surface modification on water sorption characteristic of oil palm fibre has been investigated [17]. It was found that the mechanical properties of fibres have decreased upon sorption and regains on desorption [15]. The effect of coating on oil palm empty fruit bunches (OPEFB) fibres with acrylonitrile butadiene styrene (ABS) has been evaluated [31]. The result shows

that the shear strength parameter of the fibre reinforced soil was improved significantly. It was found that the Young's modulus of the coated fibre was improved with ABS coating. However, the tensile strength of the pure fibre indicated less increased in comparison to untreated fibre. The ABS coated fibre was found to be more durable against physical and chemical destruction compared to uncoated fibre.

3. Defining Analysis

3.1 Effect of UV radiation to nanocomposite coating on Metal

The effect of UV radiation to the tribology performance of the nanocomposite coating to steel has been investigated [32]. The UV radiation was evaluated by using weather tester equipment for simulating sunlight with a light source of fluorescent UVA-340. The samples were exposed to UV radiation for 300 h at a temperature 60°C without the water condensation or spraying cycle, with intensity 0.71W/m²nm (according to ASTM G154-06). The result shows that exposure to UV for 300h at normal load of 4 N and a rotational speed of 2000 rpm (linear velocity = 0.41 m/s) didn't affect the tribology performance of the nanocomposite coating until 240,000 cycles [32].

3.2 Effect of UV light Exposure to Composite Material

Lopez et.al. [4] have investigated the effect of UV radiation to wood plastic composite. Here, a fluorescent lamp with peak emissions of 365 nm wavelength (UVA) and 313 nm wavelength (UVB) were used to expose the test coupons (20 XZ 160 X 3 mm³) of composite with UV radiation in the environment chamber. The fluorescent lamp was set up to illuminate the samples for two periods, e.g. 2000 and 4000 hours of UV exposure. The result indicated that the UV exposure provides the same effect to the Modulus of Rupture (MOR) and the Modulus of Elasticity (MOE) of the samples. It was demonstrated that the UV exposure has increased both the MOR and MOE of the samples at high temperature (40°C) with low relative humidity (34%) or low temperature (23°C) with high relative humidity (93%) [4]. Vice versa, the UV exposure has decreased MOR and MOE of the samples at high temperature (40°C) with high relative humidity(93%) or low temperature (23°C) with low relative humidity (34%) [4]. This indicated that the relative humidity also influenced to the strength of the polymer composites.

Zhang et.al. [33] have investigated the effect of UV irradiation to magnetism in SrTiO₃. The single crystalline SrTiO₃ samples were prepared from SrCO₃ and TiO₂ by the modified composite-hydroxide-mediated approach. The results showed that the ferromagnetism of SrTiO₃ has enhanced after UV irradiation. It indicated that new diluted magnetic material of oxygen vacancy rich SrTiO₃ can be obtained by UV Irradiation [31]. The presence of compatibilising agent in polymer composite has also been studied by Kruzskowska et.al [34]. The degradation of polylactide based film composites exposed to UV-C radiation at 254 nm wavelength was evaluated. It was observed that the amount of unmodified montmorillonide as nanofillers and a compatibilising agent influenced the rate of photo-oxidative degradation of composite film [34]. Incorporating nanoparticles into epoxy polymer composites and delay onset of deleterious effect of UV radiation by partially curing the samples has been investigated by Narteh et.al [35]. It shows that the addition of nanoclay has increased the viscoelastic properties of the polymer composites. It was also observed that the storage modulus and activation energy of decomposition has evolved over exposure time period. Samples with partially cured has found delayed the UV radiation degradation effects [35].

A comparative evaluation on actual and artificial UV radiation was also investigated. Sil and Chakrabarti [36] have compared both tropical UV sunlight and artificial UV radiation on PVC-ZnO composite film for its photocatalytic degradation. The degradation was measured by weight loss and followed a pseudo first order rate equation. It was observed that after 90 minutes of radiation, an

artificial UV radiation decomposed about 6.2% of its original weight, whereas tropical UV sunlight decomposed about 14.2% of its original PVC-ZnO weight [36].

Yakimets et.al. [37] have investigated the effect of UV photo oxidation cracks on behavior of thick polypropylene samples. The ageing degradation tests were done using the Suntest XLS+ containing a filtered xenon lamp, with total intensity of the lamp being about 600W/m². The samples were exposed continuously without day-night cycle. The samples were divided into four well defined periods. The first period was the incubation period (3-5 days). During this period, the effect of photodegradation of polypropylene was invisible. The spontaneous cracks were formed on the sample surfaces in the period of forming surface cracks (5 days - 3 weeks). These cracks caused the embrittlement of the material. In the third period (3 – 5 weeks) the sample surfaces with many cracks offer the optimal conditions for the development of chemy-crystallization which produces small independent crystallinities, therefore the material lost its mechanical resistance. The sample surfaces totally affected by chemical crystallisation in the stabilisation period (5-7 weeks) which was in the last period of the research. There wasn't any more cracks formed at this stage due to the exposed surfaces were completely photo oxidized [37].

Davis et al. [38] have investigated the effect of photo-oxidative degradation on fracture of the ABS (Acrylonitrile-butadiene-styrene) pipe resins. The analysis of DN10 Class 15 ABS pipe predicted a transition to brittle fracture failure occurs after 137 years. However, to accurately analyse, the effect of pipe wall thickness should also be quantified [38].

The environmental effects on the degradation behavior of sisal fibre reinforced polypropylene have been investigated by Joseph et al. [39]. There are some chemical treatments were given to sisal fibre in this research, i.e. MA-PP (Maleic anhydride polypropylene), TDI-PPG (Toluene 2,4 diisocyanate) - (Polypropylene glycol), PMPPIC (Poly[methylene poly (phenyl isocyanate)]). After exposure to UV radiation in a weatherometer for some period of time, i.e. 2, 4, 6,8 and 12 weeks, the tensile properties of both untreated and chemically treated composites were observed to have decreased due to chain scission as a result of photooxidation. After being exposed to UV radiation for 12 weeks, the untreated fibres composite still has the highest retention in tensile strength e.g. 63.0 MPa while MA-PP treated fibres composite has the lowest retention in tensile strength, e.g. 50.4 MPa [39]. The MA-PP treated fibres composite has the highest Young's modulus even for unirradiated samples (1685 MPa) or 2,4,6,8 or 12 weeks irradiated samples (i.e. Young's modulus for 12 week irradiated sample was 1063 MPa).

Thermal degradation of kenaf fibre/epoxy composite using thermo gravimetric analysis have been investigated by Azwa et al. [40]. There were 2 types of fibre used in this research, i.e. untreated and the treated fibre. For the treated fibre, during samples preparation, the kenaf fibres were treated by solution of 6% sodium hydroxide for 24 hours at room temperature. The degradation of the samples analyzed by thermo gravimetric analysis (TGA). The study concluded that the treated fibre has lowered the decomposition temperature and produced lesser char than untreated composite, caused by removal of lignin [40].

Hybrid flax reinforced supersap composites have been investigated by Zhu et al.[41]. There are five kinds of conditions of flax fibres used in these experiments, i.e. Untreated, NaOH Treatment (5% NaOH), BTCA Treatment (Alkali + BTCA (Butanetetracarboxylic acid)), APS Treatment (Alkali + APS (Amiopropyltriethoxysilane)) and Lacasse Doga (LD) Treatment. The UV aging conditioning was done in QUV accelerated weathering tester and freezer by using UVB-313 in the temperature range of -15 to 25°C, cycles for 552h (23 days). Similarly samples were kept in the Q-Sun Xe-3-HS and Q-SUN Xenon test Chamber XE-3-H/HSB/HS for being exposed to artificial weathering for 500 h with xenon arc light. Another condition of samples was the normal condition samples, which were samples without UV radiation and xenon light. The results obtained demonstrated that the untreated fibres composite has the highest tensile strength compared to others for normal condition and UV radiation test (i.e.: 185.4±8.5 MPa and 185.4±7.8 MPa respectively). But in xenon aging test, APS treatment samples have the highest tensile strength (i.e 175.1 ± 6.2 MPa) [41]. The untreated fibres composite also has highest tensile modulus compared to others, for normal condition and UV radiation

test (i.e.: 13.9±0.4 GPa and 14.0±0.3 GPa respectively). But in xenon aging test, LD treatment samples has the highest tensile modulus (i.e 11.9 ± 0.3 MPa) [41].

4. Conclusion

This paper has reviewed the effect of UV radiations on composite materials; in particular the polymer matrix reinforced natural fibre composites. It has been noted that some investigations have been conducted through some natural fibres reinforcing composite. From the review, it is well described that UV has played significant role in degrading the material strength. The fibre tensile strength was found to decrease with the duration of UV exposure time. UV radiation has been linked to the degradation of composite materials with the degradation rate depends on some key parameters such as UV wavelength, exposure time and UV intensity. The influence of using accelerated UV equipment also contributing to the degradation rate, where it degrades much faster than the normal UV exposure. Therefore this review could provide some significant areas for further development of UV exposure analysis particularly towards natural fibre reinforced polymer matrix composite materials.

Acknowledgements

The authors would like to thank the Ministry of Higher Education Malaysia and Universiti Tun Hussein Onn Malaysia (UTHM) for providing the financial support through FRGS Grant Vot 1541. Also, special thanks to Office for Research, Innovation, Commercialization and Consultancy Management (ORICC) and Faculty of Mechanical and Manufacturing Engineering for providing the facilities and assistance throughout the project.

References

- [1] Strong A B 2000 *Plastics: Materials and Processing* (New Jersey: Prentice Hall)
- [2] Gay D 2015 *Composite Materials: Design and Applications* (UK: CRC Press)
- [3] McCrum N G, Buckley C P and Bucknail C B 2005 *Principles of Polymer Engineering* (UK: Oxford Science Publication)
- [4] Lopez J L, Sain M and Cooper P 2006 *Appl. Polymer Sci.* **99** pp 2570.
- [5] Karina M, Syampurwadi A and Oggo H 2007 *J. Biol. Sci.* **7(2)** pp 393.
- [6] Zaleha M, Mahzan S and Maizlinda Izwana I 2012 *Applied Mech. Mtrls* **229-231** 276.
- [7] Samuel O D, Agbo S and Adekanye T A 2012 *J Mineral and Mtrls Charact Eng.* **11** pp 780.
- [8] Hasamudin W and Soom R M 2002 *Malaysian Palm Oil Board*, Kuala Lumpur Malaysia.
- [9] Shinoj S, Visvanathan R, Panigrahi S and Kochubabu M 2011 *Industrial Crops and Products.* **33** pp 7.
- [10] Kakou C A, Arrakhiz F Z, Trokourey A, Bouhfid R, Qaiss A and Rodrigue D. 2014 *Mater Des.* **63** pp 641.
- [11] Brinson H F and Brinson L C, 2008 *Polymer Engineering Science and Viscoelasticity: An Introduction.* (New York: Springer).
- [12] Horath L. 2001 *Fundamentals of Material Science for Technologist*, (USA: New Jersey: Prentice Hall).
- [13] Guneri A 2005 *Polymers in Construction.* (USA: Smithers Rapra Technology).
- [14] Ku H, Wang H, Pattarachaiyakooop N and Trada M 2011 *Composites Part B* **42** pp 856.
- [15] Azwa Z N, Yousif B F, Manalo A C and Karunasena W, 2013 *Mater Des.* **47** pp 424.
- [16] Nabinejad O, Sujan D, Rahman M E, Ian J D 2015 *Mater Des* **65** pp 823.
- [17] Sreekala M S and Thomas S 2003 *Comp Scie Tech* **63** pp 861.
- [18] Norul Izani M A, Paridah M T, Anwar U M K, Mohd Nor M Y and H'ng P S, 2013 *Composites Part B* **45** pp 1251.

- [19] Khalil A H P S, Marliana M M, Issam A M, Bakare I O 2011 *Mater Des* **32** pp 2604.
- [20] Moshiul Alam A K M, Reddy Prasad D M, Khan M R and Mina F 2012 *Composites Part A* **43** (11) pp 1921.
- [21] Awaja F and Pigram P J, 2009 *Polym Degrad Stab.* **94** pp 651.
- [22] Van Krevelen D W, Nijenhuis K T, 2009 *Properties of Polymer*. (Netherland Amsterdam: Elsevier).
- [23] Stempien Z, Dominiak J and Sulerzycka-Bil M, 2013 *Eastern Europe* **21** pp 96.
- [24] Diffey, BL. 2002 *Methods* **28** 4.
- [25] Witold B 2000 *Performance of Plastics*. (USA: Hanser Publisher Ohio).
- [26] Schwartz M M. 1997 *Composite Materials, Volume II: Processing, Fabrication, and Applications*. (USA New Jersey: Prentice Hall).
- [27] Dutton S and Baker A A 2004 *Composite Materials for Aircraft Structures. AIAA education series*, (USA Virginia: Blacksburg).
- [28] Sanjay K M 2002 *Composites Manufacturing, Materials, Product, and Process Engineering*. (USA Florida: CRC Press, Boca Raton).
- [29] Nguyen T C, Bai Y, Zhao X L and Al Mahidi R, 2012 *Composite Structures* **94** pp 3563.
- [30] Hashim M Y, Roslan M N, Mahzan S and Ariffin S 2014 *App. Mech. And Mater.* **660** pp. 285.
- [31] Farshid B, Fauziah A, Ahmad Shukri Y and Mastura A, 2011 *Constr Build Mat.* **25** pp 1824.
- [32] Samad M A and Sinha S K 2011 *Wear* **271** pp 2759.
- [33] Zhang S, Guo D, Wang M, Javed M S and Hu C 2015 *Appl. Surface Scie.* **335** pp 115.
- [34] Kruszkowska E O, Koter I, Wisniewska S J and Richert, 2015 *J. Photochem. and Photobio. A: Chemistry* **311** pp 144.
- [35] Narteh A T, Hosur M, Triggs E, Owuor P and Jelaani S, 2014 *Polymer Degrad and Stability* **101** pp 81.
- [36] Sil D and Chakrabarti S, 2010 *Solar Energy* **84** pp 476.
- [37] Yakimets I, Lai D and Guigon M, 2004 *Polymer Degrad and Stability* **86** pp 59.
- [38] Davis P, Tiganis B E and Burn L S, 2004 *Polymer Degrad and Stability* **84** pp 233.
- [39] Joseph P V, Rabello M S, Mattoso L H C, Joseph K, Thomas S, 2002 *Comp. Sci. and Tech.* **62** pp 1357.
- [40] Azwa Z N and Yousif B F, 2013 *3rd Malaysian Postgraduates conference* **16** pp 256.
- [41] Zhu J, Immonen K, Avril C, Brighton J, Zhu H, and Abhyankar H, 2015 *Fibers* **3** pp 76.