Physical Changes Associated with Gamma Irradiation on Composites

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Abstract*: There are various ways to improve the properties of composites such as chemical treatment, plasma treatment, rare earth treatment etc. Using ionizing radiation is also one of the methods that can be used to improve the properties of the materials. The ionizing radiation could be from gamma radiation or Electron Beam Machine (EBM). However, focus is given on the effect of gamma radiation onto the composite materials. This paper provides a review on physical changes to composites after being irradiated with gamma radiation. The physical changes involved in the review were the tensile, flexural and compression properties. From the review, there exist the advantages after being irradiated to gamma radiation whereby the exposure to gamma radiation helps in improving the composites properties.

***Index Terms*: Gamma irradiation ,hybrid composites, mechanical properties, natural fiber, physical changes**

I. INTRODUCTION

Composite materials are inhomogeneous and anisotropic materials and usually made up by combining two or more materials which often ones with different properties. The most unique property of composites is the high strength to weight ratio. Another advantage of composite materials is that it provides flexibility in design in which the composites can be molded into complex shapes. Composites have been extensively used in many applications ranging from aircraft industry, in theautomotive industry, furniture and many others. Currently, laminated composites are becoming very popular in the area of aeronautics and wind energy [1], [2].

Composites are made up of matrix and fibre reinforcement. Currently, the dominating fibre used as the reinforcement are the fiberglass, graphite fibres or carbon and organic fibres such as aramid fibres [3], [4] which are known as synthetic fibres. The choice of fibres depends on the cost, performance as well as the applications. However, with the raise of concern on environmental issues, the reinforcement has gain interest in replacing the synthetic fibre to natural fibre [5]–[7]. In producing the composites, the improvement of the strength of the end product of the composites is essential. Various methods can be done to improve the strength of the materials such as using chemical treatment [8], addition of fibres especially for natural fibres [9], hybrid-ising the reinforcement [10], [11] and using radiation technique such as gamma radiation [12] or electron beam machine (EBM). In this paper, the changes of the mechanical properties will be emphasized after the composites have been irradiated with gamma radiation.

Gamma radiation, also known as ionising radiation, is a form of electromagnetic radiation with a very short wavelength. Due to its short wavelength, it has the capability to penetrate a wide range of materials such as steel, concrete with certain thickness, polymer composites and many more. Exposure to gamma radiation is usually performed in a radiation processing plant as shown in Figure 1.

Fig. 1: SINAGAMA Irradiation Plant, Malaysian Nuclear Agency (Courtesy of Malaysian Nuclear Agency)

Prolong and unprotected exposure of gamma radiation to human cells may cause cancer. However by implementing the safe dose limit, it can be used for radiotherapy treatment to treat cancer patients. In material studies, there are profound effects in materials when it is correctly used, such

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as in the plastic, textile, wood, and rubber industries. These exposures are usually performed in a radiation processing plant.

II. METHODS TO IMPROVE COMPOSITE STRENGTH

The most important factor that contributes to the composites final mechanical properties is the interfacial characteristics between the natural fibre and polymer matrix [13]. The fibre-matrix interfacial adhesion areclassified into three main interactions which are thechemical bonding, physical adhesion and mechanical interlocking [14], [15]. Besides improving the fibre-matrix interfacial adhesions chemically, exposure to ionising radiation such as using Electron Beam Machine (EBM) and gamma radiation may also be one of the options in enhancing the properties of the composite materials.

A. Chemical treatment

In producing high quality fibres, alkaline treatment or mercerization using sodium hydroxide (NaOH) is usually used for bleaching treatment and cleaning the surface of the natural fibres [16]. Treatment with alkaline modify the natural fibres thus improve the mechanical properties of the resultant composites. Supreeth et al. [16] in his work used 5% NaOH chemical solution to treat the fibre. Egute et al. [17] conducted chemical treatment to treat the fibre in order to increase the adhesion of the fibre/matrix interface such as using maleic anhydride as the coupling agent [17]. Egute et al. [17] in his work used the alkaline solution (10% wt NAOH) to treat the fibre. Oladele et al. [18] in his work used KOH as chemical solution to treat sisal fibre. From his work, the results showed that sisal fibres treated with KOH has the best tensile and hardness properties compared to treatment using NaOH solution. Raslan et al. [19] in his work used 1% concentration of NaOH to chemically treat the bagasse fibre.

B. Hybrid Composites

Hybrid composites are becoming increasingly popular in many countries. Various ways the reinforcements being hybridised such as hybridising between synthetic-natural fibre, synthetic-synthetic fibre and natural-natural fibre. As a result, studies on the effects of mechanical properties of the hybrid composites are increasing [20]. The dominated synthetic fibres being used as reinforcement are fiberglass, carbon fibre and organic fibres such as aramid or sometimes called as Kevlar. The choice of fibres as the reinforcement depending on the applica-tions since each material has its own unique properties [21]. Fiberglass is expensive, carbon fibres are the stiffest and Kevlar are the tough-est [4], [22]. The properties of the manmade fibres are tabulated in Table 1

Besides the synthetic fibres that are very costly, there are also drawbacks of the synthetic fibre such as poor recycling capability and non-biodegradable. As a result, the choice of synthetic fibre is decreasing and currently moving towards natural plant fibre as the reinforcement since the natural fibres are low cost, biodegradable, light weight and have satisfactorily high specific strength and modulus [11]. Using natu-ral fibre also utilize the waste from plantation industry which is believed to have potential as the reinforcing fibre in polymer composites for energy absorption applications [23]–[25]. Various fibres used in producing hybrid composites are tabulated in Table 2.

C. Exposure to Radiation

Besides hybridising the reinforcements in hybrid composites, exposure to radiation is also one of the options in improving the mechanical properties. Ionising radiation, especially from the gamma source origin, offers several benefits such as continuous operation, less atmospheric pollution, minimal time requirement and many more [35]. Radiation technology is sometimes preferred compared to chemical treatment due to no catalyst or additives are used in radiation processing to initiate the reaction [17]. Besides improving the mechanical properties of the irradiated materials due to crosslinking process, this over exposure to radiation could also contribute to material degradation or chain scission process when it is exposed to certain amounts of radiation exposure [36]. However, it is noticed that different reinforcing materials have different responses limit of radiation exposure which resulted to the degradation conditions. The chain scission and cross linking processes are due to photo-degradation [4].

Degradation in composites or polymer degradation is a change in the properties under the influence of environmental conditions such as light, heat and chemical [4], [37], [38]. Radiation is another environmental factors that results in the degradation of polymer that can affect the mechanical properties, discoloration or change of shape.

Table 1: Properties of Synthetic Fibres [4]

Synthetic Fibre	Fibre Properties			
	Density (g/cm^3)	Elongation (%)	Tensile Strength (MPa)	Elastic Modulus (GPa)
E-glass	2.5	0.5	2000-3500	70
S-glass	2.5	2.8	4570	86
Aramid	1.4	3.3-3.7	3000-3150	63.0-67.0
Carbon	1.4	1.4-1.8	4000	230-240

Table 2: Selected hybrid composites from various fibres

Author	Hybrid Composites			
	Synthetic-Synthetic Fibre	Natural-Natural Fibre	Natural-Synthetic Fibre	Reference
Rashid et al.	-	-	Coir - Kevlar	[26]
Yahya et al.	-	-	Kenaf - Kevlar	[9]
Nor et al.	-	-	Bamboo - Glass	[27]
Amir et al.	-	-	Oil palm - Kevlar	[28]
Jawaid et al.	-	Jute – Oil palm	-	[29]
Alavudeen et al.	-	Banana - kenaf	-	[30]
Asaithambi et al.	-	Banana - sisal	-	[31]
Kumar et al.	-	Bamboo – banana - pineapple	-	[32]
Al-jeebory et al.	Carbon – Kevlar – araldite matrix	-	-	[33]
Guru Raja et al.	Kevlar - glass	-	-	[34]

III. GAMMA RADIATION

Gamma radiation is anionising radiation emitted from radioactive materials undergoing decay process. Cobalt-60 radioactive material is a type of radioactive material that is used in the radiation processing plant in producing the gamma radiation. The decay process in producing the gamma radiation from Cobalt-60 is shown in Figure 2.

$$^{60}_{27}Co^{60}_{28}Ni + \ ^{0}_{-1}\beta \ + \gamma$$

Fig. 2: Cobalt-60 decay process

A. Irradiation Process

Since gamma radiation is dangerous, hence it has to be conducted in an exposure room which is located in the controlled area. The measured dose at the outer wall of the exposure room is less than 2.5μSv/hr.In the gamma irradiation process, the samples need to be placed in the Research Loop Tote before entering the exposure room as shown in Figure 3. The absorbed dose of the materials being irradiated and the exposure time need to be determined before the Research Loop Tote entering the exposure room. Cericcerrous dosimeter is used to measure the absorbed dose. Only authorized personnel equip with personnel protective equipment are permitted to be in the controlled area.

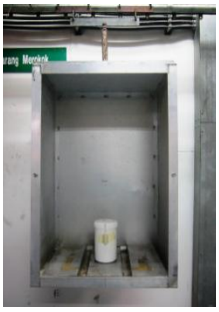

Fig. 3: Research Loop Tote (Courtesy of Malaysian Nuclear Agency)

IV. PREVIOUS RESEARCH

Since degradation of fibres and matrix after being exposed to radiation leads to loss of tensile strength which causes engineering problem, therefore, it is essential to highlight some research on the effects of gamma radiation towards properties of polymer matrix composites.

Egute et al. [17] studied the mechanical and thermal properties of polypropylene composites after the curaua fibres were treated with chemical treatment. The composites were then further exposed gamma radiation with different radiation dose. Ayma et al. [12] studied on the effect of gamma radiation on jute fibres. The source of gamma radiation used in the studies was from Cobalt-60. Silk fibre has drawn the attention in producing composites from natural fibres [35]. Silks are fibrous proteins from insects and spiders which are spun into fibres. The mechanical properties of silk fibres consist of a combination of high strength, extensibility and compressibility, hence natural silk fibre reinforced thermoplastic composites is able to replace the conventional synthetic fibre reinforced thermoplastic composites. The composites made up of silk fibre and synthetic E-glass fibre reinforced polypropylene were irradiated with gamma radiation at 2.5 – 10 kGy to study the mechanical properties [35]. The effect of radiation at 25 kGy on sisal / polyurethane composites were also studied [39]. Thermogravimetric test were conducted at composites that were irradiated with radiation. The work concluded that themechanical properties decreased after radiation incidence. However, exposure to gamma radiation has increased the impact resistance in the composites.

A. Radiation Exposure

Polymer matrices are radiation sensitive, hence it can be significantly affected by certain amounts of radiation exposure [36]. Thus, the radiation doses play as important role in observing the effect of radiation to the materials [28].

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Table 3: Radiation dose applied to various materials

Reference	Material	Radiation Dose
Vasco et al. [39]	Sisal / polyurethane composites	25 kGy
Amir et al. [28]	Kevlar / oil palm EFB hybrid composites	25 kGy, 50 kGy, 150 kGy
Ayma et al. [12]	Jute Fabric	2 kGy- 9 kGy
Egute et al. [17]	Polypropelene with curaua fiber composites	5 kGy, 15 kGy and 30 kGy
Shubra et al. [40]	Silk reinforced polypropelene/ natural rubber composites	2.5 – 5 kGy
Shubra et al. [35]	Silk / polypropylene composites E-Glass / polypropylene composites	2.5 – 10 kGy
Zhang et al. [41]	Poly p-phenylene benzobiosoxazole (PBO) fibers	5, 10, 15, 20, 25, 30, 35, 40 kGy
Zaman et al. [42]	Jute fabric Polypropylene	2.5 – 10 kGy
Raslan et al. [19]	Bagasse fiber-reinforced waste polypropelene composites	20 kGy
Xing et al. [43]	Aramid fiber-12	400 kGy
Wu et al. [36]	Epoxy /glass fiber composites	1 MGy, 5 MGy and 10 MGy

Radiation dose for various materials are tabulated in Table 3. From the table, the radiation dose to natural fiber is in the low radiation expo-sure that is in the range of 2.5 kGy – 50 kGy. The radiation dose for synthetic fiber started from 100 kGy. Determination optimum radiation dose to the materials is important because higher radiation dose in which the material could not withstand might lead to the degradation of properties and thus cause serious engineering problems.

B. Effect on mechanical properties

Effects on the mechanical properties due to exposure to radiation can be observed with various testing methods such as tensile, flexural and compression properties.In most research work, it is observed that there is an improvement of tensile strength of the samples that were irradiated compared to non-irradiated samples [9,16]. Raghavendra Supreeth et al. [16] investigated the tensile, flexural and impact properties of hybrid composites using pineapple leaf and jute fibres as the reinforcements and Bisphenol-A (BPA) as the matrix. It was observed that the tensile properties increased in gamma radiation dose up to 5 kGy. This shows better adhesion between fibre and matrix. The flexural and impact properties also showed the same trend as in the tensile properties. The optimum radiation dosage for both flexural and impact properties were observed at 5 kGy. However, radiation dosage above 5 kGy showed a decreased in the mechanical properties.

Improvement in the mechanical properties after the samples being irradiated with gamma radiation is due to cross-linking phenomena. Cross-linking is a phenomenon where small molecules join together to form larger molecules resulting in increasing the mechanical strength [16]. Besides, moisture from the composites may also be removed by gamma radiation [16]. These two factors contribute to better adhesion between the fibre and matrix. On the other hand, decreasing of mechanical properties is due to chain scission. Chian scission is a phenomenon where larger molecules break into smaller molecules.

The effect of radiation on jute fibre reinforced polyester matrix composites and reinforced polypropylene composites were investigated [7, 29]. The results from both work are in agreement with the work of Raghavendra Supreeth et al. [16] where the optimum radiation dose to obtain high tensile, bending and impact strength is at 5 kGy. The effect of gamma radiation on the mechanical and thermal properties of bagasse fibre-reinforced waste polypropylene composites was investigated by Raslan [19]. The samples were exposed at 20 kGy. From the results, the composites which were irradiated have higher tensile properties than others. This suggests that gamma radiation remove moisture from the samples resulting in the enhancement the fibre matrix adhesion, thus better tensile properties. Hardness properties of the irradiated sam-ples give higher values compared to non-radiated samples due cross linking that leads to a more rigid surface [19].

The compression properties when Kevlar/oil palm empty fruit bunch hybrid composites were irradiated with gamma radiation have been studied by Amir et al. [28]. The compression properties increased when gamma radiation is applied to the samples. The optimum radiation dose in obtaining high compressive strength is at 50 kGy. Further increase of the radiation dose will lead to decrease of compressive strength.

V. CONCLUSION

This paper has reviewed the effect of gamma radiation on composites especially in the area of natural fibres as the reinforcing materials. From the review, it has been noted that samples exposed to gamma radiation improved their mechanical properties such as the tensile, flexural, compression and impact strength. However, the optimum radiation dose is essential to obtain the required mechanical properties. Higher radiation dose will lead to degradation on composites due to chain scission phenomenon. Optimum radiation dose varies with materials. Radiation method can be one of the options to enhance the mechanical properties of composites.

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