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Influence of Gamma Radiation on Mechanical Properties of S – Glass Fiber/Epoxy Composite

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Abstract: *Glass fiber reinforced plastic (GFRP) is the primary material used for the insulation of large superconducting magnets particularly in fusion reactors and particle accelerators. In this work the effect of gamma radiation on the mechanical properties of S glass fiber reinforced epoxy resin is studied. The composite was fabricated by hand layup technique. The prepared samples were irradiated by ^{60}Co γ -source at different dose levels ranging from 500 Gy to 1500 Gy at room temperature. Mechanical properties before and after radiation were studied and compared. The tensile test and flexural test results showed decrease in strength with increasing level of absorbed dose whereas no significant change could be observed in impact test prior to and after irradiation.*

Keywords: *S – Glass fiber, epoxy, gamma radiation, tensile strength, flexural strength.*

I. Introduction

The advent of new technological devices such as fusion reactors, particle accelerators, spacecrafts etc. has imposed considerable challenges over the selection of materials to be used for shielding against the severe radiation environments exposed upon it. Conventional material like lead, is toxic whereas lead and concrete both are inflexible and bulky. Polymer composites have gained considerable importance over the past few years basically because of certain advantages like light weight, flexible, corrosion resistant etc. Glass fiber reinforced polymers with the addition of certain materials have shown exceptional physical properties and has helped in improving the mechanical properties.

The materials used for all modern radiation resisting insulation systems contain GFRP's with addition of films or dispersed particles to achieve desirable properties. Combinations of glass fiber reinforced epoxy along with polyimide films are being used in the insulation of ITER Feeder system (Xiongyi Huang et al., 2018) and Toroidal field coil [1]. Epoxies are widely used in the coating of nuclear waste and in the assembly or replacement of some structural parts (N. Rami et al., 2010).

The effect of gamma radiation on various materials has been studied and the common effects being change in appearance, chemical / physical states, mechanical, tribological, electrical and thermal properties. The predominant mechanisms of interaction of the gamma ray photons with the matter are the Compton and the photoelectric effects, and the pair production which lead to chain scission and cross linking, thereby degrading the polymer [2],[9]. Reference [3] studies the effect of gamma radiation on graphite/epoxy composite and concluded that no major changes in flexural properties were noted and also the change in failure mode at fiber resin interface for radiation doses up to 5 x l0^2 rads wasn't noticeable. R A Fouracre [4] concluded that the magnitude of current after irradiation is greater than that before exposure reason being either due to production of ions or changes in the electronic structure of epoxy. Reference [7] discussed that the impact strength and flexural strength of the epoxy nanocomposite increased on addition of 1% of Nano-clay and further decreased with increasing concentration of it. The same behaviour was observed after gamma irradiation but with slight decrease in magnitude. Abdullah Al [10] found out that gamma irradiation caused hardening of the epoxy polymer containing 2.5 wt% ZnO nanoparticles. Nishimura et al.[11] concluded that gamma ray irradiation caused degradation of ILSS of the glass cloth/Epoxy laminate structure

In the present work attempt has been made to study the effect of gamma radiation on mechanical properties of S glass fiber reinforced epoxy resin.

II. Experimental

- ***Material***

The epoxy resin used was Araldite GY 250, general purpose high viscosity unmodified basic liquid epoxy resin based on bisphenol-A. The details of the material used is listed in

Table 1.

Table 1 Details Of Materials

Content	Material	Properties
Glass Fibre	S Glass Fiber	Woven Roving Biaxial mat. 180 gsm
Resin	Epoxy Araldite GY 250	Epoxy equiv. 183 – 189 g/Eq Viscosity at 25 deg Centigrade: 10000 – 12000 mPa S
Hardener	Epoxy Aradur 140	Viscosity at 25 deg Centigrade: 300 – 600 mPa S Typical mix ratio: 50 g/100g Gel Time: 120 minutes

- ***Specimen Preparation***

Fig. 1 Test Samples

The test samples were prepared by hand layup method because of the ease of fabrication procedure. Resin and hardener were mixed in the ratio of 50:50 as per the specification provided by the supplier. A flat glass mold was used for laying up of glass fibre mat and resin alternately. Roller was used to squeeze out the air bubbles entrapped. The composite was left to cure for 48 hours at room temperature which was more than sufficient. Samples were cut from the fabricated composite as per the test requirements.

- ***Radiation Procedure***

Dose rate (Gy/hr)	Irradiation time (min)	Total absorbed dose (Gy/hr)
1.12	447 ~ 7.5 hrs	500
1.12	893 ~ 19 hrs	1000
1.12	1339 ~ 23 hrs	1500

The fabricated samples were irradiated with gamma rays from the ^{60}Co source in the Theratron machine at room temperature for approximately 24 hours. The specimens were subjected to the dose rate of 1.12 Gy/min and maximum of 1500 Gy dose was absorbed by the samples over the experimental time.

TABLE 2 RADIATION DOSE EXPOSURE

Fig. 2 Samples being irradiated by ^{60}Co source

III. Results And Discussion

- ***Ultimate Tensile Strength***

The test was performed on universal tensile testing machine with speed of 5 mm / min as per ASTM D638 – 10. The samples irradiated with different doses were loaded on the machine and results obtained are shown in figure 1. From the test results, it was noted that tensile strength appeared to reduce with increasing dose. The decrease in strength was not drastic but it degraded by very small amount for every 500 Gy.

Fig. 3 Tensile test results before and after radiation

Fig. 4 effect of gamma radiation on tensile modulus of material

Modulus of elasticity is a measure of stiffness of the material. The result depicts uneven deformation under increasing load with a peak value of 7700.56 MPa at 1000 Gy indicating high strength with minimum deformation at this point. The value dropped on further increase in dose level showing decrease in stiffness of material.

- ***Flexural Strength***

Flexural test was performed on the specimens cut according to ASTM D790 – 03 with a speed of 1.32 mm / min at ambient temperature. In this test, flexural strength was determined by performing three-point bending test and maximum shear stress was obtained from corresponding maximum load to which the specimen is subjected. The results indicated a peak value at 500 Gy dose level and is shown in figure 5.

Fig. 5 Results obtained from 3-point bend test prior to and after gamma radiation

Maximum Shear Stress showed similar trend as in figure shown above, where maximum shear value was obtained for 500 Gy dose i.e. 7.35 MPa and subsequent decline was observed for further exposure to gamma ray for higher dose.

- ***Impact strength***

The specimen was cut from the fabricated sample based on ASTM D256 with dimensions 64 * 12.7 * 3.2 mm. The test was performed on the commercially available machine in which a pendulum hammer is released from standard height to contact the specimen with specified kinetic energy. The energy absorbed in breaking the specimen is equal to the difference between the energy of the pendulum hammer at the instant of impact and the energy remaining in the pendulum hammer after breaking the specimen was noted. The specimen is notched and the depth under the notch of the specimen is 10.2mm.

Fig. 6 Energy absorbed by specimens before fracture prior to and after gamma ray exposure

It was witnessed that there was no significant difference in the readings obtained before and after radiation. The results are displayed in figure 6.

IV. Conclusion

On radiating the samples with a maximum absorbed dose of 1.5 KGy no change in the appearance was observed. The behaviour of ionising radiation on epoxies is quite complex. Results showed decrease in tensile strength with increasing level of absorbed dose. The possible reason might be accelerated oxidative degradation when irradiated with gamma rays in open air environment. Increase in elastic modulus up to 1000Gy and then rapid decline in it, maybe the indication that when subjected to low level of radiation chain polymerization occurred however further increase in absorbed dose lead to chain scission which caused degradation of the polymeric material. The test samples showed increase in flexural strength up-to an absorbed dose of 500Gy and then decline from 1000 Gy onwards indicating failure at high dose levels. Gamma radiation doesn't seem to have any appreciable effect on the impact strength of the composite samples. The results indicate a small increase in overall strength at very low dose level but decrease in mechanical properties with increasing exposure time.

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