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Effect of Exposure of Glass Fibre Reinforced Polyester (GFRP) Composite Laminates To X-Rays

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ABSTRACT: *The research presents the effect of exposure of Glass Fibre Reinforced Polyester (GFRP) composite laminates to X-rays. A set of six laminates were prepared from Chopped Strand Mat (CSM) and polyester resin matrix using hand lay-up method. The composite laminates were held at the temperature of 55°C for 1hour 30 minutes and subsequently exposed to conventional X-ray machine with high X-ray tube voltage of 70Kv at different exposure 6 mAs, 12 mAs, 18 mAs, 24 mAs and 30 mAs respectively, but one as the control sample. Flexural (3-point bend) test were conducted to determine the mechanical property of the laminates using Universal Testing Machine (UTM) M500 25CT model. The test specimen dimensions were shaped in consonant with (ASTM E4) method. It is observed that the flexural strength of the composite increased by 18.4% at the first 6 mAs of treatment and subsequently started decreasing in the order of 21.3%, 13.1%, 9.9% and 28.8% at the intervals of 6 mAs of radiation dose. The data obtained was verified with SciLab software, and it depicts a perfect correlation. However, the results of this study indicate that exposing composite laminates to X-ray radiation for 6 mAs dose will improve the flexural strength. Thereafter, the said laminates−after the early increase would start gradual and continuous degradation until failure. Generally, this research has shown that X-ray irradiation to composite laminates has a serious adverse effect.*

KEYWORDS: *X- Rays radiation, 3-point bend, Composite Laminate Degradation, Radiation Intensity, Science Laboratory software*

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I. INTRODUCTION

A composite material is a synthetic material made from a polymer matrix reinforced with fibre, which remains separate and distinct on a macroscopic level while forming a single component. Composites essentially combine the strength and stiffness of metals and the lightweight, flexibility and corrosion resistance of plastic. Their fibres are usually fibre glass, carbon, or aramid, while the polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic. Today, composite materials find a vast range of applications in many industrial sectors like the aerospace, marine, automotive, construction industries, chemical industries, health sector in the area of medical equipment/ hardware and other consumer applications due to their superior properties such as good insulation capability for electrical projects, competent in transfer of load, high strength and lightness (i.e., strength-weight ratio), and less effort and cost effective processing. In composites produced in polymer, the matrix aspect is the main portion, which is easily molded into new form and it grasps the strengthen aspect that is the subordinate portion. Strengthen aspects which is the reinforcements are usually capable of withstanding great physical force than the polymer matrix that enhances the mechanical properties of the polymer composite. When the composition is properly done, the current united material displays good properties, which certainly is preferred to the separate material.

The increased benefit of fiber-reinforced polymer composites in an out-of-door environment has led to questions concerning the environmental durability of these materials, particularly as related to high irradiation like coating of nuclear waste, component-parts of structures in nuclear power plant environment and insulator for superconductor in fast-breeder reactors— made the knowledge of radiation-induced aging of resin absolutely necessary [1].

This research will concentrate on resin matrix properties, since the photo degradation is an outside hull mechanism and is limited to degradation of mechanical properties of resin only. For this motive, samples for experiment made of polyester resin and chopped strand mat glass-fibre (CSMRP) will be prepared and treated in

an X-rays chamber. Five specimens will be manufactured and exposed to X-ray radiation at different times for 0.06 second interval and the sixth one will serve as the control sample. The graphical results obtained after testing for their flexure strength will be engaged to ascertain the effect of X-ray radiation on composite laminates and possibly predict the reliability of the laminate under the same condition.

II. LITERATURE SURVEY

Mark E.Robeson (1997) subjected composite laminates to 5-point flexural examination state, which resulted in cracks and destruction of the composite laminate. He also developed a model at which the 5-point flexural formation is represented. This results in the estimation of through-thickness apportionment of stresses and strains. Equally, he presented the theoretical analysis and the 5-point flexure examination results. The stress and strain apportionment, emerging through the theoretical model along with the awareness of the laminate piling order, was identified, to forecast the kind and destination of damages while conducting 5-point flexure examination.

Vlachos et al. (2015) conducted an experiment on the X-ray radiation reduction level by some common building materials. This was carried out particularly on the tiny shaped X-ray fields. In the course of this investigation, common building materials like plasterboard and ceramic tile were considered. An enhanced radiation was conveyed through the above mentioned two engineering materials and after which, experimental examination on the samples was done, and the effect of the transmitted radiation on the materials were noted. However, the result recorded that the plasterboard which was made to be two in one and the double strengthened in thickness ceramic tile offered a preferred shielding result.

Azim (2017) used hessian jute cloth and prepared jute-polymer composite laminates using hand lay-up method with heat pressure molding technology. He moved further and treated the prepared Jute fabrics using gamma-ray machine for radiation provision at 50 kCi Cobalt-60 of diverse gamma-ray intensities which ranged from 2 kGy to 9 kGy. After the treatment, the laminates were subjected to several mechanical tests in order to identify the extent of damage each of the samples has incurred. In this way, it was noticed that the mechanical properties of the treated laminates accelerated after exposing the sample to gamma radiation. Moreover, he equally observed that all the samples of the laminates depicted the absolute mechanical properties at 5 kGy gamma-ray doses. He equally pointed out that the accelerated strength of the jute composite while in tension with improved gamma-ray radiation intensity was as a result of the intercross-linking that took place at the interface of neighboring cellulose molecules. This competitive reaction that took place, he said, was what caused the improved strength of natural fibre. However, the acceleration of the tensile property only happened as a result of pretreatment of the samples under gamma-ray to a certain point of the treatment. And after some times, a significant decrease due to the competitive reaction under gamma radiation started.

Correiaa et al. (2005) investigated and presented experimental research result on the physical, chemical, mechanical and aesthetical variations endured by glass-fibre reinforced polyester resin matrix laminates. These studies were carried out under accelerated exposure of the composite laminate to temperature, moisture and ultraviolet radiation. Four composite laminates were subjected to the following exposure environments: (i) immersion in water at 20ºC, (ii) condensation of water at 60ºC, (iii) increased weathering QUV equipment, and (iv) accelerated weathering Xenon-arc device. When the exposures were completed and the analysis of the results commenced, they considered the sorption, flexural and tensile behaviours of the material under investigation. The chromatic and gloss variations and the chemical variations were equally checked, all by means of infrared spectroscopy. However, it was noticed that acceptable chromatic variations exists due to UV radiation. The long lasting experimental examinations demonstrated the all good response of this composite material under those unfriendly states.

III. RESEARCH ELABORATIONS

3.1: Material Preparation

A simple hand lay-up technique was chosen in this study on the bases of its unmixed nature. The mould size was left at 300mm x 300mm x 6mm on a well plumed rigid steel table and was well guided to avoid demoulding during casting. After the application of mould release agent, a measure of about 540g/cm^3 of resin was collected with 1% of accelerator (cobalt) and catalyst (MEEK peroxide) each were equally measured and mixed together in a flask. The mixture was stirred gradually at 115 RPM for about 5 minutes to achieve homogeneity with air bubble absent. Before resin impregnation, a ply of chopped strand mat synthetic fibre of about 300mm x 300mm was layered perfectly inside the mould. This process of casting took less than 20min per a mixture for each mould.

After about 36hours of cure at room temperature, the composite laminates were demoulded and subjected to a compression mould for another 24hours to enable a better profile of the laminates. At this point, the composite laminates were further heat treated in the oven for complete polymerization at the temperature of

55^0C for 1hr 30min, and was subsequently exposed to the X-ray machine with high X-ray tube voltage of 70 KV and current of 100 mA at different time range.

Table 3.1 Factorial Experimental Plan for X-ray Exposures

S/No.	FSD (cm) (KV)	System Energy (mA)	Current (sec)	Exposure time (mAs)	Intensity
A	00	00	000	0.00	00
B	90	70	100	0.06	6
C	90	70	100	0.12	12
D	90	70	100	0.18	18
E	90	70	100	0.24	24
F	90	70	100	0.30	30

The X-ray machine is ATOMAX-2 100/85 Type C model and the Focal Specimen Distance was set to 90 cm FSD (the distance from the X-ray beam source to the specimen). This exposure was carried out on each of the laminates for 0.06 sec, 0.12 sec, 0.18 sec, 0.24 sec and 0.30 sec respectively, and the sixth one was used as the control sample (i.e., there is no exposure). These X-ray exposures were carried out at St. Michael's Diagnostic entre, 102 Agbani Road, Enugu.

3.2: Specimen Preparation

The material studied was a composition of chopped strand hard mat E-glass fibre and isopthalic polyester resin as purchased from the vendor. The fibre mass fraction is 38grms in each of the laminates, while the total mass of each laminate is 553grms. Square-shape profile samples of (300 x 300 x 6mm) dimension were fabricated. Thus specimens with dimension (150 x 40 x 6mm) for flexural test were cut from all the sample profiles. These were to determine the above mentioned mechanical property of the material—polyester based composite laminate samples. The test will comprise both the unexposed and the exposed ones which were treated for different number of timescales under X-ray radiation.

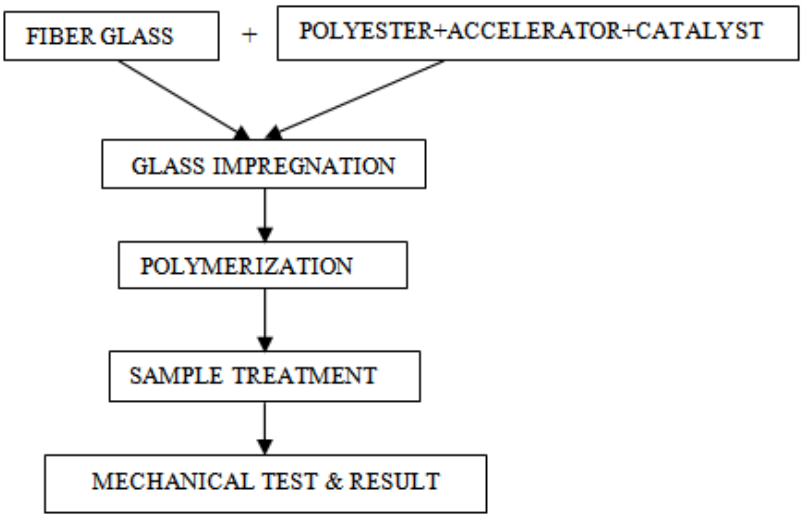

Figure 3.1: Flow chart of processing and characterization of glass fibre reinforced laminate composites.

3.2.1: Testing Methods

Specimens for flexural mechanical characterization were prepared from the laminates of the control sample and the other samples which were exposed for various periods of timescale, and tests carried out according to American Standard Testing Machine (ASTM E4) methods. The standard dimension selected is 150mm x 40mm x 6mm.

Figure 3.2: Pictorial diagram of flexural test specimen

3.3: Flexural Tests

Flexural strength which can also be addressed as bending strength has multiple techniques of approach. Among the techniques, there is three-point bending technique. This is the method adopted to measure the amount of resistance with which the polyester composite laminates opposed change of form. Its principle of operation is similar to compression experiment, but in this case, the crosshead does not apply at the composite's gauge length axis. The direction of motion is compression but the specimen is kept vertically with two-fixed pin support which is free at their ends.

The third point on the machine is what travel to flexure the specimen and the amount of force required to do so is measured. Thus the flexural strengths of the composite materials specimens are figured out using the equation below;

$$\sigma = \frac{3FL}{2bt^2} \quad (3.4)$$

Where F is the optimum load in (newton), L is the distance between the two-pin supports that is the gauge length which is 100 mm, b is the width of the specimen that valued 40 mm and t is the thickness of 6 mm. Similarly, flexural modulus can be determined using equation (3.5);

$$E = \frac{FL^3}{4bt^3d} \quad (3.5)$$

F is equally the maximum load here, L is the distance at the middle of the two supports, b is the width of the specimen, t is the thickness of the specimen, and d is the deflection in (millimeters) as a result of the applied load (F). The device used for flexural experiment is Testrometric machine, M500-25CT model. The traveling head-pin motion was made to be in the compression mode. However, the flexural strength of composite laminates lies on the mechanical properties of the combined materials and also the boundary layers response. In fibre-reinforced polyester resin matrix laminate, the region of boundary layers has a dominating influence in transferring load from matrix to fibre. Consequently, this interaction constitutes the mechanical properties degradation such as strength.

IV. RESULTS AND DISCUSSION

4.1: Presentation of Results

After all the processes of sample specimen's preparation and tests, the following results were obtained as shown in the tables 4.1 and the figures 4.1 to 4.6 below. The table were read and extracted from testrometric M500-25CT UTM generated results after test. the values of flexural strength at peak rapidly increased for each of the average strain at peak with 18.4% at the first 6mAs of X-ray radiation dose impact and subsequently started decreasing at random in the order of 21.3%, 13.1%, 9.9% and 28.8% as more timescale of 0.06sec were been permitted continuously for the rest of the specimens (see Fig. 4.7). Similarly, the value of energy to break took the same line of behaviour like the formal, only that the peak value was attained at the first 12mAs of irradiation dose (see Fig. 4.8). But looking at what is available in some of the literatures reviewed; Namibiar and Osei [5], after their investigation on percentage reduction and X-ray energy, they came up with a result that portray the decrease of reduction capability among all the composites with accelerated X-ray energy. In their work (X-ray attenuation test), they didn't observe any early increase on the attenuation capability of the composites. However, similar investigation done by [6] with gamma-ray treatment, depict the same graph trait with what is obtained in the result of this research work. An accelerated strength was noticed before finally the degradation of material strength commenced.

Table 4.1: Flexural test result of Stress at peak, Energy to break, Strain at peak and Strain at break

S/No.	Stress @ peak (N/mm^2)	Energy to break (N.m)	Strain @ peak (%)	Strain @ break (%)	Force @ peak (N)
A	997.960	2.624	1.820	2.000	846.5
B	1222.31	3.959	2.380	2.580	1036.8
C	961.767	4.354	2.500	3.085	815.8
D	836.212	3.996	3.350	3.750	709.3
E	753.216	2.774	2.280	2.804	638.9
F	536.057	1.902	1.950	2.402	454.7

4.1.1: Graphical Results Generated for Flexural Test Specimens

The flexural examination is very much important in estimating the properties of composite laminate mainly in structural applications. The flexural load–extension curves for 6mAs intervals of irradiation dose on

five samples plus the sixth one which is the control sample are shown in Fig. 4.1 to 4.6. The curves showed the damaging stages of the composites. According to [7], the sudden failure of the composite laminate can be linked to flexural failure and the gradual decrease in loading indicates shear failure as the predominant mode. In this research, the damage state can be classified as a mixed damage mode. The figures show variations in flexural properties due to different doses of irradiation on the laminate. It is noticed that the three-point bending strength of sample B is the biggest value with (1222.31 N/mm^2), among the total test conducted followed by the control sample—A and sample C: 997.96 N/mm^2 and 961.77 N/mm^2 respectively. In terms of energy to break, the sample C is found to be the highest with (4.354 Nm) compared to other samples. From the results gathered in the studies carried out from earlier researchers, it was found that the X-ray radiation dose influences the properties of glass fiber-polyester composites. But they did not take notice of the further polymerization at the first 6 mAs X-ray radiation dose. Considering graph of Fig. 4.2 (sample B), it depict that the material is ductile and the other materials; sample A, C, D, E and F are brittle at different grade— they failed more than once before final break down especially sample F.

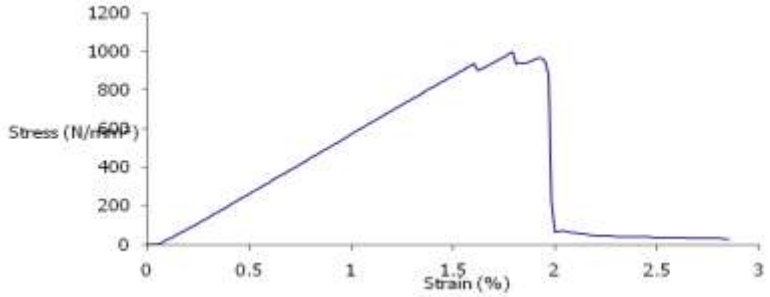

Figure 4.1: Flexural stress (σ) at yield, peak and break against strain (ε) of the control sample (A)

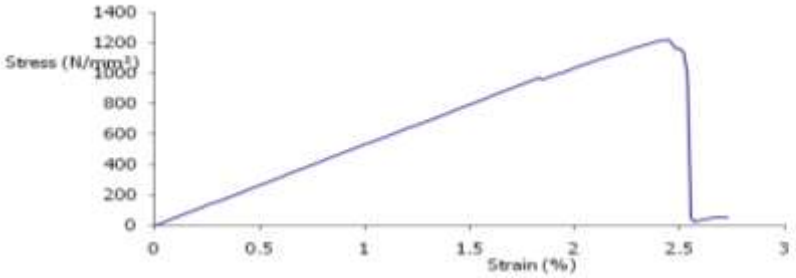

Figure 4.2: Flexural stress (σ) at yield, peak and break against strain (ε) of the sample (B)

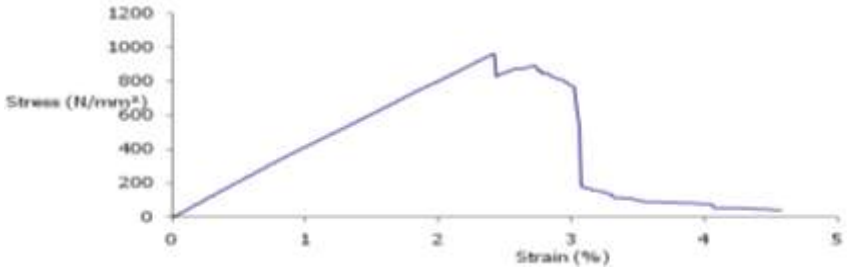

Figure 4.3: Flexural stress (σ) at yield, peak and break against strain (ε) of the sample (C)

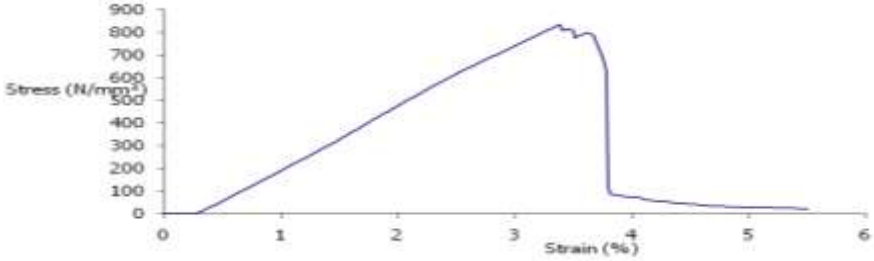

Figure 4.4: Flexural stress (σ) at yield, peak and break against strain (ε) of the sample (D)

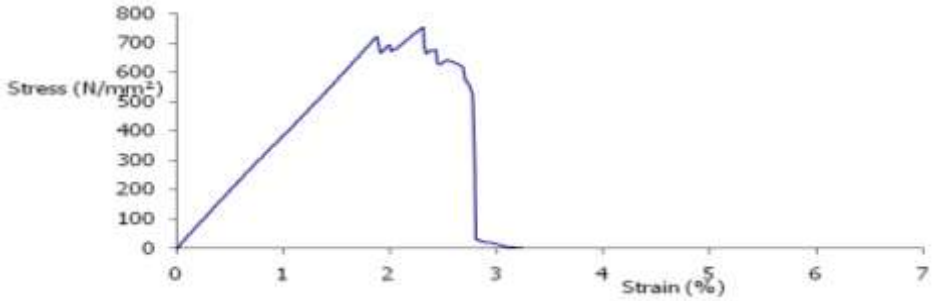

Figure 4.5: Flexural stress (σ) at yield, peak and break against strain (ε) of the sample (E)

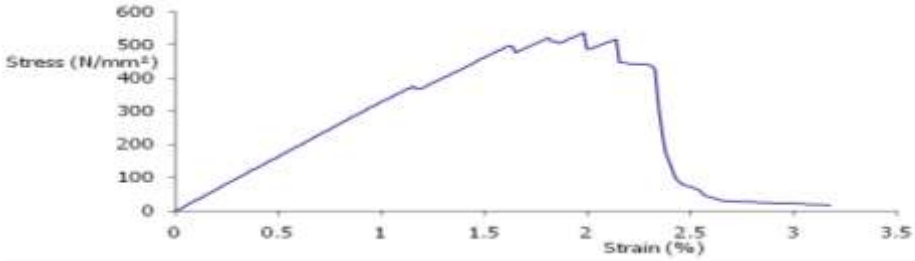

Figure 4.6: Flexural stress (σ) at yield, peak and break against strain (ε) of the sample (F)

4.2: Flexural strength experimental result discussion

The graph below is the flexural stress graph. The control sample yielded at 997.96 N/mm^2 and when exposed to X-ray intensity of about 6 mAs, the strength required increased as a result of further polymerization within the neighboring cellulose molecules. It indicate that in all the samples, more strength of about 1222.31N/mm^2 is required to break the second specimen, which was treated at the x-ray exposure indicated above, and beyond this level of intensity, the material's strength will start to depreciate and will continue until complete failure of the material.

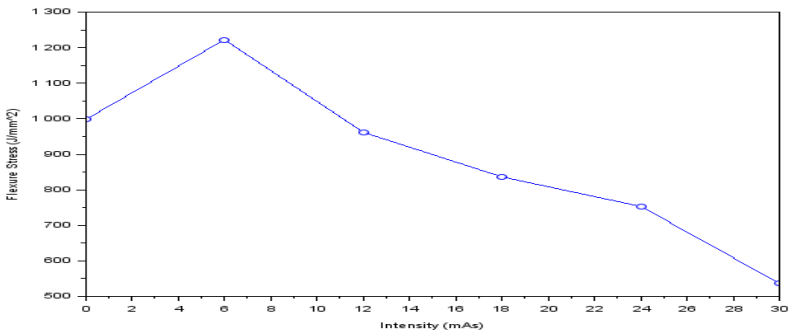

Figure 4.7: Flexural stress at peak (N/mm^2) against X-rays radiation dose in (mAs)

4.3: Energy to break flexural experiment result discussion

The energy it required to break each specimen is evidenced in this graph below. The first sample which is without any exposure (i.e zero exposure) was damaged at about 2.62 N.m and when exposed to x-rays radiation at 6mAs, the energy required to break increased to 3.95 N.m. This increase of energy to break continued up to 4.35 N.m when the specimen with 12mAs exposure was tested. However, it was discovered that subsequent specimens with increased intensity of 18 mAs, 24 mAs and 30 mAs experienced decrease in energy level to break the specimens. Thus, it may be a good prescription to expose composite laminates to X-ray intensity of 12 mAs for flexural strength improvement.

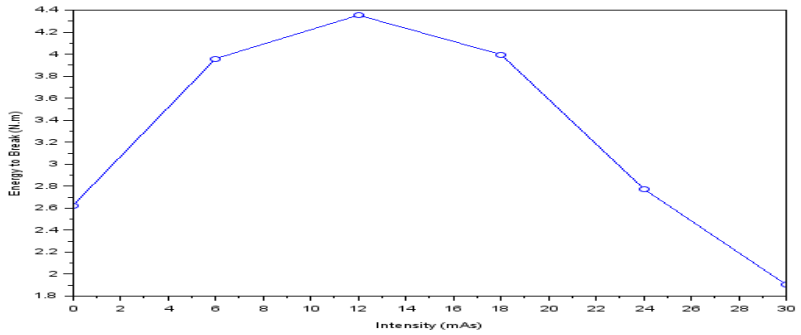

Figure 4.8: Energy to break (N.m) verses X-rays radiation dose in (mAs)

4.4: Degree of correlation between the variables, (experimental and theoretical data)

The data generated as a result of flexural strength experiment is denoted by X and the theoretical calculation which was done using Science Laboratory software (SciLab), also is denoted by Y (see Table 4.2). Although data X has a very wide margin with the data Y if the values obtained from each sample using both approaches should be compared. That does not withstand, Fig. 4.9 is the correlation graph for flexural strength. It demonstrates how well the two methods used in examining the samples related to each other. The two lines of graph has the same trait, both increased and decrease simultaneously which indicate that any of the two methods can be used.

Table 4.2: Data for Correlation Coefficient on Flexural Strength Results

n	X	Y	X^2	Y^2	XY
1	997.960	88.177	995924.16	7775.71	88000.11
2	1222.310	108.000	1494041.74	11664.00	132009.48
3	961.767	84.979	925001.53	7221.60	81731.21
4	836.212	73.885	699247.16	5459.73	61787.56
5	753.216	66.552	567340.37	4428.90	50126.79
6	536.057	47.365	287360.32	2243.92	25393.16
	Σx 5307.530	**Σy** 468.970	**Σx²** 4968915.28	**Σy²** 38793.86	**Σxy** 439048.31

Correlation coefficient (r), =

$$\frac{n\sum xy - (\sum y)(\sum x)}{\sqrt{[n\sum y^2 - (\sum y)^2]\ [n\sum x^2 - (\sum x)^2]}}$$

Flexural strength variables correlation (r_{xy}) = 1.0000

The two variables from the flexural strength examination correlated perfectly well.

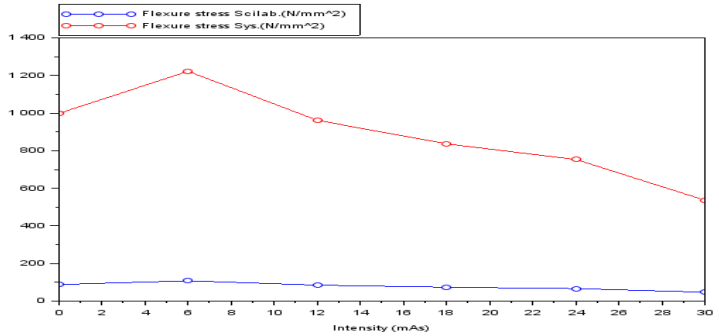

Figure 4.9: Flexural strength graph showing the relationship between the two methods

V. CONCLUSION

The consequences of this present investigation are the effect of exposure of composite laminates to X-rays radiation on the flexural properties of GFRP composite laminates. The effect of X-ray radiation on composite laminates was investigated by testing for flexural strength of the fabricated composite laminates. The following observations are made based on the extensive experimental studies and comparative analysis of the data obtained. It was shown that flexural properties accelerated with X-ray treatment which took place up to a

certain level and then started decreasing due to scission reaction which equally occurred simultaneously under X-ray radiation. Also, for high X-ray radiation dosage, poor composite adhesion, delamination and competition reaction between chain scission was observed particularly at 30mAs dose of X-ray radiation.

REFERENCES

[1]. Singh R. P. (2001) Effect of climatic and radiation ageing on properties of VPS-7 glass fiber reinforced epoxy compsite [Online], Available from: https://www.researchgate.net/publication (Retrieved 16/08/2017)

[2]. Mark E. Robeson (1997), Analysis of five-point bending of composite laminates, Volume 40, Issues 3–4, 3–4, pp 213-221

[3]. Vlachos et al. (2015) Effect of ultraviolet and x-ray radiation on optical properties of epoxy polymers dyed with organic phosphors, Journal of Physics Conference Series: Material Science and Engineering, Volume 168, conference 1

[4]. Correiaa J.R., S. Cabral-Fonsecab , F.A. Brancoa , J.G. Ferreiraa , M.I. Eusébiob and M.P. Rodriguesb, (2005) Durability of glass fiber reinforced polyester (GFRP) pultruded profiles used in civil engineering applications composites in construction, Third International Conference Lyon, France, Civil Engineering Department, Technical University of Lisbon.

[5]. Nambiar S., Osei E. and Yeo J. (2011) Polymer composite-based shielding of diagnostic X-rays, Journal of medical physics Volume 38, pp 3720.

[6]. Azim A. (2017) Effect of Gamma Radiation on the Properties of Jute Reinforced Polyester Matrix composites [on line], Available from: https://www.researchgate.net/publication [accessed August 28 2017].

[7]. Pothan L., Mai Y.W., Thomas S., Li R.K.Y., (2008) Tensile and flexural behavior of sisal fabric/polyester textile composites prepared by resin transfer molding technique J Reinf Plast Compos, pp. 1847-1866.

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