EFFECT OF CURING CYCLE AND EVALUATION OF MECHANICAL STRENGTH OF GLASS/EPOXY POLYMER COMPOSITE

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Abstract— Composite of Glass fiber reinforced with Epoxy resin is fabricated by conventional hand layup method, to study effect of curing temperature(140^{0}C,150^{0}C and 160^{0}C) with curing time period(1,2 and3Hrs) on composite material and also optimization of curing temperature and curing time period. Grey relation analysis has been carried out to optimize different mechanical strength such as tensile strength, flexural strength, inter laminar shear strength.

Keywords- Glass/Epoxy,Curing,Fabrication,Hand layup,Grey relation analysis.

1. Introduction

Composite materials are available in nature or engineered by fusing of two or more materials with considerably different chemical and physical properties which remain distinct at microscopic or macroscopic level within the finished structure. The constituent material is basically of two categories: reinforcement and matrix, the matrix supports the reinforcement against the mechanical and environmental damage accured by surrounding and maintaining their relative position, while the reinforcement gives physical properties and special mechanical such as dielectric, strength, stiffness etc.

Curing is an irreversible reaction where chemical covalent cross-links are formed which are thermally and mechanically stable.The curing process plays a major role in achieving the final mechanical properties and chemical resistance of the material. State of polymer resin is liquid (soft) before the fabrication of composite,which then changes to solid matrix (hard) after curing.For the fabrication of composite, two types of resins are used i) primary resin (matrix) ii) secondary resin (hardener). Most commonly used primary resins are epoxy, unsaturated polyester and polyurethane. Secondary resin i.e. hardener is added for curing purpose. Most commonly used secondary resin includes amines or peroxides. During cross linking, the state of matrix changes from liquid to gel and then transforms into solid. Curing can be done at room temperature as well as at elevated temperature.This depends on composition of resin and hardener. Optimum curing results in a perfectly cross-linked polymer network which leads to increased Tg (glass transition temperature) and mechanical properties. The Tg depends on different factors, including composition of the resin molecule, curing agent, curing time, cross-linking density and temperature. Generally, during post curing the Tg increases with increasing post curing temperature but it will not exceed the cure temperature. There are several parameters that define the post-cure process.When the temperature increased than Tg, the material looses their mechanical properties. Two biggest variables are temperature and time, but also the time between initial curing and post curing and temperature profile gradient play a role. post curing process can play crucial role in obtaining optimum mechanical and thermal properties of polymer matrix composites.Present investigation includes the effect of post curing parameters (post curing temperature and time) on tensile strength, flexural strength and ILSS strength.And grey relation analysis used to optimize the mechanical strengths.

2 Literature review

R K Prusty and B C Ray et al: study is Emphasized on the impact of post curing parameters on thermal as well as mechanical behaviour of glass fiber reinforced polymer (GFRP) composite. Post curing of E-glass/epoxy GFRP was carried out at 3different temperatures (80°C, 110°C and 140°C) for different time periods (2h, 4h, 6h, 8h and12h). Short beam Shear (SBS) test was performed on each of the post cured samples to determine the apparent Interlaminar Shear Strength (ILSS) and the corresponding Tg was also evaluated using differential scanning calorimetry (DSC) analysis. The results revealed that the ILSS and Tg are significantly affected with post curing parameters. No significant change in ILSS was obtained at 80°C over the entire curing time. In case of 110 °C a smooth increment in ILSS was observed with time (till 12 hrs).For samples post cured at 140 °C a rapid improvement in ILSS takes place with time followed by saturation.

Jaan KERS1,Kaspar TALL et al : In this research examination is done to see the effect of different post cure parameters on a polymer matrix particulate reinforced composite material(neopentyl glycol and isophthatic acid based on polyster resin). The goal is to evaluate the importance of different factors and to suggest a well-balanced post cure mode that supports the application of the material. For the determination of the suitable post cure parameters test slabs were casted and post cured with varying time and temperature. Glass transition temperature, softening in ethanol, surface hardness were determined. It is shown that the material should be cured at 60°C–80°C at the time period of 2hrs-12hrs.With higher temperature and extended time of cure the glass transition temperature raises but the material becomes too brittle.

R. M. Rudd, S.R. Ghafarian, A: The effect of post curing on Tensile and flexural strength as well as its effect on the impact energy of a Glass/Phenol-Formaldehyde (Novolac) composite is studied. A set of samples was post cured in step increasing temperatures for equal time, they were post cured in 75 C (2 hours), 95 C (2 hours), 130 C (2 hours), 160 C (2hours), 200 C (2 hours) for the total time of 10 hours. The other two set of samples were post cured in two temperatures of 160 and 200 C for different time periods. The results clearly show that the post curing has a detrimental effect on Tensile and flexural strength of the composite. On the contrary, it improves the impact resistance of it.

3. Methodology

The methodology adopted to carry out the research is as follows:

- Material selection.
- Laminate preparation using hand layup technique.
- Post curing of laminate at different temperature using micro woven.
- Preparation of specimen by cutting the laminate as per the ASTM Standards.
- Specimens were subjected to tensile, flexural. ILSS test.
- Grey relation analysis for optimization of results to get best combination of parameters.

3.1 MATERIAL SELECTION

The selected materials and their properties for the preparation of laminates are shown in table 1.

Reinforcement	Matrix material	Hardner
E-glass of 360 GSM bidirectional woven roving	Epoxy resin(LY556) [Aralide]	Hardner(HY951) [Arudur]
Density of fiber $\acute{\rho}_f$=2.54 g/cc	Density of Epoxy resin $\acute{\rho}_r$ =1.15-1.20g/cc	
Young's modulus of E-glass fiber 70-74N/mm^2		

Table no:1 Selected Material And Material Properties

3.2 Fabrication of GFRP Composite

The selected Woven fabric E- glass fibre were cut into the size of 15X15 cm to form 5 layer sheets and weighed by using electronic weighing machine. Epoxy resin was weighed to be 40% of the total weight of the fibre. Then hardener is added which is equal to 10% of the weight of epoxy resin respectively. Glass fibre/polyester laminate have been prepared by hand lay-up method and cured in a microwave oven.

(a) (b) (c)

Figure no 1: a) Cured Laminate b) Prepared Specimen for Tensile and Flexural test c) Prepared Specimen for ILSS Test

3.3 Tensile test

ASTM D3039 standard is used for the tensile testing. Tensile test was done on 10kn capacity computer controlled UTM,. The length of the specimen is 125 mm, width of specimen is 12.5 mm and thickness of specimen is 2 mm.The test speed at 2mm/min, The test setup for tensile testing is shown in fig number 2

Figure no: 2 Tensile test set up

3.4 Flexural test

ASTM D7264 standard is used for the flexural testing of laminate structure. Flexural test was done on 10kn capacity computer controlled UTM, Flexural test was done on 10kn capacity computer controlled UTM,. The spam length for flexural test is 90 cm. The length of the specimen is 125 mm width of specimen is 12.5 mm and thickness of specimen is 2mm. The test speed at 5mm/min, The test setup for tensile testing is shown in figure no 3

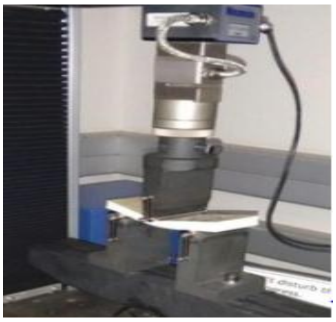


Figure no: 3 Flexural test set up

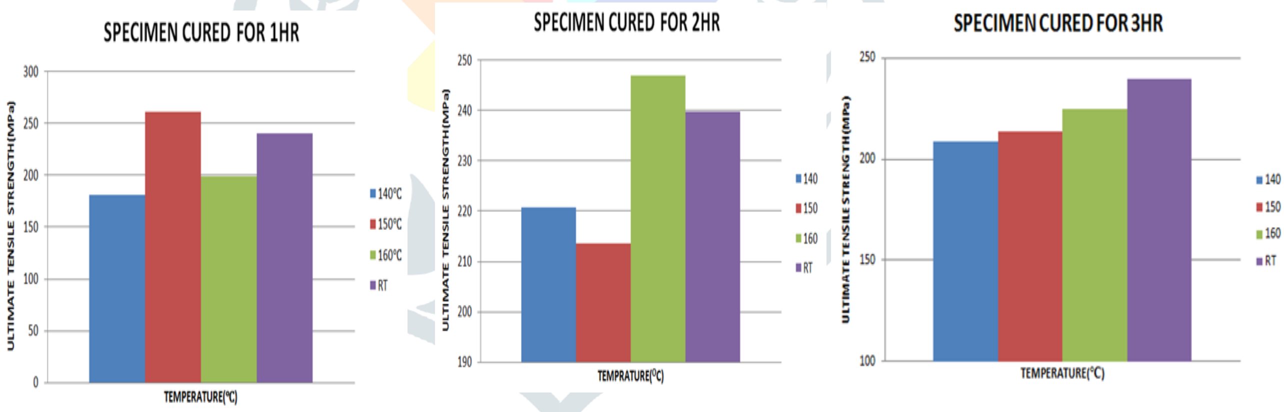
3.5 ILSS test

ASTM D2344 standard is used for the Inter laminar shear strength testing of laminate structure. ILSS test was done on 10kn capacity computer controlled UTM, The spam length for this set up is 90 mm. The length of the specimen is 50 mm width of specimen is 10 mm and thickness of specimen is 2mm. . The test speed at 1.3 mm/min,. The test setup for tensile testing is shown in figure no 4

Figure no: 4 ILSS test set up

4 Results and discussion

4.1 Tensile strength



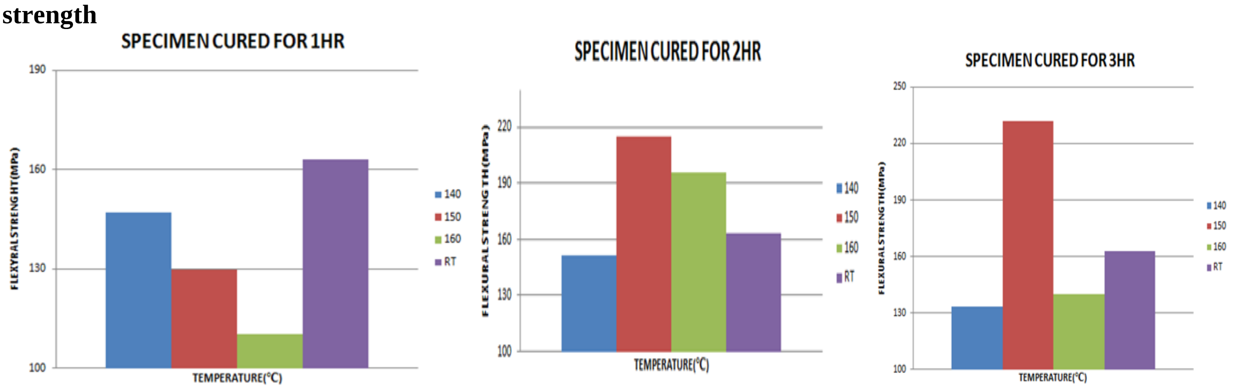
(a) (b) (c)

Figure no: 5 UTS Of A Specimen Cured At 140 150 160^{o}c Temperature For 1,2,3hrs Time Period.

The above figures 5(a),5(b),5(c) shows that, specimens cured for different temperatures(140 150 160 ^{o}C) and different time period(1,2,3 Hrs) and compared with specimen cured at room temperature.

- The ultimate tensile strength of 1Hr cured specimens at 140°C,150°C,160°C,and room temperature are 180.96MPa, 260.08MPa,198.31MPa,239.655MPa respectively. Among which 150°C temperature cured specimen recorded maximum ultimate tensile strength.
- The ultimate tensile strength of 2Hr cured specimens at 140°C,150°C,160°C,and at room temperature are 220.616MPa,213.47MPa,246.84MPa,239.655MPa respectively. Among which 160°C temperature cured specimen recorded maximum ultimate tensile strength.
- The ultimate tensile strength of 3Hr cured specimens at 140°C,150°C,160°C,and at room temperature are 208.632MPa,195.18MPa,224.61MPa,239.655MPa respectively. Among which room temperature temperature cured specimen recorded maximum ultimate tensile strength.

4.2 Flexural strength



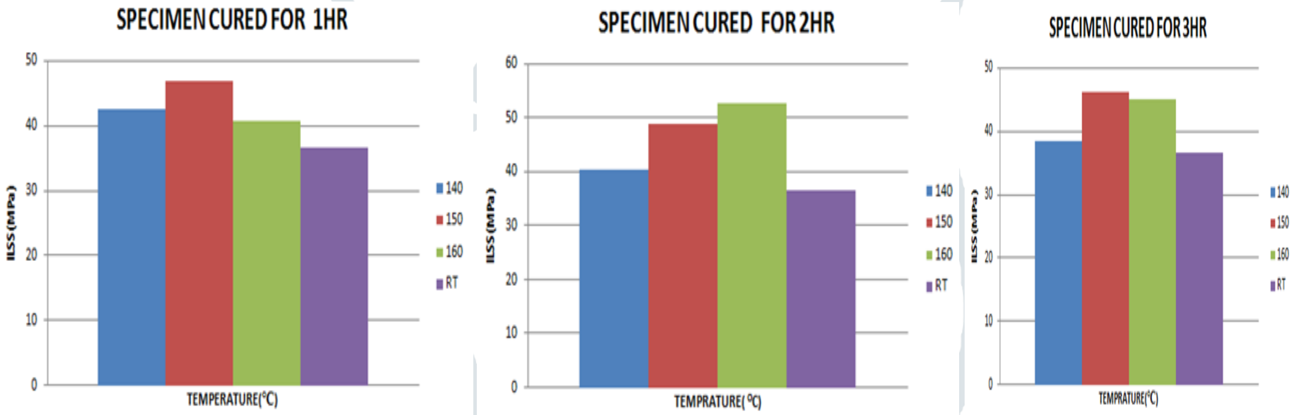
(a) (b) (c)

Figure No: 6 Flexural Strength Of A Specimen Cured At 140 150 160°c Temperature For 1,2,3Hrs Time Period.

The above figures 6(a),6(b),6(c) shows that, specimens cured for different temperatures(140 150 160°C) and different time period(1,2,3 Hrs) and compared with specimen cured at room temperature.

- The Flexural strength of 1Hr cured specimens at 140°C,150°C,160°C,and at room temperature are 110.205MPa, 129.75MPa, 146.90MPa,163.044MPa respectively. Among which Room temperature cured specimen recorded maximum flexural strength.
- The Flexural strength of 2Hr cured specimens at 140°C,150°C,160°C,and at room temperature are 151.38MPa, 215.055MPa, 195.768MPa,163.044MPa respectively. Among which 150°C temperature cured specimen recorded maximum flexural strength.
- The Flexural strength of 3Hr cured specimens at 140°C,150°C,160°C,and at room temperature are 133.164MPa, 231.876MPa, 140.113MPa,163.044MPa respectively. Among which 150°C temperature cured specimen recorded maximum flexural strength.

4.3 ILSS



(a) (b) (c)

Figure No 7 ILSS Of A Specimen Cured At 140 150 160°c Temperature For 1,2,3Hrs Time Period.

The above figures 7(a),7(b),7(c) shows that, specimens cured for different temperatures(140 150 160°C) and different time period(1,2,3 Hrs) and compared with specimen cured at room temperature.

- The ILSS of 1Hr cured specimens at 140°C,150°C,160°C,and at room temperature are 42.5MPa, 46.76MPa, 40.62MPa, 36.52MPa respectively. Among which 150°C temperature cured specimen recorded maximum ILSS strength.
- The ILSS of 2Hr cured specimen at 140°C,150°C,160°C,and at room temperature are 40,35MPa, 48.79MPa, 52.65MPa, 36.52MPa respectively. Among which 160°C temperature cured specimen recorded maximum ILSS strength.
- The ILSS of 3Hr cured specimens at 140°C,150°C,160°C,and at room temperature are 38.51MPa, 46.21MPa, 45.11MPa, 36.52MPa respectively. Among which 150°C temperature cured specimen recorded maximum ILSS strength.

4.4 Grey relation analysis

In Grey relational analysis, experimental data i.e. measured features of quality characteristics are first normalized to range between zero & one. This process is known as Grey relational generation. Based on normalized experimental data, Grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Overall Grey relational grade is determined by averaging the Grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated Grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation with the objective function which is the overall Grey relational grade.

EXP NO	NORMALIZED VALUES			GREY RELATIONAL COEFFICIENT			GREY GRADE	RANK
	TENSILE	FLEXURAL	ILSS	TENSILE	FLEXURAL	ILSS		
1	1	0	0.2821	1	0.3333	0.4105	0.5812	4
2	0.49879	0.3384	0.1305	0.4994	0.4304	0.3650	0.4316	8
3	0.6503	0.1886	0	0.5884	0.3812	0.3333	0.4313	7

4	0	0.1606	0.5834	0.3333	0.3733	0.5452	0.4172	9
5	0.1674	0.8618	0.7270	0.3752	0.7833	0.6468	0.6017	3
6	0.5892	1	0.5445	0.5489	1	0.5232	0.6907	1
7	0.781	0.3015	0.1492	0.6954	0.4171	0.3700	0.4941	5
8	0.1674	0.7032	1	0.3752	0.6275	1	0.6675	2
9	0.4483	0.2458	0.4667	0.4755	0.3986	0.4838	0.4526	6

Table no 2 Grey relational coefficient, grey grade and rank

5 Conclusions

From the experimentation of Tensile, Flexural, ILSS, for different cured temperature (140,150,160 ^{0}C) and time (1,2,3 Hr) we conclude that

- The maximum ultimate tensile strength is obtained for 150 ^{0}C temperature at 1 Hr time period cured specimen i.e, 260.08 MPa.
- The maximum flexural strength obtained for 150 ^{0}C at 3 Hr time period cured specimen i,e.231.876 MPa.
- The maximum Inter laminar shear strength obtained for 160 ^{0}C temperature at 2 Hr time period cured specimen i.e, 52.65 MPA
- The optimized results using grey relation analysis is 150 ^{0}C at 3 Hr time period cured specimen.

5.1 Scope for future work

- The heat absorption of laminates in microwave oven can be studied by using differential scanning calorimeter(DSC)
- Surface morphology of failed surface can be studied by using scanning electron microscope (SEM).
- Fracture and fatigue study can be done on Glass/Epoxy polymer composite.
- Mechanical strengths at below room temperature can be evaluated.

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