Processing and Characterization of Infrared Cured Glass and Carbon Fiber Reinforced Polymer Composites

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***Abstract*- Fibre reinforced polymer (FRP) composites are widely used in the area of aerospace, marine structures, sports equipment, electrical panel boards, medical prosthesis etc. The main objective of this project is to evaluate the mechanical properties such as Tensile and flexural strength of thermally cured and infrared cured GFRP, CFRP and Hybrid (CFRP + GFRP) composite laminates. It is concluded that GFRP, CFRP and Hybrid (CFRP + GFRP) composites can be successfully cured by infrared curing with lesser curing cycle time without sacrificing any mechanical properties.**

Keywords: Fibre reinforced polymer (FRP), Tensile and flexural strength, GFRP, CFRP and Hybrid (CFRP + GFRP) composite laminates.

I. INTRODUCTION

There are plenty of materials available to engineers for the design and manufacturing of products for various applications. These materials range from ordinary materials like brass, cast iron, copper which is available for several hundred years, to the more recently developed, advanced materials i.e. composites, ceramics and high performance steels. Due to wide choice of materials, today's engineers are posed with a big challenge for right selection of material and right selection of manufacturing processes for an application.
Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure. Composite Materials have come to existence as long as the history of human being is known. The demand for high performance composites was further aggrandized by the high cost of fuel which resulted from the energy crisis during the 1970s. Glass-Fiber-Reinforced Polymer Composites (GFRPs) have found extensive applications including fiber-glass boats, pressure vessels, and airplane panels. Glass fibers are the earliest known fibers in advanced composites compatible with Polyester and Epoxy matrices. Carbon-Fiber-Reinforced Polymer Composites (CFRPs) are known for their strength, durability and light-weight. Application of CFRP includes sport goods and components in aerospace industry [1].

2. LITERATURE REVIEW AND PROBLEM DEFINITION

Literature review indicates a very limited work on infrared curing of polymer composites. Following section briefly presents work carried out by other researchers. Ali Belharmra et al [3] have done an extensive review of technology and applications of infrared heating and have described the basic principle behind the technology and its important properties. They have discussed the applications of IR for metal processing, powder coating and local workspace heating and other advantages of IR.
Kiran kumar P et al [4-6] have discussed in their work that the infrared curing can be a viable alternative for curing of GFRP composites. Their studies have established the broad wave of 3-8 micrometer range can effectively be used for curing of glass fiber reinforced epoxy matrix polymer composites. They have custom designed an Infrared and hot air oven for the purpose of curing of GFRP composites.
Based on this survey it is understood that there is a need for optimizing the IR cure properties which is the major interest of the work undertaken.
Based on the above the problem for this investigation is formulated as "Processing and Characterization of Infrared cured Glass and Carbon Fiber Reinforced Polymer Composites".

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3. OBJECTIVES

- To evaluate the mechanical properties such as tensile & flexural strength of thermally cured and infrared cured GFRP and CFRP composites.
- To evaluate the effectiveness of IR curing process.

4. METHODOLOGY

- Fabrication of GFRP & CFRP composites.
- Thermal & IR curing of the above composites.
- Determination of mechanical properties by standard test procedures.

Polymer Matrix Composites (PMC):

A polymer is a substance composed of molecules with large molecular mass composed of repeating structural units, or monomers, connected by covalent chemical bonds. The term is derived from the Greek words: *polys* meaning many, and *meros* meaning parts.

Polymers are divided into two broad categories.

- ***Thermoplastic*** – A thermoplastic, also known as thermo softening plastic, is a polymer that turns to a liquid when heated and freezes to a very glassy state when cooled sufficiently. Most thermoplastics are high-molecular-weight polymers whose chains associate through weak Van der Waals forces, stronger dipole-dipole interactions and hydrogen bonding or even stacking of aromatic rings (ex. Nylon, polystyrene, polyethylene etc.)
- ***Thermosets*** - Thermoset is a polymer material that irreversibly cures. The cure may be done through heat generally above 200 °C, through a chemical reaction or IR processing. Thermoset materials are usually liquid or malleable prior to curing and designed to be moulded into their final form, or used as adhesives. (Ex. polyester, vinyl ester, epoxy, phenolic etc.

Polymer composites are consisting of the following materials
1. Matrix material and
2. Reinforcement material.

Glass Fibre:

Glass fibre is formed when thin strands of silica-based or other formulation glass is extruded into many fibres with small diameters. The reinforcing dispersed phase may be in the form of either continuous or discontinuous glass fibres.
The types of Glass fibre most commonly used are:

- E-glass (Electrical glass fibre) – The most popular and inexpensive glass fibre made of alumino-borosilicate glass, mainly used for glass-reinforced plastics.
- S-glass (Strength glass fibre) – Stronger than E-glass fibres, used in military application and in aerospace.
- C-glass (chemical glass fibre) – Corrosion and chemical resistant glass fibres, used for manufacturing storage tanks, pipes and other chemical resistant equipment.

Carbon Fibers:

Carbon fibres are fine filaments composed largely of elemental carbon with structure and properties varying from those of amorphous carbon to crystalline graphite. Carbon fibre posses a wide range of physical and chemical properties. The structure and properties of carbon fibre are dependent on raw material used. The reinforcing dispersed phase may be in the form of continues and discontinues carbon fibres of diameter about .0004" commonly oven into a cloth.

Carbon fibres are used for reinforcing polymer matrix due to the following properties

- Carbon fibres have the highest specific modulus and specific strength of all reinforcing fibre material.
- They retain their high tensile modulus and high strength at elevated temperature.
- At room temperature carbon fibres are not affected by moisture or a wide variety of solvents, acids, and bases.
- These fibres exhibit a diversity of physical and mechanical characteristics, allowing composites incorporating these fibres to have specific engineered properties.

Processing Of Polymer Composites

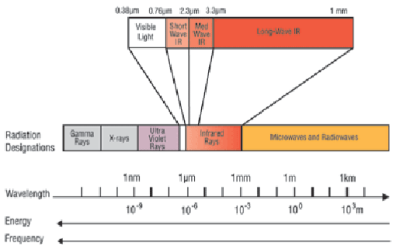
Hand lay-up is an open contact moulding in one-sided moulds, and is the least costly and most commonly used process for making fiberglass composite products and is the most common method of producing composites parts in the aircraft industry. Usually a special gel coat is sprayed against the mould before the layers of fabric are applied and this gel coat provides a high surface quality and a non-tacky surface. This is the slowest of the many processes for forming reinforced thermosets, but also the cheapest in mould costs. There is no size restriction on the articles to be laid up, and the method allows the designer remarkable flexibility. Changes to the design are easily made by altering the inexpensive molds. But clearly the quality of the products depends on the care used by the layup operator [9].

Fabrication of GFRP by hand layup

Curing Process:

Thermal Curing: In thermal curing the oven comprises a plurality of side walls defining an enclosed oven chamber and a heating element for heating the air within the oven chamber. An intake blower is configured to receive air from the ambient and force the ambient air into the oven chamber, thereby maintaining the air pressure therein at a relatively higher pressure than the pressure of the ambient air. This prevents airborne particulate contaminants from being drawn into the oven chamber. An air filter operatively associated with the intake blower to filter the air forced into the oven chamber. The oven also has an exhaust blower configured to draw air from the oven chamber and exhaust the air to the ambient. The exhaust blower works in conjunction with the intake blower to provide air exchange with the ambient while maintaining the relatively higher pressure state within the oven chamber.

Infrared Curing:



Infrared energy is a form of radiation, which falls between visible light and microwaves in the electromagnetic spectrum. Like other forms of electromagnetic energy, IR travels in waves and there is a known relationship between the wavelength, frequency and energy level. That is, the energy (temperature) increases as the wavelength decreases as shown in fig shown Unlike convection, which first heats air to transmit energy to the part, IR energy may be absorbed directly by the coating. It may also be reflected or transmitted to the substrate. When the equipment is properly matched with the application either absorption or transmission (to heat the part) may become the primary method used to achieve cure.

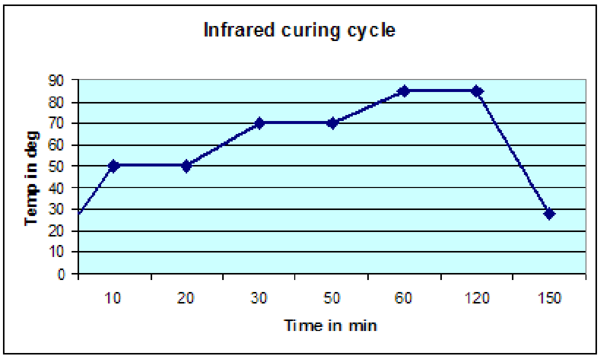
5. EXPERIMENTAL STUDY

Fabrication of Glass Fibre Reinforced Polymer Composites (GFRP)

Fabrication of GFRP is done by using LY556 epoxy resin and HY951 hardener and 13 layers of glass fibers. Weight of the glass fibre, amount of the resin and hardener is taken according to the following calculation.
Weight of the glass fiber (13 layers) =127 gm
Ratio of carbon fiber and resin hardener mixture is 65:35.
Weight of resin hardener mixture =127*35/65= 68.38gm
Weight of resin hardener mixture *25% wastage =68.38*1.25=85.4 gm
Ratio of resin and hardener is 100:11.
Weight of the resin =85.4 *100/111=77gm
Weight of the hardener =85.4*11/111= 8.4 gm

Fabrication of Carbon Fibre Reinforced Polymer Composites (CFRP)

Fabrication of CFRP is done by using LY556 epoxy resin and HY951 hardener and 13 layers of carbon fibers. Weight of the carbon fibre, amount of the resin and hardener is taken according to the following calculation.
Weight of the carbon fiber (13 layers) = 73gm
Ratio of carbon fiber and resin hardener mixture is 65:35.
Weight of resin hardener mixture =73*35/65=39.3 gm
Weight of resin hardener mixture *25% wastage = 39.3*1.25=49.13 gm
Ratio of resin and hardener is 100:11.
Weight of the resin =49.13*100/111=44.14 gm
Weight of the hardener =49.13*11/111=4.8 gm

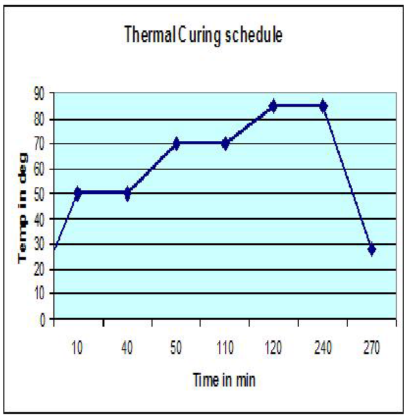


Fabrication of Hybrid Composites (Glass Fibre + Carbon Fibre):

Fabrication of hybrid composites is done by using LY556 epoxy resin and HY951 hardener 7 layers of carbon fibers and 6 layers of glass fibers. Glass fibres are bonded to carbon fibres on both end faces. Weight of glass and carbon fibres, amount of resin and hardener is taken according to the following calculation.
Weight of the carbon fiber (13 layers) = 93gm
Ratio of carbon fiber and resin hardener mixture is 65:35.
Weight of resin hardener mixture =93*35/65=50.07gm
Weight of resin hardener mixture *25% wastage =50.07*1.25=62.59 gm
Ratio of resin and hardener is 100:11.
Weight of the resin =62.59 *100/111=56.39gm
Weight of the hardener =62.59 *11/111=6.20gm

Thermal Curing:

The GFRP & CFRP laminate after fabrication is cured under room temperature for 24 hours. Then it is placed in an Infra-Therm chamber. The thermal chamber more precisely "Infra therm chamber" has four heaters in all the four sides and a blower to maintain the uniform temperature. Here the program is fed into the PID (programmable integrator differentiator) and the power supply is controlled automatically. Thermal curing cycle is as shown in fig below:



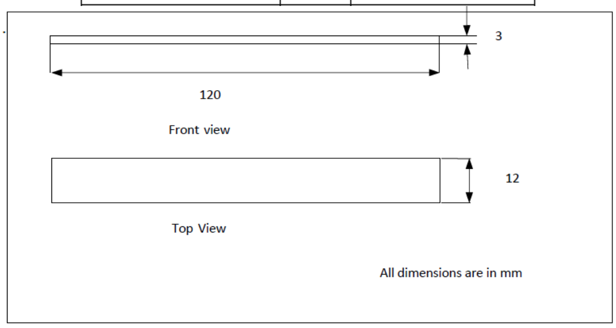
Temperature Changes	Time in Minutes
RT(30^{0}c) to 50^{0}c	10
50^{0}c soak	30
50^{0}c to 70^{0}c	10
70^{0}c soak	60
70^{0}c to 85^{0}c	10
85^{0}c soak	120
85^{0}c to RT	30

Infrared Curing: In the infrared curing the IR heaters provided in the chamber produces IR rays and the blower helps in, maintain the constant temperature inside the temperature the laminate is cured for 2.5 hours in the IR rays. The temperature measurement is done by means of an optical pyrometer. Here the power supply is done.

Temperature Changes	Time in Minutes
RT(30^{0}c) to 50^{0}c	10
50^{0}c soak	10
50^{0}c to 70^{0}c	10
70^{0}c soak	20
70^{0}c to 85^{0}c	10
85^{0}c soak	60
85^{0}c to RT	30

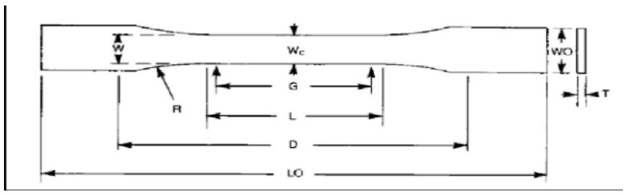
(Infrared+Thermal) Curing: The GFRP & CFRP laminate after fabrication is cured under room temperature for 24 hours. Then it is placed in Infra-Therm chamber. The laminate is cured for 2.5 hours (IR schedule) both IR and thermal power should be on. Program is feeded into PID and power supply is done both automatically and manually. Optical pyrometer is used for temperature measurement. Table shows the curing procedure for this method.

Temperature Changes	Time in Minutes	
	IR	THERMAL
RT(30^{0}c) to 50^{0}c	5	5
50^{0}c soak	5	5
50^{0}c to 70^{0}c	5	5
70^{0}c soak	10	10
70^{0}c to 85^{0}c	5	5
85^{0}c soak	30	30
85^{0}c to RT	15	15



6. PREPARATION OF TEST SAMPLES

Tensile Test Specimen.



Tensile test specimens are prepared according to ASTM (D638) as shown in fig

W—Width of narrow section	13
L—Length of narrow section	57
WO—Width overall	19
LO—Length overall	165
G—Gage length	50
D—Distance between grips	115
R—Radius of fillet	76

Tensile Test:

In a tension test, the test specimen elongates in a direction parallel to the applied load. In a simple tension test, the load is applied by gripping opposite ends of the specimen and paralleling it apart. This test is conducted in computerized universal testing machine and its maximum load capacity is 20KN. Thickness of the test specimen is 3mm.

The two important mechanical properties obtained by conducting tension test are:

- Young's modulus of specimen.
- Ultimate tensile strength of specimen.

Flexural Test Specimen:

Flexural test specimens are prepared according to ASTM (D790) as shown in fig.

Flexural Test:

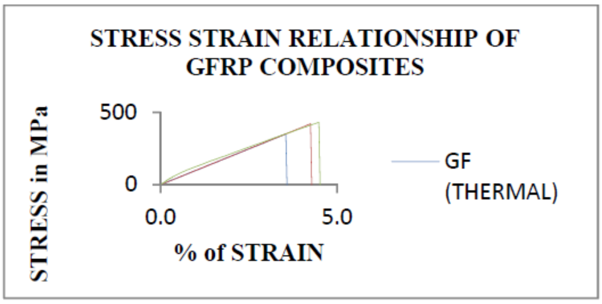
The flexural strength of a material is defined as its ability to resist maximum bending under applied load. Flexural strength also known as modulus of rapture or bending strength. The transverse bending test is most frequently employed, in which a rod specimen having either a circular or rectangular across section is bent until it breaks using a three point flexural test technique. Flexural strength represents the highest stress experienced within the material at its moment of bending. This test is conducted in computerized universal testing machine and its maximum load capacity is 20KN. Thickness of the test specimen is 3mm.

7. RESULTS AND DISCUSSIONS

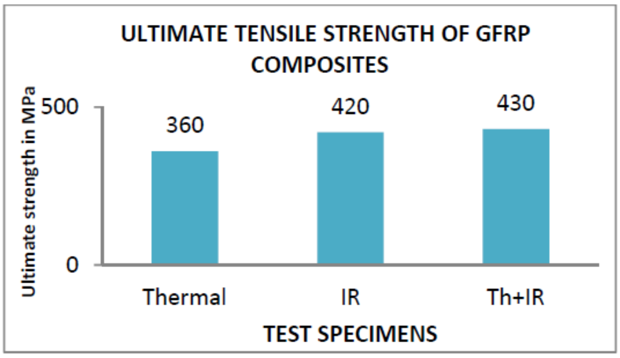
Tension Test

Methods of Curing	Ultimate Strength (MPa)	Young's Modulus (GPa)
Thermal	360	19.8
Infrared	420	21.8
Thermal + IR	430	18.6

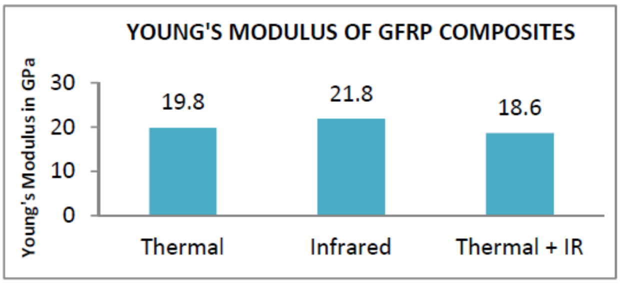
Tensile Test Result of GFRP Composites



Stress Strain Diagram for GFRP Composites



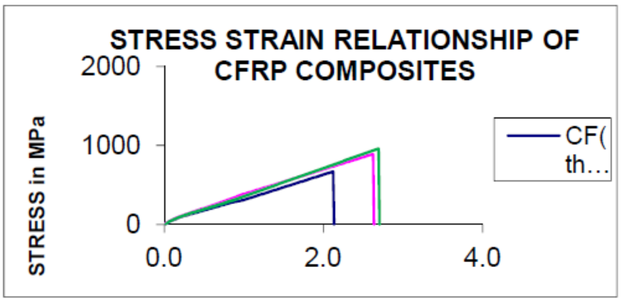
Ultimate Tensile Strength of GFRP Composites



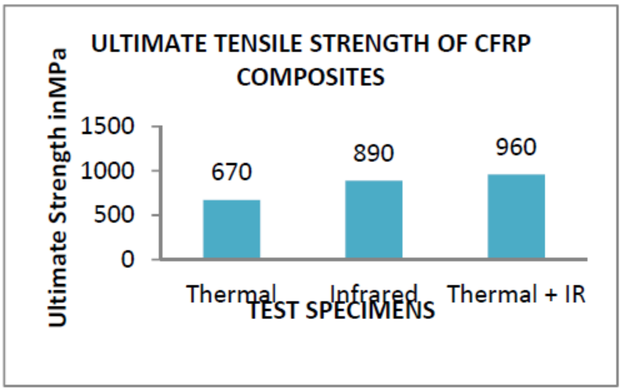
Young's Modulus of GFRP Composites

Methods of Curing	Ultimate Strength (MPa)	Young's Modulus (GPa)
Thermal	670	43.2
Infrared	890	77.6
Thermal + IR	960	56.3

Tensile Test Result of CFRP Composites



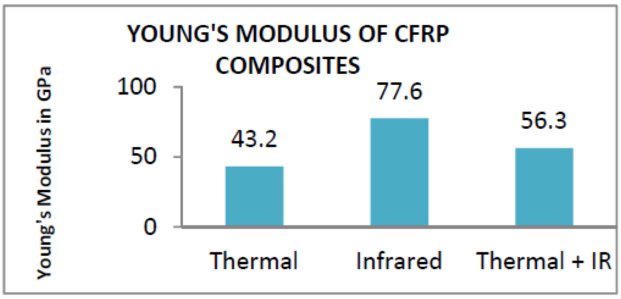
Stress Strain Diagram of CFRP Composites



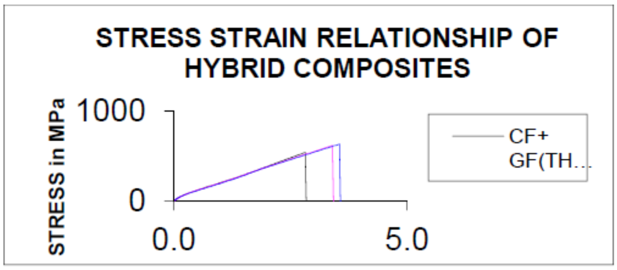
Ultimate Tensile Strength of CFRP Composites

Methods of Curing	Ultimate Strength (MPa)	Young's Modulus (GPa)
Thermal	540	38.9
Infrared	618	41.1
Thermal + IR	630	35.2

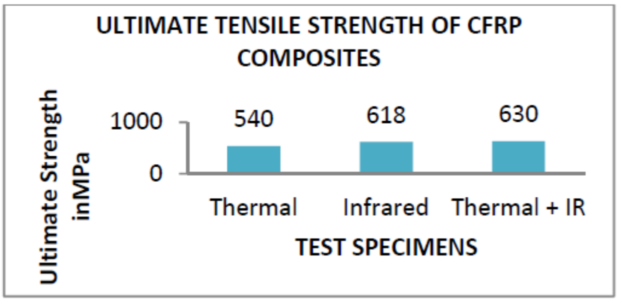
Tensile Test Result of Hybrid Composites



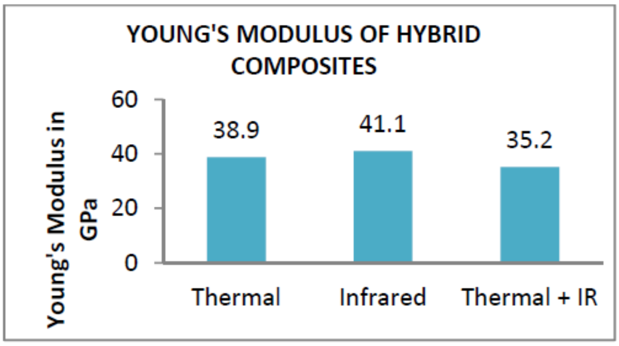
Young's Modulus of CFRP Composites



Stress Strain Diagram of Hybrid Composites



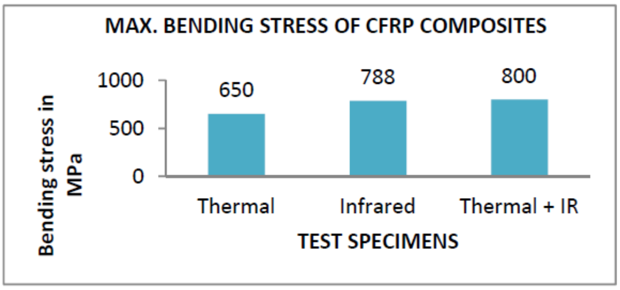
Ultimate Tensile Strength of Hybrid Composites



Young's Modulus of Hybrid Composites.

Methods of Curing	Maximum Bending Strength (MPa)
Thermal	270
Infrared	360
Thermal + IR	380

Flexural Test Result of GFRP Composites

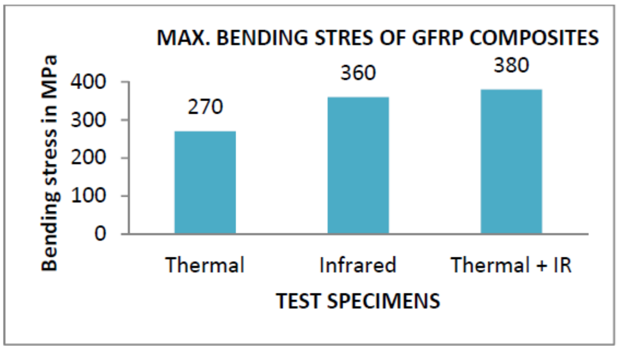


Flexural Strength of CFRP Composites

Methods of Curing	Maximum Bending Strength (Mpa)
Thermal	425
Infrared	570
Thermal + IR	550

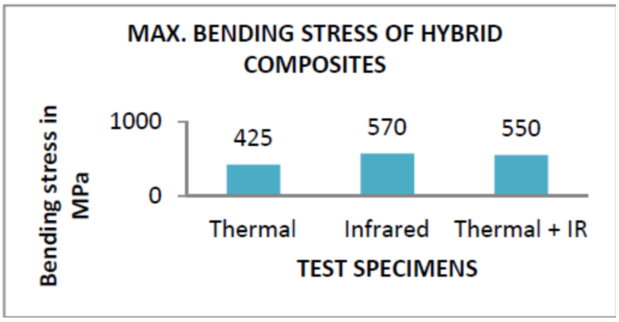
Flexural Test Result of Hybrid Composites

Flexural Test:



Flexural Strength of GFRP Composites

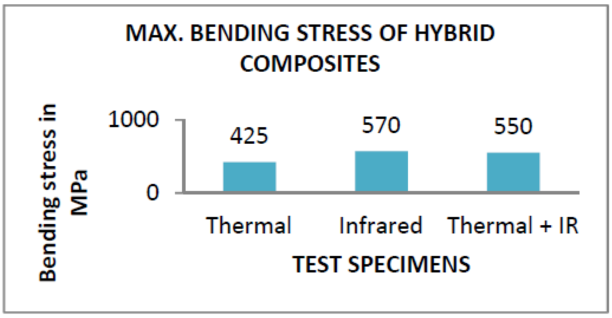
Methods of Curing	Maximum Bending Strength (Mpa)
Thermal	650
Infrared	788
Thermal + IR	800



Flexural Strength of CFRP Composites

Methods of Curing	Maximum Bending Strength (Mpa)
Thermal	425
Infrared	570
Thermal + IR	550

Flexural Test Result of Hybrid Composites



Flexural Strength of Hybrid Composites

8. DISCUSSIONS

The results of tensile and flexural strength discussed above indicate that IR curing is viable curing method for CFRP & GFRP composites. IR curing has higher value compare to thermal curing for all the tested laminates. (IR+Thermal) curing combination has marginally increased strength indicating IR is sufficient enough curing of polymer composites.

The results are better in case of IR curing since it is volumetric heating mode and the curing take place simultaneously throughout the composite laminate, unlike in thermal curing where heat flows from outer layer to inner core layer and the curing takes place in stages resulting in higher time consumption residual stresses within the composite. Though IR is energy efficient method some amount of heat is lost due to the moisture present in the medium between the composite and IR source.

In case of (IR+Thermal) combination this moisture is removed due to envelop of hot air circulating around the composite. Therefore loses are minimized and incident IR radiation is entirely utilized in curing of composite laminate. Higher degree of cure leads to improved strength as seen from result.

The CFRP composites have higher tensile and flexural strength since carbon fibre have higher strength compare to glass fibre. The important point to be considered is that IR radiation is well received by carbon fibre as they are good conductor than glass fibre, and therefore better bonding between matrix and reinforcement interfacial strength is increased and better strength in CFRP composite.

Hybrid composite have less strength compare to CFRP composite but they play vital role in mitigating the properties of both glass fibre and carbon fibre. Corrosion is avoided by using outer glass fibre layer & increasing strength by inner carbon fibre layer the number of layers can be attend according to required strength this work will help the designer to understand the properties of carbon fibre, glass fibre & hybrid composites w.r.t IR & Thermal curing.

Finally it can be concluded that CFRP, GFRP & Hybrid composite laminates can be cured by IR curing with less curing cycle time without sacrificing any mechanical properties.

9. CONCLUSIONS AND FUTURE SCOPE

Composite material is a material composed of two or more distinct phases (matrix phase and dispersed phase). The distinct advantage of polymer composite is that they can be fabricated according to customer requirement. In this work an effort has been made to evaluate the mechanical properties such as Tensile & Flexural strength of thermally cured and infrared cured GFRP, CFRP & Hybrid (GFRP+CFRP) composites laminates. GFRP, CFRP & Hybrid (GFRP+CFRP) composite laminates were cured by IR curing & Thermal curing.

It can be concluded that Infrared cured composite laminates have high Tensile and Flexural strength compared to thermally cured laminates.

CFRP composites have high Tensile & Flexural strength compared to GFRP composites and Hybrid (GFRP+CFRP) composites.

Infrared curing is a better curing process compared to thermal curing process as IR curing cycle time is less than thermal curing.

(IR+Thermal) curing combination has marginally increased strength indicating IR is sufficient enough curing of polymer composites. Similar studies can be taken up by employing different radiation curing techniques.

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