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HYGROTHERMAL DEGRADATION STUDIES ON E-GLASS WOVEN ROVINGS-EPOXY COMPOSITE

G Mounik[1*] and K Manikantesh[2]
[1]M.Tech research scholar, [2]Assistant Professor
Dept. of Mechanical Engineering, PBRVITS, Nellore, AP, India-524201

ABSTRACT: - Composite Materials figure among the rapidly emerging ones in the materials scenario due to their wide spread application potential in industrial sector. Their applications touch several engineering fields like marine, land transportation (automobiles, railways) construction, structural elements in machinery,, electrical, wind energy, material transportation piping systems, leisure & sports goods, aircraft interiors, military aerospace etc, The list is endless since these materials offer attractive benefits over conventional ones due to substantial weight savings leading to energy savings, resistance to corrosion, lower conversion costs due to part count reduction.

In spite all the above advantages, the origin of these materials is not more than 5 decades and a lot of things on the behaviour of them under different environments is yet to be understood, if they have to be deployed in key application areas. In marine applications like boats and fishing trawlers, they are exposed to saline water throughout their service life. Both E-glass & Epoxy resin and the composite derived from them are known to absorb moisture either by direct wetting or on exposure to high humidity environment. It is also a known fact that the extent of moisture absorption is a function of the temperature and the process of manufacture.

In this study, the property degradation of the selected material manufactured by compression moulding was investigated as a function of temperature after direct wetting in saline medium for varying periods.

It is hoped that generation of such data will help in determining the active service life of products, beyond which, they need to be discarded to prevent catastrophic failures.

1. Introduction:

Composites are combination of two or more materials (reinforcing elements, fillers, and composite matrix binder), differing in form or composition on a macro scale. Rather, they are a judicious mixture of the reinforcements and the matrix. The constituents retain their identities, that is, they do not dissolve or merge completely into one another although they act in concert. The properties of a composite will be different from those of the constituents in isolation and set of performance characteristics is greater than that of the components taken separately The term "composite material" refers to a substance made up of two or more separate phases (the matrix phase and the dispersion phase), with bulk properties very different from those of its component parts.

MATRIX PHASE: Matrix is the name of the initial phase, which has a continuous character. The matrix is typically less rigid and more ductile. It shares a burden and holds the dispersed phase.

DISPERSED (REINFORCING) PHASE: The matrix contains the second phase (or phases) in a discontinuous form. The dispersed phase is the name of this second phase. Dispersed phase is occasionally referred to as reinforcing phase because it is typically stronger than the matrix.

2. **LITERATURE REVIEW AND OBJECTIVE:** The time-temperature superposition principle (TTSP) is used to predict the long-term fatigue life of various FRP laminates combined with resins, fibers, and fabrics for marine use in temperature and water environments. Plain fabric CFRP laminates T300 carbon fibers/vinyl ester (T300/VE) served as the base material for the five types of FRP laminates that were used in this study. For marine use, the first type of FRP laminate for T300/VE was a combination of two different fabrics: flat yarn plain fabric T700 carbon fibers/vinyl ester (T700/VE-F) and multi-axial knitted T700 carbon fibers/vinyl ester (T700/VE-K). The second type of FRP laminate for T300/VE was a combination of two different types of fibers and matrix resins: plain fabric T300 carbon fibers/epoxy (After molding, these five types of FRP laminates were prepared under Dry, Wet, and Wet+Dry water absorption conditions. These FRP laminates were subjected to a variety of temperatures and strain rates for the three-point bending constant strain rate (CSR) tests under three different conditions of water absorption. Additionally, the specimens were subjected to a variety of temperatures and frequency settings for the three-point bending fatigue tests.

The behavior of carbon fiber composite (CFC) composite T-joints is studied in relation to temperature and moisture. Throughout the course of their lifespan, T-joints may be subjected to temperature and moisture. Temperature and moisture diffuse into T-joints under these conditions. As a result, the laminates lose their stiffness and strength properties. The properties of the lamina material at elevated temperatures and concentrations of moisture are also taken into account in the analysis.Deflections are presented in the form of contours, and maximum stresses developed in the Redux layer are presented in tabular forms. Two stacking sequences with clamped boundary conditions are considered for each variation in moisture and temperature.

The elastic properties of glass/epoxy woven-fabric composites under hygrothermal loading were predicted by using three analytical models originally developed for the prediction of room-temperature elastic properties of woven-fabric composites. In this analysis, the dry and wet bulk resin properties tested at similar temperatures as the composites were used to predict the overall elastic properties of glass/epoxy plates. It is assumed that the fibres are not affected by both temperature and moisture. It was found that the predicted elastic properties of both satinweave and unidirectional fabric composites are in good agreement with experimental values..

The current review manages both trial and mathematical examination on the free vibration conduct of overlaid composite plates exposed to differing temperature and dampness. For the hygrothermal loading of composite plates and their vibration, a straightforward laminated plate model is developed. In order to carry out each and every one of the calculations that are required, a MATLAB-based computer program using the finite element method is developed. The woven fiber glass/epoxy examples were hygrothermally molded in a mugginess bureau where the circumstances were kept up with at temperatures of 300-425 K and relative dampness going from 0% to 1.0% for dampness focuses. Quantitative outcomes are introduced to show the impacts of math, material and overlay boundaries of woven fiber cover on the free vibration of composite plates for various temperature and dampness focuses. Laminates with simple supported and clamped boundary conditions and various aspect ratios and side-to-thickness ratios exhibit a decrease in natural frequency in Hz with the increase in temperature and moisture concentration.

3. MATERIAL SYSTEMS

3.1 FIBRE:

A composite material is formed by reinforcing plastics with fibres. The fibres form the building block for a composite structure. For an enhanced knowledge on fibres, it is inevitable to study the functions it performs:

The main functions of the fibresin a composite are:

- To carry the load. In a structural composite, 70 to 90 % of the load is carried by fibres.
- To provide stiffness, strength, thermal stability, and other structural properties in the composites.
- To provide electrical conductivity or insulation, depending on the type of fibre used.

Different types of fibres available are:

- Carbon fibres.
- Glass fibres.
- Aramid fibres.

FIBRE TYPE COMPARISONS:

Comparing the properties of all of the fibre types with each other, shows that they all have distinct advantages and disadvantages. This makes different fibre types more suitable for some applications than others.

'A' indicates a feature where the fibre scores well.

'C' indicates a feature where the fibre is not so good.

Property	Aramid	Carbon	Glass
High Tensile Strength	B	A	B
High Tensile Modulus	B	A	C
High Compressive Strength	C	A	B
High Compressive Modulus	B	A	C
High Flexural Strength	C	A	B
High Flexural Modulus	B	A	C
High Impact Strength	A	C	B
High Interlaminar Shear Strength	B	A	A
High in-plane Shear Strength	B	A	A
Low density	A	B	C
High Fatigue Resistance	B	A	C
High Fire Resistance	A	C	A
High Thermal Insulation	A	C	B
High Electrical Insulation	B	C	A
Low Thermal Expansion	A	A	A
Low Cost	C	C	A

Woven Fabrics:

In the making of laminates, the fibre used is the plane weave oven roving'shaving trade name WR 360.

The interlacing of warp (90°) and weft (0°) fibers in a regular pattern or weave style results in the production of woven fabrics. The mechanical interlocking of the fibers maintains the fabric's integrity. The weave style is primarily responsible for determining a fabric's drape, surface smoothness, and stability. Drape is the fabric's capacity to conform to a complex surface. The right combination of fibretex and the number of fibers/cm2 determines the area weight, porosity, and, to a lesser extent, wet out. The following is a brief description of some of the weave designs that are found most frequently.

3.2 RESIN:

A **matrix** material fulfils several functions in a composite structure, most of which are vital to the satisfactory performance of the structure. Fibres in and of themselves are of little use without the presence of a matrix material or binder. The important functions of a matrix material include the following:

- The matrix material binds the fibres together and transfers the load to the fibres. It provides rigidity and shape to the structure.
- The matrix isolates the fibres so that individual fibres can act separately. This stops or slows the propagation of a crack.
- The matrix provides a good surface finish quality and aids in the production of net-shape or near-net-shape parts.
- The matrix provides protection to reinforcing fibres against chemical attack and mechanical damage (wear).
- Depending on the matrix material selected, performance characteristics such as ductility, impact strength, etc. are also influenced. A ductile matrix will increase the toughness of the structure. For higher toughness requirements, thermoplastic-based composites are selected

The failure mode is strongly affected by the type of matrix material used in the composite as well as its compatibility with the fibre.

4. PROBLEM FORMULATION

One of the first fundamental facts of which human beings become aware is that nothing lasts forever. Life may come to a sudden end or last longer, but still for only a finite period. This latter case is normally supplemented by a reduction in efficiency, known as **aging**. This human life experience is directly reflected in materials science; under a high load a structure or a component can fail at once, whereas it can effectually sustain lower loads.

The composite structures are being used in marine applications like, boat hulls etc. Apart from these, the composites are used as structural materials exposed to different kinds of degrading environment like temperature, relative humidity. By varying the combinations of fibre and epoxy, the desired properties can be obtained, thereby, increasing the working life of the structure.

From the literature survey related to glass fibre-epoxy composites, the following gaps were identified:

- Experimentation data related to mechanical behaviour of a glass-epoxy composite with woven roving's (Plain Weave) and epoxy resin, which pose superior properties is not available.
- Environmental effects under hygrothermal conditions on this combination of loftiest materials for a long time period have not been studied so far.

  From the gaps in the literature survey, the problem to be studied was formulated. It was decided to study the **effect of moisture, heat** (i.e. **hygrothermal effect**) for a specified time period. The change in physical & mechanical properties at macroscopic and microscopic levels was to be analysed. It was decided to attempt to further relate the macroscopic behaviour and microscopic behaviour shown by the composite structures under exposure to environmental conditions.

5. SAMPLE FABRICATION AND ANALYSIS

5.1 TOOL DRAWING:

The designing of the tool is a very critical in the making of the laminates. The quality of the laminate eventually depends upon the mould. Hence, the design of a tool plays a pivotal role in manufacturing.

The tool design involves the design of the mould. The mould determines:

- Dimension of the laminate.
- Surface finish of the laminate (on both the sides).
- Quality of the laminate made, i.e., laminate without any **air gaps** in between the layers.

An idealmould should provide:

- Uniform thickness of the laminate.
- No blow holes between the layers of the laminate.
- Zero bending of the laminate, i.e., the laminate must be perfectly straight in case of polygonal moulds.

- The weigh load applied by the tool (male mating part) on the layers must be isotropic (i.e., it must be uniform throughout).

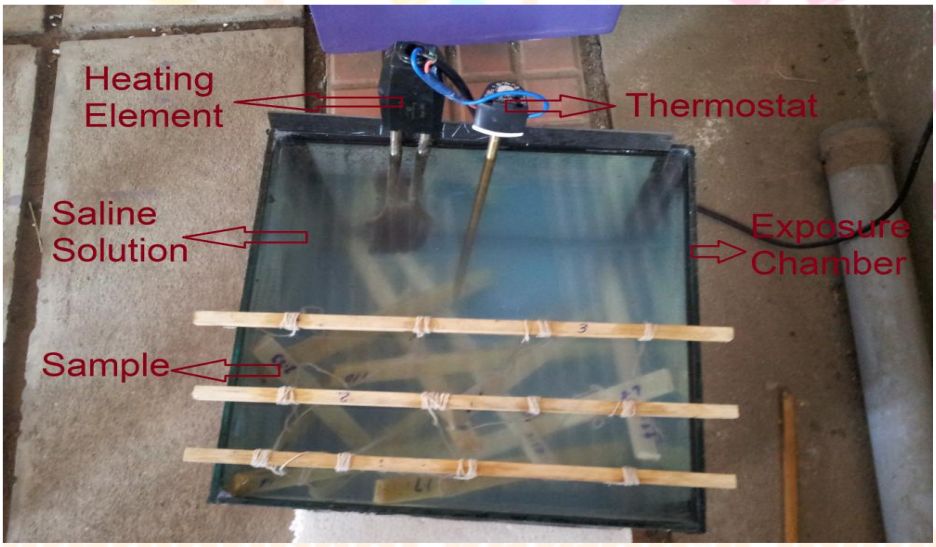
6. TEST SET-UP

A set of accelerated aging and natural environment tests has been carried out to evaluate performance of glass fibres-epoxy composite structures in tropical environment. The novelty of the experiment was that the accelerated environmental exposure was given. Thus field environment very similar to tropical climate was simulated.

6.1 Designing of an Exposure Chamber:

For this simulation, there is a requirement of a chamber that can accommodate and expose the required count of specimens to a particular condition. So, as per the requirement, the exposing chamber has been selected. The exposing chamber is made up of glass with dimensions of (300*300*300) mm.

SETUP FABRICATION:



6.2 Testing Apparatus:

The setup basically consists of following main elements:

ITEM NAME QUANTITY

1) Exposure Chamber - 01
2) Heating Elements - 01
3) Temperature Controllers – 01
4) Saline Solution - Full tank solution

Exposure Chamber: The experimental setup consists of well insulated hot water bath to avoid heat loss to environment. The specimens are to be kept fully immersed into the bath below a plate. The specimen are numbered numerically and kept in bath for respective time.

Heating Elements: The setup was heated with help of commercially available heating rod elements. The heater is connected to temperature controller (***THERMOSTAT***). The wattage of rod was 100KW with single phase connection. As the temperature reaches the required value the power supply of rods were cut off by controllers.

Temperature Controller: The objective of this set up was to maintain the bath temperature at specified value till the duration of experiment. Hence for this purpose a thermostat was used to automatically cut-offs and on the heater, eventually making the solution bath at required temperature.

Saline Solution: In the experiment, the nominal salinity of 2-5% in sea water is kept in mind and the testing has been classified accordingly. Testing has been decided to carry out at the maximum salinity i.e 5% salinity

7. EXPERIMENTATION

7.1 Testing Parameters:

The testing takes into consideration many factors that seriously brings out a change in the mechanical properties of the composite specimen. There are two kinds of testing parameters:

1) Fixed parameters
   - Relative Humidity.
   - Cross head speed of the UTM machine (Strain rate of the specimen).
2) Variable parameters
   - Concentration of the bath.
     - ✓ 5% salinity solution
   - Temperature of the environment.
     - ✓ Ambient room temperature at 32°C
     - ✓ Elevated temperature of 50°C
     - ✓ Elevated temperature of 85°C
   - Time duration of exposure to degrading environment.
     - ✓ 1hr, 5hr, 10hr for ambient temperature
     - ✓ 30mins, 60mins, 90mins for elevated temperatures

So, the specimen's exposition to the degrading environment has been done considering the above parameters (both fixed and variable).

7.2 Pre-baking of test specimens: As this research work is very useful in the life assessment of a composite structure of a particular combination of fibre-resin, ultimate care has been taken and all the experimentation has been done under secure and precise conditions.

All the way starting from manufacturing to pre-testing, the specimens have been exposed to natural environment. Due to this, there is every possibility of the composite specimen absorbing moisture from the environment, thereby degrading the strength of it. So in order avoid the false values and carry out experiments for accurate results, all the 72 specimens are **BAKED**in a **hot-air oven**at 100deg C for 24hours.

The main aim of this process is to make the moisture/ water vapour contained by the composite specimen to evaporate. This results in providing the composite specimen's with no traces of moisture in it.

After baking the specimens, the original weight of the specimens is calculated with a high precision digital balance up to 3 decimal places in grams.

7.3 Volume Fraction of Fibre in the laminate made:

Rule of mixtures:

Whilst deformation of homogeneous, isotropic materials can be described relatively simply by use of Young's and Shear moduli, which are bulk properties of the raw material simple properties of composite

materials can be estimated based on the contribution of each part of the composite. This method is referred to as the rule of mixtures (RoM).

For a 2 component composite:
$V_f + V_m = 1$

Procedure to calculate Volume Fraction:

- Cut the specimen into a small piece of dimension (10*10*3.75) mm and place it in the crucible as shown Specimen for heating

- Weigh the specimen before placing it in the furnace.
- Now place the crucible carrying specimen in a muffle furnace at 6000 to 7000C for 3 hours that the resin comes out totally leaving out the fibre.
- After removing out the fibre alone, its weight is again calculated.
- Hence by calculating the volume of fibre, volume fraction of fibre is obtained.
- Two specimens are tested to ascertain the values of volume fraction to be uniform throughout.

Calculations of cold setting:

- Weight of the total composite (fibre + matrix) = 0.700gm
- Weight of the fibre left after heating = 0.500gm
- Weight of the resin in the composite = 0.200gm
- Density of the fibre (woven roving) = 2540gm/cm³
- Density of the resin(epoxy-LY556) = 960gm/cm³

Hence, calculating the volume fraction:

- Volume of fibre in the composite specimen (Vf) = (0.500/2540) = 0.00019685cm³
- Volume of the matrix in the composite specimen (Vm) = (0.200/960)=0.000208333cm³

According to the rule of mixtures,

For a two component composite:

Total volume (V) = (Vf) + (Vm)

= 0.00040518cm³

Hence, Volume Fraction of Fibre= $\frac{volume of fiber}{volume of composite}$

$= \frac{0.00019685}{0.00040518}$

=0.48582996

Hence, it shows that the **volume fraction of fibreof cold setting laminate** is around **48.582996%** in the total composite.

Calculations of hot setting:

- Weight of the total composite (fibre + matrix) = .580gm
- Weight of the fibre left after heating = 0.450gm
- Weight of the resin in the composite = 0.130gm
- Density of the fibre (woven roving) = 2540gm/cm³

- Density of the resin(epoxy-LY556) = 960gm/cm³

Hence, calculating the volume fraction:

- Volume of fibre in the composite specimen (Vf) = (0.450/2540) = 0.00017716cm³
- Volume of the matrix in the composite specimen (Vm) = (0.130/960) =0.00013541cm³

According to the rule of mixtures,

For a two component composite:

Total volume (V) = (Vf) + (Vm)

= 0.00031258cm³

Hence, Volume Fraction of Fibre = $\frac{volumeoffiber}{volumeofcomposite}$

$=\frac{0.00017716\text{cm}^3}{0.00031258\text{cm}^3}$

= 0.566780373

Hence, it shows that the **volume fraction of fibre of cold setting laminate** is around **56.6780373%** in the total composite.

8. RESULTS AND DISCUSSIONS

The research includes the study of the composite structures exposed to a degrading environment. Simulating the real time environment and studying the properties before and after exposure of the specimens.is Hence both the kinds of study have been analysed:

- Macroscopic Behaviour.
- Microscopic Behaviour.

8.1 Macroscopic behaviour:

Macroscopic study of the specimens before and after dipping into the brine solution bath, include:

- Observing the macroscopic properties like strength deterioration due to moisture gain.
- Some scalingon the surface of the composite specimen.

The tensile strength has been calculated by testing the exposed specimens in a UTM of 400KN max. load capacity. Testing has been done immediately after removal of exposure from degrading environment.

Fig 8.1 Specimens undergoing tensile testing in a UTM

The tensile strength for a virgin specimen under standard conditions was found to be **450.0MPa**, for a thickness of 3.75mm and an area of cross section of 56.25mm² for cold setting tensile specimen.

The tensile strength for a virgin specimen under standard conditions was found to be **475.5Mpa** for thickness of 3.5mm and an area of cross section of 56.25 mm²

The short beam shear maximum load on the specimen as per standard testing values is **0.9 KN** for cold setting laminate.

The short beam shear maximum load on the specimen as per standard testing values is **1.2KN**for hot setting laminate.

The **cross head speed** of the UTM plays a very crucial role in deciding the exact tensile strength of the specimen. Hence, the mechanical testing for tensile strength on a UTM, a constant cross head speed of 1.1mm/min has been maintained.

8.2 Microscopic behaviour:

Microscopic study includes, observing the specimen before and after immersion under an electron microscope to study the grain size variation. Also the surface hardness can also be studied.

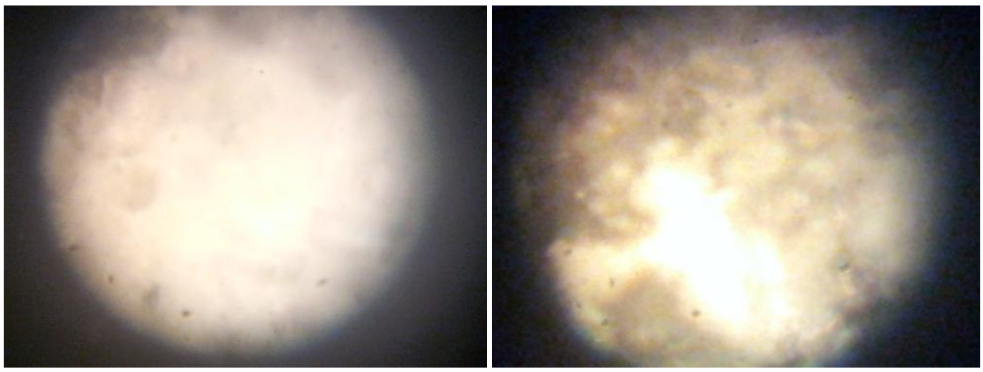


Fig 8.2 Figure showing the microscopic difference between the specimens before and after dipping.

8.3 Moisture Gain calculations:

Moisture gain plays a pivotal role in the degradation of mechanical properties. Gravimetric trends monitoring the weight change of a material over time allow for the interpretation of diffusion phenomena through the application of diffusion models. Knowledge of the process of water sorption in a polymer composite provides for an understanding of physical processes which occur as the water and constituent elements interact. When considering the uptake of water in material exposed to humid air and liquid water, it is assumed that the only sorbing substance is water molecules. The apparent moisture content at some time t, Mt, is calculated using the initial weight after pre-conditioning W0 and the "wet" weight after environmental exposure Ww

$$Mt = (Ww-W0)/ W0$$

The weights of all specimens before and after the dipping are tabulated. The following shows the moisture gain in grams and percentage w.r.t the original weight of the specimen.

1) 5% brine solution at ambient temperature of hot setting tensile test specimen

Dipping time of specimen	Weight of specimen before dipping (W)		Weight of specimen after dipping(w)		Moisture gain %	
	Unsealed specimen	Sealed specimen	Unsealed specimen	Sealed specimen	Unsealed specimen	Sealed specimen
Dipping time 1 hour	23.9360	23.934	23.9369	23.9349	0.0037%	0.0021%
Dipping time 5 hours	23.008	24.548	23.009	24.5489	0.0043%	0.0036%
Dipping time 10 hours	23.691	23.869	23.699	23.872	0.0337%	0.0125%

1) 5% brine solution at 50°C of hot setting tensile test specimen

Dipping time of specimen	Weight of specimen before dipping (W)		Weight of specimen after dipping(w)		Moisture gain %	
	Unsealed specimen	Sealed specimen	Unsealed specimen	Sealed specimen	Unsealed specimen	Sealed specimen
Dipping time 30 minutes	22.848	23.776	22.854	23.780	0.0262%	0.0168%
Dipping time 60minutes	23.731	23.257	23.741	23.265	0.0421%	0.0344%
Dipping time 90 minutes	24.386	24.663	24.398	24.663	0.0492%	0.0405%

Hot-setting Laminate Tensile Test:

Bath temperature	Holding time	Control value	Tensile strength (Mpa)	
			Unsealed	Sealed
Ambient temperature	1 hour	476.19	438.09	457.14
	5 hours	476.19	419.05	438.09
	10 hours	476.19	400.00	419.05
50°C	30 minutes	476.19	413.14	427.11
	60 minutes	476.19	392.15	407.41
	90 minutes	476.19	371.40	389.97
85°C	30 minutes	476.19	389.43	408.54
	60 minutes	476.19	370.37	392.16
	90 minutes	476.19	352.83	373.48

Cold-setting Laminate Tensile Test:

Bath temperature	Holding time	Control value	Tensile strength	
			Unsealed	Sealed
Ambient temperature	1 hour	424.77	391.11	408.88
	5 hours	424.77	373.33	390.07
	10 hours	424.77	355.55	372.34
50°C	30 minutes	424.77	371.35	388.00
	60 minutes	424.77	353.67	370.37
	90 minutes	424.77	335.98	352.73
85°C	30 minutes	424.77	351.80	368.42
	60 minutes	424.77	334.21	350.87
	90 minutes	424.77	316.62	333.33

Hot-setting short beam shear test:

Bath temperature	Holding time	Control value	Short beam shear strength (Mpa)	
			Unsealed	Sealed
Ambient temperature	1 hour	31.42	30.14	31.10
	5 hours	31.42	29.22	30.55
	10 hours	31.42	28.07	29.65
50°C	30 minutes	31.42	29.76	30.75
	60 minutes	31.42	28.65	29.85
	90 minutes	31.42	27.43	28.79
85°C	30 minutes	31.42	28.76	29.93
	60 minutes	31.42	27.43	28.72
	90 minutes	31.42	26.15	27.45

Cold setting short beam shear test:

Bath temperature	Holding time	Control value	Short beam shear strength (Mpa)	
			Unsealed	Sealed
Ambient temperature	1 hour	26.76	24.62	25.75
	5 hours	26.76	23.47	24.64
	10 hours	26.76	22.09	23.39
50°C	30 minutes	26.76	23.52	24.75
	60 minutes	26.76	22.25	23.57
	90 minutes	26.76	20.79	22.16
85°C	30 minutes	26.76	22.37	23.62
	60 minutes	26.76	21.01	22.25
	90 minutes	26.76	19.89	20.85

9. CONCLUSIONS

The main aim of this dissertation lies in finding the durable life of the composite structure under degrading environment. From the experiments conducted, the scope of work indulges in:

- Calculations for the volume fraction of fibre.
- Moisture gain trends for different temperatures which vary with time.
- The hygrothermal degradation has been studied and the deterioration rates of tensile strength have been studied.
- Hot setting laminate is proved experimentally to have a good strength when compared to cold setting laminate.
- **And more importantly in this project we had tried to improve the properties of material by changing the hardner from cold setting of our senior batch to hot setting laminates of our project.**
- **Another improvement is that we had improved our project by manufacturing using Compression moulding instead of hand layup which is used by our senior batch**.

Hot setting Tensile strength

Holding time	% gain in weight after exposure			Tensile Strength after exposure. (Mpa)			% Degradation in tensile strength		
	32°c	50°c	85°c	32°c	50°c	85°c	32°c	50°c	85°c
After first holding time	0.0037 % 0.0021 %	0.0262 % 0.0168 %	0.0729% 0.0692%	438.09 457.14	413.14 427.11	389.43 408.54	8.0010% 4.0000%	13.2405 % 10.3068 %	18.2196 % 14.2065 %
After second holding time	0.0043 % 0.0036 %	0.0421 % 0.0344 %	0.1128% 0.0944%	419.05 437.19	392.15 407.41	370.37 392.16	11.9994 % 8.1900%	17.6484 % 14.4438 %	22.2222 % 17.6463 %
After third holding time	0.0337 % 0.0125 %	0.0492% 0.0405%	0.1689 % 0.1466 %	400.00 416.27	371.40 389.97	352.83 373.48	15.9999 % 12.5832 %	22.0059 % 18.1062 %	25.9056 % 21.5691 %

In the above table red text indicate unsealed specimen and blue text indicate sealed specimen

Cold setting tensile strength

Holding time	% gain in weight after exposure			Tensile Strength after exposure. (Mpa)			% Degradation in tensile strength		
	32°c	50°c	85°c	32°c	50°c	85°c	32°c	50°c	85°c
After first holding time	-0.0078% 0%	-0.0080% -0.0038%	-0.0353% -0.0230%	391.11 408.88	371.35 388.00	351.80 368.42	7.9242% 3.7408%	12.5762% 8.6564%	17.1787% 13.2660%
After second holding time	-0.0235% -0.0039%	-0.0158% -0.0077%	-0.0632% -0.5810%	373.33 390.07	353.67 370.37	334.21 350.87	12.1108% 8.1691%	16.7384% 12.8069%	21.3197% 17.3976%
After third holding time	-0.0273% -0.0078%	-0.0194% -0.0116%	-0.0691% -0.7330%	355.55 372.34	335.98 352.73	316.62 333.33	16.2958% 12.3431%	20.9030% 16.9597%	25.4608% 21.5269%

In the above table red text indicate unsealed specimen and blue text indicate sealed specimen

Hot setting Short beam shear strength

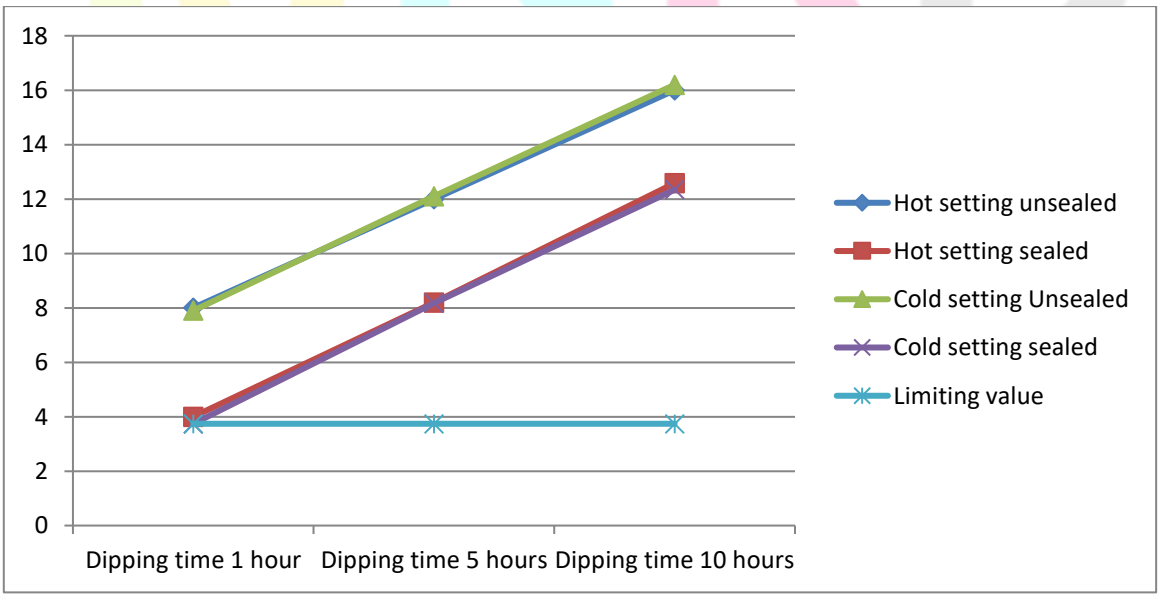
Holding time	% gain in weight after exposure			Tensile Strength after exposure. (Mpa)			% Degradation in tensile strength		
	32°c	50°c	85°c	32°c	50°c	85°c	32°c	50°c	85°c
After first holding time	0.0168% 0.0166%	0.0367% 0.0170%	0.1117% 0.0746%	30.14 31.1	29.76 30.75	28.76 29.93	4.0738% 1.0184%	5.2832% 2.1323%	8.4659% 4.7422%
After second holding time	0.0371% 0.0316%	0.0550% 0.0337%	0.1487% 0.1117%	29.22 30.55	28.65 29.85	27.43 28.72	7.0019% 2.7689%	8.8160% 4.9968%	12.6989% 8.5932%
After third holding time	0.0735% 0.0434%	0.0645% 0.0559%	0.2594% 0.1494%	28.07 29.65	27.43 28.79	26.15 27.45	10.6619% 5.6333%	12.6989% 8.3704%	16.7727% 12.6352%

In the above table red text indicate unsealed specimen and blue text indicate sealed specimen

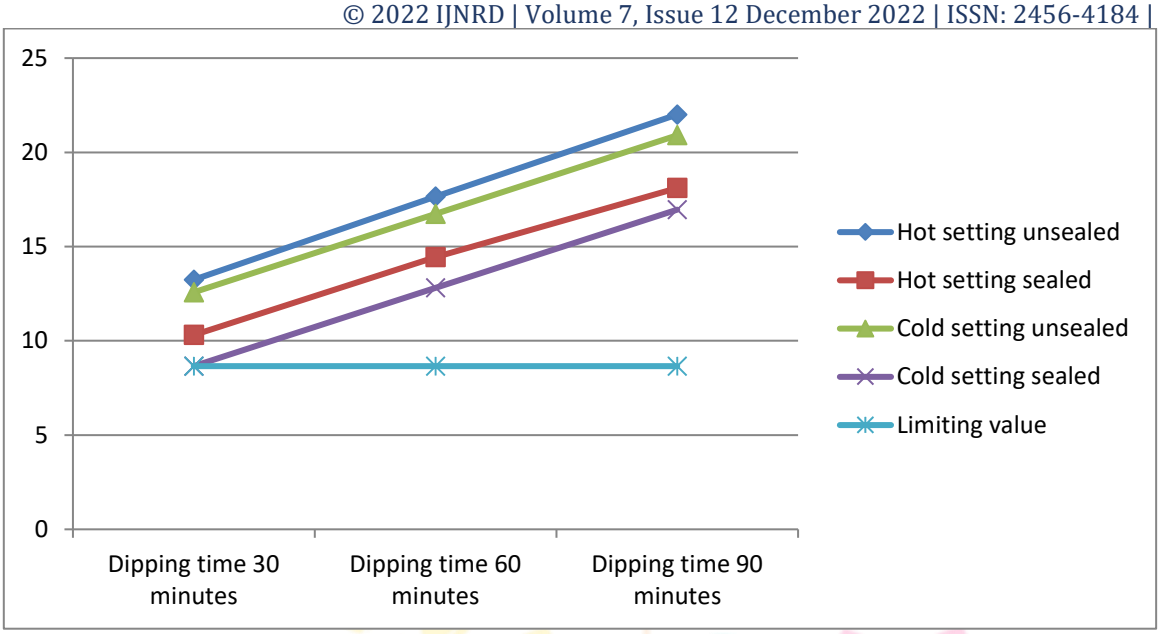
Cold setting Short beam shear strength

Holding time	% gain in weight after exposure			Tensile Strength after exposure.			% Degradation in tensile strength		
	32°c	50°c	85°c	32°c	50°c	85°c	32°c	50°c	85°c
After first holding time	0% 0%	-0.0314% 0%	-0.0657% -0.0325%	24.62 25.75	23.52 24.75	22.37 23.62	7.9970% 3.7742%	12.1076% 7.5112%	16.4050% 11.7339%
After second holding time	-0.0164% 0%	-0.0499% -0.0323%	-0.0981% -0.0454%	23.47 24.64	22.25 23.57	21.01 22.25	12.2944% 7.9222%	16.8535% 11.9207%	21.4872% 16.8535%
After third holding time	-0.0317% -0.0161%	-0.0633% -0.0488%	-0.1337% -0.0797%	22.09 23.39	20.79 22.16	19.89 20.85	17.45% 12.5934%	22.3094% 17.1898%	25.6726% 22.0852%

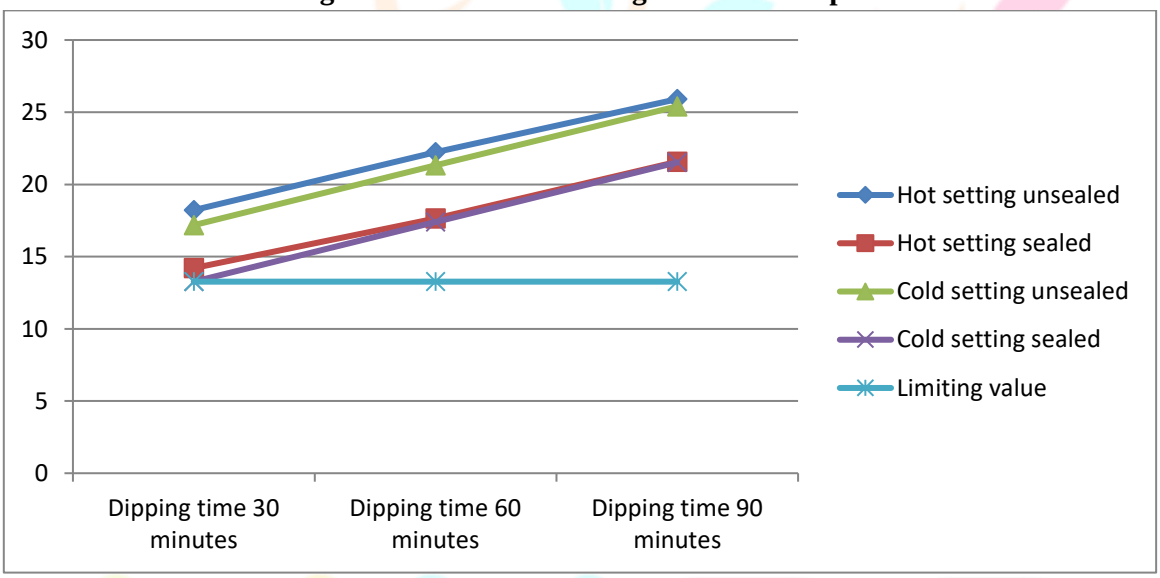
In the above table red text indicate unsealed specimen and blue text indicate sealed specimen



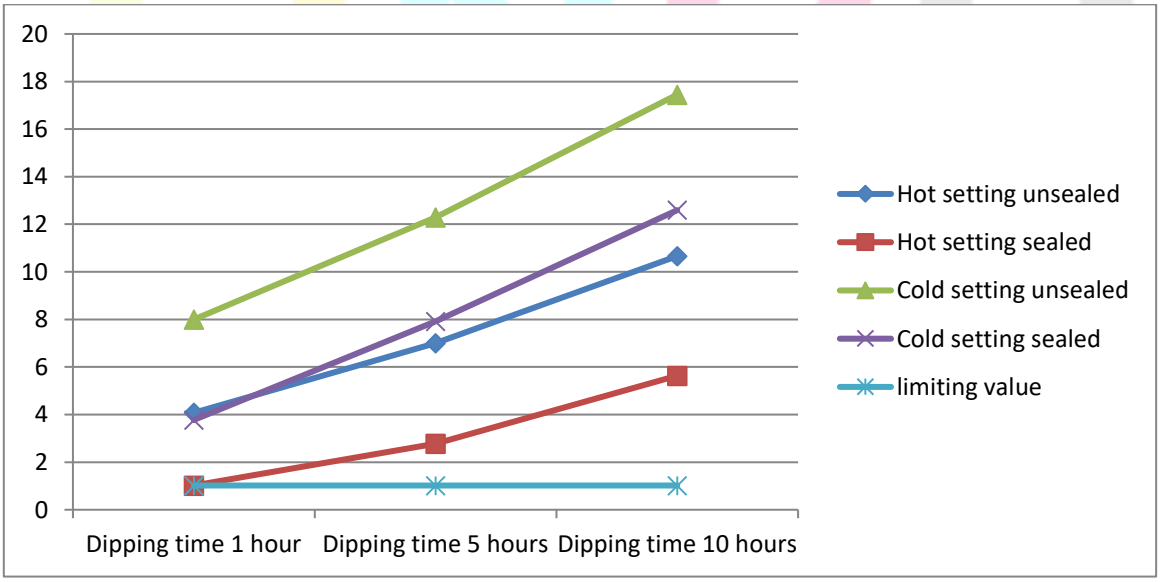
% of degradation in tensile strength at ambient temperature



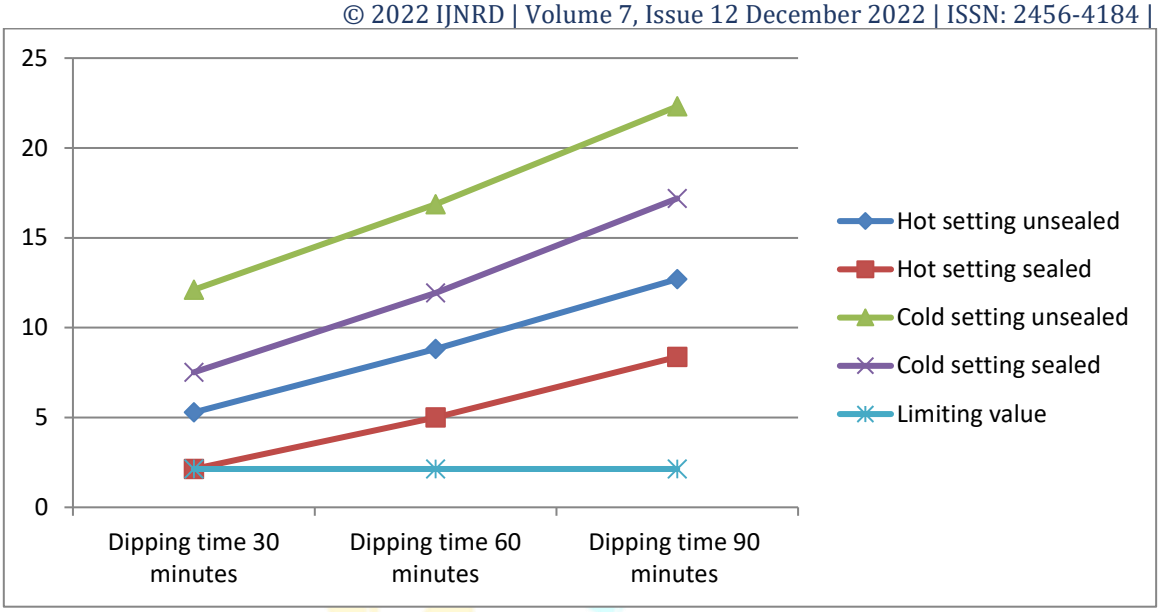
% of degradation in tensile strength at 50°C temperature



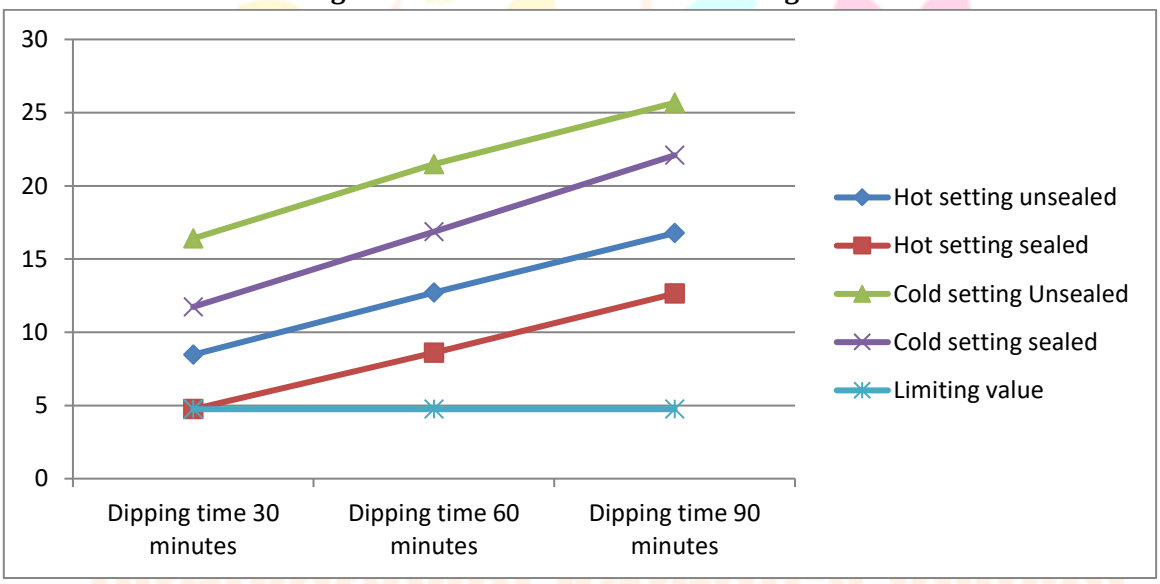
% of degradation in tensile strength at 85°C temperature



% of degradation in Short beam shear strength at ambient temperature



% of degradation in Short beam shear strength at 50°C

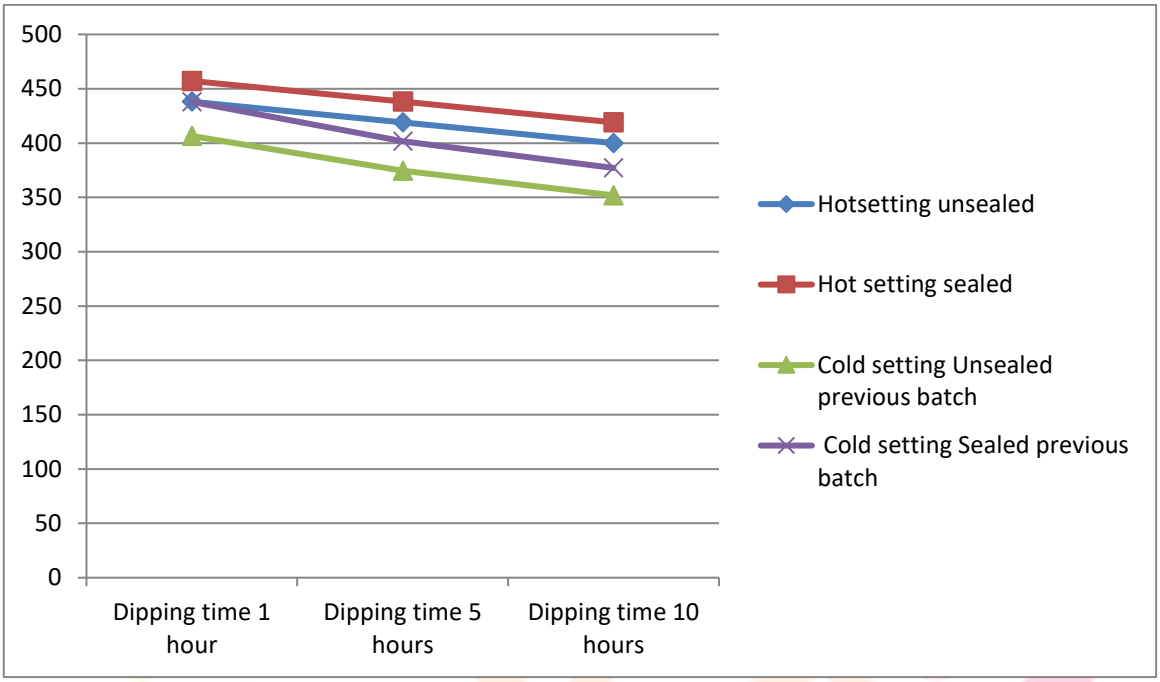


% of degradation in Short beam shear strength at 85°C

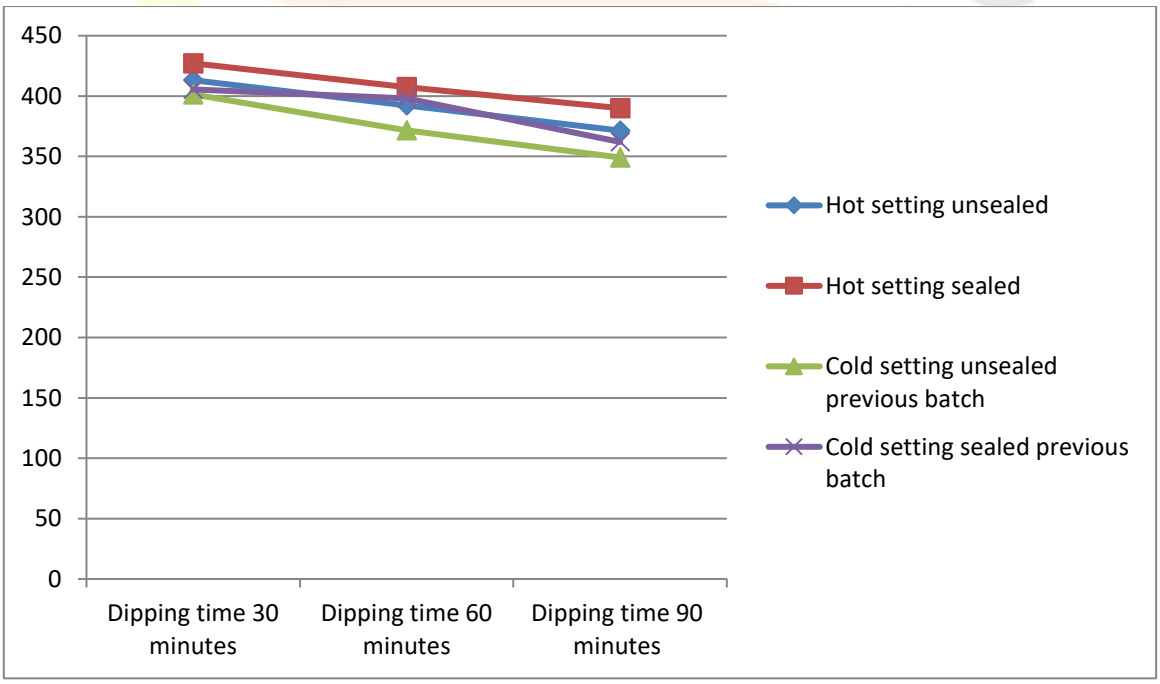
The following table consists of values obtained by our batch using compression moulding and earlier investigators using hand lay-up specimens

Bath temperature	Holding time	Control value		Tensile strength (Mpa)			
				Unsealed		Sealed	
Ambient temperature	1 hour	476.19	449.58	438.09	406.52	457.14	437.93
	5 hours	476.19	449.58	419.05	374.50	438.09	401.73
	10 hours	476.19	449.58	400.00	351.87	419.05	377.08
50°C	30 minutes	476.19	449.58	413.14	401.38	427.11	405.49
	60 minutes	476.19	449.58	392.15	371.63	407.41	398.12
	90 minutes	476.19	449.58	371.40	349.12	389.97	361.95
85°C	30 minutes	476.19	449.58	389.43	376.66	408.54	384.30
	60 minutes	476.19	449.58	370.37	368.90	392.16	371.30
	90 minutes	476.19	449.58	352.83	336.66	373.48	351.78

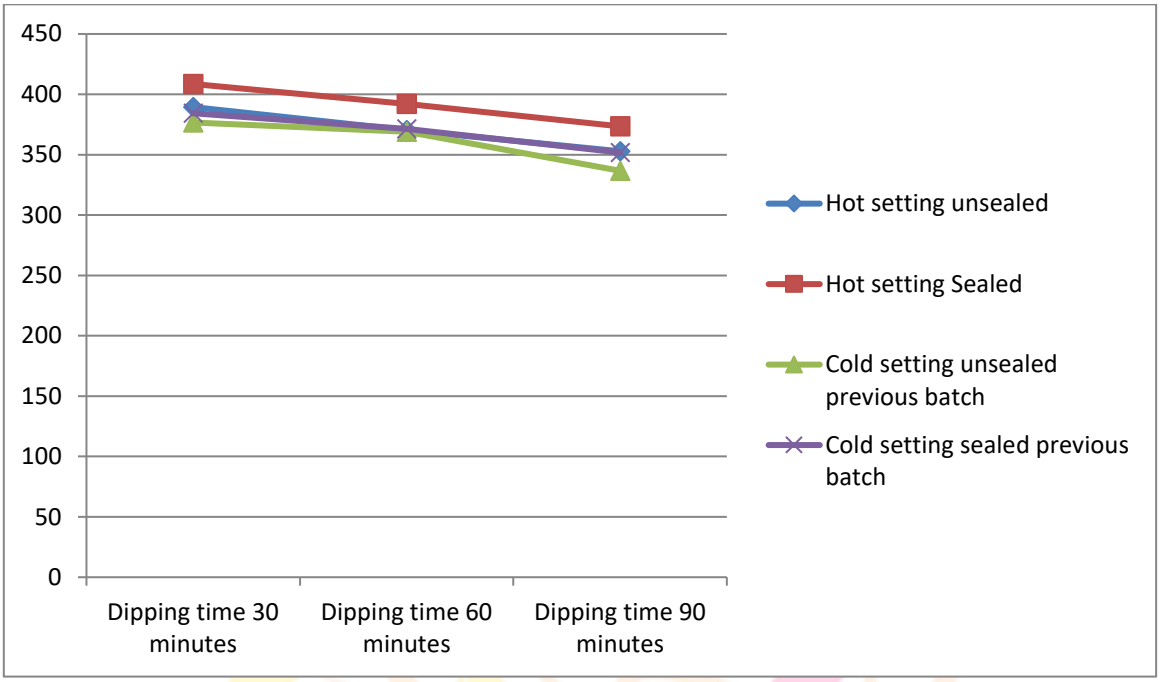
In the above table the values in red colour are the values of our senior batch and the values in black colour are our project details Comparision of Tensile strength between our project and our previous project at ambient temperature



Comparision of Tensile strength between our project and our previous project at 50°C



Comparision of Tensile strength between our project and our previous project at 85°C



From the above three graphs it is evident that the tensile strength of hot setting laminate (Our project values) is greater than the tensile strength of the cold setting laminate of our previous batch. Hence it is clarified that the tensile strength of the composite material had increased with change in manufacturing process from Hand layup at atmospheric pressure to Compression moulding process applied at 8 bar pressure.

The extension from our previous project we had manufactured Hot setting and Cold setting laminates and the strengths of the respective material when observed it is evident that Hot setting laminates had a higher strength than Cold setting laminates and in addition to that we had performed Short beam shear and the short beam shear strength values are also tabulated above in the report earlier pages.

10. Scope for Future Work

The present research has been carried out for the dissertation, based on few assumptions, standards and degrading models. Due to the very high count of specimen requirement we have restricted ourselves to only 3 different temperatures, for accelerated ageing. But the experimentation was carried out based on both sealed and unsealed specimens. The environment of exposure was taken at 5% only. The relative humidity of the surroundings was maintained constant.

As there are many parameters that can be taken into consideration, the following works can be expected to be carried out in the future:

- The hygrothermal degradation studies of composite laminates with different volume fraction of fibres can be experimented.
- The duration of current experiment can be increased to see the effect in long term environment.
- The same study can be carried out for different concentrations of brine solution and also solutions apart from brine, like alkali solutions etc.
- Having this research carried out for only few temperature differences, the same can be carried out for many more working temperature differences.
- Relative humidity also plays a crucial role. This dissertation can be carried out at various RH values and find the % degradation
- The dissertation is restricted to only max. Ultimate Strength and short beam shear strength. This can be carried forward in the study of degradation in flexural strength, bending strength etc.

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