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Review on Behaviour of FRP composites subjected to Elevated Temperatures

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Abstract* — FRP bars are increasingly used in many industries viz construction, automobile, electrical and defence to name few [1]. Mechanical strength, durability and stability are the few important parameters to select the FRP bars produced through Pultrusion process [3]. When these FRP bars are exposed to high temperatures, the change in the material properties affects the overall structural performance. FRP's are the best choice for corrosion resistance requirements. In this paper, the investigators [2] tested GFRP (Glass fiber reinforced polymers) to check the tensile properties at high temperature. Specimens were exposed to high temperatures and tested for tensile strength. It is observed that there is a strong effect of heat on tensile strength and Young's modulus. In specific ultimate strength shows a constant degradation as temperature increases. By contrast, the Young's modulus is subject to different changes at different temperatures.

***Keywords*— pultrusion, FRP, mechanical strength**

I. INTRODUCTION

Polymer matrix composites (PMC) have established themselves as engineering structural materials, not just as laboratory curiosities or cheap stuff for making chairs and tables. Glass fiber reinforced polymers and Carbon fiber reinforced polymers represents the largest class of PMC. The pultrusion process is continuous and therefore the costs reduce with respect to other methods of fabrication, especially when high volumes of production are reached. Generally the profiles and rods are made from polyester, epoxy or vinyl ester resin as matrices, with glass, carbon or aramid fibres as reinforcements. It is not easy to set up a procedure to evaluate temperature resistance because of the many aspects to be taken into account and of the different types of physical and chemical changes provoked by different exposure to heat. This paper presents a procedure to expose FRP rods made from a polyester resin matrix and glass fibers, to elevated temperatures in a tubular oven with controlled air flow.

II. PULTRUSION PROCESS

Pultrusion is a composite fabrication process designed for structural shapes. The investment cost is very high and therefore only feasible for mass production parts. Fibers are drawn through a resin bath and then through a forming block. Heaters are used to insure fast curing through steel dies and then the part is cut to proper length. Pultruded parts are strongest in the longitudinal direction because of their fiber orientation. Fiber orientation can be changed to increase strength in other directions. Solid, open sided and hollow shapes can be produced at almost any length. Cores such as foam and wood can be built inside of the pultruded shapes. Due to the pressure and designs of production, protruded production can be up to 95% effective in material utilization [8]. The schematic of pultrusion process is shown in figure 1.

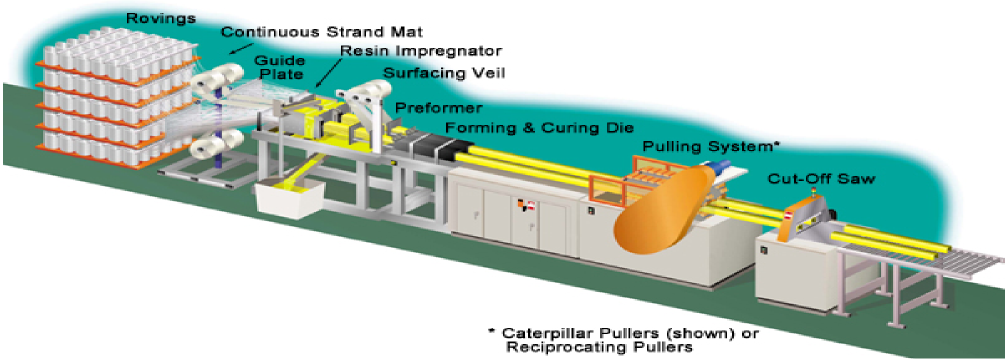

Figure1: pultrusion process

GLASS FIBERS

Glass fibres (GF) are the most common reinforcement for polymeric matrix composites. Their principal advantages are the relationship between their low cost, high tensile strength, high chemical resistance, and insulating properties. The disadvantages are low tensile modulus, relatively high specific gravity, sensitivity to abrasion during handling, low fatigue resistance, and high hardness. E-glass and S-glass are the types of fibers more commonly used in the fiber-reinforced plastic industry-glass fibers have the lowest cost of all commercially available reinforcing GFs, which is the reason for their widespread use in the fiber-reinforced plastic industry. The properties of the glass fibers used in this investigation is shown in table 1.

TABLE1: PROPERTIES OF GLASS FIBER

FIBER TYPE	TENSILE STRENGTH(MPA)	YOUNG'S MODULUS (GPA)	DENSITY (KG/M^3)	COEFFICIENT OF THERMAL EXPANSION (K^{-1})
E-glass	1250	70	2550	$4.7X\ 10^{-6}$

EPOXY RESIN

Epoxy resin has been used in a wide range of fields, such as paints, electricity, civil engineering, and bonds. This is because epoxy resin has excellent bonding property, and also after curing, it has excellent properties on mechanical strength, chemical resistance, and electrical insulation. In addition, epoxy resin is able to have various different properties as it is combined and cured together with various curing agents. This issue describes the types of curing agents for epoxy resin and characteristics comparing to Three Bond products. The epoxy resin compositions of three bond currently on the market are the three bond 2000 series (base agent for epoxy resin), the three bond 2100 series (curing agent for epoxy resin), and the three bond 2200 series (one-part thermal cure epoxy compound resins). The properties of the matrix material (epoxy) used in this investigation is shown in table 2.

TABLE 2: PROPERTIES OF EPOXY RESIN

TEST	RESULT UNIT	REQUIREMENT	RESULT
Colour on gardener scale	GS	0 to 1	0.08
Epoxy value	Eq/kg	5.25 to 5.4	5.38
viscosity@25^0c	MPas	1000 to 12000	11250
Martens value	^{0}C	145 to 175	152

III. EXPERIMENTAL PROCEDURE

A. OVEN

Following the 'Standard recommended practice for determining permanent effect of heat on plastics' (ASTM D794-68) [9] an oven with controlled horizontal air flow was used. The oven used follows the 'Standard method test for elevated temperature aging using a tubular oven' (ASTM D1870-68) [10], is composed of a central metallic testing chamber, where two side walls are provided with holes containing valves for forced-draft air circulation.

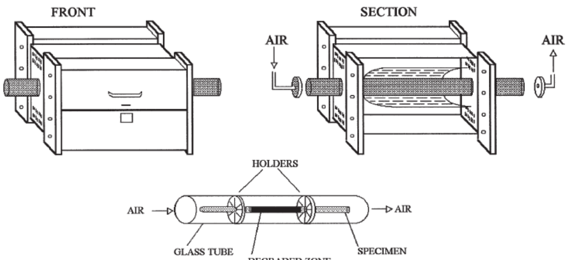

Figure 2: Oven

The Oven used in this experiment is shown in figure 2. The circular rod is placed inside a glass tube, which can reach a maximum temperature, and positioned through two side walls of the metallic testing chamber using suitable specimen holders in such a way as to permit the free flow of air around the specimen. The air temperature in the oven is monitored by a Eurotherm 818P control system which can make 16 temperature segments (8 ramps and 8 permanence). The specimens were placed inside the tube making sure that at least 20 cm of their length was directly applied by the heat flow produced from electrical resistors positioned around the tube which contains the specimen (see Figure 2). The heated air in both the chamber and in the tube flows by means of a mechanical agitator. The oven is designed to assure air circulation free from contamination by volatile constituents present in the material from which the specimens are made. The heat is applied in a static way and the temperature is recorded near the center of the chamber. The air velocity can be measured by means of a velometer. In our case this measurement was not taken because the air flow is used only to assure the absence of contamination from volatile constituents. The maximum temperature in the testing chamber, fixed for each group of specimens, was reached by means of a constant increment of 5^0C per minute.

This temperature was held for one hour to degrade the specimens and it was then decreased down to the standard laboratory atmosphere temperature with the same previous thermal gradient (5^0C/min). Figure 3 summarises all this information. By utilizing this procedure the specimens were exposed to the following temperature:
200^0 - 250^0 - 300^0 - 325^0 and 350^0 C.

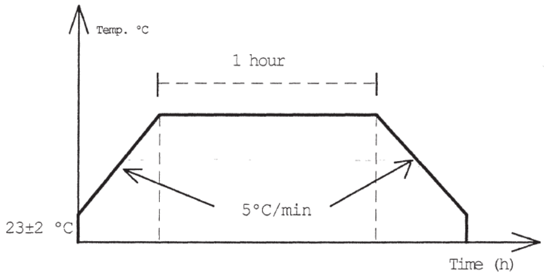

Figure 3: Variation of Temperature during the Exposure

B. METHODOLOGY

The methodology to determine the ultimate strength and the Young's modulus of the specimens degraded by elevated temperature exposure is summarized below. The process varies according to whether it is relative to the determination of the ultimate strength or the measurement of the Young's modulus. In the first case a preload of 3 KN was applied to assure the elimination of possible parasite effects, due to the movable parts of the tension testing apparatus. Then, with a cross-head displacement speed of 2 mm/min (monitored by the 'ER' electronic system) the complete failure of each specimen was reached. In the case of undamaged specimens, it is necessary to check where the failure takes place. On the contrary, in this particular case this is not needed because, obviously, the failure will be in the central degraded zone. In the case of the Young's modulus determination, the values of the ultimate loads (PU) were used to start from the 10–20% of them to assess all the movable parts of the testing apparatus. After this, the load was reduced to 5% of PU, considering this as the instrumental zero for the load and the deformation measurements. Then two cycles were carried out reaching a load of approximately 20 KN, to decrease the scattering in the results. Finally, the specimen was loaded up to complete failure, monitoring the load levels and the strains with a regular interval of 5 KN. In particular the strains were recorded by means of the clampon strain transducer which was clamped on the measurement central zone by a sufficient pressure.

IV. EXPERIMENTAL RESULTS

In Table 3 for the specimens of 12 mm and 22 mm diameter, the geometrical data are reported. In particular, in these tables, the total length (L_{TOT}) of the specimens, the length of the zones where the grips are applied (L_{GRIP}), and the length of the zone where the end effects vanishes reaching a uniform distribution of stresses (L_{DSV} = De Saint Venant length), are reported. The ultimate loads and strengths, and the Young's moduli for each maximum temperature of exposure and for each specimen, are reported in Table 4 for the specimens of 12 mm diameter, and in Table 5 for the others of 22 mm diameter. For the exposure temperature of 325^0C only the data relative to three specimens are reported because, for one specimen, slip between the grip and the rod was detected. In particular, for the determination of the Young's modulus, the preload for the specimens with 12 mm diameter was fixed to 3 KN, while for the ones with 22 mm diameter the preload was fixed to 8 KN.

TABLE 3: GEOMETRICAL DATA OF THE SPECIMENS.

Specimen	Total length (mm)	Grip length (mm)	L_{DSV} (mm)	Diameter (mm)
12	451	145	50.5	12.56
22	550	156	89.0	22.29

TABLE 4: 12MM DIAMETER SPECIMENS

Temp.	Specimen	Ult. load (KN)	Ult. strength (MPa)	Young's mod. (MPa)
	A12-1	57.0	464.48	31811
200 °C	A12-2	58.5	469.16	–
Group A	A12-3	59.5	477.18	31688
	A12-4	56.0	456.33	31117
	B12-1	54.5	430.23	29263
250 °C	B12-2	59.5	484.85	32355
Group B	B12-3	54.0	433.07	–
	B12-4	53.5	429.06	31422
	C12-1	42.5	340.85	–
300 °C	C12-2	39.5	321.87	28445
Group C	C12-3	42.0	336.84	28688
	C12-4	39.5	316.79	30331
	D12-1	27.0	220.02	–
325 °C	D12-2	26.5	215.94	29636
Group D	D12-3	23.0	187.42	30120
	D12-4	27.0	216.54	29111

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TABLE 5: 22MM DIAMETER SPECIMENS

Temp.	Specimen	Ult. load (KN)	Ult. strength (MPa)	Young's mod. (MPa)
	A22-1	151.5	385.82	–
200 °C	A22-2	148.0	378.93	–
Group A	A22-3	158.0	405.26	30173
	A22-4	147.0	379.09	30957
	B22-1	151.5	382.39	–
250 °C	B22-2	145.0	370.54	30398
Group B	B22-3	142.5	362.25	29708
	B22-4	141.5	362.29	30272
	C22-1	100.0	256.04	–
300 °C	C22-2	104.0	269.65	26290
Group C	C22-3	98.5	254.01	25805
	C22-4	102.5	265.76	25692
	D22-1	63.0	161.59	18898
325 °C	D22-2	65.0	166.72	–
Group D	D22-3	69.0	178.42	23771
	–	–	–	–
350 °C	E22-1	55.0	140.82	11284
Group E				

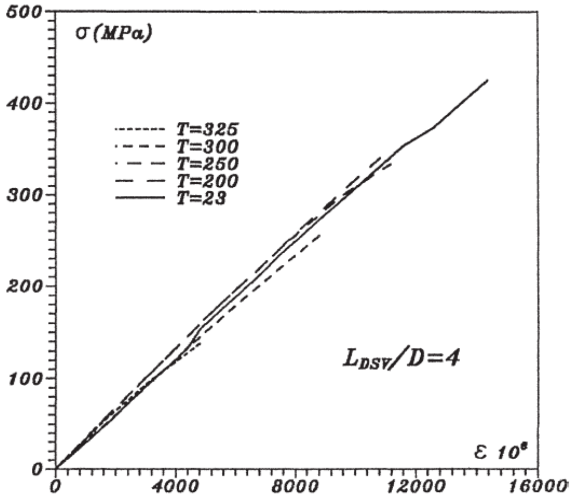

Figure 4: Stress- Strain curve for 12mm diameter

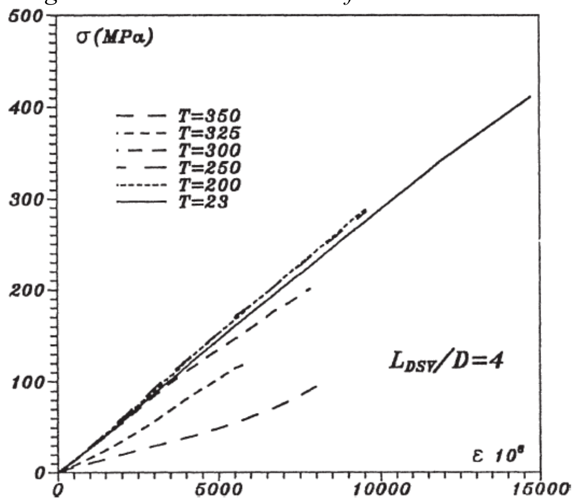

Figure 5: Stress- Strain curve for 22mm diameter

For the 12 mm diameter specimens, a stable value for both the ultimate load and the Young's modulus up to a temperature of 250^0 C is evident. When the temperatures reach the values of 300 and 325 ^{0}C, the values of the Young's modulus and of the ultimate load become one half of the 200^0 C analogous mechanical properties. Moreover, for the 22 mm diameter specimens, the Young's modulus is practically constant up to 250^0 C but, when the temperature increases, reaching 300^0– 325^0 and 350^0 C, a strong decay in the Young's modulus becomes evident. Ultimate strength reduction is already present at 200^0 C. In Figures 4 and 5, for one specimen in each group with different diameter and maximum temperature, the stress–strain curves are reported and are compared to the analogous stress–strain curve obtained at laboratory temperature (23^0 C).

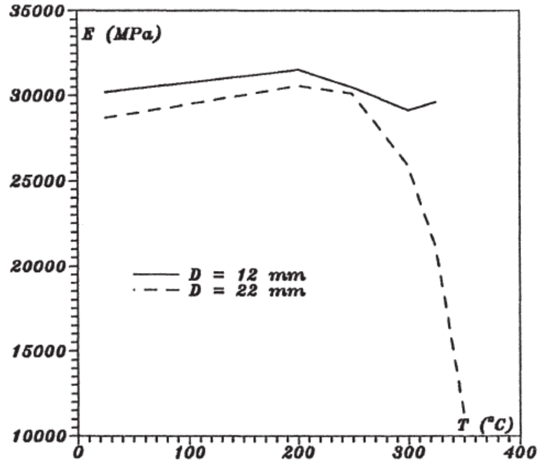

Figure 6: Variation of Young's modulus v/s Temperature

Observation of the two pictures clearly shows a bigger reduction in the values of the Young's modulus for the 22 mm diameter specimens. However, they show a practically linear dependence between the stresses and the strains. In Figures 6 and 7 the average values of the Young's moduli and of the ultimate strengths are reported for each value of the maximum temperature reached. These results are also reported in Figure 6 for the Young's modulus, and in Figure 7 for the ultimate strengths.

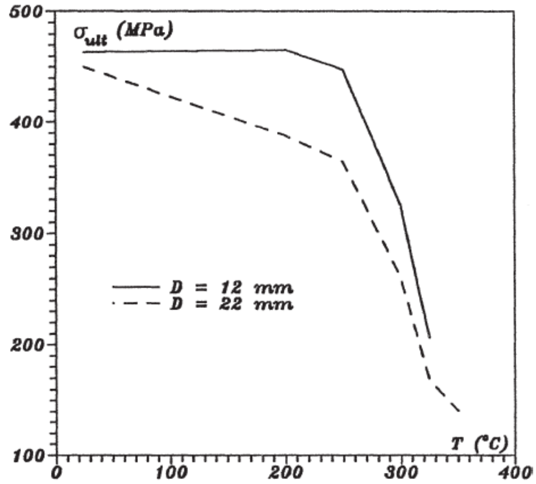

Figure 7: Variation of Ultimate Strength v/s Temperature

From observation of the figures, it is clear that the ultimate strengths decrease when temperature increases. On the contrary, the Young's modulus value shows a small increase when the temperature is less elevated, while it will also degrade (as for the ultimate strengths) when the temperature reaches elevated values. The small increase in the Young's modulus value for the specimens exposed to a maximum temperature of 200^0 C, is probably due to the formation of further cross links between the polymeric chains of the thermosetting resin.

CONCLUSION

In this paper the effects on FRP rods made from glass fibres and epoxy matrix of an exposure to elevated temperatures were experimentally determined. ASTM standards were used to set up a correct procedure to first degrade the specimens and then test them in a tensile testing machine. In particular the effects on the ultimate strengths and on the Young's modulus were studied. The results show a degradation of the tensile ultimate strengths when temperature increases. The determination of the Young's modulus shows specific temperatures where its value increases with respect to the undegraded analogous specimens. These first results will be incorporated in a larger set of results relative to various experimental and theoretical aspects of the analysis of the inclusion of FRP rods in classic civil engineering structures. In particular the authors are currently working on analogous tests in an environment similar to the concrete material in which the rods are generally plunged. Also the most common chemical attacks will be taken into account, such as alkaline or salt attacks.

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