The Structural Features of Glass Fibre Reinforced Polyester Matrix Composites

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ABSTRACT:

Production of a better material is made more likely by combining two or more materials with complementary properties. The best combination of strength and ductility may be accomplished in solids that consist of fibres embedded in a host material. Polyester is a suitable component for composite materials, as it adheres so readily to the particles, sheets, or fibres of the other components.

The best known form of resin impregnated glass fibres is GRP (Glass Reinforced Polyester). The fibres may be woven together, pressed into a mat, or used as a random "wool".

In this study, the structural properties of glass fibre reinforced polyester matrix composites were studied. Glass fibre content varied from 9 to 33% wt. in the composites; the other materials (polystyrene, zinc stereate, alkaline peroxide, magnesium oxide, pigment paste, calcite, etc.) were included to make up the percentages of polyester matrix. To investigate the structural properties, Charpy impact, tensile, bending and hardness tests were utilised. For microstructural study, optical and scanning electron microscope techniques were used. The results are tabulated depending upon the glass fibre rates.

Keywords: Glass reinforced polyester (GRP), glass fibre, polymer, mechanical properties, microstructure.

I. INTRODUCTION

Since nondeforming particles give the maximum strengthening possible from a dispersed phase, various methods have been used to obtain this type of structure. The important properties of the reinforcing fibres are their high strength and high modulus of elasticity. For applications in which a high strength-to-weight ratio is important, non-metallic fibres such as boron have a distinct advantage because of their low density. The metal or alloy chosen for the matrix must combine adequate strength and ductility with other properties that make it compatible with the fibre in question. Composite materials can be classified referencing the type of matrix materials as metallic, polymeric and ceramic based composites. They can also be grouped according to the type of reinforcement as fibre, particulate and laminate composites. One of the most widely used ceramic based composites is glass fibre reinforced, polyester matrix composites /1/.

In a recent work /2/, the effect of the addition of carbon fibres (SCF) on the mechanical and electrical properties of conductive polymer composites (CPC) with polyester and polyepoxy matrices has been studied. Electrical measurements show a small amplitude PTC effect between 90 and 160°C. The percolation threshold is reached for about 1% v/v SCF and higher conductivity is obtained with polyester matrix. Up to 3% v/v, a good correlation is found between resistivity and relative Young's modulus.

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In another study /3/, the manomer conversion of dental composites during visible light irradiation was monitored *in situ* by infrared spectroscopy. The relationship between the degree of conversion and mechanical properties was obtained by evaluating the microhardness of composites with different degrees of conversion. The relationship obtained was then used to identify the evaluation of the mechanical properties during photopolymerization.

Another paper /4/ describes the results of falling weight impact tests on glass-fibre-reinforced laminates. In this work, the impact behaviour of cross-ply laminates based on a brittle unsaturated polyester resin was compared. The penetration energy of the various composite laminates appeared to be mainly influenced by the type of reinforcement, whereas damage development during (repeated) impact was strongly influenced by both fibre architecture and resin. No significant effect of the different material parameters investigated on the number of impacts to penetration (impact fatigue lifetime) was observed. Especially when the repeated impact energy is normalised is normalised with respect to the penetration energy, all laminates showed similar bahaviour.

The static and fatigue behaviour of two fibre-reinforced composites was characterised /5/ after samples were subjected to both natural and accelerated aging. The composites consisted of a thermoplastic matrix reinforced with glass or carbon fabric. Natural aging involved exposing samples to the elements over a period of two years, while accelerated aging was conducted in a saline solution during 200 days. Subsequently, static and fatigue tests were carried out with the aim of determining the mechanical properties of the materials after exposure. A negligible decrease in the value of these properties was observed, while different behaviour was detected depending on the type of aging of the material.

Alampalli *et al.* reported /6/ on fibre reinforced polymer composites for the superstructure of a short-span rural bridge. In this paper, they described one application that allowed a bridge superstructure to be replaced in significantly less time than a conventional bridge project, in a cost-effective manner. The bridge design, fabrication, installation, proof-testing, and cost-benefit details were summarized.

The mechanical response of a prototype joint between a glass-fibre reinforced polymer superstructure and a steel hull formed via a resin infusion process was examined in a paper by Clifford *et al.* /7/. The GRP-steel interface was shown to be critical to the mechanical performance of the joint. The effects of post-cure temperature and surface preparation on the GRP-steel interface were evaluated through the use of the four-point bend delamination test. The results showed interfacial toughness to increase greatly with surface roughness for low surface roughness up to a particular roughness above which no further increase was obtained. A similar increase was observed for low temperature post-cure, but for higher temperatures a significant decrease was observed.

The effect of weld-lines on the tensile strength of injection moulded styrene maleic anhydride (SMA) reinforced with 20, 30, and 40% weight fractions of short glass fibres, was investigated /8/ between 25 and 120°C. The weld-line was formed in the moulded specimens by direct impingement of two opposing melt fronts. In the absence of weld-lines, the tensile strength increased linearly with temperature. In the presence of weld-lines, the tensile strength increased linearly with phi (f) and decreased linearly with temperature. In the presence of weld-lines, the tensile strength of the matrix and its composites was greatly reduced. A significant drop in weld-line strength was noted with increase in temperature.

The dry sliding wear behaviour of woven glass fibre reinforced polyester composites has been studied /9/ by using a pin-on-disc machine. The friction and wear experiments have been conducted on three different orientations of glass fibre with respect to sliding direction. The coefficient of friction and wear of the composites at various applied load and sliding speeds have been determined. The lowest coefficient of friction and wear values observed were for the fibres oriented in the 0°-90° direction, and the highest was for normal-longitudinal (N-L) orientation. The applied load further increased the friction and wear behaviour was dominated by a number of mechanisms. The wear of the fibres was dominated by the fibre fracture. The fibres were fractured because of bending of fibre due to dragging by steel disc in the sliding direction. The microscopic observations of the worn surfaces revealed

and supported the involved mechanism.

A study /10/ was carried out to overcome the disadvantages generated by the loosened nanoparticle agglomerates dispersed in polymer composites; an irradiation grafting method was applied to modify nanosilica by covalently bonding polyacrylamide (PAAM) on to the particles. When the grafted nanosilica was added to epoxy, the curing kinetics of the matrix was accelerated. Morever, the grafting PAAM was able to take part in the curing of epoxy so that chemical bonding was established between the nanometer fillers and the matrix. Sliding wear tests of the materials demonstrated that the frictional coefficient and the specific wear rate of nanosilica/epoxy composites are lower than those of the unfilled epoxy.

A research /11/ was also carried out to inspect the mechanical and microstructural properties of some polymer matrix composites. In this study, several glass fibre reinforced polyester matrix composites were investigated for better understanding of the structural features with the addition of glass fibres.

II GLASS FIBER REINFORCED POLYESTER (GRP)

Glass reinforced polyester (GRP) is utilised in many production areas in the world. In GRP composites, glass is used as reinforcement material, providing tensile strength, and matrix is positioned in the surroundings of the reinforcement material. That matrix provides strength to pressure, hardness resistance and protects the fibre surfaces, and behaves as a binder. The features of the matrix affect the characteristics of the composite material in a scale. As a reinforcement material, glass fibre develops the mechanical properties /1/.

The features of the GRP, its performance and behaviour during the work depend upon the characteristics of the structural compounds, volume percentages, structural and configurational arrangements, intereffects, interface and interphase. The most important factors affecting the performance of the fibre-matrix composites are the shape, length orientation of the fibre, the properties of the matrix and the characteristics of the fibre-matrix interface. The properties of glass reinforcement composites are tabulated in Table 1 for the present study.

Table 1
The properties of glass reinforcement composites

Materials	Glass fibre (%) wt.	Density (g/cm^3)	Tensile strength (MPa)	Bending Strength (MPa)
Polyester (BMC) *	10	1.89	21	83
	15	1.85	27	96
	30	1.85	41	124
Epoxy (BMC)	30	1.75	100	180
	65	1.85	140	300
Polyester (SMC)**	25	1.85	68	190
Lay up	30	1.50	124	240
Injection	28	1.49	103	194

* (BMC) : Bulk moulding compound
**(SMC) : Sheet moulding compound

During heat curing of unsaturated polyester resin at 700°C temperature, hardening time with gelling is affected by the following factors: type of the resin, type and amount of hardener, working temperature, type of heat transfer in die.

III. EXPERIMENTAL PROCEDURE

At least 5 specimens were prepared for each experiment and the average value was evaluated. The experimental atmosphere was performed at 23°C ± 2 and %50 ± 5 humidity. Samples were pressed at 150°C temperature and 150 Bar pressure by transfer moulding method. The density of the matrix was 1.6 -2.0 g/cm^3. In this study, orthoflalytic thermoset resin was used for the composite.

Polystyrene solution is a kind of filler material that includes between 5 - 30 % wt. of the resin. Zinc stereate is a kind of die release used in the polymer-based composite, which material generally comprises 2 - 6 % wt. of the resin. Peroxide is a kind of catalyst, which starts the reaction. This is used at temperatures over 120°C, and contains 2 - 4 % wt. of the quantity of resin. In this study, alcyl peroxide was chosen.

Magnesium oxide was used as a filler material to

improve the heat distribution in the hardened thermoset resin system. The quantity of the material was between 0.1- 0.5 % wt. of the resin. Pigment paste dye was used for the colouring of the glass reinforced polyester dough. The quantity of that dye was about 1.5 - 15 % wt. of polyester. Calcite was used as a filler; it protects volumetric shrinking of polyester molecules during hardening, affects the hardening rate, and improves viscosity, charpy strength, hardness, wear resistance, water absorption, deformation temperature and surface quality /12-16/. The particular diameter preferred was less than 10 ∝m. The quantity of calcite (calcium carbonate in powder form) used was about 130 - 200 % wt. of resin. The percentages of experimental compounds of the typical composite are presented in Table. 2.

Glass fibre improves the strength of the composite and bears the load /12-17/]. The properties of this glass fibre are as follows /18/]: E glass, 12 mm length, 10-12 ∝m diameter, 2.56 g/cm^3 density and tensile strength is about 1400-2100 MPa. The drawings of charpy, bending and tensile test specimens are illustrated in Figs. 1-3.

IV. RESULTS AND DISCUSSION

The tensile specimens were produced according to the standard of DIN 53464 and this test of the present composite materials was performed by a thermometric tensile machine /13/. These specimens were drawn at a constant temperature (20°C) and speed (10 mm/min). The experimental results of these specimens are presented in Table.3. It can be seen from this table that the tensile strength is raised with the reinforcement glass fibre quantity. The reason is that glass fibres bear

Table 2
Percentages of experimental compounds of the composite.

Unsaturated polyester	% wt.	20.9	20	19	18.1	17.2	16.3	15.4
Polystyrene solution	% wt.							
Zinc stereate	% wt.							
Peroxide	% wt.							
Magnesium oxide	% wt.							
Pigment paste dye	% wt.							
Calcite	% wt.							
Sub-total	% wt.	91	87	83	79	75	71	67
Glass fiber	% wt.	9	13	17	21	25	29	33
Total	% wt.	100	100	100	100	100	100	100

Table 3
Ultimate tensile strength and yield strength of different composites.

Mix. No:	Glass fibre (%) wt.	Max. Load (N)	Tensile strength (MPa)	% ε for max. Load (%)	E (MPa)	Yield strength (% 0.1 ε) (MPa)
9G12	9	165.97	41	2.65	2694	8.1
13G12	13	173.28	43	2.36	2711	9.4
17G12	17	183.77	46	2.38	2071	8.8
21G12	21	193.30	48	2.28	3259	8.5
25G12	25	196.50	49	2.12	3423	8.9
29G12	29	174.17	47	1.67	4028	8.5
33G12	33	199.70	50	1.93	2833	11.0

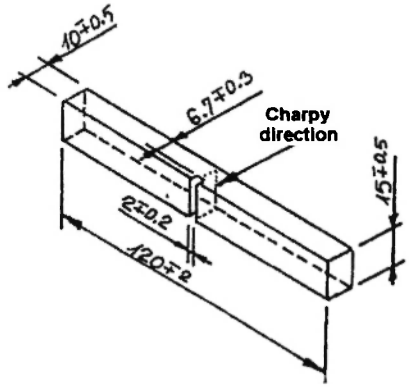

Fig. 1: Drawing of Charpy test specimen.

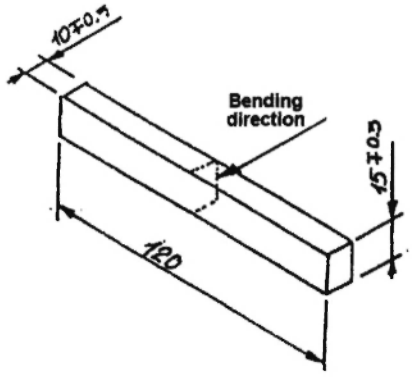

Fig. 2: Drawing of bending test specimen.

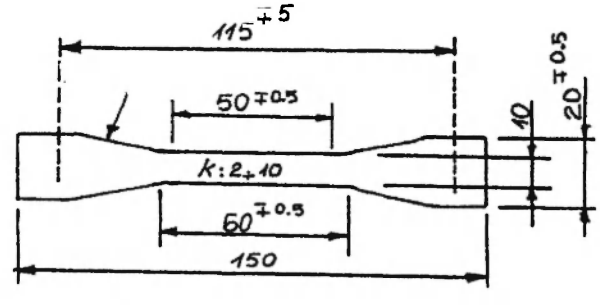

Fig. 3: Drawing of tensile test specimen.

load and the matrix transfers the load to the fibres. The upper tensile strength is 500MPa, which is achieved at 33% wt. glass fibre in the polyester matrix. This does not illustrate the maximum value, because on adding more glass fibre more tensile strength is gained. The reason for not adding more fibre into the polymer matrix is that dough does not become wet enough in the case of more than 33% wt. of glass fibre.

In the Barcol hardness method, a Barcol impressor (model number 934-1) is utilised for the hardness measurement of polyester based composites. This method is similar to shore scleroscopy and the indicator is calibrated before the experiment. During the test, the legs of this device must be on the same plane as the surface of the specimen for the correct measurement. This method is very practical and easy to apply. Hardness was measured according to ASTM D2583 using a Barcol 934-1 device. The achieved hardnesses are presented in Table 4, depending upon glass fibre percentage: It is seen from this table that hardness is gradually increased by the glass fibre percentage. The hardness value of polyester is about 50-70 Barcol. The reason for this indistinct hardness variation is that the matrix affects the hardness more than the fibre. Breaking work (absorbed energy) of polyester based composites was measured by means of a Charpy device forming samples suitable for DIN 53453 or TS 1004 /13/. The dimensions of the samples were 10x15x120 mm and the notch was formed on the 15 mm surface. The area in the tensile axis was 7x15 square millimetres. The impact results are illustrated in Table 5. It can be seen from this table that fracture work and impact toughness are increased by the glass fibre increments. The possible reason for this may be that the fibres in the specimens are perpendicular to the fracture direction.

Table 4
Barcol hardnesses of different composites

Mix. No	Glass fibre % wt.	Barcol hardness
9G12	9	57
13G12	13	56
17G12	17	60
21G12	21	61
25G12	25	58
29G12	29	62
33G12	33	64

Table 5
Impact energy and notch toughness of different composites.

Mix. No	Glass fibre % wt.	Impact energy (Nm)	$b*h_K$ (cm^2)	a_k notch toughness ($kgcm/cm^2$)
9G12	9	58.6	1.05	55.81
13G12	13	61.4	1.05	58.476
17G12	17	72.1	1.05	68.667
21G12	21	73.4	1.05	69.905
25G12	25	73.5	1.05	70
29G12	29	91.2	1.05	86.857
33G12	33	93.8	1.05	89.333

The bending specimen was performed with a thermometric micro 350 bending device to measure bending strength /4/. The bending was done until failure occurred. The dimensions of the specimens were 10x15x120 mm. The load was employed onto the 15 mm surface (h=10mm). A thermometric device micro 350 type, 1000kg capacity and 2/10000 sensitivity, was utilised for bending experiments. The results are presented in Table 6. It is seen from this table that bending strength is increased with the glass fibre increment. The obtained upper value is 146 MPa. This does not reflect the maximum value, because adding more glass fibre than that value possibly gives more bending strength. The reason for not adding more fibre into the polymer is due to unsuitable wetness of the dough with more than 33% wt. glass fibre. The

Table. 6
Bending strength result of different composites.

Mix. No	Glass fibre (%) wt.	Max. load (N)	Max. strength (MPa)	Max. bend (mm)
9G12	9	86.97	8.70	2.10
13G12	13	112.54	11.25	2.57
17G12	17	91.87	9.19	1.843
21G12	21	120.80	12.08	2.60
25G12	25	116.18	12.73	2.51
29G12	29	109.46	10.59	1.72
33G12	33	145.83	14.58	2.45

microstructure of the polyester based composite materials was studied by optical microscope and SEM. These results are illustrated in Figs. 4-9 for different magnification and different volume of glass fibre. The high magnification image of the composite is shown in Fig. 4 for 29% wt. volume of glass fibre. The parallel glass fibres into the polyester matrix are shown in Fig. 5 for 17% wt. volume of glass fibres reinforced composite at the different magnification and for the 9 and 21% wt. volume of glass fibre, the fibre parallel and perpendicular to the polyester matrix are bestowed in SEM (Figs. 6, 7). Because tensile strength and hardness are proportional to each other, these results are consistent with polyester /19,20/ and metal matrix /21, 22/ composites. By increasing the amount of glass fibre,

Fig. 4: Perpendicular glass fibre in the polyester matrix (x500, 29G12)

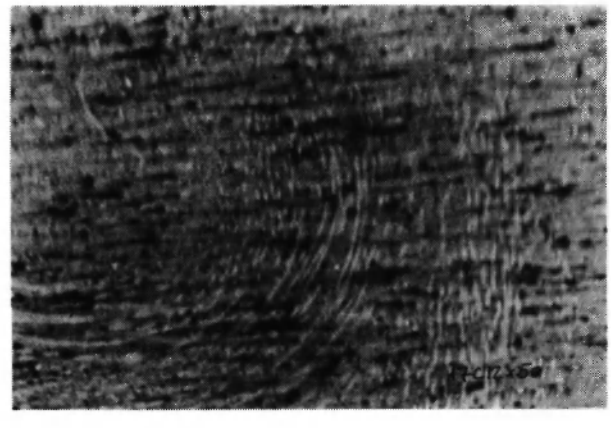

Fig. 5: Parallel glass fibres in the polyester matrix (x50, 17G12)

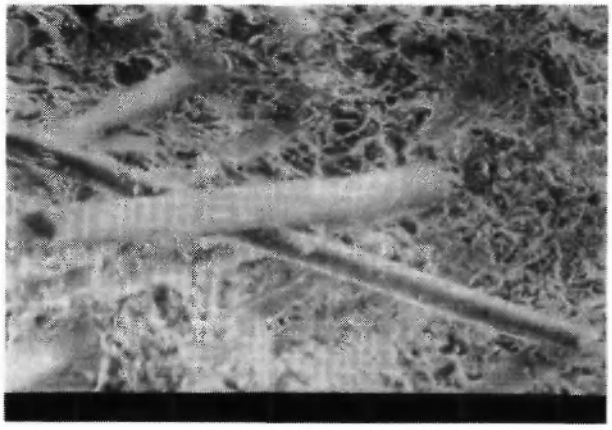

Fig. 6: General view of both parallel and perpendicular glass fibres in the composite (9G12)

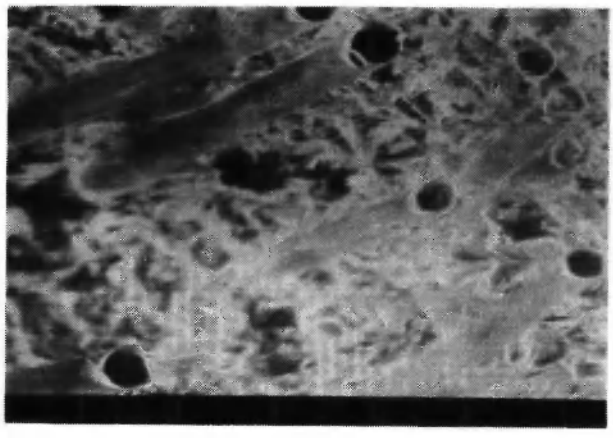

Fig. 7: General view of both parallel and perpendicular glass fibres in the composite (21G12)

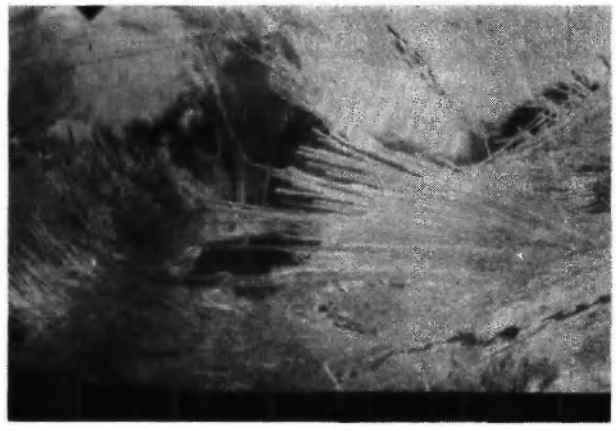

Fig. 8: General view of both parallel and perpendicular glass fibre in the composite (29G12)

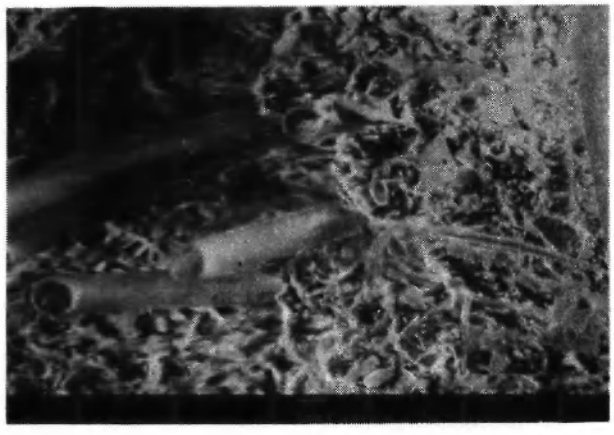

Fig. 9: General view of parallel glass fibre in the composite (21G12)

yield (proof stress) and tensile strength are gradually increased. These two behaviours are parallel to each other. This is consistent with polyester /19,20/ and metal matrix /23/ composites.

An optical microscope was utilised for the investigation of microstructures. Various magnifications (x50 up to x1000) were used in the microscope for the microstructures. The microstructure of the matrix is seen for 21% wt. glass fibre SEM (Figure 7). The parallel fibres in the polyester matrix are observed in Figure 5 for 17% wt. glass fibre. The perpendicular glass fibre in the polymer is shown in Figure 4 for 33% wt. glass fibre. The different magnifications of the microstructure of the glass fibre and the polyester matrix are illustrated in SEM (Figs. 6-7) for 9% wt. and 21% wt. glass fibre, respectively. It is seen from the figures (Figs. 5-7) that the microstructure is homogeneous and mechanical properties are improved with the glass fibre volume fraction increment. General views of both parallel and perpendicular glass fibres in the composite are also shown in Figs. 8-9.

Impact toughness and tensile strength were

continuously developed with the glass fibre increment. However, impact toughness increased faster than tensile strength. These results are generally consistent with previous works /20-24/. The modulus of elasticity and the yield strength ($\delta_{0.1}$) quickly improved with the glass fibre increment. It is seen from Table 3 that increments of E and $\delta_{0.1}$ are nearly parallel to each other. This is consistent with the general composite rules /25/].

Tensile and bending strength increased with the glass fibre increment. The reason for the parallel behaviour of bending and tensile strength is that load transfer rises and the tensile and bending strength increases with the growth in the amount of glass fibre. This is consistent with previous work /20/]. It is seen from Table 3 that tensile strength was increased by the glass fibre increment; however elongation was decreased with the increasing of glass fibre, because the rigidity of the composite increases with the glass fibre increment, while elongation decreases. This is also consistent with the general rules regarding composites /25/.

V. CONCLUSIONS

(a) With the addition of glass fibre (between 9 and 33%wt) to a polymer matrix, an increase in hardness is obtained.

(b) Tensile strength is increased with the glass fibre increment due to the load transfer phenomenon.

(c) With the addition of glass fibre to polymer matrix, the breaking work and Charpy strength are continuously and quickly increased, since the fibres in the specimen are oriented perpendicular to the Charpy direction.

(d) Bending strength is quickly increased with the increase of the glass fibre increment in the polymer matrix.

(e) Tensile and yield strength are increased with the increase of the glass fibre increment; as the more glass fibre, the more load is carried.

(f) Charpy and tensile strengths are increased with the increase of the glass fibre increment.

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