研　究　速　報
UDC 691.328.2 : 678.07

Properties of Fiber Reinforced Plastic Rods for Prestressing Tendons of Concrete (2)
——Behaviour of Fibers for FRP Rods Under Tensile Loading——
プレストレストコンクリート用FRP緊張材の特性(2)

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1. INTRODUCTION

The employment of FRP rods in structures has evolved due to their merits such as high strength, durability, low electric conductivity and light weight. Therefore, research work has been devoted to investigating their behaviour under loading cases commonly encountered in practice. This has led to long reports full of questions about the rods behaviour. Hence, it seems reasonable to investigate the behaviour of rods main component (fibers). This, hopefully, leads to answers for the queue of questions we have (through appropriate models), and consequently suggests optimum combination of components and efficient use of the rods.

In this research, we report the tensile testing of three kinds of fibers (viz. aramid, carbon and glass) as a first step of fiber testing series.

2. SPECIMENS PREPARATION AND TESTING PROCEDURES

Fibers were separated from different places along the rolls and single fibers were attached separately to standard pieces of ordinary paper (JIS-R-7601/1986) using instant adhesive. The paper was punched near both ends to ease mounting in the machine chucks, Fig. 1(a). Testing machine has a capacity of 300 gms. and can provide many cross-head speeds through a gear box. However, only the lowest three speeds have been chosen to study the effect of strain rate. Those speeds have been confirmed by monitoring them using a transducer and data logger. The machine is connected to a plotter that monitors, on a chart, the load development during the experiment.

Due to the cross-head speed limitation (minimum), strain rates used for rod testing could not be provided using standard specimens. Hence, a few number of non-standard specimens have been prepared to get the trend of strength change. Table 1 shows the combinations of fiber lengths and crosshead speed together with the number of tested specimens (in parentheses).

The specimen was mounted first in the upper chuck, using a bolt, and the chuck was fitted to the machine. Lower chuck was fitted free to the cross-head that was raised later to allow mounting the specimen in the chuck. The paper containing the fiber was cut on both sides of the fiber leaving it as the only connection between the two chucks. Figs. 1 (b & c) show schematic configuration just before loading and photograph for the test arrangements. Finally, the cross-head was lowered at constant speed and the load level was hardcopied onto the plotter chart.

3. FIBER DIAMETER MEASUREMENT

The resulting Load-Time curves can be transformed into stress-strain curves using appropriate factors. Time-strain factor depends on cross-head speed, chart speed and fiber length whereas load-stress factor depends on the fiber diameter. Since accurate stress values were required, the fibers diameters were measured using SEM (Scanning Electronic Microscope).

Fiber diametmers have been determined using a reference line and measurements have been made on different fibers at different sections yielding, in total, 100 pieces of data for each kind of fibers. The mean values of fiber diameters with main statistical charac-

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Table 1 Different Combinations of Cross-head Speed and Fiber Length

Fiber Length (mm)	Cross-head Speed (mm/min.) 0.4	1.0	3.3
25	Aramid (54) Carbon (48) Glass (55)	Aramid (50) Carbon (51) Glass (50)	Aramid (50) Carbon (51) Glass (50)
50	Aramid (10) Glass (10)	None	None
125	Carbon (7)	None	None

Table 2 Statistical Characteristics of Fibers Diameters

Material	Mean diam. (μm)	Variance (μm²)	Std. Deviation (μm)	Coeft. of Variation C.O.V.
Aramid	12.15	.1715	.4141	.0341
Carbon	6.68	.1973	.4441	.0664
Glass	12.77	.3659	.6049	.0474

Table 3 Statistiacl Characteristics of Fibers Tensile Parameters

Material		Strength (kg/mm²)	Max. Strain (×10⁶)	Elasticity Modulus (kg/mm²)
Aramid	Mean	389	44116	8355
	Variance	1297	71824000	1168800
	Std. Devn.	36	8475	1081
	C.O.V.	.092	.192	.129
Carbon	Mean	335	13882	22730
	Variance	2719	9905400	4633100
	Std. Devn.	52	3147	2152
	C.O.V.	.155	.228	.095
Glass	Mean	251	28871	8551
	Variance	7579	81579000	2655000
	Std. Devn.	87	9032	1629
	C.O.V.	.347	.313	.191

teristics of the measurements are shown in Table 2. The low scattering of results and the constant diameter along the single fibers (confirmed from observation of SEM photographs) indicate good production geometry. This, also, justifies the use of only mean diameter values in statistical characterisation of fibers strength.

4. EXPERIMENTAL RESULTS ANALYSIS

Mean strength values for all fibers have been calculated at different strain rates. The results are plotted in Fig. 2. The leftmost points are not connected to the corresponding curves as they represnt the results of non-standard specimens and their numbers were quite limited. One can easily find out that there is no strain rate dependence of the tensile strength for all fibers, and there is some indication that the non-standard specimens gives almost the same strength values (except carbon fibers).

The former finding justifies the use of all the tested standard specimens, regardless of strain rate, for experimental results analysis.

Samples of output curves is shown in Fig. 3. Carbon fibers have exhibited the most neat curves among all fibers although, in a few cases, curves with yield-like portion (at high stresses) have been reported; but the majority have sharp linear shape. On the contrary, aramid fibers have shown curves which were not, in

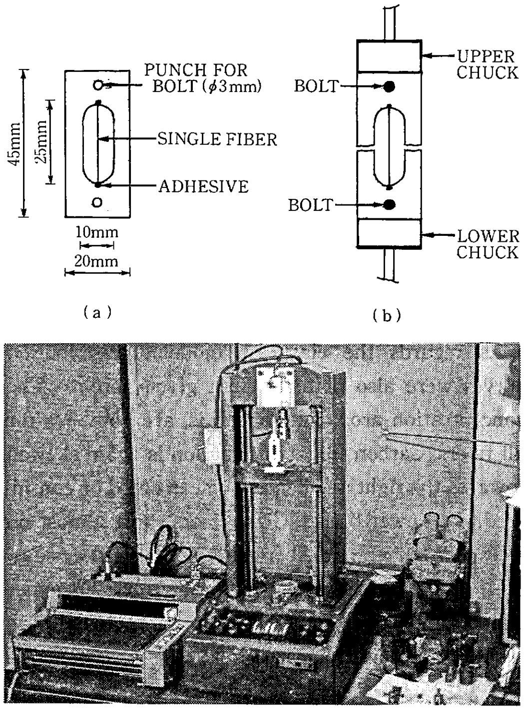

Fig. 1 (a) Standard Fiber Specimen
(b) Final Configuration Before Loading
(c) Experiment Arrangements

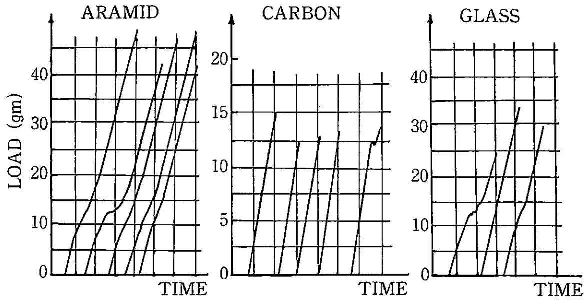

Fig. 3 Samples of Output (Load-Time) Curves

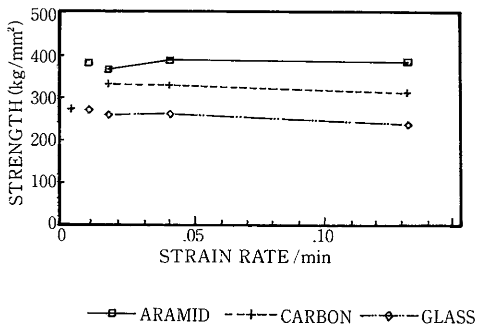

Fig. 2 Variation of Strength Mean Values With Strain Rate

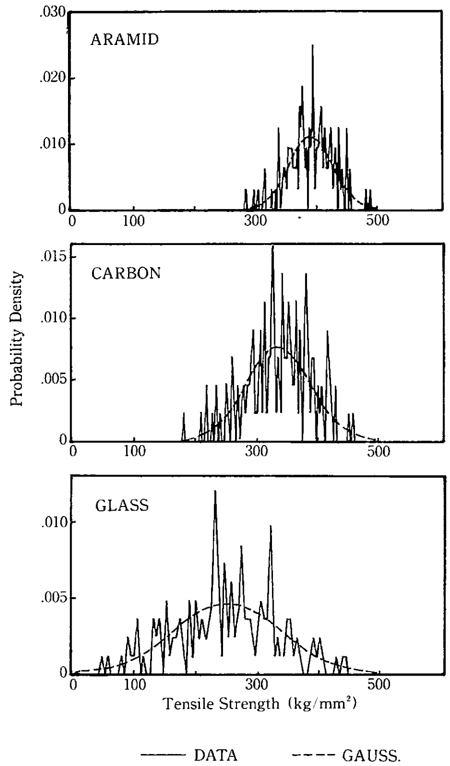

Fig. 4 Fiber Tensile Strength Distributions

general, perfect lines. More than half of the curves had yield-like portion and/or drops. Glass fibers were in between those two extremes where some interrupted curves (similar to aramid) have been reported.

It was straight forward to obtain the tensile parameters (strength, elongation and elasticity modulus E) from carbon curves and perfect linear glass and aramid curves. On the other hand, aramid and glsss curves lacking linearity have been approximated to the straight lines having the dominant slope in the output curves. Curves have been given grades to allow sieving them for more reliable data evaluation.

In order to evaluate the experimental data and the fibers quality, statistical analysis was essential. Main statistical characteristics for tensile parameters of fibers are shown in Table 3. The tensile strength

Table 4 Concluding Characteristics of Fibers

Material	Diameter (μm)	Strength (kg/mm^2)	Max. strain ($\times 10^6$)	Elasticity Modulus (kg/mm^2)
Aramid	12.15	389	44116	8355
Carbon	6.68	335	13880	22730
Glass	12.77	251	28871	8551

distributions, for data and corresponding Gaussian models, are shown in Fig. 4. As regards the strength, only the values lying within (MEAN±3*STANDARD DEVIATION) were considered (almost all data). In case of max. strain and elasticity modulus, only curves of satisfactory linearity were considered.

5. DISCUSSION

All the fibers have shown at least some neat linear curves. In order to interpret the yield-like portions and drops, we should consider the load level. The yield-like portion has taken place only within the load range 13~15 gms. This explains why it rarely appeared in carbon curves that have mean max. load of 13 gms. It also attributes this behaviour to the common part among all the specimens (i. e. paper) as its bearing failure around the bolt. Drops in the loading curves have been observed at high loads (more than 20 gms.), and it cannot be interpretted as a consequence of testing more than one fiber at a time; because of the drop values (within 20% of the total) and the elasticity modulus of the curve. Reasonable cause of these drops is the sliding of the paper edge on bolt teeth. For aramid, maximum elongation is 1 mm and if the mean teeth hight is .2mm, slip will cause load drop of 20%.

As regards strength distributions, the experimental data accumulates gradually towards the center for both carbon and aramid. However, in case of carbon, the distribution is skewed to the right which means that the mean is affected by very low strength values and the mean might increase if more data were collected. In the case of aramid, the distribution assures good production quality and fibers ductility due to its low standard deviation and there is almost no skewness. Glass fibers show large scattering and there is no distinct center for the data. Hence, more data is required to assure the mean value.

As regards the elasticity modulus, distribution curves were also obtained (not given herein). The concentration around the mean is, also, obvious for all fibers. Carbon fibers distribution is again skewed towards the right and hence its mean could be considered as a lower bound. Glass fibers show almost no skewness but aramid fibers distribution is skewed to the left implying the current mean to be an upper bound for elasticity modulus mean and more data are required for confirmation.

6. CONCLUSIONS

1) Stress-strain relationships for tested fibers are essentially linear up to failure and there is no strength dependence on strain rate.
2) There is some indication that strength is independent on length (for aramid and glass fibers).
3) Recommended values for fibers strength, maximum strain and elasticity modulus are presented in Table 4 with the fibers mean diameters.
4) For more complicated investigation of fiber behaviours, the bearing area of the fiber holding material should be carefully considered (e.g. using different material).

ACKNOWLEDGEMENTS

The authors would like to express their gratitude towards Prof. KAGAWA (IIS, 4th division) and his laboratory staff for providing the fiber testing machine and many helpful advices during experiments excution. Also, authors are quite grateful to TEIJIN company which supplied the fibers used in this research.

(Manuscript received, December 27, 1990)