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Effective Use of Adhesive for Continuous Glass Fiber Reinforced Cement

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ABSTRACT

Glass roving reinforced cement planks were manufactured in use of adhesives for laboratory experiments. Some favorable properties of post-hardened adhesive coated glass roving facilitated the moulding process and improved flexural properties of planks. The hardened adhesive protected the glass roving during the manufacturing process. The adhesive coated glass roving was used in a form of latticework and the glass roving was easily orientated at the designed position in the plank. The strength and toughness of planks matched those of plywood in comparison with samples of the same thickness.

INTRODUCTION

From the fireproof point of view, noncombustible building materials replacing timber and plywood have been an important subject to be studied. The technology of composite materials is expected to bring available means to develop noncombustible building materials (1-4). For example, fiber reinforced hydraulic materials such as asbestos cement, glass fiber reinforced cement and fiber plaster board have had practical applications for building materials. Concerning with the strength of glass fiber reinforced composite materials, continuous glass fiber reinforcement is much preferable to short glass fiber reinforcement (5). Problems obstructing

Table 1 Materials

Pre-hardened adhesive coated glass roving reinforced planks	α-calcium sulfate hemihydrate	on the market, Specific gravity 2.74
	Retarder	Citric acid, Starch
	Aggregate	on the market, Plastering artificial lightweight fine aggregate, Volumetic specific gravity 0.3
	Glass roving	on the market, ER2310 (JISR3412)
	Glass chopped strand	on the market, Length 19 mm
	Adhesive	on the market, Epoxy resin, Hardening time 1 day around
Post-hardened adhesive coated glass roving reinforced planks	Normal portland cement	on the market, Specific gravity 3.15
	α-calcium sulfate hemihydrate	on the market, Specific gravity 2.74
	Retarder	Citric acid, Starch
	Aggregate	on the market, Structural artificial lightweight fine aggregate, Volumetic specific gravity 1.04
	Glass roving	on the market, ER770 (JISR3412)
	Adhesive	Polyvinyl acetate resin emulsion

the use of continuous glass fiber reinforced cement took place in the process of fabrication. As shown in the case of continuous glass fiber reinforcement with portland cement and gypsum, substantial problems in the process of fabrication are on the following;

1 The insufficient bond strength between glass fiber and matrix.
2 The weak protection of glass fiber from the mechanical shock in fabrication and the chemical erosion by matrix.
3 The unstable orientation of continuous glass fiber to the designed position.

Authors carried out some experimental study on the continuous glass fiber reinforced cement in use of adhesives which resulted in solutions for these problems.

Table 2 Sections of pre-Hardened Epoxy Resin Coated Glass Roving Reinforced Planks

Section A ; Glass roving up.4, lo.4
Section B ; Glass roving up.8, lo.8
Section C ; Glass roving up.4, lo.4 Cavities ϕ 9 or 12mm × 4
Section D ; Glass roving up.8, lo.8 Cavities ϕ 9 or 12mm × 4
Section E ; Glass roving up.4, lo.4 Cavities ϕ9 or 12mm × 7
Section F ; Glass roving up.8, lo.8 Cavities ϕ9 or 12mm × 7

(Width 150 mm, Length 600 mm)

EXPERIMENTAL METHOD

Procedure and Materials

Glass roving reinforced cement planks were experimentally manufactured. Performancies of planks were examined by flexural test. Materials used in this study are shown in Table 1.

Adhesives

Adhesives were used in two ways of application called pre-hardened and post-hardened. Pre-hardened adhesive was expected to increase the bond strength between glass roving and matrix. Epoxy resin was used as pre-hardened adhesive. Post-hardened adhesive was expected to protect the glass roving, to compose the glass roving in a form of latticework and also to increase the bond

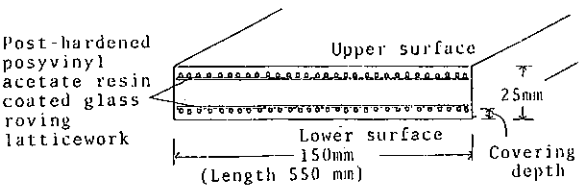


Fig. 1 Section of Post-Hardened Polyvinyl Acetate Resin Coated Glass Roving Reinforced Planks

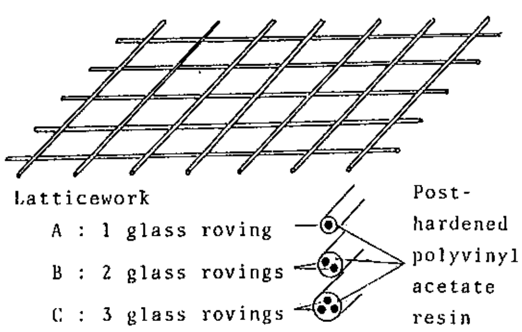


Fig. 2 Latticework of Post-Hardened Polyvinyl Acetate Resin Coated Glass Roving

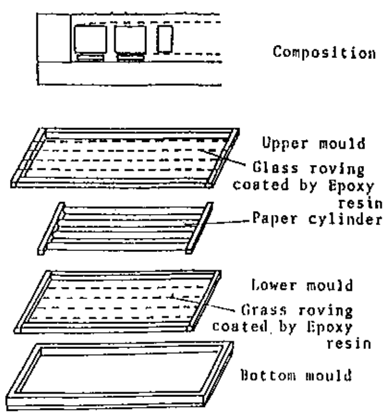


Fig. 3 Mould for Pre-Hardened Epoxy Resin Coated Glass Roving Reinforced Planks

strength. In the conventional way post-hardened adhesive was not expected to increase the bond strength, but in the present study polyvinyl acetate resin emulsion was adopted as post-hardened adhesive, which indicated adhesive trait and improved the bond strength as the dry-hard adhesive coating the latticework absorbed the water in matrix.

Sections of Planks

Table 2 is the sections of planks reinforced with pre-hardened epoxy resin coated glass roving. Paper cylinders were used to decrease weight. The thickness of plank was 25 mm. The width and length were 150 mm and 600 mm. 4-9 pieces of glass roving were embedded in either upper and lower surfaces. The cross sectional area of glass roving was about 0.009 cm^2 and the cross sectional area content of glass rovings in one side of plank to the whole section was 0.096-0.19 %.

Fig. 1 is a section of plank reinforced with post-hardened polyvinyl acetate resin coated glass roving. There were no hollows in the section. The thickness of plank was 25 mm. The width and length were 150 mm and 550 mm. The glass roving was used in a form of latticework. Three kinds of latticework indicated in Fig. 2 were formed. Each latticeworks A, B and C had 30, 60 and 90 pieces of glass roving per 15 cm width of plank. The cross sectional area of a piece of glass roving was about 0.003 cm^2. The cross sectional area content of a latticework to the whole section was 0.24-0.72 %.

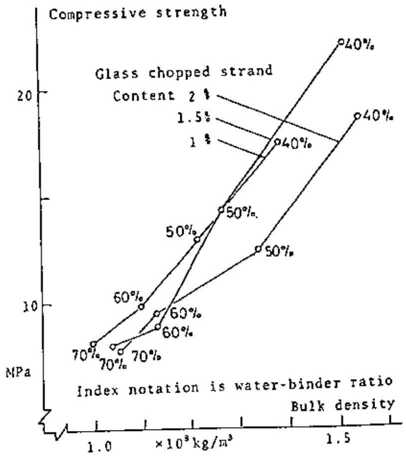


Fig. 4 Compressive Strength of Matrices of Pre-Hardened Epoxy Resin Coated Glass Roving Reinforced Planks

Table 3 Pre-Hardened Epoxy Resin Coated Glass Roving Reinforced Planks

Plank No.	1*	Mix compositions by weight				Bulk density ($10^3 \frac{kg}{m^3}$)	Ultimate flexural load (10N)
		2*	Water	Aggregate	Glass chopped strand		
201	A	100	50	25	-	1.06	68
202	C		70	38	1.5	0.92	28
203			60	24		0.99	36
204			50	14		1.23	37
205			40	5		1.46	33
206			50	22	1.0	1.07	23
207	E		70	50	1.0	0.93	55
208			70	38	1.5	0.94	23
209			60	24		0.95	22
210			50	14		1.06	28
211			40	5		1.21	53
212			50	22	1.0	1.04	42
213	B		50	25	—	1.20	130
214			40	10	1.0	1.40	103
215			40	—	2.0	1.53	179
216	D		40	5	2.0	1.38	135
217			40	5	1.5	1.32	142
218			50	25	—	1.02	106
219			50	25	0.75	1.04	114
220			45	10	1.5	1.26	77
221			40	5	1.0	1.55	74
222	F		50	25	—	0.96	121
223			40	5	1.5	1.36	104
224			40	5	1.0	1.49	72

1* Section (Table 2) 2* α-calcium sulfate hemihydrate

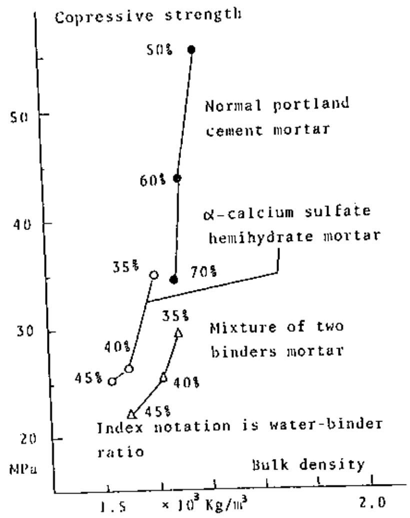


Fig. 5 Compressive Strength of Matrices of Post-Hardened Polyvinyl Acetate Resin Coated Glass Roving Reinforced Planks

Mix Proportions of Matrices

Matrices for the planks reinforced with pre-hardened epoxy resin coated glass roving were composed with α-calcium sulfate hemihydrate, retarder, plastering artificial light weight fine aggregate, glass chopped strand and water. Mix proportions of matrices are shown in Table 3. Glass chopped strand was used to improve the brittleness of matrix. As the volume content of aggregate increased, the bulk density and workability of mixture decreased. Then the volume content of aggregate was determined at the maximum volume which might not suffer to the workability of mixture in the moulding process.

Two kinds of cement, retarder, structural artificial light weight fine aggregate and water were used for the matrices of post-hardened polyvinyl acetate resin coated glass roving reinforced planks. Normal portland cement, α-calcium sulfate hemihydrate and the mixture of these two cements were the binders of matrices. In the case of mixture, normal portland cement content to the total binder was 20 %. Mix proportions of matrices are shown in Table 4.

Table 4 Post-Hardened Polyvinyl Acetate Resin Coated Glass Roving Reinforced Planks

Plank No.	1*	Mix proportions by weight: Binder	Water	Aggregate	Bulk density (10^3 kg/m^3)	Ultimate flexural load of each plank (10N)
301	A	100 (α-calcium sulfate hemi-hydrate)	35	150	1.60	232, 200
302			40		1.57	220, 210
303			45		1.56	246, 180
304	B		35		1.60	370, 344
305			40		1.57	360, 240
306			45		1.54	382, 376
307	C		35		1.63	460, 447
308			40		1.56	452, 422
309			45		1.50	358, 314
310	–		35		1.60	113, 110
311			40		1.59	102, 92
312			45		1.57	102, 92
401	A	100 (Mixture of two binders)	35	150	1.63	222, 156
402			40		1.62	198, 158
403			45		1.56	172, 162
404	B		35		1.64	245, 228
405			40		1.60	250, 240
406			45		1.53	280, 252
407	C		35		1.65	400, 378
408			40		1.60	353, 289
409			45		1.57	330, 315
410	–		35		1.68	129, 111
411			40		1.63	110, 110
412			45		1.58	99, 92
501	A	100 (Normal portland cement)	50	200	1.72	149, 102
502			60		1.68	102, 95
503			70		1.65	186, 98
504	B		50		1.64	242, 200
505			60		1.67	230, 198
506			70		1.64	237, 286
507	C		50		1.68	226, 218
508			60		1.68	268, 216
509			70		1.62	250, 214
510	–		50		1.72	68, 36
511			60		1.71	52, —
512			70		1.64	55, 38

1* Latticework for reinforcement (Fig.2)

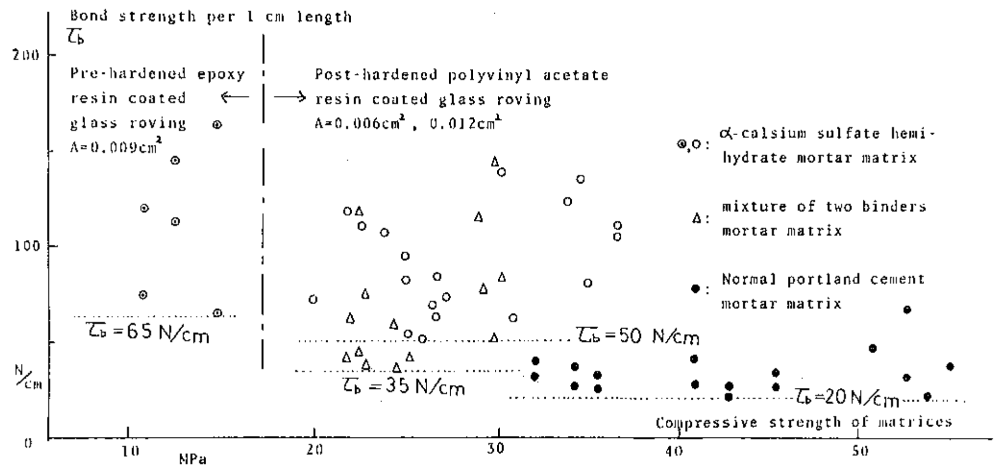


Fig. 6 Bond Strength

Moulding

Planks reinforced with pre-hardened epoxy resin coated glass roving were casted on the mould in Fig. 3. Mixture for matrix, upper and lower moulds on which pre-hardened epoxy resin coated glass rovings were braided, and paper cylinder were laminated on the bottom mould. The hardening time of epoxy resin was controlled to be longer than the final set of binder of matrix. Hardened planks were cured under ordinary room temperature for 6-14 days before measurement.

Polyvinyl acetate resin emulsion added glass rovings were braided in a form of latticework shown in Fig. 2. After the resin became hard by dring, the latticework was cut with 15 cm$\times$55 cm. The mixture for matrix and two pieces of latticework were laminated in a mould. Planks with gypsum matrix were cured in a heater controlled at 50°C and other planks were cured under room temperature 20°C. Planks were tested at 10-13 weeks age.

Flexural Test of Planks

Planks were tested using simple beam with center point loading of 50 cm span. Deflections of center point of the planks were measured by dialguages.

Tests on Glass Roving and Materials

The tensile strength of glass roving was tested by adding weights one by one hunged through a piece of glass roving. Specimens of glass roving were coated with polyvinyl acetate resin. The bond strength was tested by pulling out the glass roving which was embedded in matrices by 1, 2 or 3 cm length. The compressive strength of matrices was tested following the test method in JIS R5201 with 4×4×16 cm specimens.

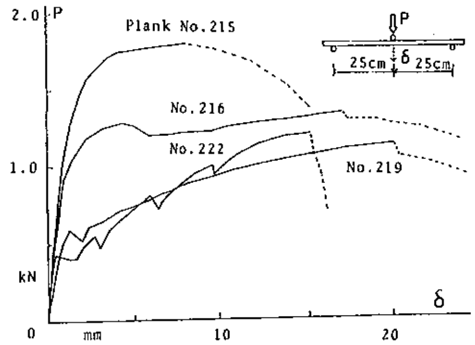


Fig. 7 Load Deflections of Pre-Hardened Epoxy Resin Coated Glass Roving Reinforced Planks

RESULTS AND DISCUSSION

Tensile Strength of Glass Roving

The glass roving endured the tensile load 1.20 kN and was cut at the tensile load 1.25 kN per 1 mm^2 cross sectional area. The tensile strength of glass roving was evaluated 1.2 GPa.

Compressive Strength of Matrices

Fig. 4 is the compressive strength of matrices of pre-hardened epoxy resin coated glass roving reinforced planks. With the bulk density decreased, the compressive strength of matrices went down. The compressive strength of matrices of post-hardened polyvinyl acetate resin coated glass roving reinforced planks is shown in Fig. 5.

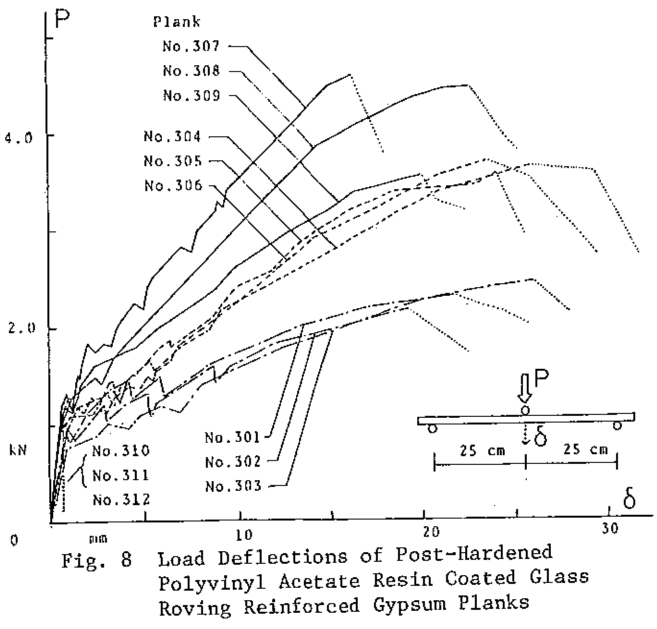


Fig. 8 Load Deflections of Post-Hardened Polyvinyl Acetate Resin Coated Glass Roving Reinforced Gypsum Planks

Bond Strength

The bond strength between adhesive coated glass roving and matrices is shown in Fig. 6. The minimum values of each bond strength are indicated by dotted lines. The bond strength between post-hardened polyvinyl acetate resin coated glass roving and normal portland cement matrix was relatively small.

Moulding of Planks

Several properties of adhesive were taken into consideration when pre-hardened epoxy resin coated glass roving reinforced planks were moulded. The fluidity to coat the glass roving immediately, the viscosity not to remove from the glass roving, the hardening time longer than the final set of binder of matrix and the adhesive strength with wet matrices were requested. It was not difficult with a small specimen in a laboratory but almost impossible with an actual size building material to satisfy these requests. Pre-hardened adhesive coated glass roving is not profitable to reinforce hydraulic matrices.

The moulding of post-hardened polyvinyl acetate resin coated glass roving reinforced planks was easy and some peculiar strong points were realized. The dry-hard adhesive protected the glass roving from the mechanical shock during the moulding. The glass roving was used in a form of latticework and was easily orientated at the designed position in the plank. The moulding procedure was not influenced by the hardening time of adhesive.

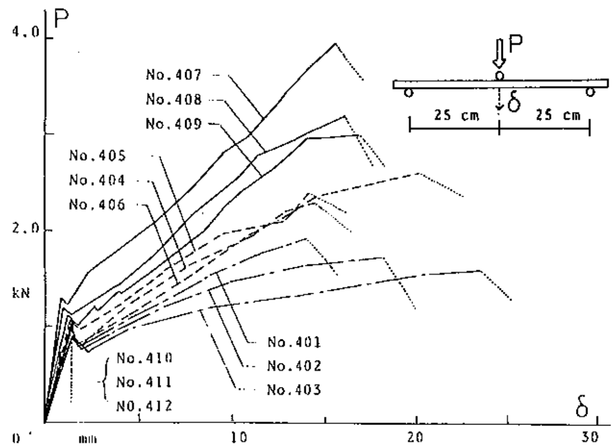


Fig. 9 Load Deflections of Post-Hardened Polyvinyl Acetate Resin Coated Glass Roving Reinforced Two Binders Planks

Flexural Performancies of Planks

Pre-Hardened Epoxy Resin Coated Glass Roving Reinforced Planks. The ultimate flexural loads of planks are shown in Table 3. Section B, D and F planks indicated relatively high ultimate flexural loads. At the most preferable case, the ultimate flexural load 1.2 kN corresponded to the bulk density 960 kg/m^3. Fig. 7 is the flexural load deflections of representative planks. The deflections of planks at the ultimate flexural load were 10-20 mm which corresponded to 2-4 % of loaded span. After the load crossed the ultimate flexural load, No. 215, 216 and 219 planks including the glass chopped strand in the matrix could carry fairly large load.

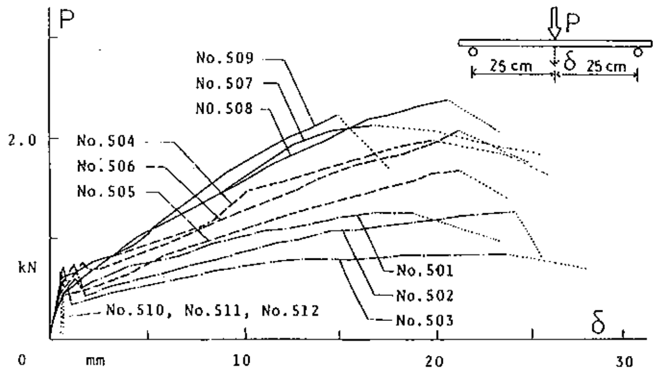


Fig. 10 Load Deflections of Post-Hardened Polyvinyl Acetate Resin Coated Glass Roving Reinforced Normal Portland Cement Planks

Post-Hardened Polyvinyl Acetate Resin Coated Glass Roving Reinforced Planks. The ultimate flexural loads of planks are shown in Table 4. Some planks indicated remarkable ultimate flexural loads over 4 kN. The highest ultimate flexural load 4.6 kN corresponded to 37 MPa modulus of rupture which surpassed the one obtained by the conventional technology, such as spray up short glass fiber reinforcement. For instance 10-20 MPa modulus of rupture was reported (1,2). Figs. 8-10 are the load deflections of planks. In the first stage of loading, the deflection of plank was small and at around 1 kN load first cracks initiated in the tension zone of middle section. After the initiation of first cracks the deflection increased faster than before as the load increased. The first cracks grew and new cracks were not observed on some normal portland cement planks. These planks were considered to be destroyed because of the insufficient bond strength. With respect to other planks the first cracks indicated little growth and new cracks initiated in the tension zone along the plank. When the load approached the ultimate flexural load, the compression zone of matrix at the middle section

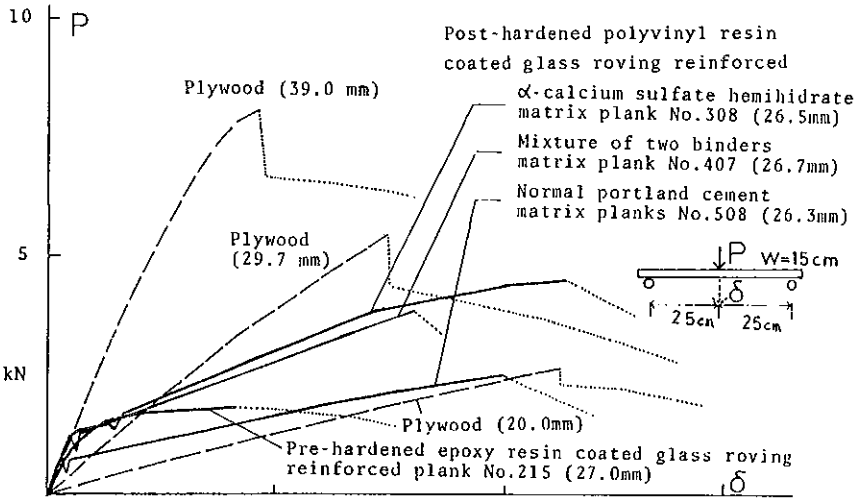


Fig. 11 Flexural Performancies of Planks

Table 5 Theoretical and Experimental Ultimate Flexural Loads of Post-Hardened Polyvinyl Acetate Resin Coated Glass Roving Reinforced Gypsum Planks

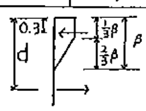
Plank No.	Cross sectional area of a latticework a cm²	Bond strength N/cm τ_b	Strength of matrix ×10 Pa: Compressive f	Strength of matrix ×10 Pa: Shearing τ_s	Effective thickness (cm) d	Possible flexural load caused by ×10N: bond strength P_b	Possible flexural load caused by ×10N: shearing strength P_s	Possible flexural load caused by ×10N: tensile strength of glass roving P_t	Possible flexural load caused by ×10N: comperssive strength of the matrix P_c	Theoretical ultimate flexural load ×10N	Experimental ultimate flexural load ×10N
301			349	23	2.24	588	1352	213	258	213	232, 200
302	0.09		266	18	2.25	591	1063	214	198	198	220, 210
303			252	17	2.23	497	995	212	185	185	248, 180
304			349	23	2.18	572	1316	415	343	343	370, 344
305	0.18	50	266	18	2.22	583	1049	423	269	269	360, 240
306			252	17	2.33	612	1040	444	276	276	382, 376
307			349	23	2.22	583	1340	635	431	431	460, 447
308	0.27		266	18	2.27	596	1073	649	341	341	452, 422
309			252	17	2.14	562	955	612	293	293	358, 314

$P_b = 2.30 \frac{7}{8} d \cdot \tau_b \quad P_s = 2.15 \frac{7}{8} d \cdot \tau_s \quad P_t = 12100 \cdot \frac{7}{8} d \cdot a$

$P_c = \frac{4}{50} \{ \sigma_t \cdot a \cdot (d - \beta) + \sigma_c \cdot a \cdot (\beta - 0.3) + 15 \frac{23}{54} \cdot f \cdot \beta^2 \}$

$\beta; \ \frac{4 \cdot 15}{9 \cdot 7.5} \beta^2 + 2 \cdot a \cdot \beta - (d - 0.3) a = 0 \quad \sigma_t = \frac{75 \cdot 3}{2} \frac{d - \beta}{\beta} \cdot f \quad \sigma_c = \frac{\beta - 0.3}{d - \beta}$

Stress distribution on the middle section of the plank



stared to fructure partially. The glass roving was not cut. Table 5 is the theoretical and experimental ultimate flexural loads of gypsum planks. The theoretical ultimate loads of planks except No. 301 were determined caused by the compressive strength of matrix. This was supported by the experimental result. For the energy absorbing factor of planks realizing high strength and toughness, the partial fructure of compression zone of matrix was prefered to the slip of interface between glass roving and matrix.

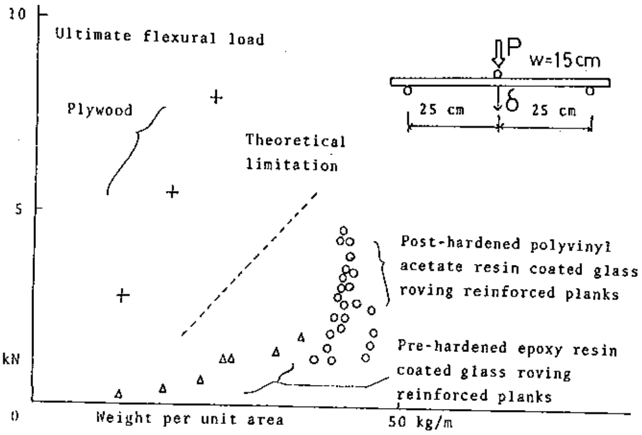


Fig. 12 Ultimate Flexural Loads and weights per Unit Area of Planks

Comparison with Plywood

Fig. 11 shows flexural performancies of moulded planks and plywood. Post-hardened polyvinyl acetate resin coated glass roving reinforced planks were excellent in terms of strength and toughness. The flexural performancies of these planks were a match for those of plywood. Fig. 12 is the ultimate flexural loads and weights per unit area of the planks. The lightening of weight was not considered with post-hardened polyvinyl acetate resin coated glass roving reinforced planks which were heavier than plywood. The dotted line in Fig. 12 is the prediction of planks which could be fabricated by the way presented in this study.

CONCLUSION

Glass roving reinforced cement planks were manufactured in use of adhesives for laboratory experiments. The modulus of rupture of planks indicated up to 37 MPa and the deflection reached to 2 - 4 % of loaded span at the ultimate flexural load. These values surpassed the ones of conventional glass fiber reinforced cement planks and matched those of plywood in terms of the same thickness. These favorable properties of planks were realized by the post-hardened adhesive coated glass roving which facilitated following three points.

1 After the moulding, the dry-hard adhesive absorbed the water in matrix and indicated adhesive trait bringing the enough bond strength between glass roving and matrix.
2 The hardened adhesive protected the glass roving during the manufacturing process.
3 The glass roving was used in a form of latticework and the orientation of glass roving was easy at the designed position in the plank.

An experiment on the durability of post-hardened adhesive coated glass roving reinforced cement planks is on going.

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