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EXPERIMENTAL FOUNDATIONS OF THE USE OF MEDIUM BASE CONTENT GLASS
FIBER REINFORCED PLASTIC MATERIALS IN SHIP BUILDING

by

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Experimental Foundations of The Use of Medium Base Content Glass Fiber Reinforced Plastic Materials in Ship Building

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Before 1979, the regulations of major ship building countries required the use of E glass fiber (with base content less than 1%) in ship building. Recently (1985), some of these countries stopped clearly specifying the requirements. Since so far there is no such requirements of the use of glass fiber in ship building in this country, the use of E glass in ship building was followed. However, this country has been producing large quantities of glass fibers with medium base content, (the total quantity has reached 90% of the total glass fiber produced), and the quality is similar to the C glass fiber used internationally. Due to the abundant supply of the raw materials and the lower melting/fabrication temperatures, the price of these glass fibers is lower than the base-free glass fibers by 40% and the total cost for ship building (ship body) is lowered by 15-20%.

The glass fiber cloth with medium base content, which costs less than base-free glass fiber cloth, has undergone many dry, wet comparison tests and the reinforced plastic material made with different glass fibers has undergone extended period boiling water, sea water immersion, extended boiling sea water destructive tests and many mechanical strength tests. Large quantities of test results have shown that the medium base level glass steel treated with reinforcing type immersion agent is not just better than the resin-free base-free glass fiber, required by the ship building regulations, in water resistance capability, the mechanical strength, elastic modules also meet the classification requirements set by major ship classification societies; thus provided the experimental evidence of the possibility of ship building using this material.

I. INTRODUCTION

In many countries, the fiber and its product used in reinforcing glass steel materials is the so called E glass; or namely base-free glass. In this country, the reinforcing material used in glass steel was medium base content (about 90%) glass fiber.[1] Its properties was similar to the C glass.

To adopt medium base glass fiber as the reinforcing material for glass steel is something unique in this country. In other countries, the C glass was used as the penetration resistant resin layer of the glass steel or the surface material used to improve the outlook of the products of C glass. Early in the 60's in this country, the medium base level glass fiber was produced indigenously. The fiber

did not contain boron; the supply of raw material was abundant; the cost was less; the melting/fabrication temperature was lower; and the properties of these glass fibers met the requirements for other manufacturing processes such as knitting and threading. The cloth made of these fibers treated with the same immersion reinforcing agent (811) cost less than the cloth made with base-free fiber by 40%. [12]

Among the major ship building countries (USA, USSR, Japan, UK and France), [14, 15, 17] it was clearly required that reinforced glass fiber used in ship building should be made of boron silicate E glass (with less than 1% of base) by USA, UK and France. The USSR's 1978 regulation [13] did not clearly specify, nor did Japan's 1985 regulation. [18] If this country would specify medium base content glass fiber to be used in ship building, there must be large quantities of experimental data as the supporting evidence. However, this would no doubt be a major contribution to the ship building industry of the world.

The strength of the material used for glass steel ship building; the medium base content cloth made of glass fiber treated with 811 reinforcing immersion agent, was higher than the cloth made of resin-free, coupling agent-free, 711 base-free fiber. In this way, the disadvantages of lower strength (14%) [11] of the medium base content fiber than the base-free fiber could be overcome. Of course, the strength of the base-free glass fiber treated with 811 immersion agent (with coupling agent) was also very high and, therefore, was used as a comparison in this paper.

In this country, the medium base content fiber was used in water resistant products such as cooling tower body, cooling tower fan blade, corrosion engineering of water dam (about 10000m²) and in the automobile industry.. Since the materials for ship building also have to be water resistant, the water resistance capability of this material was tested and also the possibility of using this material in ship building was investigated.

II. TESTS CONDUCTED BY GLASS FIBER INDUSTRY

During prolonged immersion of the ship body in the sea water, water molecules penetrate into the material through the fiber surface. This will cause the failure in coupling between the substrate and the fiber, even induce the failure of the substrate and degradation of the strength of the glass steel. According to this service condition, the following tests were performed: wet strength test after 2 hours water boiling; destructive test of property change after prolonged water boiling; property test after prolonged immersion in sea water; and destructive test of property change after prolonged sea water boiling.

Currently, an internationally popular index of strength is the wet strength after 2 hours water boiling. For this reason, a more extended test program was carried out under this category including: tensile strength; elastic modules

in tensile test; bending strength; elastic modules in bending test; compressive strength; elastic modules in compressive test; impact strength; and shear strength in between layers.

The tests mentioned above were carried out by the glass fiber and glass steel industries. They have done a more elaborate comparison of different immersion agents and different glass fibers. An example of the contents of the glass fibers used in these tests is shown in table 1. The discussion of various test results are as follows:

1. Water Resisting Capability of Medium Base Content Glass Fiber Cloth Without Immersion Agent Treatment

According to test standard, the strength variation was obtained by testing, in short term and prolonged water boiling test, cloths of dimension 25x100mm. After the wet strength of 2 hours water boiling was obtained, the cloth was boiled again until the fiber lost its strength (about 360 hours). From figure 1, it can be seen that there is a crossover of the curves at approximately 100 hours and after this period the tensile strength of the medium base content cloth was better than that of the base-free cloth. In the earlier periods; before boiling and 10 hours after boiling, the tensile strength of the medium base content cloth was lower than that of the base-free cloth by about 14%.

2. Water Resisting Capability of Medium Base Fiber Glass Steel

The strengths of glass steels made from the base-free fiber cloth treated with 811 immersion agent and medium base fiber cloth were tested by a prolonged (48 hours) water boiling test. The properties of the glass steel made of 711 base-free fiber used originally in ship building were used as a comparison and the bending strength was used as an index. From figure 2, the strength of medium base 811 was inferior to that of the base-free 811 but superior to that of the base-free 711.

When immersed in the sea water at room temperature, the strength of the glass steel reinforced by medium base cloth was not degraded after 90 hours (both 811 and 711 immersion agents). However, the retaining ratio of the glass steel reinforced by 711 base-free cloth dropped to about 60%, as shown in figure 3.

Even more critical is the property test after prolonged boiling in sea water. This is a destructive test with both the effects of high temperature and chlorine ion. The test temperature of 100°C already exceeded the service temperature of polyester resin. The test results showed that the properties of medium base 811 were better. All these three materials showed plateau after boiled in sea water for extended periods and the retaining ratio of the glass steel reinforced by 811 medium base content cloth was higher than the other two, as shown in figure 4.

3. Wet Strength of Glass Steel Reinforced by Short-Cut Glass Fiber Blanket

Short-cut glass fiber blanket can be made of C glass. In this country, this type of material has been in production for more than 3 years. In the glass steel made of this material, the fibers in the resin substrate are shorter, discontinuous, and therefore are much more effective in improving water resisting capability. The Japanese standard requires that the retaining ratio be no less than 84%. In fact, the retaining ratios for the glass steel made of short cut medium base or base-free blankets are better than this requirement, as shown in table 2.

4. Various Wet Strengths of the Medium Base Glass Steel

Using the method of testing wet strength after 2 hours water boiling, the 5 various strengths (8 indices) of the knitting products of medium base 811, base-free 811, and base-free 711 were tested and the results are shown in table 3.

From table 3, the absolute values of the 8 indices of medium base 811 glass steel are inferior to those of the base-free 811, but the retaining ratios of most categories are better than base-free 811 and most of these parameters are better than those of the base-free 711. For this reason, the glass fiber and glass steel industries concluded that the water resisting capability of 811 medium base cloth is better and the wet strengths of various properties are better than the base-free 711 originally used in ship building.

III. EVIDENCE FROM FOREIGN RESEARCHES AND SHIP BUILDING PLANTS

The results cited above were confirmed by the glass fiber and glass steel research institutes in ShiangHai, Beijing, NanJing, ChiangJu, and Harbin [2, 3, 4, 5, 7, 18]. To test the properties more extensively and to amplify its influence abroad, the medium base content glass fiber was sent to the United States of America for an independent test by an American company with its own resin. Table 4 shows the results from that company. Even though the absolute values of the results in some categories fell short of the indices of that company, the retaining ratio of the bending strength and the elastic modules reached the requirement.

In order to spread its influence in the ship building industry, the author also performed some tests in ShiangJu Ship Building Company at the Jujiang area and the JiangXin Ship Building Company along the Changjiang. Table 5 shows the results of medium base cloth and base-free cloth tested in these places. The results showed that, based on either absolute values or retaining ratios, the medium base 811 cloth is better than the base-free 711 cloth originally used in ship building.

Similarly, tests with an aim to confirm the applicability of the glass steel reinforced with short-cut medium base

glass fiber and base-free fiber blankets were also performed in these two companies. The results showed that the strength, wet strength and its retaining ratios are better, as shown in table 6.

IV. APPLICATION IN ACTUAL SHIP BUILDING

Take, for example, a fishing boat with the largest dimension [9]. The 18.5m shrimp catching boat designed and built in 1985 by JianJiang Fishing Boat Company had the major dimensions as follows:

length	18.48m
width	4.48m
distance between two poles	16.87m
depth	2.00m
average depth immersed in water	1.48m
capacity at full load	56.8t
speed at full load	9 knots
main engine power	99.3kW (135 hp)
sailing district	type II sea area
weight (including fuel)	34.5t

After a year and a half of sailing, two boats were examined in July, 1987. The material used by these boats was medium base content fiber treated with 711 agent (CWR400R711). These boats passed the examination since the dry and wet strengths of the glass steel satisfied the safety design requirements.

Since the building material of these boats was glass steel, the fuel consumption was 18% less than wooden boats and it was much faster. In fishing seasons, these boats could sail ahead of other boats and, therefore, the profits gained was more than other boats. The similar and improved models of these boats were already built in four ship building companies [10].

V. DISCUSSION OF MECHANISMS

From the crossover of the curves in figure 1, it is clear that the long term water resisting capability of the medium base content glass fiber is better than that of the base-free glass fiber. As indicated in figure 2, the dry strength of medium base 811 glass steel was lower than the base-free 811, but the difference became smaller as the boiling time became longer. This benefit of the medium base glass fiber is no doubt very attractive to its users. From figure 3, it can be seen that the water resisting capability of medium base glass steel after 90 hours of immersion in sea water at room temperature is superior to the glass steel reinforced by base-free glass steel.

These properties of medium base glass fiber should have a common internal reason. Reference 2 presented a preliminary discussion of this point.

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Table 1. Fiber glass composition used in tests [5] (%).

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	B ₂ O ₃	Na ₂ O	K ₂ O
Base Free Glass Fiber	54.34	14.75	0.42	16.39	4.66	8.84	0.32	0.17
Medium Base Glass Fiber	66.19	7.44	0.24	9.96	4.35	—	11.13	0.62

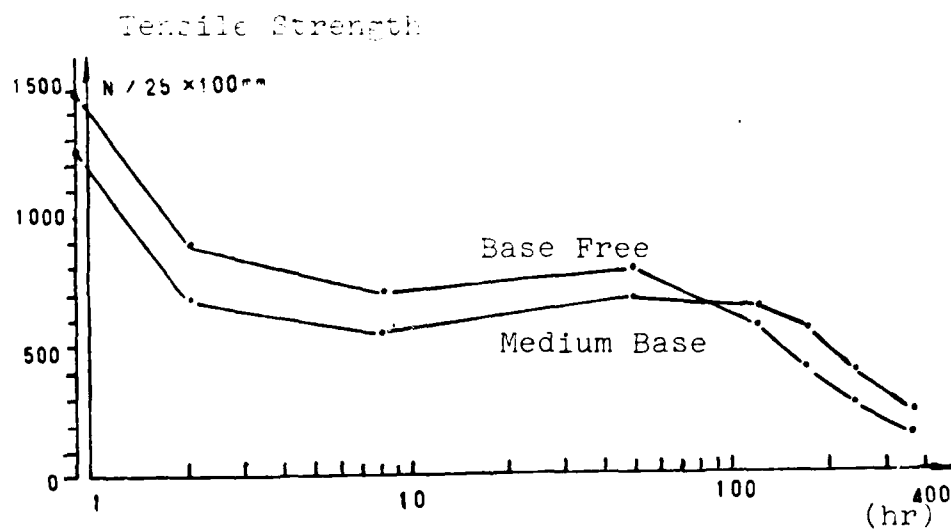


Fig. 1. Prolonged water boiling tensile strength of 811 immersion glass fiber cloth.

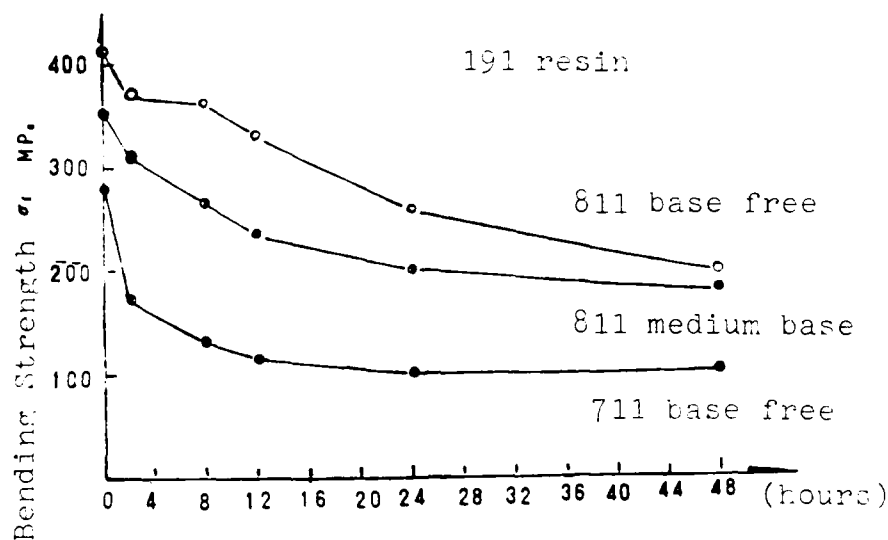


Fig. 2. Bending strength of glass steel after long term boiling.

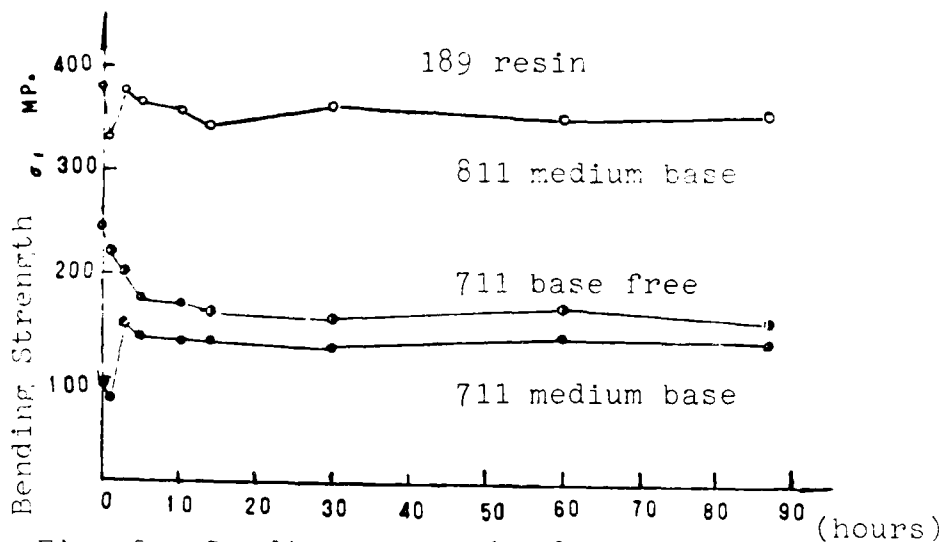


Fig. 3. Bending strength of glass steel after sea water immersion at room temperature.

Table 2. Bending strength of short-cut glass fiber blanket glass steel (191 resin).

Name	Glass Fiber Content (%)	Bending Strength	
		Dry/2 hrs water boiling (MPa)	retaining ratio (%)
Japanese Standard JIS R3411-1979	30 $\pm$ 5	>125/ >105	84
253 plant short-cut glass steel	30	190/180	85
253 plant short-cut glass steel	30	170/160	94

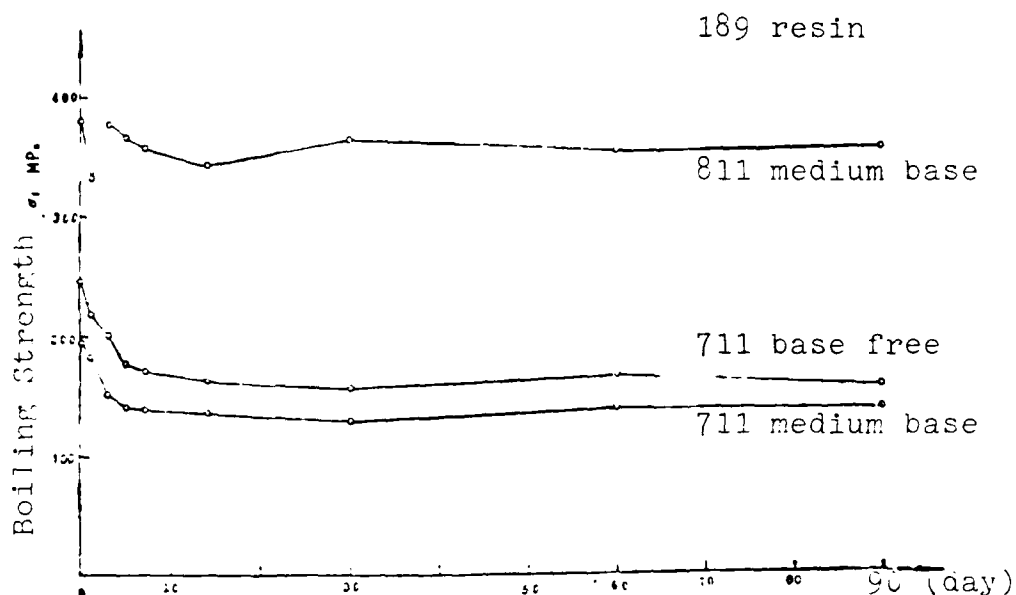


Fig. 4. Bending strength of glass steel after long term boiling in sea water.

Table 3. Wet strength of medium base and base free glass steels after treated with 711 or 811 immersion agents.

Fiber 189 resin content Category and Quantity	Base 0.4 711 Free		Base 0.36 811 Free		Medium 0.36 811 Base	
	47%		46%		46%	
	dry/wet	retaining ratio (%)	dry/wet	retaining ratio (%)	dry/wet	retaining ratio (%)
Strength MPa	277/154	55.6	378/286	75.7	333/298	89.5
Bending Modulus $\times 10^4$ MPa	1.46/0.70	48.4	1.79/1.28	71.5	1.35/1.07	79.3
Strength MPa	307/246	80.1	350/344	98.3	276/277	100.4
Tensile Modulus $\times 10^4$ MPa	1.36/1.18	86.8	1.70/1.48	87.1	1.43/1.24	86.7
Strength MPa	105/67.2	64.0	200/168	84.0	193/173	92.7
Compressive Modulus $\times 10^4$ MPa	1.40/0.86	61.1	1.56/1.26	80.8	1.52/1.12	73.7
Impact Strength J/cm ²	21.2/24.7	116.5	32.6/33.9	104.0	35.0/29.8	85.1
Shear Strength MPa	20.7/16.2	78.3	37.8/32.5	86.0	37.7/34.6	91.8

Table 4. Test results of 811 immersion agent treated glass steel performed by an American company.

Compression Products	Sampling Direction	Bending Strength (MPa)		Bending Modulus ($\times 10^4$ MPa)		Tensile Strength (MPa)	
		dry/wet	retaining ratio (%)	dry/wet	retaining ratio (%)	dry/wet	retaining ratio (%)
The Company Indices with 40% Glass Content	longitude	492/422	85	1.34/1.12	85	316/281	90
	longitude	422/358	85	1.26/1.05	85	253/225	90
253 Plant Base Free 811 Cloth with Glass Content of 40.5~43.5%	longitude	425.3/364.9	85.8	1.59/1.86	104	312.8/265.0	84.7
	longitude	554.7/525.0	94.3	1.74/1.78	102	454.1/409.8	90.2
153 Plant Medium Base 811 Cloth with Glass Content of 42.5~44.2%	longitude	414.1/369.1	89.1	1.53/1.48	96.4	312.8/264.3	84.7
	longitude	431.6/388.1	89.9	1.62/1.60	98.4	329.0/275.6	83.8

Note: Wet state is after 2 hours water boiling with 1050-5 resin.

Table 5. Ship building company test results - comparison of base ree and medium base cloth reinforced glass steels.

Comparison Group	Reinforcing fiber	Tensile Strength σ_s (MPa)		Bending Strength σ_f (MPa)		Impact Strength (unnotched) (J/cm ²)				
		dry/wet		dry/wet		dry/wet		retaining ratio (%)		
		Brand	Immersion Agent	Jujiang	Changjiang	Jujiang	Changjiang	Jujiang	Changjiang	
I	EWR 400 R811	359/357	99374/338	90355/282	79290/233	80	25/24	96	22/23	105
	EWR 400 R711	285/251	88249/203	82245/128	52230/119	52	15/16	107	15/15	100
	CWR 400 R811	384/350	91330/304	92473/431	91251/233	93	27/24	89	29/22	76
II	EWR 600 R811	316/303	96281/234	83251/194	77255/177	69	31/31	100	33/36	109
	CWR 600 R811	356/353	99290/268	92319/318	99245/235	96	28/25	89	36/38	106
III	EWR400R811U41	620/580	94548/481	88719/504	70659/380	58	42/43	100	36/39	108
	CWR400R811U41	638/614	96501/462	92857/696	81532/536	101	57/50	88	28/25	98

Note: 8 layers, 189 resin, wet strength tested after 2 hours water boiling.

Table 6. Ship building company test results - comparison of base free and medium base cloth reinforced glass steels.

Comparison Group	Brand Name of Reinforcing Fiber	Tensile Strength σ_t (MPa)				Bending Strength σ_b (MPa)				Impact Strength (J/cm ²)			
		dry/wet		retaining ratio (%)		dry/wet		retaining ratio (%)		dry./wet		retaining ratio (%)	
		Jujiang	Changjiang	Jujiang	Changjiang	Jujiang	Changjiang	Jujiang	Changjiang	Jujiang	Changjiang	Jujiang	Changjiang
I	EM 300	124/125	101	84/71	85	226/190	84	130/95	73	13/14	108	7/8	114
	CM 300	146/132	90	97/99	102	211/165	83	136/113	83	13/10	77	9/9	100
II	EM 450	175/171	98	102/91	89	259/223	86	171/172	101	17/15	88	12/11	92
	CM 450	125/118	94	92/97	105	185/182	98	166/157	95	17/15	88	11/10	91
	EM 450	133/139	105	109/106	97	211/184	87	142/159	112	13/13	100	12/12	100

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