CROSS-POINT BINDERS FOR GLASS FIBER MAT UTILIZING ELECTRONIC ION EFFECT

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ABSTRACT

We have succeeded to develop a technique enabling molecular level composite treatment by utilizing electrical characteristic (ion) of the materials to form 3D micro-structure, and it can bind three-dimensionally and selectively cross points of continuous (fibriform) object of nanometer size with high-speed and low cost.

Application fields of the proposed technique may be fiber process, composite material process, and electronic material process. We present here results applied to forming mat structure which is formed by resin binding between fibers composed of short glass fibers.

KEYWORDS: Fiber mat, Binder, Cross point, Ion, Glass fiber

1. INTRODUCTION

It is important to know the distribution of binder in glass fiber mat [1-3]. Fig.1 shows a conventional binding state without control, where requested binding or coating treatment according to the design was impossible. Fig.2 shows surface binding treatment of only designed filament cross points by techniques newly developed by us. The developed technique made it possible to bind selectively only the cross points of microfilament, and further made possible the binding treatment of only the surface of cross points of filament bundles.

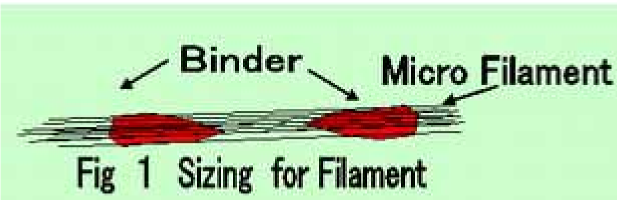


Fig 1 Sizing for Filament

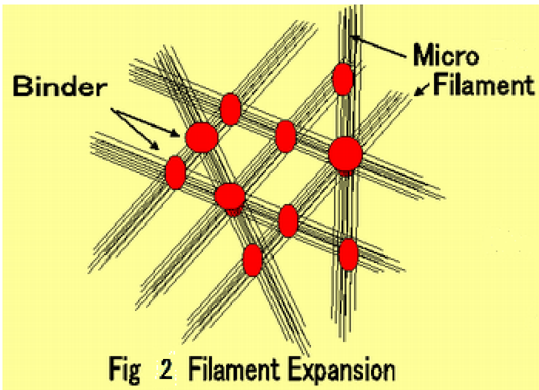


Fig 2 Filament Expansion

2. CROSS POINT CONDENSATION OF BINDER

There are two types of binder of Pw (dry binder of powder state) and Em (micro-binder dissolved into solution). Both types of binder condense to the cross point by the same principle. The basis of the principle is that in case of the filament being glass fiber the surface is electrically negative, water is neutral, and the newly developed binder is positive. At the cross point of the filament, since the density of the glass is dense, electrical pulling power is larger than the other points. When the water is sprayed to the filament, the binder/ water is pulled to the cross points and forms water ball as well as (with) the binder. Practically by making the electrical condensing power strong, it makes possible to improve the efficacy of condensation. The material having this electrical characteristics is surfactant for water. For example, in case of the filament being glass fiber and the binder is PET (unsaturated polyester) or PVAC (acetic acid vinyl), etc., it becomes possible to condense in the selected order by utilizing temperature characteristics. Thus, condensing the binder to the cross points of the fiber bundle, drying off the water, and melting the binder by heating, the target object is bound and treated (see Fig.3).

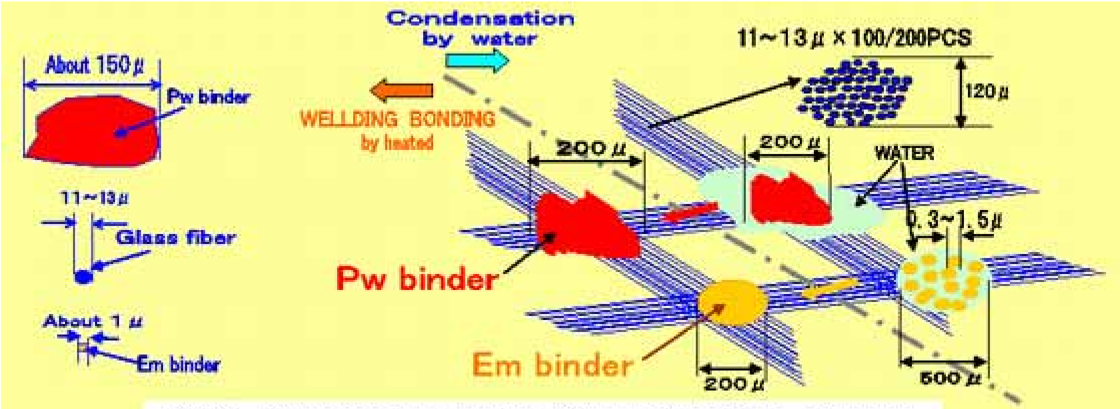


FIG 3 Hypothetical model of condensation process

Particle size

Particle sizes of the Pw and Em binders are selected based on the filament size. It became known from their structural model and experiments that the optimum particle size of Pw binder is 10 times of filament diameter, e.g., 150 microns, and that of Em is 1/10, e.g., 1 micron, where the maximum binding strength is obtained.

Modeling and electrical field strength

We make a model of contacting and crossing fiber bundles with diameter d at a right angle as shown in Fig.4 and 5. To make further simplify the model, we assume the minus charge is distributed equally along the center line of each bundle. Then, the relative electrical field strength along the lines (1)-(3) around the cross point in Fig. 4 and 5 is given as follows.

(1) Along the line perpendicular to and crossing the center line of a fiber bundle:
The line is {x=0, z=0.5d}. The relative electrical field strength at x=X is given by integrating along-line component (the 2nd term in Eq.(1)) of electrical field (the 1st term) inversely proportional to square of the distance from the upper bundle, and that by lower bundle has no effect with balancing such that

$$f_1(X)= \int_{-\infty}^{\infty} \frac{-1}{X^2+(Y-y)^2} * \frac{X}{\sqrt{X^2+(Y-y)^2}}\, dx \qquad \text{Eq.(1)}$$

$$= \int_{-\infty}^{\infty} \frac{-X}{(X^2+(Y-y)^2)^{3/2}}\, dx$$

(2) Along the line above d from the lower bundle (x=0, z=d):

$$f_2(Y)= \int_{-\infty}^{\infty} \frac{-Y}{(x^2+Y^2+(0.5d)^2)^{3/2}}\, dx$$

(3) Along the line above d from the upper bundle (y=0, z=2d)

$$f_3(X)= \int_{-\infty}^{\infty} \frac{-X}{(X^2+y^2+(2.5d)^2)^{3/2}}\, dy$$

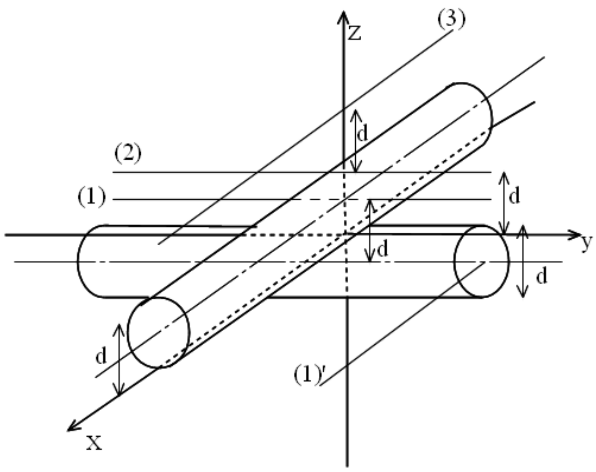


Fig.4: Model of cross point of fiber bundles.

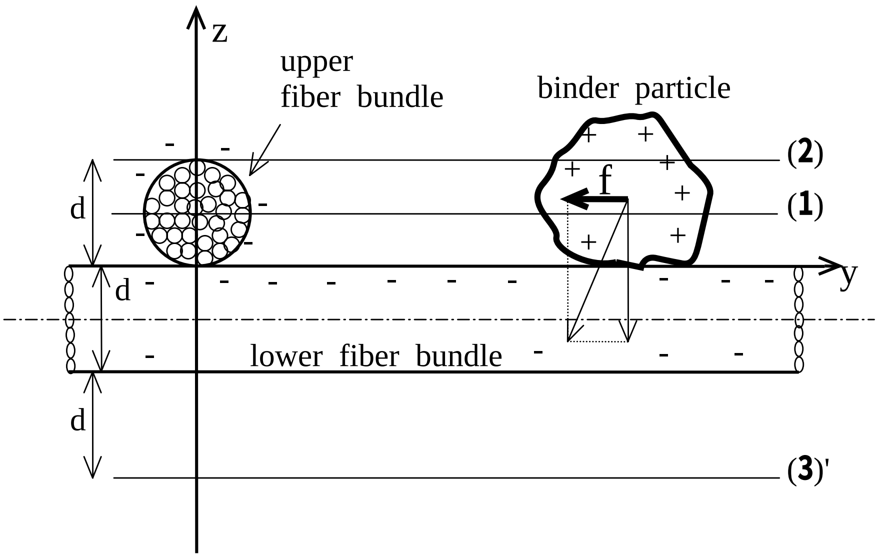


Fig.5: Cross section of the model.

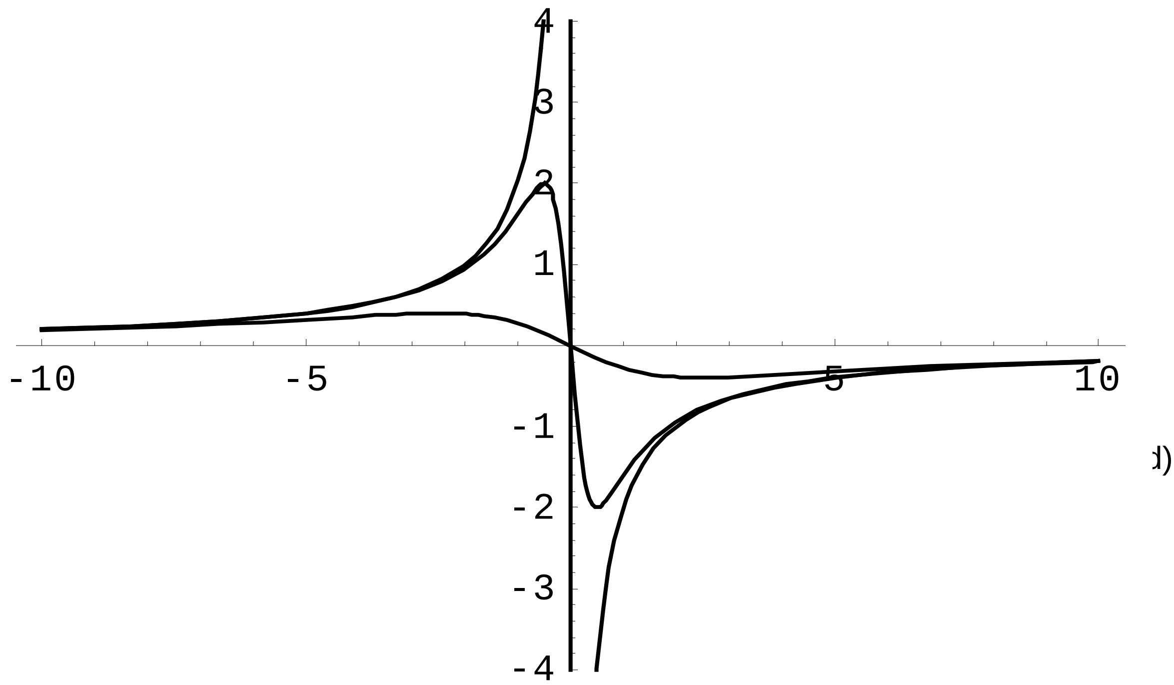


Fig.6: Electrical field strength around the cross point of fiber bundles.

The relative field strength is calculated as shown in Fig.6. The bundle diameter d is typically 120 [μm], and the binder particle size is typically 150 [μm]. First, the particle around the fiber bundle, typically 1 [mm] (8.3d) apart from the fiber bundle is attracted to the fiber bundle along line like (1)’. The force is the same as (1) given by Eq.(1). Then, the binder particle within 1 [mm] distance from the cross point is attracted to the cross point also by the force given by (1) when the particle size is the same as the fiber bundle diameter d. If the particle diameter is twice of d, it is attracted by the force given by (2). Typically, the binder particle may be attracted by the force between (1) and (2). If the binder particle is attached to the reverse side of the cross point as (3), attracting force is weak. Thus we can see that the binder particles around the cross point are attracted to the cross point.

3. CONTROL OF BINDER

Control of particle size of Em binder and effect of condensation

The size of the Em binder condensing to cross points of filament influences the binding strength largely. Therefore, it is important to control the particle size of the binder. It can be treated to the necessary particle size by condensing the dispersed dissolved Em binder. There are two kinds of condensations; one-liquid condensation and two-liquids condensation. One-liquid condensation can be attained by stopping function of the surfactant with heating. Tow-liquids condensation can be attained by reacting and condensing two Em's of cation and anion with different electrical charges. In case of using the Em binder, both of the condensation of the dispersed binder and the cross point condensation are necessary. Reaction type of the two-liquid condensation is illustrated in Fig.7. Fig.8 shows an example of applied to glass fiber mat with 450g/m**2, 13 micron, 100 PCS, 50mm Cut, using NBL NS-001 binder. We can see that condensation effect of the Em binder gives 2-5 times of the strength compared with the conventional method.

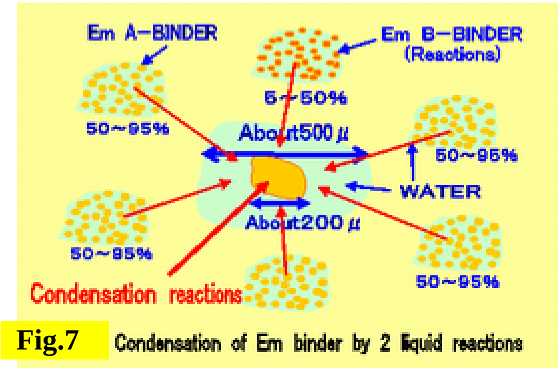


Fig.7 Condensation of Em binder by 2 liquid reactions

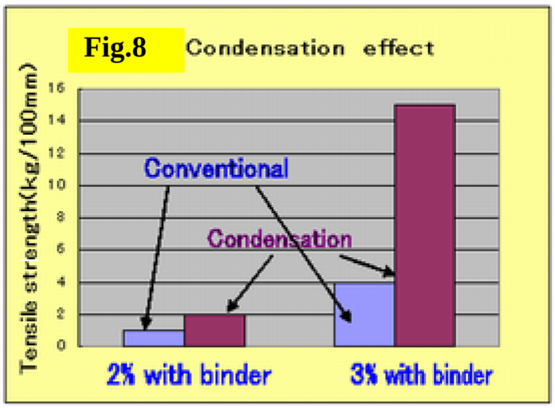


Fig.8 Condensation effect

Effective cross point binding

Fig.9 shows schematic illustration when using glass fibers. When binder is dissolved, it penetrates normally into inside of fiber bundle by the affinity with filament surface. If the osmosis happens, binder for cross points between filament bundles is consumed at inside of the fiber bundle, and effective cross point binding is not attained (Fig.9 left). However, by adding special surfactant (Matrix-01/02) developed by NBL Co., Ltd, surface structural binding of the fiber bundle is attained as shown in the right of Fig.9. This effect gives 2-3 times of strength up.

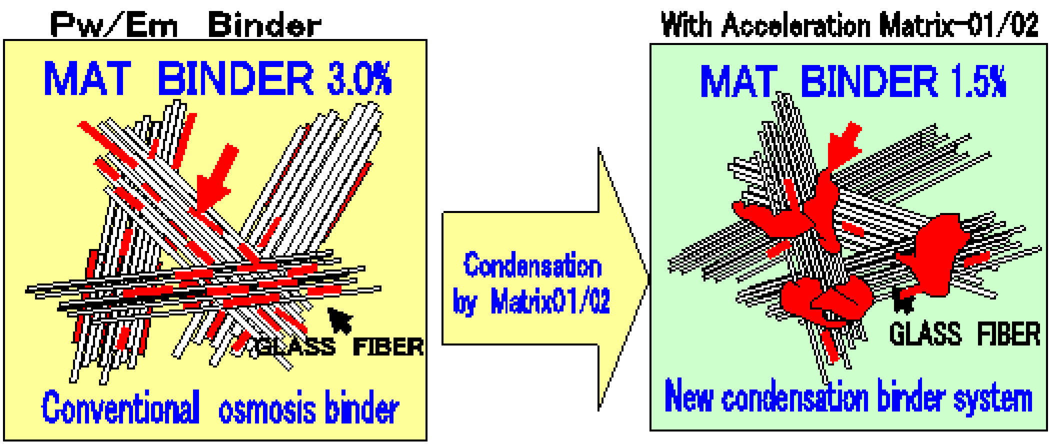


Fig.9: Acceleration for Binder "NBL-MATRIX-01/02"

Characteristics of NBL-Matrix-01/02
Material: special surfactant
Quantity used: 0.36% of fiber glass dry weight
Solution: water rate 76%wt (solid rate 24%wt)
Viscosity: 4-10 cps
Dry up temperature: 170 Centigrade

Fig.10 shows experimental results of E-glass, 13 microns, 200PCS, 50mm cut, CS mat 450g/m**2, and binders used: Bis A EO, Pw binder (NBL-555). Fig.10 shows relation of added binder vs. tensile strength. Effect of adding Matrix-02 developed by NBL shows about three times up in strength.

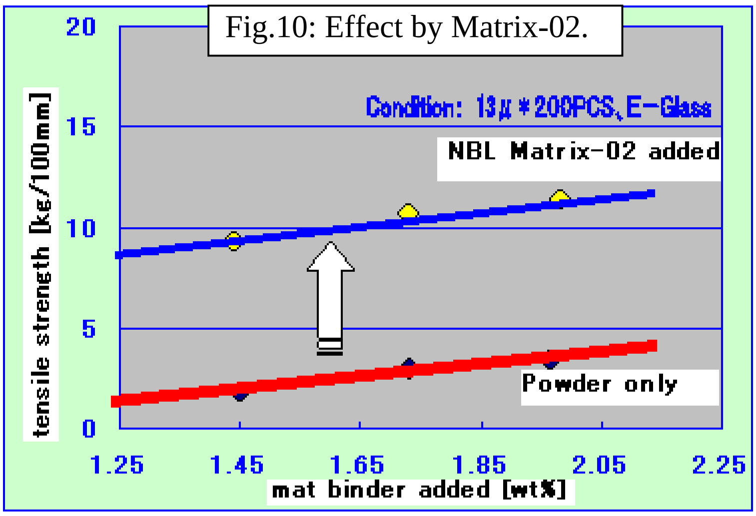


Fig.10: Effect by Matrix-02.

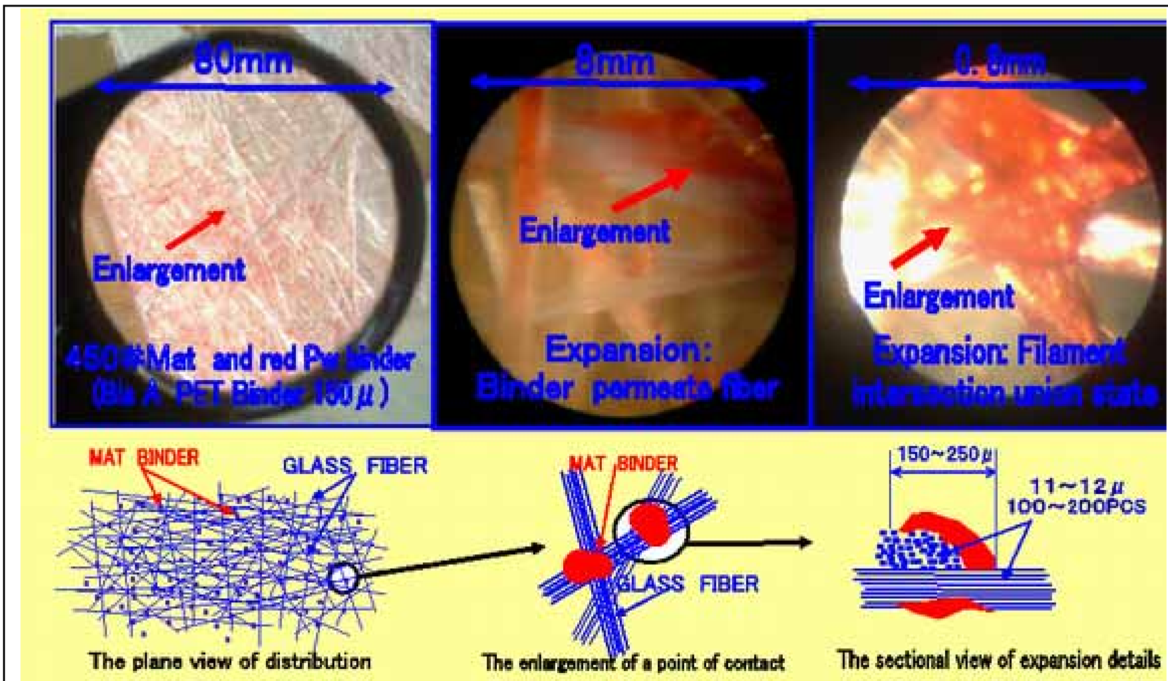


Fig.11 Condensed type microphotograph of Pw binder for fiber glass mat

4. MAT PRODUCT

Application results to glass fiber mat

Fig.11 shows an application result to glass fiber mat. We can see that the Pw binder stained in red adheres properly to cross points of the glass fiber. Fig.12 shows photographs of electron microscope showing binding state of the glass fiber bundle and binder. Left panel shows binding state between fibers when the diameter of the fiber is 12 microns and size of the focusing Em binder is about 1 micron, where we can see also cut off point of the fiber. Adhered material covering surface of the fiber bundle is the mat binder in the central panel. Left panel shows clearly that mat binder does not penetrate into inside of the fiber bundle, and binding is done on surface of the bundle. By these photographs, it is proven that the binder is bound to filament surface at cross points of filament bundle in the 3D binding processing of glass fiber bundle with micro-filament.

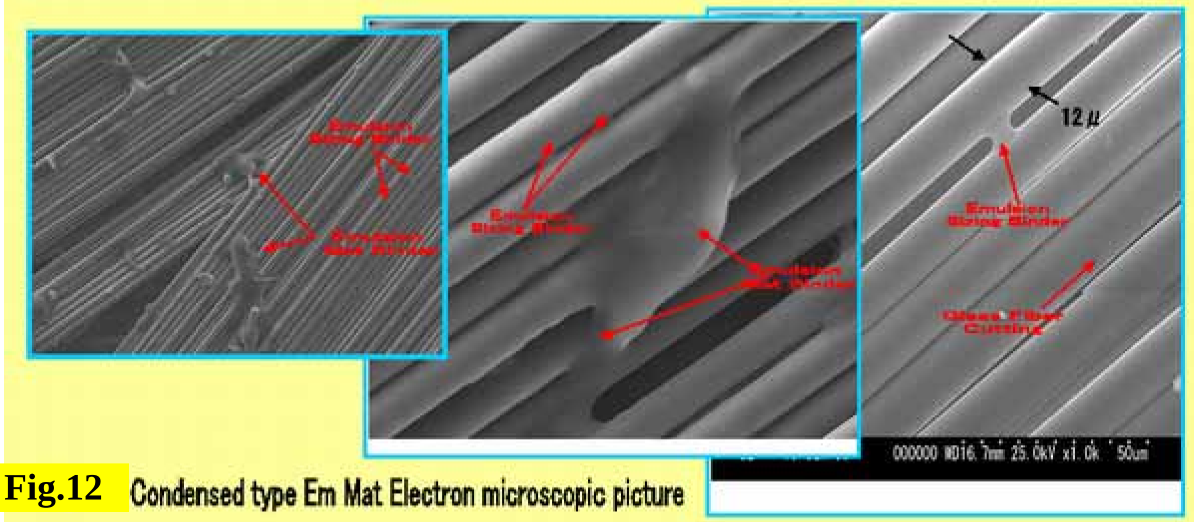


Fig.12 Condensed type Em Mat Electron microscopic picture

Effect of new Pw binder

Fig.13 shows effect of the performance improvement by the new technique of binding cross points of micro-filament developed by NBL. This processing technique is applicable to both of the Pw/Em binders, which condenses binder to the target points by utilizing electronic ion energy. From the figure, we can see that the new technique have ten times of strength up compared with the conventional tensile strength. For example, in order to obtain strength of 13 kgf/10cm, previously 3.5% of mat binder is required. Condensing to the cross points by adding 0.3% of Matrix-01, however, we can do with only 1.2% of binder. Further, it is possible to increase the quality such as surface of the product is smooth and has less nap. As a result, developed "ion condensation method" ensures higher quality than the conventional one, and largely reduce the material cost. The visaul appearance of the product is shown in Fig.14.

Characteristics of products

Physical characteristics including rigidity of the mat produced using the binder and tensile strength are shown in Fig.15. Fig.16 (a) shows how to count the wet out time showing how soon the mat is wet out. Fig.16 (b) is the produced mat showing how much the styrene flows up vertically in the produced mat and dissolves the binder at the cross point of the fibers and the corresponding mat area becomes white. Fig.16 (c) shows how to count the time up to the produced mat is broken when the end of mat is dipped into the styrene solution. Fig.17

shows how to measure the decreased rate of the bending strength of FRP made using the mat after immersed into the boiling water of 95 C deg by the three point method.

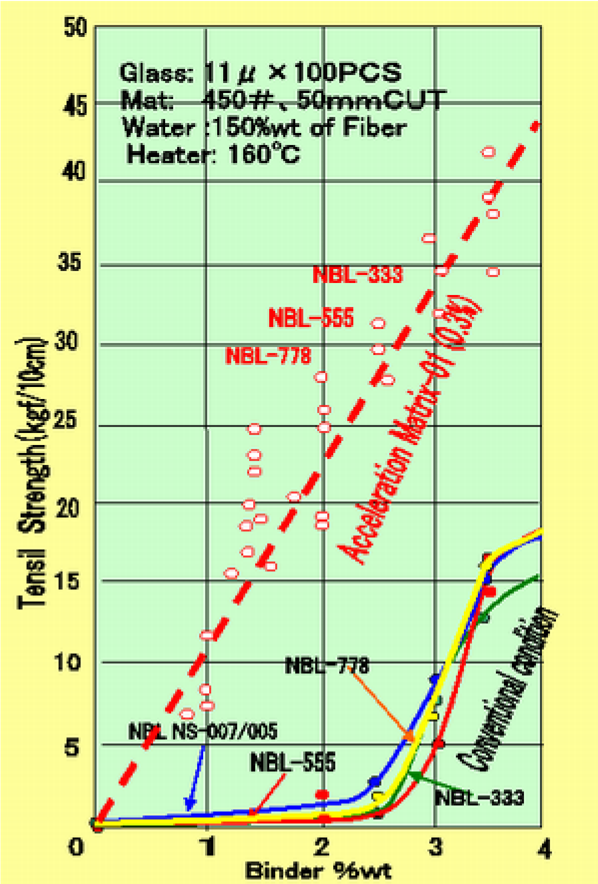
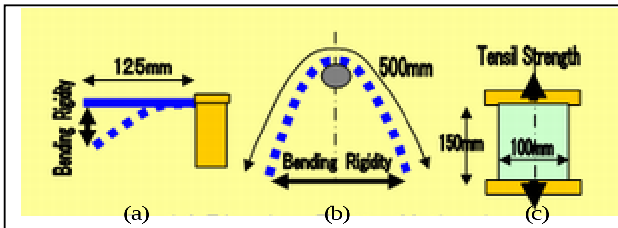


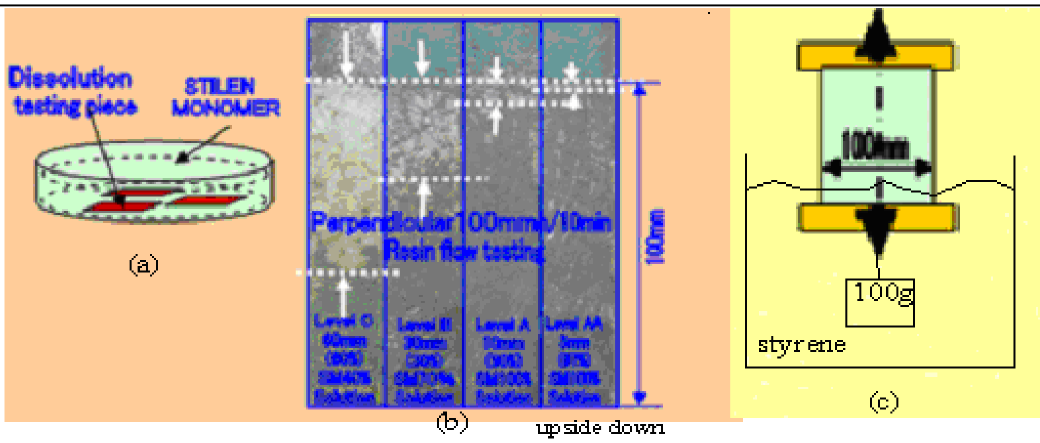
Fig.13 Mat binder and tensile strength.

Fig.14: Appearance of product.



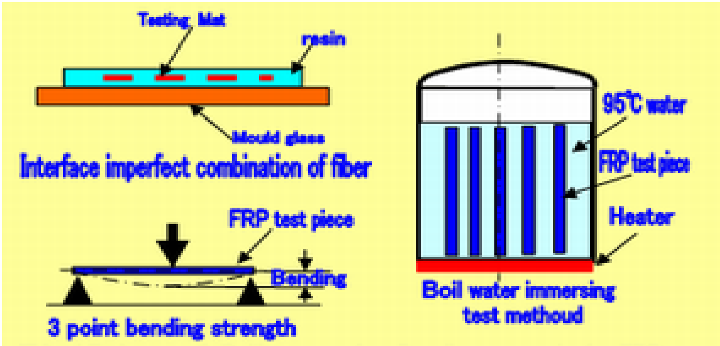
Product mat (g/m**2)	Pw450	Em450
(a) Bending rigidity(mm/125mm)	>20	>60
(b) Bending rigidity(mm/500mm)		<80
(c) Tensile strength (kg/100mm)	>14	>6

Fig.15: Fiber glass testing method.



Product (g/m**2)	Pw450	Em450
(a) Wet out time (sec)	<10	<10
(b) Resin omission at 10 min (mm/100mm)	>3	>10
(c) Resin dissolution (min/100 mm*100g)	0.5-1	0.5-1

Fig.16 Dissolution test method of mat binder



Product(g/m**2)	Pw450	Em450
100hr strength decrease (%)	none	<5
500hr strength decrease (%)	<5	<15
1000hr strength decrease (%)	<10	<30

Fig.17: Bending strength of FRP after boiling, which is made from mat using proposed binder.

5. DISCUSSION

It was only discussed from electrical ion force effect in this paper. However, the effect of viscosity change of the binder and pressing speed according to the temperature change should be investigated [2, 3] for the present thermoplastic binders of Em type and Pw type.

6. CONCLUSIONS

It has been succeeded that when NBL Matrix-01 Em mat binder is applied to glass fiber mat, material cost of up to 80% can be reduced, and also Pw mat binder up to 70%. Thus, we could confirm the effect that 70-80% of the material cost can be reduced.

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