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Preparation of Lightweight High Strength Mortars and Concrete Containing Scrapped FRP Fine Powder

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Mortar was prepared with aggregate of FRP fine powder as well as sirasu baloon. The mortar containing FRP as part of the aggregate became more lightweight by heating at 200℃, when its flexural strength increased up to 2.5 times and its compressive strength upto 3.5 times.

1. Introduction

FRP (glass fiber reinforced plastics) is widely used for auto parts, small-sized boats, bathtubs, etc. as a material with lightness, high strength, and durability.Its use is increasing yera by year, reaching nealy 500,000 tons per year at present.

On the other hand, the quantity of scrapped FRP is also increasing.But its disposal and recycling have constituted a great social problem, as there is no effective reusing system for it.

In Germany, the ERCOM shredder system was developped to recycle SMC automobile parts for reuse in existing SMC production lines. After shredding the SMC parts, the material is further processed by grinding the sheredded, material into powder/fiber mixture, drying the material, air separating and sieving into various sizes and as a results, depending on the type of composite, it is reported that the fiber with powder randing in the particle sizes of 0.25～3.0mm, and 3～15mm are obtained.

The authos[1] have endeavored for the preparation of light weight mortar with an aggregate of fine-powdered (10～20μm in diameter) FRP waste to utilize the scrapped FRP.

Minute examinations of the preparing conditions showed that a mortar with an aggregate of fine-powdered FRP (FRP morta) can be lightened and strengthned by high temperature curing at about 200℃. But its mechanism has not been clarified.

This study aimed to find a preparing process of FRP mortar with less weight and higher strength by examining the material combination, curing conditions, and fiber addition at FRP mortarmolding.

Then, the examine the possibility of recycling scrapped FRP, its fine powder and ash were produced and mixed into concrete. Setting time test, drying shrinkage test, accelerated carbonation test,and compressive strength test were carried out on the set concrete to investigate the effects of the kind of fine powder on (1) slump flowand air content, (2) compressive strength, (3)drying shrinkage, and(4) carbonation depth.

2. Preparation of FRP micro fine powder

FRP fine powder was prepared on the FRP pulverizer (ASAOKA Co. Ltd.) as shown in Fig.1. The FRP pulverizer was devoted consis ting of (1) automatic feeder, (2) micropowdering machine, (3) unground material separatoy, (4)electrostatic remover, and (5) micropowder collector .

The FRP pulverizer features a new grinding technology using diamond wheel cutter capable of pulverizing waste SMC, BMC, hand lay up, synthetic marble, and CFRP materials into micropowder instanteneously in one process. The stand ard diamond wheel cutter(250mm in diameter, 300mm in width) rotates at 800rpm. The cut of size (under 50 x 250 x 600mm) waste materials are fed into the automatic feeder against the diamond wheel cutter to be micro-powdered, drown to the micropowder collector by passing througha separator where the unground material is separated and an electrostatic remover is incorporated to prevent spontaneous explosion. The minimum cutting capacity of the micropowdering machineis 50kg/hr depending on the cuting size of the waste materials.

In observing the micropowder processed by the diamond wheel cutterwith a scanning electron microscope. As can be seen from Photo 2, there are, in part, comparatively large powder around 20 μm but themajority is less than that and around 4~5 μm. By incresing the magnification further, many powder around 2 μm can be recognized. Also, as glass fiber in its fiber from was recognized, the cut section was observed by the microscope. The cross section shows that the glass fiber was cut instantaneously with a very sharp edge. Also, very minute powder less than 1 μm attacched the glass fiber can be seen.

Nevertheless, the grain diameter of the micropowder is within the range from 0.4μm to 100μm but the grains around 16 μm is the greatest and the average grain diameter is 13.5 μm.

3. Experimental

3.1. Material used

Normal Portland cement was used, as obtained commercially. Aggreates used for the preparation of FRP mortar were Sirasu balloon(Sankilite B03) and fine powder of silica fume. FRP fine powder was made by pulverizing a plastic bathtub produced by hand lay up method,using an FRP pulverizer

(Asaoka Co. Ltd.). Its average particle size was 15μm. Fig.2 shows the particle distribusion of FRP fine powder.

Five kinds of fiber were used to reinforce the mortar: fly ash fiber (Itochu Co. Ltd., 10~20mm in fiber length, 12.6 μm in diameter, 1246MPa in tensile strength, and 63GPa in elastic modulus),asbestos (LAB Chrysotile Inc., 4T-300, 8~12mm in fiber length), Vinylon (Unichika Co. Ltd., AB 1800, 6mm in fiber length) , polypropylene (5mm in fiber length) ,and carbon fiber (pitch-based chopped strand, 5mm in fiber length).

3.2. Prepation of FRP mortar

The preparation procedure of FRP mortar was shown in Fig.3. Mixture of fine-powdered FRP and Sirasu balloon with a certain compounding ratio was added to normal Portland cement, and stirred.

The compounds obtained had an FRP/cement ratio (FRP/C) of 0.47 anda Sirasu ballon /cement ratio(S/C) of 0.28. Water was added so that the water/cement ratio(W/C) would be 0.75, which was stirred in amortar-mixer.

It was poured into a mold (JIS:4cm x 4cm x 16cm), and before its fluidity was lost, it was pressurized through a pressing board with an oil press (3.9MPa, 15min.). After one days standing it was unmolded and cured in water for a week. Then it was heated in a drier kept at 200°C for three hours for high-temperature curing in order to give higher strength.

Moreover, lightneing and strengthening of FRP morta was tested by replacing some part (10~30%) of cement with silica fume. FRP mortars without high temperature curing, and those without pressurization were also prepared for comparison.

3.3. Preparation of FRP mortar

Normal Portland cement was mixed with a certain quantity of water to make cement paste. Each kind of the fibers was mixed into this cement paste by 3% weight of the cement.

Premixuture of FRP fine powder and Sirasu balloon was added to it, poured into a mold (4cm x 4cm x 16cm) after stirring, and pressurized (3.9MPa, 15min.) before losing fluidity.

After one day's standing it was unmolded, cured in water (one week), and allowed high temperature curing (200°C, 3hr) to prepare fiber-reinforced FRP mortar.

3.4. Preparation of FRP concrets

River sand was used as fine aggregate of the concrete, crushed stone as coarse aggregate, and naphtalene-derived and carboxylic acid-derived high range water reducing agents were used as admixtures. FRP fine powder was made by pulverizing molded FRP, and FRP ash was obtained by calcinating it at 800°C.

In the mixed concrete, 5% of cement was replaced by FRP fine powder or FRP ash. The mix of concrete was W/C:35% and S/a:51.8%. Unit contents of the concrete containing FRP finepowder were cement: 486kg/m^3, FRP fine powder or ash; 24kg/m³, fine aggreegate: 860kg/m³, coarse aggregate: 806kg/m³, and water: 170kg/m³.

3.5. Measurement

Bending strength and compressive strength of the FRP mortar prepared were measured by JIS R 5201. At the bending test, deflection at the central part of t he specimen was measured under the maximum load.

4. Results and cosideration

4.1. Strength (FRP mortar without fiber reinforcement)

Table 1 shows the bulk density and mechanical strength of FRP mortars prepared with and without pressurization or high temp eraturecuring. Figures in parentheses a fter the mean values show the differences of minimum and maximum values from the mean, respectively. In the comparison of the properties of two FRP mortars whose only difference is with and without high temperature curing, FRP mortar with high temperature curing (No.2) was more lightend than that unheated (No.1) and its bending strength and compressive strength were raised by factors of 2.5 and 3.5, respectively.

This shows that FRP mortar is lightened and strengthened by heat-ing. As it was considered that compactification of FRP mortar is necessary for its strengthening, compactifications by pressurizationand by the use of fine aggregate (silica fume) were examined.

In result, considerably lightweight FRP mortar with high strength(No.3) was obtained only by high temperature curing and pressurization. When the s ubstitution rate of silica fume for cementwas raised from 0.1 to 0.3, bulk density decresed and compressive strength incresed, while deflection showed a tendency to decrease.

4.2. Strength (FRP mortar with fiber reinforcement)

Table 2 shows the kind of fiber, combination, bulk density, and mechanical strength of FRP mortars with fiber reinforcement. Bendingstrength and deflection of FRP mortar reinforced with asbestos(No.12) were much greater than those of FRP mortar without reinforcement. Meanwhile, for FRP mortars reinforced with fly ash fiber, polypropylene, Vinylon, and carbon fiber (No. 8, 9, 10, and 11), mechanical strength decresed, though defflection increased.

As to FRP mortars reinforced with poly-propylene and with Vinylon, when their fractured sections were observed, ordinally white to orenge fibers had changed to brown. This suggests that the fibers were degraded by heating during the high temperature curing to be useless for reinforcement.

In case of carbon fiber, its dispersion was not enough to reveal strength. From the se results, it is concluded that the fiber to be used for the reinforcement of FRP mortar is limited to asbestos out of the five kinds used here.

When strengthening by fine-powdered aggregate (silica fume) for the fiber-reinforced FRP mortar was tried, a lightweight and high-strength FRP mortar (No. 13) was obtained, which had a bulk density of 1.01g/cm³, a bending strength of 7.1MPa, and a compressive strength of 41MPa.

4.3. Properties of concretes contained FRP fine powder

Concrete, in which 5% of cement was replaced by FRP fine powder or ash, showed the following results regardless of the kind of fine powder.

(a) Table 3 shows in slump flow of FRP micro powder contained concrets. Slump flow decreased.

(b) Table 4 shows in setting time. Setting time was effected in kinds of high range water reducing agents.

(c)Table 5 shows in compressive strength FRP micro powder contained concrets. The compressive strength was 90～103% of that of reference concrete.

(d) Drying shrinkage (26 weeks) was 114, 126 % of the reference concrete.

(e) Carbonation depth (26 weeks) was not recognized. These proved the possibility of recycling scrapped FRP as aggregate for concrete in the form of fine powder or ash.

5. Application of FRP mortars for constructi on materialas.

The apprication of FRP mortars is various construction materials,such as the sidewalk concrete flags, the artificial wood of concrete (Fig.5), the centrifugal concrete pipe with luster surface (Fig.6), and tne surface mortar layer on concrete blocksfor retaing wall and revetment, laying blocks (Fig.7).

6. Conclusion

Mortar containing fine-powdered FRP w as lightened and strengthned by high-temeperature curing. Its mechnaical strength was greatly improved by to reduce the structural porosity for its compactification. Moreover, strengthening of FRP mortar was obtained by addition of as bestos and partial replacement of cement by silica fume.

(The author is grateful to Mr. Toshihiko Asada in Asaoka Co. Ltd. for suuplying FRP fine powder.)

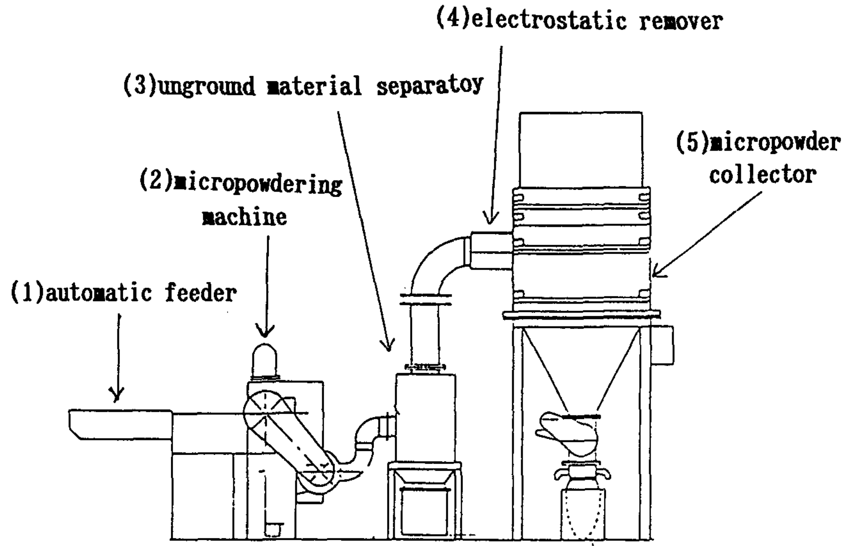

Fig.1 FRP pulverizer.
(1)automatic feeder, (2)micropowdering machine,
(3)unground material separatoy, (4)electrostatic remover,
(5)micropowder collector

Table 1 Mechanical strength of FRP Mortars

No.	Press. (MPa)	Curing Temp. (℃)	SF (C+SF)	Bulk density (g/cm^3)	Bending strength (MPa)	Compressive strength (MPa)
1	0	R.T	0	1.15 (-0.01~+0.05)	1.4 (-0.1~+0.2)	4.0 (-0.3~+0.5)
2	0	200	0	1.08 (-0.02~+0.03)	3.4 (-0.4~+0.2)	13.7 (-0.5~+1.4)
3	3.9	200	0	0.97 (-0.03~+0.06)	5.3 (-0.8~+0.4)	29.5 (-0.7~+1.2)
4	3.9	200	0.1	1.12 (-0.02~+0.03)	6.5 (-1.0~+0.5)	24.5 (-1.4~+0.3)
5	3.9	200	0.2	0.99 (-0.01~+0.01)	6.6 (-0.4~+0.3)	31.2 (-2.5~+1.6)
6	3.9	200	0.3	0.98 (-0.05~+0.03)	5.2 (-0.5~+0.2)	35.2 (-0.2~+0.9)

W/C:0.75, Sirasu/C:0.28, FRP/C:0.47, SF:Silica fume

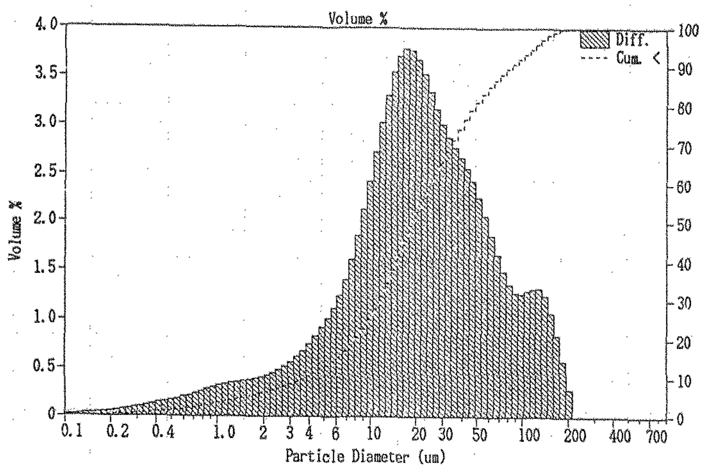

Fig.2 The particle distribusion of FRP fine powder.

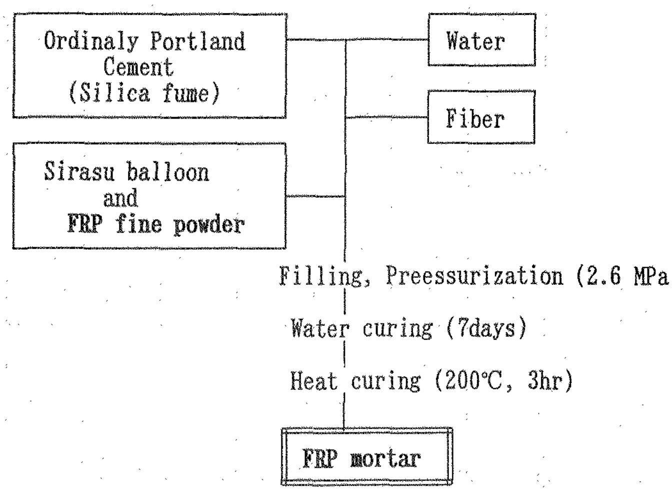

Fig.3 Preparation procedure of FRP mortar.

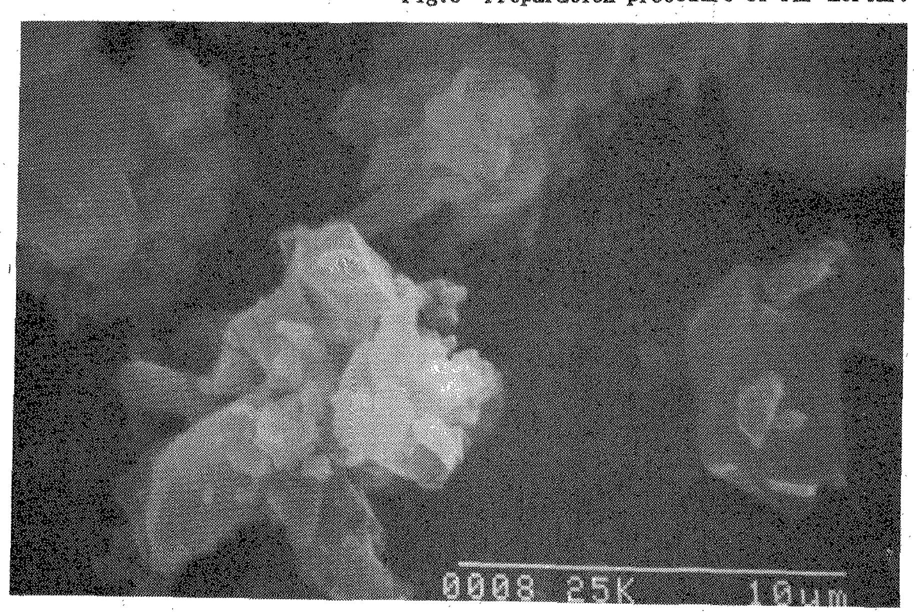

Fig.4 FRP micro fine powder observed by SEM .

Table 2 Mechanical strength of fiber reinforced FRP mortars

No.	Fiber	SF /(C+SF)	Bulk density (g/cm³)	Bending strength (MPa)	Compressive strength (MPa)
7	—	0	0.97 (-0.03～+0.06)	5.3 (-0.8～+0.4)	29.5 (-0.7～+1.2)
8	Fly ash fiber	0	1.11 (-0.05～+0.04)	5.2 (-0.2～+0.3)	21.2 (-1.7～+0.8)
9	Polypropylen	0	1.29 (-0.02～+0.04)	4.0 (-0.8～+1.5)	15.3 (-1.3～+0.4)
10	Vinylon	0	1.11 (-0.10～+0.04)	3.5 (-1.1～+0.1)	15.1 (-2.6～+0.3)
11	Carbon fiber	0	1.14 (-0.02～+0.03)	4.5 (-0.7～+0.3)	21.7 (-1.2～+1.1)
12	Asbestos	0	1.17 (-0.03～+0.03)	6.3 (-0.5～+0.2)	27.2 (-1.4～+1.9)
13	Asbestos	0.2	1.01 (-0.03～+0.01)	7.1 (-0.4～+0.2)	41.0 (-2.8～+2.0)

W/C:0.75, Sirasu/C:0.28, FRP/C:0.47, Fiber/C:0.03, SF:Silica fume

Table3 Slump flow and air contents of concretes contained FRP fine powder and FRP ash.

Kind of high quality AE water reducing agent	Kind of concrete	Unit contents kg/m³				Slump flow mm	Air content %
		Cement	Powder	S	G		
Carboxylic acid derived	Refer. FRPpowd. FRP ash	486 462 462	— 24 24	860	806	650×635 555×550 570×565	2.8 15.0 4.6
Naphtalene derived	Refer. FRPppwd. FRP ash	486 462 462	— 24 24	860	806	495×495 415×395 415×420	3.4 2.7 3.7

W/C 35%、 S/A 51.8%, W 170kg/m³, Weight 2.322kg/l,

Table 4 Setting test of concrete contained FRP fine powsder and ash.
(Used of carboxylic acid derived high range water reducing agent)

Setting time	Kinds of concrete		
	Refference	FRP fine powder	FRP ash
Start (hr−min)	6-40 (6-44, 6-41)	8-10 (8-07, 8-11)	5-40 (5-42, 5-42)
Final (hr−min)	8-20 (8-23, 8-21)	10-15 (10-12, 10-14)	7-25 (7-22, 7-30)

Table 5 Commpressive strengths of prepared varrious concretes.

Kind of high range AE water reducing agent	Kind of concrete	Compressive strength N/mm^2		
		7 day	28 day	91 day
Carboxylic acid derived	Reference	70.6	84.6	93.5
	FRP powder	31.6	39.9	42.8
	FRP ash	63.6	76.9	88.1
Naphtalene derived	Reference	64.7	81.9	98.5
	FRP powder	63.0	76.0	94.2
	FRP ash	62.9	76.0	95.9

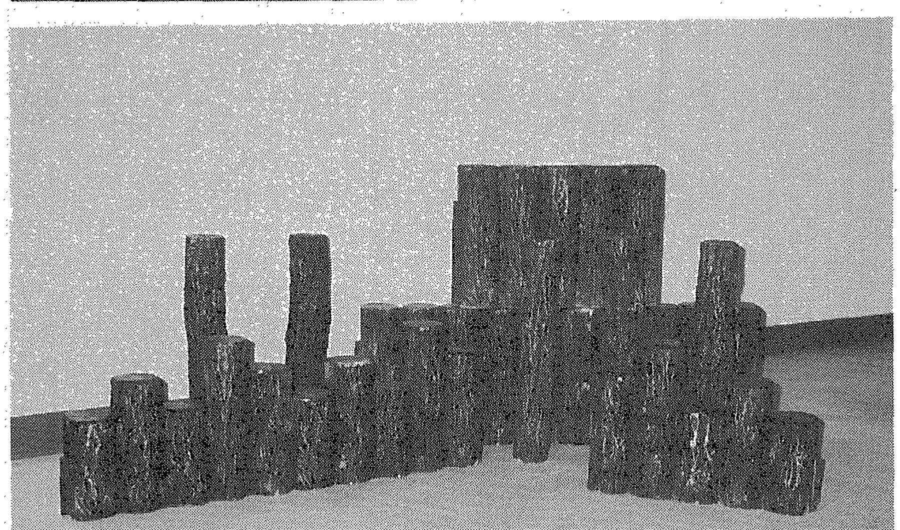

Fig.5 The sidewalk concrete flags and the artificial wood of concrete containing FRP fine powder.

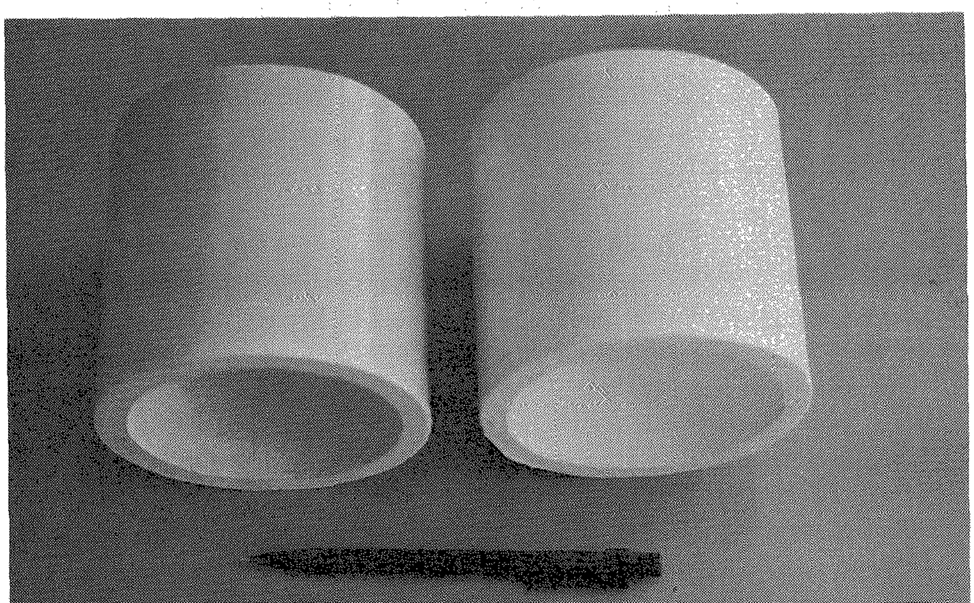

Fig.6 The centrifugal concrete pipes with luster surface containing FRP fine powder.

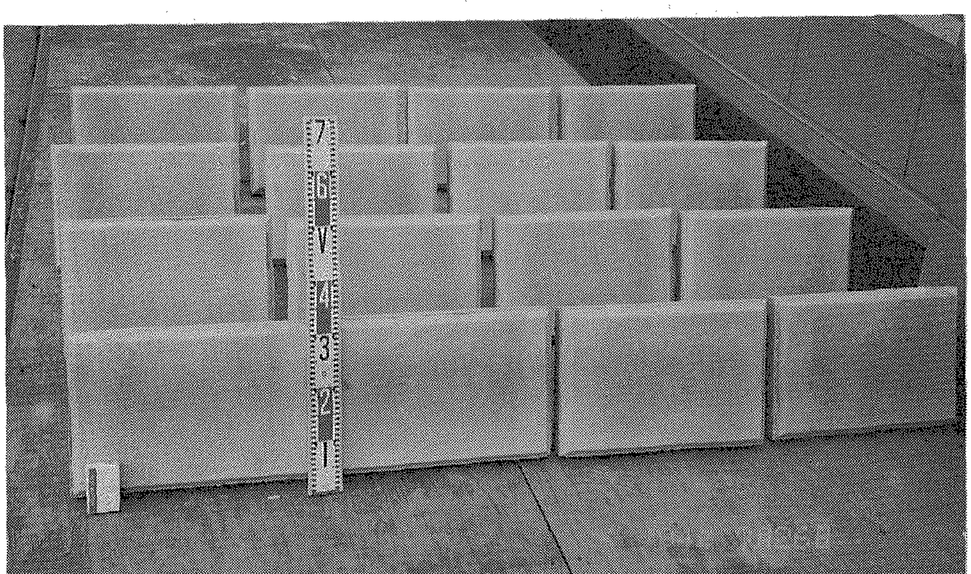

Fig.7 Tne surface mortar layer on concrete blocks for retaing wall and revetment, laying blocks containing FRP fine powder.