Authorized values of size effect of strength that were obtained by the Bureau of Reclamation for compressive strength of plain concrete and published in their Concrete Manual (17) were plotted in Fig.-18. The measured values showed a good linearity in logarithmic plane suggesting possible applicability of Weibull's theory to concrete. By the least square method, uniformity coefficient for plain concrete was obtained as 9.05 which is reasonable with reference to the coefficient of variation calculated by equation-8 and the bending to tensile strength ratio from equation-9.

Size effect of MMA impregnated mortar obtained from splitting tests of cylinders (polymer loading 10.5%) and that of polymer emulsion pre-mixed mortar obtained from compressive strength of cylinders are shown in Fig.-19. In the latter case, the mortar contained styrene and acrylic resin copolymer emulsion in the amount of 20% of cement weight. Uniformity coefficient of polymer premixed mortar was more or less of the same order as the value for plain concrete, while the value for PIC was very high suggesting very uniform material was obtained through the impregnation.

SHRINKAGE DUE TO POLYMERIZATION

Shrinkage occurs through two stages of impregnation treatment namely through initial drying and through polymerization. The shrinkage through polymerization is peculiar to PIC and could be several times greater than the normal drying shrinkage as is shown in Fig.-20, where such shrinkage is plotted against polymer loading. The measurements were made by the method prescribed in ASTM C490-65T. Samples were all impregnated completely and polymer loadings in this figure were controlled by varying the amount of water and aggregates. Polymerization was accomplished by heating at 60° C for 16 hours, and using 0.5% of ABN catalyst.

Even for the same base material, different monomer systems cause different amounts of shrinkage and presumably the difference in the other polymerization conditions might have some influence. A cross linking agent such as B-GP tends to increase the shrinkage. If impregnation conditions and type of base material (cement or gypsum) are fixed, shrinkage due to polymerization linearly increases with polymer loading. It is expected that the shrinkage due to polymerization will be less for a base that has higher modulus of elasticity. But the reverse is the case as is clearly seen in Fig.-20 with cementitious base and gypsum base having a lower modulus of elasticity. It was presumed that the difference in microstructure and hence the difference in mobility of polymer molecules during polymerization might have something to do with the amount of the shrinkage.

APPLICATIONS

Polymer Impregnated Concrete

Pump beds for a sulphuric acid factory were made of PIC as shown in Picture-6. Cast iron or stainless steel coated with leaden homegen has been used to date for this type of member, but their life was considered to be one year at most. The pump bed made of PIC has not been corroded yet after its two years of service. In highly corrosive environment, PIC could be used not only as small members such as pump bed, floor lining, culvert etc. but also as structual precast members such as beams, floors or columns.

Picture-7 shows an application as cover plates of a trench type cable pit. In this case use of reinforcement had to be avoided since heat generation and power loss due to magnetic field caused by high voltage single cable should be minimized. High strength and light weight of the member were also required. A similar application as bottom plates of viaduct cable racks is shown in Picture-8. This viaduct penetrates highly corrosive space haunted with waste gas, and an anti-corrosive material was required as the bottom plates of the cable rack since they are not replaceable once constructed. Normal stainless steel was not resistant enough and 18-8 stainless steel was more expensive than PIC. Bending strength high enough to withstand dragging force of cable was required.

Characteristics of PIC such as high strength, water tightness anti-corrosiveness etc. make the material suitable for underwater structures. Window frames of an underwater restaurant were manufactured by PIC as shown in Picture-9. Use of PIC had an advantage in fitting the frame to reinforced structure.

Cement paste mixed with 5 to 15% of asbestos and modified with water retaining agent can be extruded. This member, when impregnated, exhibits 1500 to 2700 kg/cm^2 of compressive strength and 400 to 670 kg/cm^2 bending strength. Lathe working and screw cutting is feasible for this material. Picture-10 shows an anti-corrosive sash fabricated utilizing these characteristics. A long-term durability test is being made for this sash in a corrosive area of a factory.

Terrazzo obtains 20% increase in its lusture through impregnation treatment. Its performance as outdoor finishing material, including evaluation of weather resistance and prevention of efflorescence, together with the possibility of thinning down the thickness is being tested.

Gypsum Polymer Composites

Properties of polymer impregnated gypsum such as strength, hardness, water absorption, and wear resistance are strikingly changed from those of original gypsum, and will enable wider uses of gypsum. Good moldability of gypsum attributed to its properties of rapid hardening, accuracy in control of dimensions, and easy demolding could be utilized.

Since the polymer impregnated gypsum has a transparent texture similar to that of natural stone which is lacking in artificial stone of polyester, it could be used for wall finishing material. Impregnated statues of gypsum obtain marble like appeal and could be valued as outdoor accessories. (Picture-11) Making use of its adaptability in colouring, daily necessaries and other miscellaneous goods can be manufactured. A furniture like garden table set (Picture-12) could also be manufactured.

CONCLUSION

By impregnating cementitious materials with monomer and polymerizing them insitu, a new material having high strength and high uniformity coefficient as evaluated by Weibull's theory is obtained.

In order to maintain a high quality in products, conditions of drying, evacuation, impregnation and polymerization should be suitably selected and mix proportion of the base material should be optimized with reference to the most important property required for its use.

Strength of PIC is influenced by self stress that might be generated in polymer and concrete phases due to the shrinkage through polymerization of monomer and the difference in thermal coefficients of expansion of polymer and concrete. Annealing or dosage of a plasticizer of good quality be helpful in reducing these self stresses.

Though there are many other problems to be solved in the future, products that were manufactured by the treatment method established to date exhibit good performance records in actual applications though limited in examples.

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REFERENCES

1. Steinberg, M., Dikeou, J.T., et al, "Concrete-Polymer Materials, First Topical Report", BNL 50134 (T-509), December 1968

2. Steinberg, M., Dikeou, J.T., et al, "Concrete Polymer Material, Second Topical Report", USBR REC-OCE-70-1 and BNL 50275 (T-602), December 1969

3. Dikeou, J.T., Steinberg, M., et al, "Concrete Polymer Material, Third Topical Report", USBR REC-ERC-71-6 and BNL 50275 (T-602), January 1971

4. Dikeou, J.T., Steinberg, M., et al, "Concrete Polymer Material, Fourth Topical Report, USBR REC-ERC-72-10 and BNL 50328, January 1972

5. Eiichi Tazawa, Sadao Kobayashi, et al, "Basic Studies on Resin Impregnated Cementitious Products", Concrete Journal, January 1971, (in Japanese)

6. Sadao Kobayashi, Eiichi Tazawa, "Polymer Impregnated Concrete", Plastic Age, June 1971, (in Japanese)

7. O'Brien, J.L., Gornick, F., Journal of American Chemical Society, vol. 77, 4757 (1955)

8. Henning, A.H., Krekeler, K., et al, "Untersuchungen zur Bestimung des Zeitstanderhaltens thermoplastische Kunststoffe bei Zug" und Biegebeanspruchung", Westdeutscher Verlag, Koeln und Opladen (1965)

9. Griffith, A.A., "The Phenamena of Rupture and Flow in Solids", Transactions of Royal Society, A. 221, 163 (1920)

10. Berry, J.P., Journal of Polymer Science, 50, 107 (1961)

11. Berry, J.P., Journal of Applied Physics, 33, 1741 (1962)

12. Benboe, J.J., Roesler, F.C., Proceeding of Physical Society, 70B, 201 (1957)

13. Broutman, L.J., McGarry, F.J., Journal of Applied Polymer Science, 9, 589 (1965)

14. Jones, R.C., Lecture Note of MIT (not published), (1965)

15. Moavenzadeh, F., Kuguel, R., "Fracture of Concrete", Journal of Material, 4. No. 3, 1969

16. Weibull, W., Proceeding of Royal Swedish Institute of Engineering Research, (Stockholm), No. 151, 1939

17. Concrete Manual, United States Department of the Interior, Bureau of Reclamation, (1950)

Table-1 Effect of Polymerization Temperature on the Molecular Weight of in PIC

Polymerization Temperature (°C)	$\bar{M}n \times 10^{-4}$	(η)
60	38.9	1.73
70	19.3	1.26
80	15.3	0.856
100	6.2	0.350

Table-2 Intrinsic Viscosity (η) of PMMA Extracted from the Samples described in Fig.-6

Sampling Section	(η)
a	1.74
b	1.72
c	1.69
d	1.43

Table-3 Concentration of Polymer in PIC

	k_{pl}	Polymer loading (%)
Concrete	0.065∿ 0.13	3.9∿ 7.9
Mortar	0.21 ∿ 0.28	13.0∿ 17.5

Table-4 Surface Energy of Materials

	γ(cm·kg/cm^2)	Reference	Method
PMMA	0.3	10)	Tensile
	0.14	11)	Cleavage
	0.49	12)	Wedge Splitting
	0.12	13)	Cleavage
	0.36	14)	Calculated from Gc
Concrete	0.0032	15)	Bending
Mortar	0.0046	15)	Bending

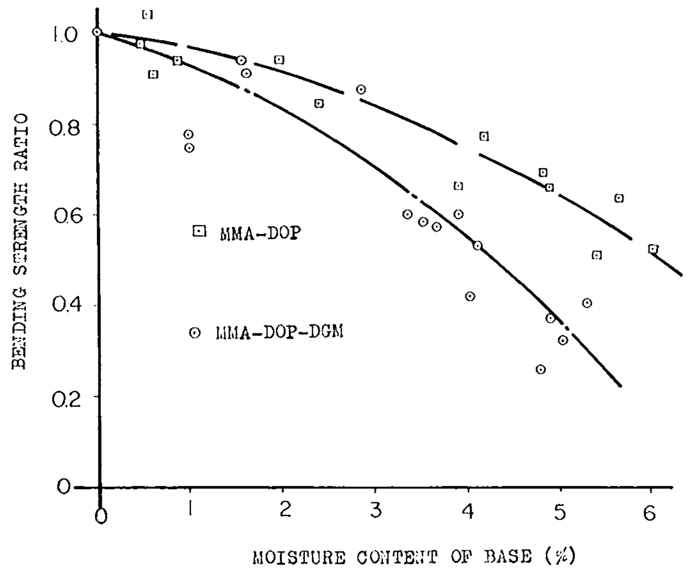

Fig.-1 Effect of Moisture Content of Mortar on Bending Strength

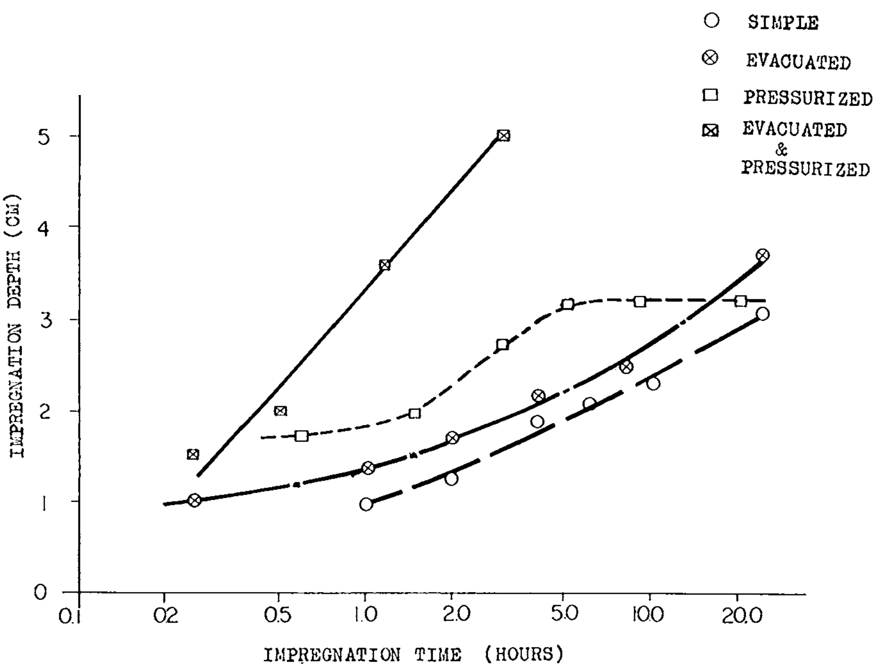

Fig.-2 Impregnation Method and Impregnation Rate

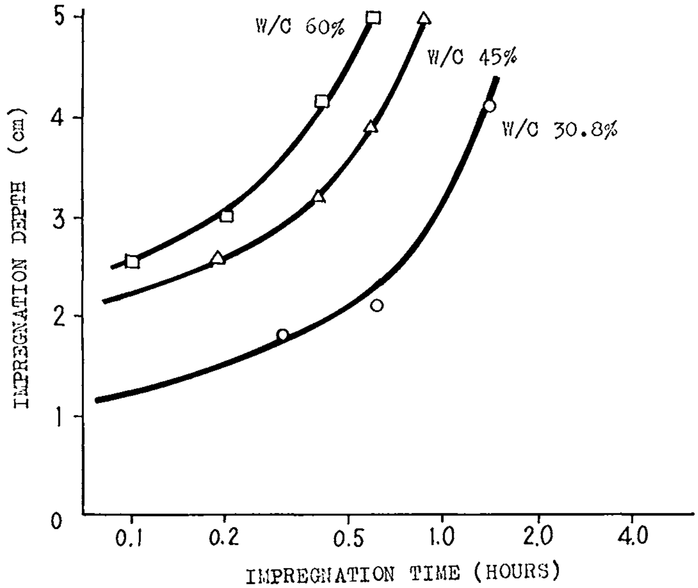

Fig.-3 Water Cement Ratio and Impregnation Rate

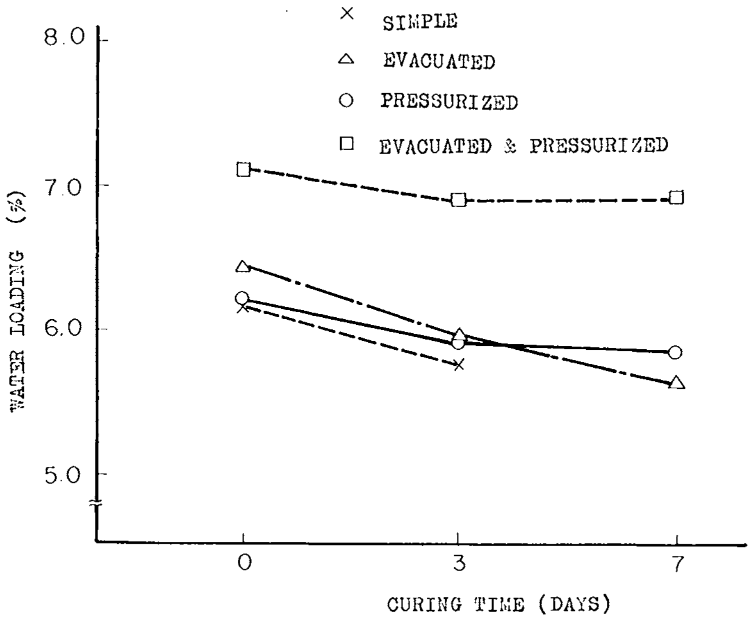

Fig.-4 Degree of Impregnation and Method of Impregnation

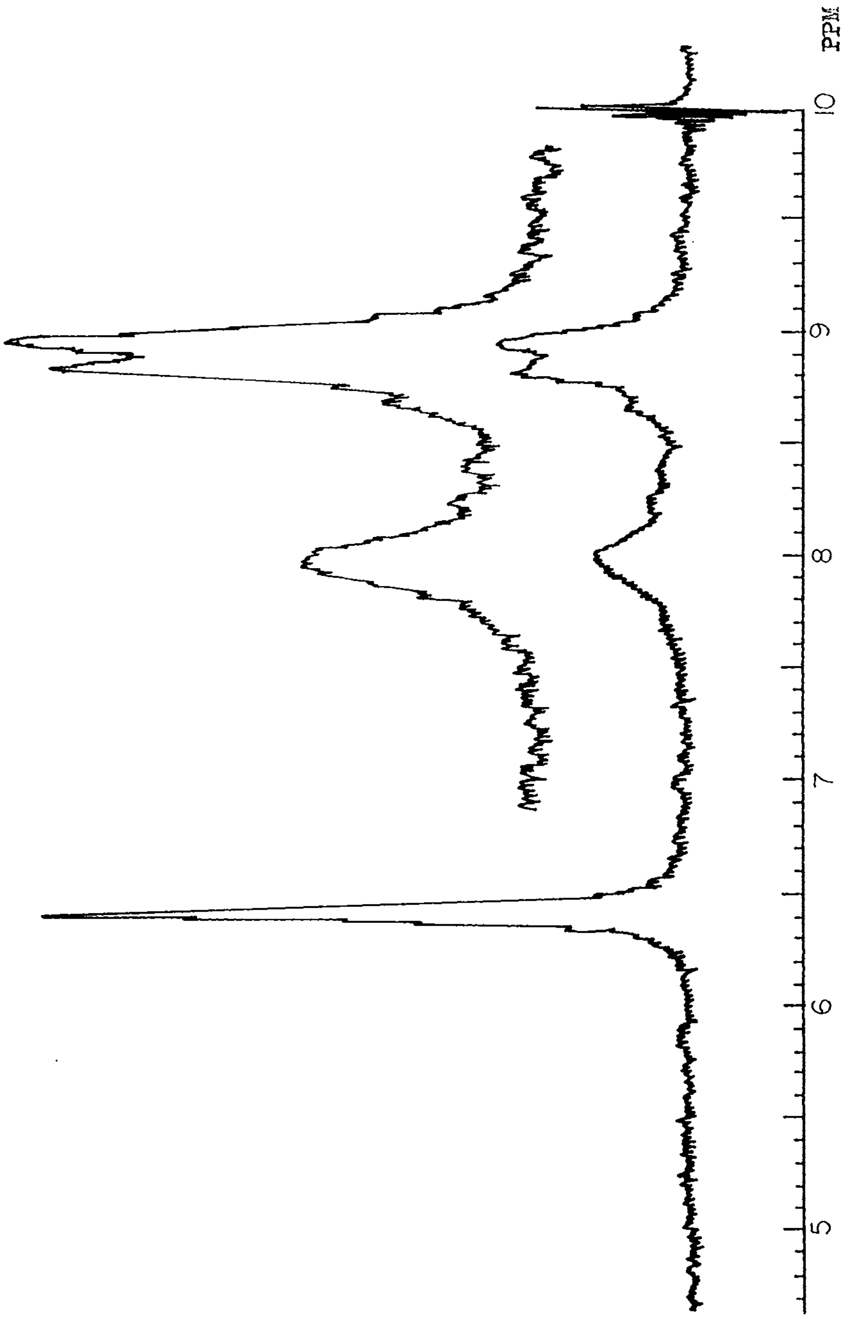

Fig.-5 NMR Spectrum of PMMA Extracted from PIC

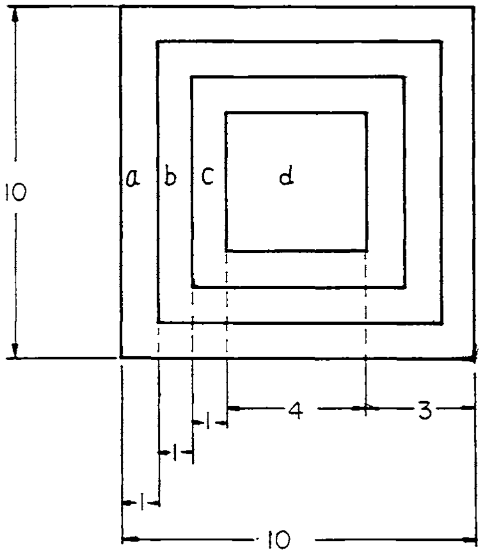

Fig.-6 Sampling Section

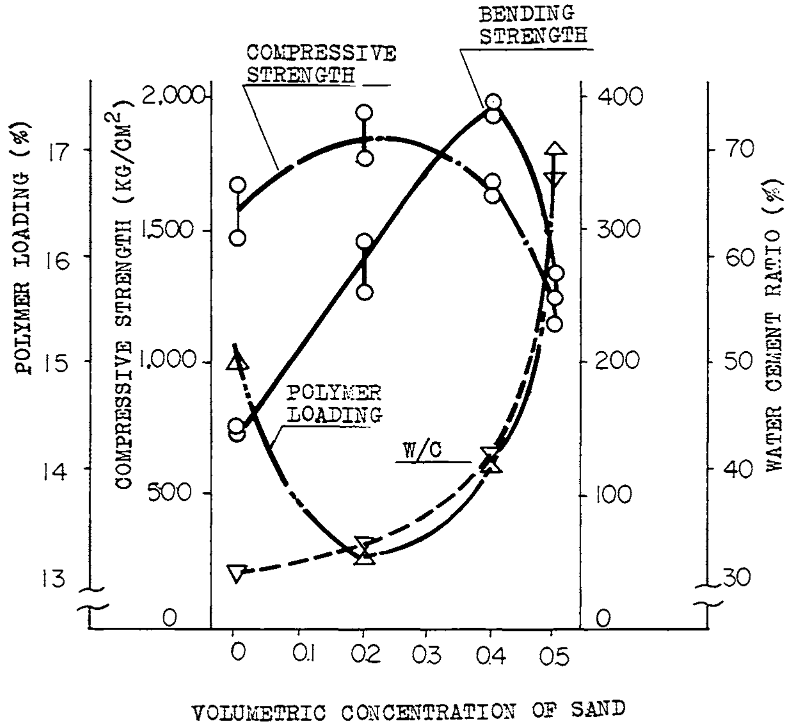

Fig.-7 Effect of Volumetric Concentration of Sand on Strength of PIC