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Physical and mechanical properties of a new type of polymer concrete

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ABSTRACT

Title of Thesis : **Physical and Mechanical Properties of a New type of Polymer Concrete**

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Thesis directed by : **Dr. Chen-Chong Lin**

A new type of Polymer concrete is an admixture of a special Latex, Portland cement and Sand. It has high bond strength, quick curing, durability and adequate strength. The Mechanical and Physical properties were investigated in this paper. Reinforcement with Glassfiber was done and its properties compared to those of control specimens. The heat generation in Polymer Concrete (PC) and its relationship with the properties of PC was also investigated.

Resin and water ratio of 3:1 was found out to be the most desirable for a special latex and the optimum mixed proportion was chosen as 1:1.5:2.5 for latex : cement : sand. Comparing with ordinary concrete, the compressive strength and bending strength was increased by about 3 times and about 5 times respectively. The optimum mixing ratio of the Polymer Concrete which had the best cost efffectiveness was found to be 1:1.5:2:0.5 for latex : cement : sand : fly ash.

The effect of the heat of reaction , catalyst and the

promoter on the strength of polymer concrete was also investigated in this research.

PHYSICAL AND MECHANICAL PROPERTIES OF A NEW TYPE OF POLYMER CONCRETE

By

KHOO KYAN BIN

Thesis Submitted to the Faculty of The Graduate School
of the
New Jersey Institute of Technology
In Partial Fulfillment of the Requirements for the Degree
of
Master of Science in Engineering Science
1986

APPROVAL SHEET

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I. INTRODUCTION

Progress in the construction industry can result only from the continual search for and adorption of new materials. Among new materials that have been proposed are several types of Polymer modified concrete. Concrete prepared from Portland cement, sand, aggregate and water, has many defects such as poor adhesive of fresh concrete to old concrete, poor resistance to the action of chemicals and water, inferior resistance to abrasion and breakdown due to repeated freeze-thaw cycles. Cement-based products posses excellent compressive strength , but their flexural, tensile and impact strengths are limited. These deficiencies have historically eliminated portland cement materials from consideration of use in thin coating or in marine constructions, where the corrosion of concrete elements is always very serious.

Over the years, considerable elements have been carried out in the field of polymer concrete as the improved construction materials : Development of concrete containing polymer materials (1). The manufacture methods of polymer concrete include : (a) monomer impregnation of normal hardened concrete followed by in-situ polymerization (PIC); (b) mixing a monomer of resin with an aggregate and polymerizing or curing the material after its placement (PC); (c) addition of a polymer or its precursor during the mixing of ordinary fresh concrete with polymerization or curing initiated after placement of the material (PCC).

Although these polymer concrete, including PIC, PC and PCC, have attained some remarkable results, but invariablely their disadvantages of processing methods and high cost outweigh their advantages of the improvements in strengths, and they are financially and economically impractical for cast-in-place applications. Most of polymer in the traditional polymer concretes are thermoplastics. The thermosetting polymers can bind the aggregates more strongly than thermoplastics. Among them epoxy and unsaturated polyester are wellknown. However, if thermosettings are used as PCC type, polymerization and hydration react infavorable and are incompatible simultaneously.

In this study, a new class of polymer concrete is developed, in which hydration of cement and curing of a thermosetting resin can take place simultaneously during the mixing of the concrete components. This is a mixture of a very special unsaturated polyester latex combined with portland cement, aggregate in the proportions similar to those used for normal concrete, except that the special latex replaces water. This is different from so-called unsaturated polyester concrete (UP-PC), which is manufactured by binding aggregate with polyester resin as a binder without portland cement and water (2)(3). This is also different from the polymer latex modified concretes such as acrylics (4) or SBR emulsion.

The overall objective of this research was to find an optimum formulations for the new type of polymer concrete and its reinforcement by fiber. The effect of different variables, such as heat of reaction, catalyst, composition and promoter on setting time and strength was investigated. Long term tests for corrosion resistance (e.g. one year long) was also conducted in the laboratory.

The results from this study will give a comparision of machanical and physical properties of polymer concrete and convensional concrete.

II. Theoretical Background of Polymer Concretes

(1) Literature Background

Polymer Concrete is a composite material formed by polymerizing a monomer and aggregate mixture. It is used to replace portland cement as a binder for the aggregate (5). The properties of polymer concrete are dependent on time, temperature, the chemical structure and molecular architecture of the polymer chains and on the interactions between chains (5).

Polymer concrete has been investigated and studied in many countries throughout the world since the early 1950's. Monomers, Prepolymers and aggregates have been used in a wide variety of situations. While epoxy resins are commonly used in polymer concrete, much consideration has been given to the use of cheaper vinyl monomers such as polyester styrene, furane derivative and methyl methacrylate (MMA) or acrylonitrile (AN) mixture because the use of these monomers has generally led to superior properties in the composite. Such liquids have high surface tensions, low viscosities, good wetting properties, relative low costs and high reactivities (6). Setting time can be readily varied from a few minutes to hours. One must realize that shrinkage strains vary from polymer to polymer depending on the monomers used, and should be considered in any application. As a result, the technology for polymer concrete is continually producing findings on the material itself and of the different applications for polymer concrete. The most significant use today in this country is the resurfacing of bridge decks and roadways.

(2) Advantages and Disadvantages of polymer concrete

Previous studies of polymer concrete have been directed towards the chemical makeup of the polymers and different applications that polymer concrete may be useful in further studies in mechanical, thermal and physical properties have all basically concluded the following : (5)(6)(7)(8)

(a) Flexural strength of polymer concrete is much higher than for conventional concrete. The strength is limited by the aggregate.

(b) Tensile and compressive strengths are high compared to conventional concrete. The use of silane coupling agents has shown to improve the compressive strength (improves bond strength) in polymer concrete.

(c) Shear capacity for flexural members are higher than conventional concrete because of the higher tensile strength capacity of polymer concrete.

(d) Bond strength between polymer concrete and reinforcing bars has been indicated from testing to be higher than with conventional concrete and reinforcing bars.

(e) The deflection of some polymer concrete elements is less than that of a conventional concrete element because the modulus of elasticity is greater than that of portland cement concrete. The epoxy polymer, however, have a lower modulus of elasticity and greater deflection.

(f) Temperature and humidity of the environment affect the creep of the polymer concrete.

(g) Thermosetting polymers such as epoxy and polyester produce shrinkage during polymerization.

(h) Shrinkage during hardening and temperature expansion can be controlled by the addition of aggregate filler.

(i) Abrupt changes can occur in the mechanical properties of the polymers when the temperature exceeds the Tg. (glass transition) temperature.

(j) The ductility and resistance to crack propagation increased when fibers were added to the mix.

(k) Polymer concrete is lighter in weight than portland cement concrete and is waterproof.

(l) Resistance to acids, salts and other chemicals is relatively higher than portland cement.

Mixing of the polymer concrete can usually be done in conventional mixing equipment used for portland cement concrete; however, some present cleaning problems and some present volatile and explosive dangerous when mixed. Methyl Metharcrylate (MMA), a monomer used after for polymer concrete requires an non-sparking and explosion-proof mixing device (5).

Chemicals used for the monomers may be toxic and can cause irritation when not used properly. Manufactures of monomers supply all the necessary data for mixing and curing of their products (5)(9). It has also been stated that a background in chemistry could benefit the individual who could do the mix design.

The good mix design accounts for the aggregate's void ratio. The void ratio is crucial in knowing the amount of polymer to be added to the mix. A good mix will have the correct amounts of each monomer required. Early studies have found that if the aggregate has a moisture content of less than two precent, good mechanical properties of the material are obtained

Forms which will hold the polymer concrete for curing require a special mold releasing agent in order to free the specimen later. Paraffin wax, car wax, vegatable oils and silicon gels are only a few which can be used. Some of these releasing agents can be sprayed on the like conventional form oil; however, several have to be brushed on by hand, which is very labor intensive, that is, it requires a fair amount of man hours. It is very beneficial to use steel forms. Also, form life is much longer when steel forms are used than wooden forms with polymer concrete.

Consolidation of the polymer concrete may be done with external vibrators, tapping, rodding and a vaccum to remove the entrapped air. For mixes which are volatile and explosive in nature, external vibrators are recommended. These are easily attached to the outside of the forms in a pre-selected area so that consolidation is even throughout the members.

Curing times vary between the different types of monomers and the temperature conditions. Generally, curing time is between a few minutes and several hours.

Cleaning of equipment used in mixing, placing and consolidation require solvents, which will cause the chemicals to break down. Disposal of waste and excess polymer concrete can be a problem. Compliance with disposal regulations is a must.

(3) New type of Polymer Concrete

A wide range of concrete-polymer composite materials is under investigation in a number of laboratories around the world. For this materials development, the older technology of hydraulic cement concrete is combined with the newer technology of polymer to form new and improved materials of construction. Polymer impregnated precast concrete (PIC) is the more developed of the composites and exhibits the highest degree of strength and durability properties improvements. Polymer concrete (PC), an aggregate bond with polymer appears to be a promising material for cast-in-place applications. Numerous applications of PIC are presently under development which indicates a large potential for this material.

Polymer cement concrete (PCC) is a premixture of cement paste and aggregate to which a monomer is added prior to setting and curing. The introduction of various organic materials to a concrete mix has been tried numerious times in the past. The results obtained are either disappointing or relatively modest in improvement of strength and durability. In many cases materials poorer than concrete are obtained. Under the best conditions, compressive strength improvement over conventional concrete of nearly 50 % are obtained with relatively high polymer concentrations of nearly 30 % .

Polyester-styrene, epoxy-styrene, furans and vinylidene chloride have been used in PCC with limited success. This is explained by the fact that organic materials are incompatible with aqueous systems and in many cases, interfere with the alkaline cement hydration process. The incentive to attain improved premix concrete materials is that it can be cast in-place for field applications, whereas PIC requires a precast structure. Although, PCC has many high qualities and competitive cost, there is not much breakthrough.

The strength and durability of concrete depend chiefly on the amount of water used, owing to the hydrolysation of cement with water. This main chemical reaction gives normal concrete its strength. On the other hand, most of monomers will not polymerize or cure in the presence of water. This is why normal polymer concrete consists of polymer with aggregate without cement and water. From polymer science point of view, only a type of thermosetting resins take place polymerization (or curing) in the concrete mixtures. In fact, a concrete which uses polyesters or epoxy resin has been developed. However, results of these polymer concretes are restricted to specialized applications only, because of their high cost. Post World War II years have seen an immense growth in the concrete industry, with numerous products being developed to alter the properties, workability, weight reduction and finish of the material for on-site use and precasting. The breakthrough in polymer concrete was not achieved until innovation of new kind of polymer emulsion which can added into the concrete mixture to intensify the hydrolysation of cement by absorption of water contained in the polymer emulsion and in the same time the curing reaction takes place with polymer in the mixture after the loss of water during the absorption of water by cement. This special polymer emulsion (or Latex) consists of unsaturated polyester and water which is dispered in w/o type emulsion with about 2 - 5 um diameter droplets (10)(11). The latex is mixed with cement, sand, aggregates and water in proportions similar to those used for standard concretes; however, the similarity ends there because the strength of the two are vastly different.

The interaction between polymer and concrete in this new type of polymer concrete is quite different from others. A continuous polymer film is formed within the paste. This film can effectively coat the walls of the capillary pores. Also, the high tensile strength of the polymer film can offset the brittle nature of the paste and inhibit crack propagation under stress.

There are two kinds of chemical reaction that give the bonding force of the polymer concrete.

(a) Hydrolysation of cement (20) and

(b) Curing reaction (or) Polymerization reaction

Hydrolysation of cement will give out three products : Tobermorite (C-S-H gel), $Ca(OH)_2$, Ettringite. [C : CaO, S : SiO_2 , H : H_2O]. Among them, the bonding force of the C-S-H gel is the strongest and the reaction is as follow :

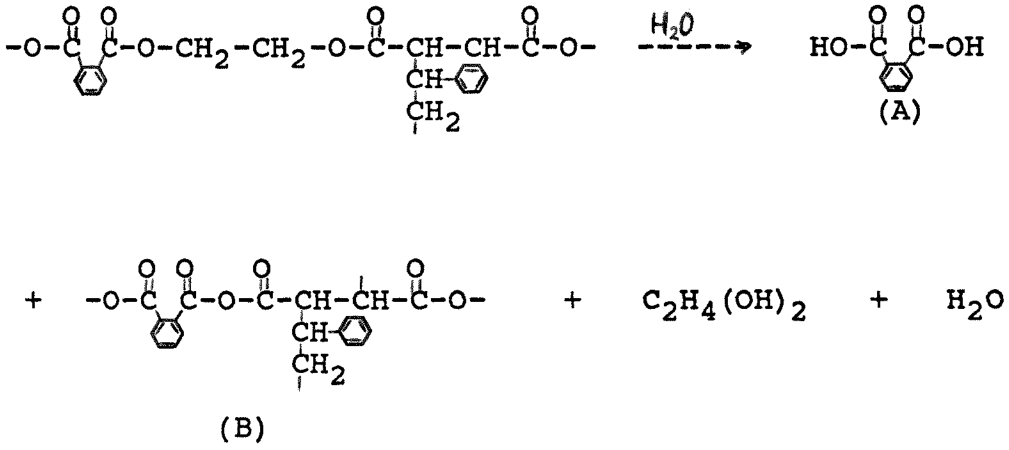
$$3\ CaO\ .\ SiO_2 + H_2O \dashrightarrow Ca(OH)_2\ (s) + x\ CaO\ .\ ySiO_2\ (aq)$$

If there is excess of water , x CaO . y SiO_2 will go on react with water and give out $Ca(OH)_2$.

The three methods mostly used to start the polymerization of the monomer are :

(i) Thermal - catalyst
(ii) Promoted - catalyst
(iii) Radiation

Higher mechanical strength can be get from method (ii). The hydrolysis mechanism for unsaturated polyester-styrene copolymer system is proposed. As shown below, the hydrolysis of the copolymer in an autoclave may produce monomer (A) having -COOH acid groups and polymer (B) having -CO-O-CO- acid anhydride groups, with ethylene glycol [$C_2H_4(OH)_2$] and water being produced as by-products. Therefore, it is readily apparent why conventionally produced polymer concrete containing UP-St copolymer is unsuitable for use in hydrothermal enviroments.



The addition of polymer latex generally improves the properties of fresh concrete. The very small (0.01 to 1 um in diameter) spherical polymer particles that make up the latex act much as entrained air bubbles to improve the workability and decrease the bleeding of the paste. Usually, the latex also entrains considerable amounts of air, due to the action of the emulsifying surface-active agent that stabilize the latex.

Optimum properties of polymer concrete are developed only when the dispersed latex is converted to a continuous polymer film within the concrete. The removal of water in the paste by hydration of the cement will help film formation to occur, but this will not happen if continuous moist curing is employed. Some recommend only 1 to 2 days of moist curing followed by drying at 50 % RH to encourage film formation, although this does not allow the full strength of the paste to develop. Furthermore, with some polymer , some hydrolysis of the polymer can occur on prolonged exposure to the moist, alkaline enviroment of saturated concrete, leading to a loss of strength. For stable polymers, exposure to a relative humidity in the range 80 to 95 % is said to give optimum results, allowing both slow, continued hydration of the cement and coalescence of the latex to a continuous film.

Polymer concrete also shows considerable improvement in durability over plain concrete. This is due in part to the improved resistance to tensile cracking. When cracks do form, they are kept very small and thus do not become a point of weakness for further environmental attack. It is thought that polymer films bridge the cracks and hold them closed. Also, it is believed that a polymer film lining the pores will tend to reduce the permeability of the concrete and prevent the entry of aggresive agents.

The high cost of the polymer concrete must be offset by the improved performance; thus applications take advantage of improved durability, flexibility, and bonding abilities.

(4) Heat of Reaction of Polymer Concrete

Immediately after the polymer concrete is mixed, the mixture will generate out heat of reaction, sometime high up to 80 C. The heat of reaction is mainly generated from the following two chemical reactions during mixing.

(a) Hydrolysation of cement

(b) Curing reaction

Hydrolysation of cement is the reaction between the cement and the water. When the polymer concrete is mixed, cement will react with the water containing in the latex, and give out some heat. Until the water in the latex is completely consumed by the reaction with cement, curing reaction will carry out between the cement and the polymer. The polymerization is started by mean of promoted-catalyst method and there are crosslinking reactions and a large amount of heat will generate. As there is relationship between the heat of reaction and the bonding force inside the polymer concretes with the same compositions, the strength can be predicted from the amount of heat generated. Very strong bonding force between the polymer and the aggregate can be expected if the heat of reaction is very high.

The amount of heat generated out from the reactions is mainly depend on the amount of catalyst and promoter added into the mixture, since they are the main chemicals that effect the reaction. The larger the amount of catalyst is added, the greater the heat will generate out from the mixture. If no promoter is added into the mixture, it will take a long time to reach the peak of the heat generated and maximum temperature is also very low. If large amount of catalyst is added, the maximum of very high temperature can be reached in a short period. There is a certain limit that the catalyst and the promoter can be added, beyond that limit, instead of initiating and accelerating the reaction, it can hinder the reaction and cause the polymerization to be incompleted. Also, the generated heat will be very small.

(5) Glassfiber reinforced Polymer Concrete

Glassfiber reinforced polymer concrete is polymer concrete containing discontinuous, discrete fibers of short length and small diameter. Fibers in the concrete serve as crack arrestors by applying pinching forces at crack tips, thus delaying the appearance of cracks and creating a stage of slow crack propagation. The ductility of the composite is increased many fold, compared to the unreinforced matrix, with a corresponding increase in the strength.

It is claimed that when the glassfiber bundles are mixed with the mortar, the glassfiber filaments are surrounded by the polymer particles and thus are screened off and protected against the migration of cement hydration products, as well as possible chemical attack. Additional of glassfiber into the mortar will change the structure of the ordinary mortar (12)(13)(14)(15)(16)(17).

Generally, there are two kinds of fiber.

(1) Low modulus, high elongation fiber

(2) High modulus, high strength fiber

Although adding of glassfiber can not increase much in compressive strength, the bending strength can be increase by nearly two to three times. Glassfiber will reduce the shrinkage of cement paste by about 20 % . Thus, fiber simply seem to act as rigid inclusion in the matrix, without producing much effect because of their low volume. However, and more important, fibers have been very effective in reducing shrinkage cracking, and this should have a very beneficial effect on the durability of the concrete.

(6) Fly Ash in Polymer Concrete

Cement is the most cost and energy intensive compound of concrete (18). Accordingly, replacement of cement with fly ash is increasing, due to energy, environmental and economic considerations, and potentially better workability, durability to chemical attack and lower heat of hydration. It is generally accepted that fly ash increases the workability of concrete due to the " Ball bearing " action of the spherical particles. Fly ash also improves the overall grading in the mix by smoothing out the particle size distribution in the fine range.

It has been recognized, for instance, that fly ash can contribute to the strength of concrete in three ways, namely; by a reduction of the water content needed for a given slump; by increasing the volume of the paste in the mixture; and by pozzolanic reaction (19). For instance, it is general knowledge that :

(a) Fly ashes of different origins may have significantly different behavior in concrete.

(b) The same fly ash may behave differently with portland cements of different types or even with the same types of cement from diferent places.

(c) The effect of a fly ash can change with the age of concrete. For instance, fly ash typically reduces the early strength of concrete but can increase the strength of same concrete at age of 28 days. However, some class fly ashes may exhibit approximately equivalent performance at early ages.

(d) Fly ash containing concrete may need more favorable curing conditions (temperature, humidity) than plain portland cement concrete.

III. EXPERIMENTAL PROGRAM

(1) Materials

(a) Portland Cement

Portland cement type I was used in this research. Its compound compositions are shown in Table (1) and (2).

(b) Sand

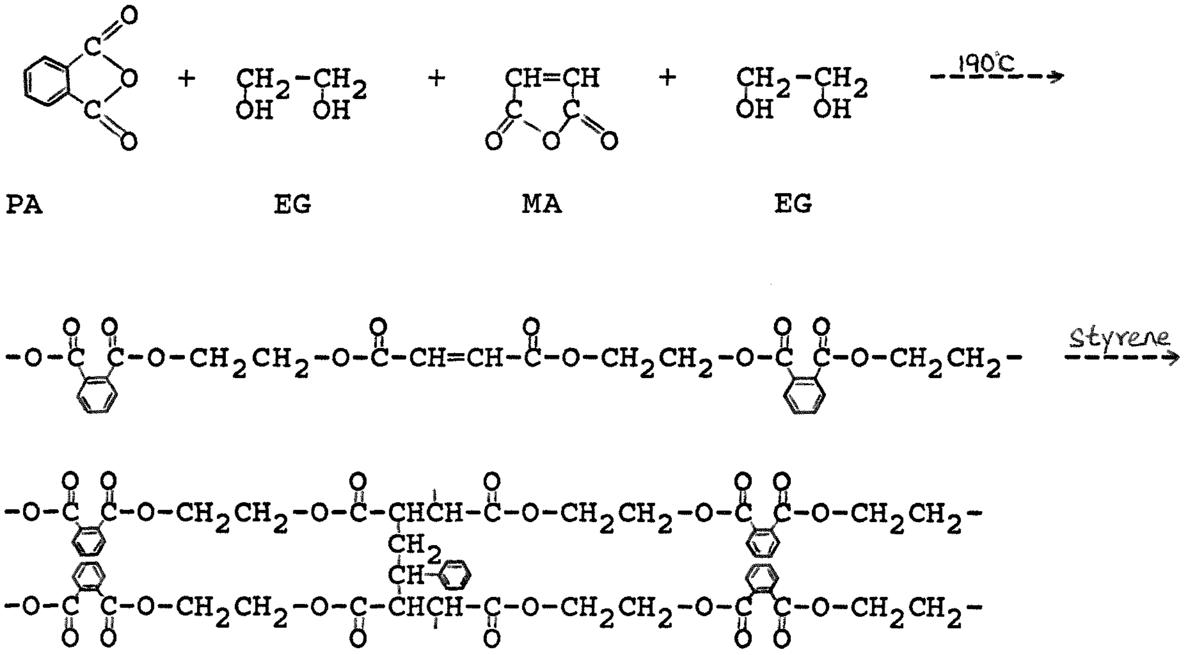
Dry river sand was used in this research and its properties are described in Table (3).

(c) Fly Ash

Chemical composition and some physical and mechanical characteristics of the fly ash used in this study is shown in Table (4).

(d) Unsaturated Polyester

The unsaturated polyester used in this research contained > 50 % of unsaturated polyester and < 50 % of styrene monomer. The chemical reaction to the final product is as follow :



PA : Phthalic Anhydride

MA : Maleic Anhydride

EG : Ethylene Glycohol

The properties of unsaturated polyester is shown in Table (5).

(e) Emulsifier

Dodecyl sulfate or Span 80

(f) Promoter

Dimethyl Aniline

(g) Catalyst

Benzoyl Peroxide

(h) Glassfiber

The properties and compositions of the glassfiber is shown in Table (6).

(2) Proportioning and Mixing

(a) Latex

Unsaturated polyester-styrene containing <0.10 % of promoter was mixed with water in the agitator to get a white viscous latex. Optimum ratio of water and resin was found in order to get a very stable emulsion to be used for a long time.

(b) Polymer concrete

All the specimens could be seperated into three catagories :

(i) Ordinary polymer concrete

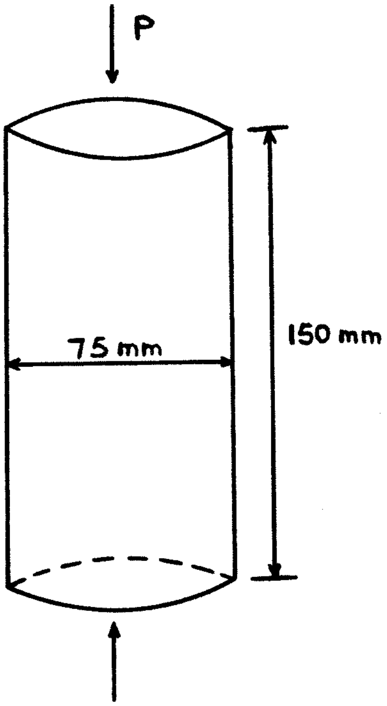
(ii) Additional of fly ash in polymer concrete

(iii) Glassfiber reinforced polymer concrete

The test specimens were polymerized by the catalyst. Two percent, which was based on the ratio of resin used, of benzoyl peroxide by weight was added as a catalyst. Mix data for these specimens were summerized in Table (7). 5 minutes of mixing time was allowed before casting. After mixing, they were poured into the standard 3-in-diam x 6-in-long cylinders until each was nearly 1/3 full. A stirring rod was then used to swirl out entrapped air from the sides of the forms. One or two wiping motions were generally required. The form was then filled and the concrete surface was flattened using a screed or similar device. During the mixing, heat will be generated due to hydration and curing reactions possibly up to 80 C. After about 5 minutes, the mixture becomes viscous and paste-like, which possesses the shaping characteristics. After about 20 - 30 mins, the mixture mass is no longer fabricable because of hardening. Within its pot life, the mixture mass must be casted into the cylinder. The samples were then cured at room temperature and average humidity conditions for 7 to 28 days.

(3) Instrumentations and Readings

(a) Compressive strength



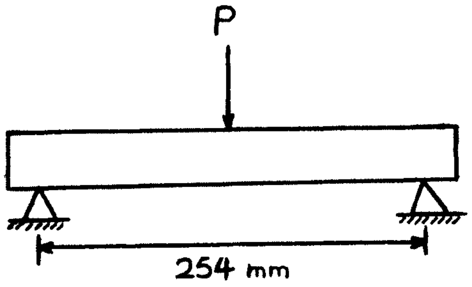
Compressive strength of all the specimens was determined with the Soiltest CT 775 Machine. Before the specimens were tested, both sides of each cylinder shaped specimens were sulfur caped to get two smooth surface so that the load would be equal. The amount of load in pound was recorded directed from the machine and converted into psi.

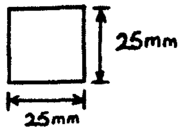
psi = Force / Area

Area of the cylinder = 7.07 sq in

(b) Bending Test

All the bending test were done on the MTS 810 Material Test System Machine.





$$\sigma = M\,Y / I$$

$$I = b\,h / 12$$

$$M = P/2 \times L/2$$

σ : Bending strength

M : Momemtum

h : Height of the bar

b : Broad of the bar

L : Effective length

P : Load

(4) Test Procedure

(i) Method of selecting the most satisfactory mix proportion for the polymer concrete

The optimum mix proportions of the polymer concrete were selected by the following considerations.

(1) To acheive good workability

(2) Setting time must be long enough for casting

(3) To possess high strength

(4) To have high cost effectiveness

(ii) Test on properties of polymer concrete

For each test, 3 specimens were casted and the tests were done on the 1 , 7 and 28 days after casting.

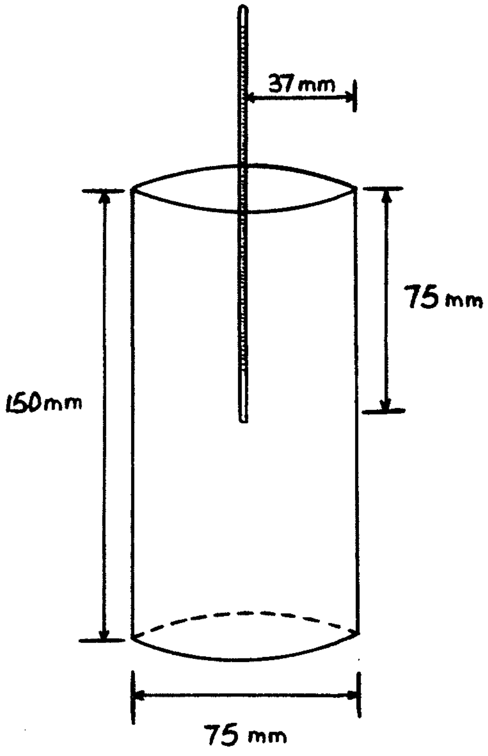
(a) Compressive Test

Polymer concrete specimens of 3-in-diam x 6-in-long cylinders for compressive strength test were molded and cured at room temperature and average humidity conditions for 1, 7 and 28 days. After fixed period of curing, the compressive strength of the specimens were determined with the Soiltest Machine.

Three samples for each same mix proportion were casted for each test.

(b) Test on Heat of Reaction of polymer concrete

After casting the polymer concrete into the test cylinder, a thermometer was dipped into the center of the cast to record the rise of the temperature due to hydration and curing reactions. The rised temperature was recorded at every 10 minutes time interval until the temperature returned to the room temperature. For each specimens, the thermometer was dipped to the same depth as shown in the figure.



(c) Test on other properties

The effects of the catalyst and promoter on the compressive strength and bending strength were also test in this research. Specimens with different ratio of catalyst or promoter were casted to test their strength on 1, 7 and 28 days of curing period. Reinforcement of polymer concrete was also done by adding certain amount of glassfiber into the mix and investigated their effect on the strength of the polymer concrete. In order to find a more economic polymer concrete, fly ash was also used in the compositions and its effect on the strength of the polymer concrete was also studied.

(d) Test on Corrosion

After demolding, the specimens were submerged into different kinds of chemical solutions for a period of one month and half years . Then their physical and mechanical properties were tested and compared with the same sample without treatment with chemical solutions. The following solutions were used in this test.

(1)	Sodium sulphate	10 % concentration
(2)	Sodium chloride	10 % concentration
(3)	Hydrochloride acid	20 % concentration
(4)	Caustic Soda	10 % concentration

(5) Motor oil

(e) Bending Test

Different mix proportion of polymer concretes were casted in the measurement of 50 x 50 x 300 mm forms. Three specimens for each mix proportions were casted and left to be cured at room temperature and average humidity for 1, 7 and 28 days before they were tested. At the same time of measuring the bending strength, the energy absorption was also recorded.

IV. RESULTS AND DISCUSSION

The results of this research were presented in the forms of figures. When choosing the optimum proportion for the latex, the stability of the emulsion and the strength of the products were the main factors to be considered. Excess amount of water would decrease the strength of the polymer concrete, as it would decrease the curing rate of the polymer and at the same time, it could creat a lot of porosity in the matrix. When there was not enough water, it would not only decrease the strength of the hydrolyzation of cement but also would decrease the cross linking bond strength of the polymer. Both of them would decrease the strength of the polymer concrete. So the water content in the latex was one ofthe most important factors to be considered to find the optimum mix proportion of the polymer concrete.

Strength , workability and setting time of the polymer concrete were the main factors to be considered when choosing the optimum proportions. Participation of sand in the mix could not give any strength to the concrete but it could decrease the strength with increasing the amount. It need a certain amount of cement to hydrolyze with water so that there would not too much water remain in the mix to influence the curing reaction of the polymer. So, it was important that exact amount of cement could be chosen to complete the hydrolysation with all the water contained in the latex so that the curing reaction of the polymer would not be disturbed. This study found that the polymer concrete with latex : cement : sand ratio of 1 : 1.5 : 2.5 was the optimum mixed proportion.

In Fig (1),(3) and (5), the exothermic temperature of each specimens were recorded in every 10 minutes time interval until its returned to room temperature. This heat was generated from the hydrolysation of cement and the curing reaction of the polymer. The amount of heat generated was mainly depended on the compositions of the mix and the amount of catalyst and promoter added.

In figure (3), the effect of catalyst on the exothermic temperature was shown with specimens having the same compositions but different amount of catalyst. The temperature of the specimen with a higher ratio of catalyst could go up very high in a short period of time. But to those with lower ratio of catalyst, longer time was needed to reach the highest temperature which was also lower than the former. With larger amount of catalyst , the curing reaction could complete in a shorter time and larger amount of heat of reaction could be generated. If the excess amount of catalyst was added in the mix, the rate of curing would be too fast that there would not have enough time for casting and also the workability would become very bad. In this research, the optimum amount of catalyst to be used was found to be 2 percent based on resin. Compositions could also effect the exothermic temperature of the specimens with the same amount of catalyst. In figure (1), the maximum temperature could go up to nearly 50 C. The maximum temperature and the time to reach the highest temperature could decrease when fly ash or glassfiber was added in the mix. The purpose of the promoter in the latex was to initiate the curing reaction. Without the promoter, it would take a long time to start the polymerization. Heat could be used to start the polymerization, but in this study, all the specimens were cured in room temperature and room humidity. In figure (5), it showed that the increase of the amount of promoter in the mix could shorter the time period to reach the maximum temperature and also increase the amount of generated heat. But in this research , it found out that there was a certain limit amount of promoter that could be added into the mix. Beyond that limit, instead of giving out large amount of heat , only small amount of heat was generated. The strength was also found to be decreased. This could be explained that the excess amount of the promoter would disturb the polymerization and caused it to be incompleted. Due to the incompletement of the crosslinking reaction inside the concrete, the strength would be lower than before. The optimum amount of promoter to be added in the mix was found to be 0.2 percent of the resin.

In figure (2),(4),(6) and (7), strength vs. curing time for the specimens were shown. All the specimens were cure for 1, 7 and 28 days before their strength were determined. From these figures, we could see that the strength of the specimens were mainly depended on the ratio of the catalyst and compositions. In figure (4) and (10), stronger compressive strength could be get by increasing the amount of catalyst to a certain limit. It happened the same way for promoter, as we could see from the figure (7) and (6), with increasing of the amount of promoter, the compressive strength and bending strength could also increase a little bit. In figure (2), it showed that the reinforced polymer concrete could give the highest strength. As shown in figure (9), the compressive strength could be increased by increasing the amount of glassfiber content. But, when the glassfiber content was exceed about 4 per cent of the total mix, workability of the mixture would become very bad and difficult for casting. The compressive strength of the glassfiber reinforced polymer concrete was 3 times stronger than the conventional concrete. This study also found out that the addition of fly ash into the polymer concrete could increase the compressive strength by nearly 2.5 times.

From the above discussion on the heat generation in polymer concrete and strength of the polymer concrete, we found out that there had relation between them. As we discussed before, the heat of reaction of the system was generated by the two main reactions initiate during the mixing. If the two reactions reacted very vigorous, the bond strength between the matrix would be very strong, that was the strength of the products would be very high, Also lots of heat would generated out when the reactions were very vigorous. From the figures, it was distinguished that the specimens which generated a higher heat, would possess a higher strength among their same catagories. But , when fly ash or glassfiber was added, although they possessed very high strength, their heat of reaction was not very high. This was due to the lower heat of hydration of the ash. So, the strength of the specimens with the same compositions would increase with the increase in the maximum exothermic temperature. The generated heat could be increased by increasing the amount of catalyst or promoter or changing the proportions of the compositions. But, when the exothermic temperature was too high, the pot time would become too short and also the workability would be very bad. This study found that polymer concrete with latex :

cement : sand : flyash : glassfiber ratio of 1:1.5:2:0.5:0.2 was the optimum mixed proportion from both strength and workability point of view.

In figure (8), corrosion test was done for the polymer concrete in chemical solutions. The compressive strength of polymer concretes in sodium chloride and sodium sulfate solutions was found to be unchanged but those in morter oil, hydrochloric acid and caustic soda could loss a little strength in the long period. The physical appearance of all the specimens in different chemical solutions could remain unchange.

In Table (10), cost effectiveness (strength / cost) of each specimens were shown and compared with each other. It showed that if higher strength was not necessary for the application of the polymer concrete , specimen with latex : cement : sand : fly ash ratio of 1 : 1.5 : 2 : 0.5 had the highest cost effectiveness. That mean it was more economic to use this kind of specimen when the necessary strength was not exceeded 6000 psi. When very high strength was needed, glassfiber reinforced polymer concrete was much superior to be used. If cost effectiveness was to consider, reinforced polymer concrete with 2 percent of glassfiber will be the best. So, although the polymer concrete was more costy than the conventional concrete, when higher strength was required for the application , it was still more economic to use polymer concrete.

V. CONCLUSION

From this paper of research, it can be seen that polymer concrete is much superior than the conventional concrete in every properties. Although the cost is much higher, if consider the properties such as the cost effectiveness, corrosion, attack by different chemicals and requirement of higher strength, polymer concrete is still a very useful material for any purpose.

This study showed that the strength of polymer concrete could be predicted from the amount of generated heat. For the same composition, the larger the generated heat, the higher the strength could get due to the completement of crosslinking reaction. When cost effectiveness was considered, the polymer concrete with latex : cement : sand : flyash ratio of 1 : 1.5 : 2 : 0.5 was the best proportions to be used.

One day after mixing, polymer concrete can gain about 90 % of it strength and reach nearly its full strength in 7 days. The setting time is about 20 - 40 minutes varying with different proportions of different compositions. The compressive strength and bending strength of the polymer concrete is about 3 and 5 times thats of conventional concrete. There was no corrosion and chemical solutions used in this research done no effect on the polymer concrete in the long period.

IV. RECOMMENDATION

In this research, it is clear that polymer concrete is much superior than the conventional concrete in every properties. Only one type of polymer was used in this study. There may have some other polymer which may act even better than the one used. Much higher strength and better quality polymer concrete can be get by further research bytrying different kinds of polymer and composition. Due to the limit of this research, only the analysis of the heat generation in the polymer concrete was studied. Further research can be done to find the mathermatical relationship between the generated heat and the strength of the polymer concrete.

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TABLE 1.

Oxide and Compound Compositions of Typical Portland Cement

Typical Oxide Composition	Percent
CaO	63.0
SiO_2	20.0
Al_2O_3	6.0
Fe_2O_3	3.0
MgO	1.5
SO_3	2.0
K_2O	1.0
Na_2O }	
Other	1.0
Loss on ignition	2.0
Insoluble residue	0.5

Calculated Compound Composition	Percent
C_3A	10.8
C_3S	54.1
C_2S	16.6
C_4AF	9.1

TABLE 2.

Main compounds of Portland Cement

Name of Compound	Oxide Composition	Abbreviation
Tricalcium Silicate	3 $CaO.SiO_2$	C_3S
Dicalcium Silicate	2 $CaO.SiO_2$	C_2S
Tricalcium Aluminate	3 $CaO.Al_2O_3$	C_3A
Tetracalcium Aluminoferrite	4 $CaO.Al_2O_3.Fe_2O_3$	C_4AF

TABLE 3.

Properties of Sand

Maximum size, in (mm)	0.05 (1.2)
Fineness modulus	2.48
Specific gravity	2.65
Water absorption percent	2.71
Unit weight, lb/l (kg/l)	3.59 (1.63)

TABLE 4.

Chemical composition and some physical and mechanical Characteristic of Fly Ash (22). (ASTM C618, Class C)

Constituents	Weight Percent
SiO_2	48.9
Al_2O_3	23.9
Fe_2O_3	3.4
CaO	15.3
MgO	0.5

TABLE 5.

Properties of Unsaturated Polyester

Specific gravity	1.10 - 1.11
Weight per liter	1.11 - 1.12 kg
Boiling range	> 145 C
Flash point	89.F

TABLE 6.

Properties of Glassfiber

Composition	Percent by mass
SiO_2	53.8
Fe_2O_3	0.3
TiO_2	0.2
Al_2O_3	12.7
ZrO_2	0.1
CaO	20.9
MgO	0.4
Na_2O	1.4
K_2O	0.6
B_2O_3	8.5
LOI	1.0

TABLE 7.

Mix proportions

Specimen	Compositions					
	Latex*	Cement	Sand	Flyash	Glassfiber	Peroxide**
A	1	1.0	3.0			0.6
B	1	1.0	3.0			1.0
C	1	1.0	3.0			2.0
D	1	1.5	2.5			2.0
E	1	1.5	2.0	0.5		2.0
F	1	1.5	2.5		0.10	2.0
G	1	1.5	2.5		0.20	2.0
H	1	1.5	2.0	0.5	0.05	2.0
I	1	1.5	2.0	0.5	0.10	2.0
J	1	1.5	2.0	0.5	0.20	2.0
K	0.13***	1.0	3.0			

* Resin : Water = 3 : 1

** Percent based on resin

*** Water

TABLE 8.

Compressive strength changing with time

Specimen	Compressive Strength (psi)		
	1 Day	7 Days	28 Days
A	3400	3500	3889
B	3500	3600	4059
C	3950	4000	4526
D	4900	5000	6082
E	7300	7400	7920
F	5900	6000	6789
G	6400	6500	7199
H	7420	7500	8250
I	7550	7650	8486
J	7900	8000	8698
K	2400	2700	2970

TABLE 9.

Bending strength changing with Time

Specimen	Bending Strength (psi)		
	1 Day	7 Days	28 Days
E	2500	2676	2840
E*	1820	1847	2000
J	2860	2879	3150
J*	2750	2779	3000

* Without promoter

TABLE 10.

Cost Effectiveness

Specimen	Cost (c/lb)	Compressive Strength (psi)	Strength / Cost >3000psi	Strength / Cost >4000psi	Strength / Cost >6000psi
A	12.53	3889	23.26	-2.88	-55.04
B	12.89	4059	26.86	1.51	-49.20
C	13.61	4526	36.63	12.63	-35.37
D	13.77	6082	73.15	49.42	1.95
E	13.71	7920	117.33	93.49	45.80
F	16.17	6789	76.60	56.38	15.95
G	18.53	7199	74.05	56.42	21.15
H	15.14	8250	113.31	91.73	48.56
I	16.11	8486	111.31	91.02	49.29
J	18.77	8698	99.21	81.80	46.98
K	1.15	2970	-8.50	-291.70	-858.27

TABLE 11.

Effect on Strength in Chemical Solution

Solution	Compressive Strength (psi)			
	1 Days	1 Month	3 Months	6 Months
Normal*	4950	6082	6082	6082
NaCl	4950	6080	6075	6080
Na_2SO4	4950	6075	6080	6080
HCl	4950	5700	5730	5700
NaOH	4950	5700	5700	5700
Oil	4950	5870	5870	5880

* Without treatment with Chemical Solution. Ratio of Latex : Cement : Sand is 1 : 1.5 : 2.5 with 2 % of catalyst which is based on Resin.

TABLE 12.

Effect of Promoter on Compressive Strength

Percent of Promoter*	Compressive Strength (psi)**
0.00	5900
0.05	6050
0.10	6350
0.20	6500

* Percent based on Resin

** 28 days of curing

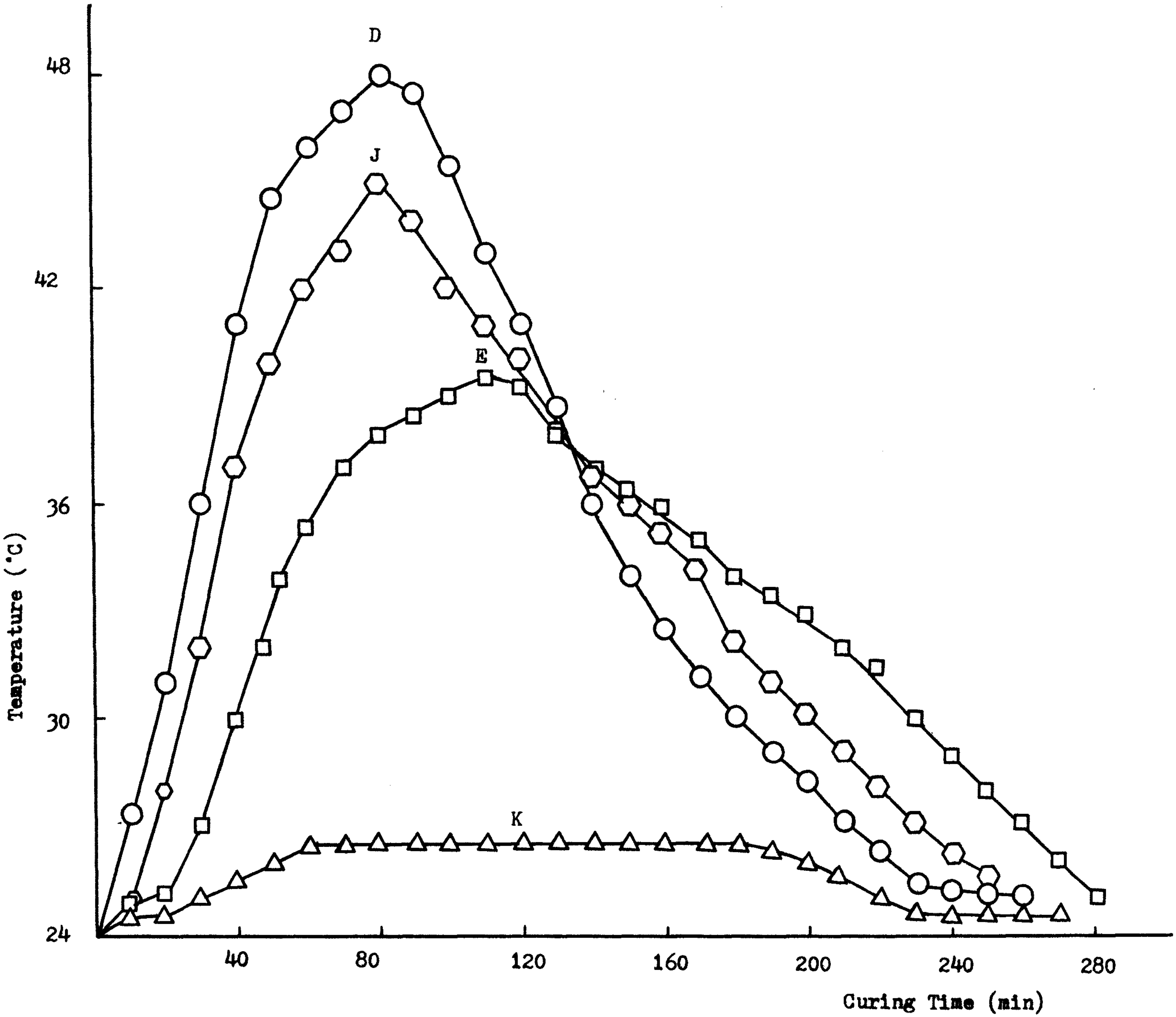


Fig. 1. Composition Effect on Temperature

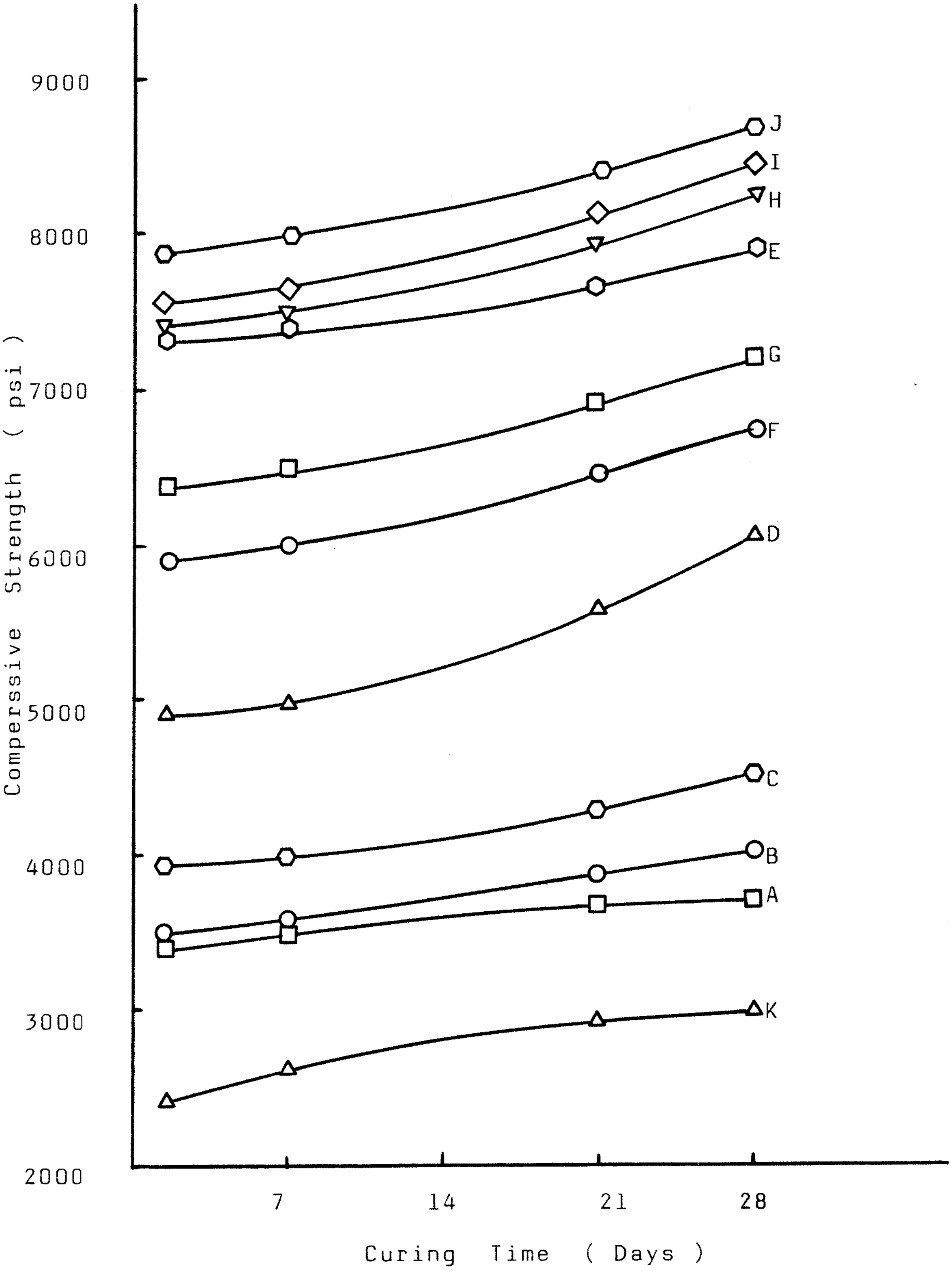


Figure 2. Composition Effect On Compressive Strength

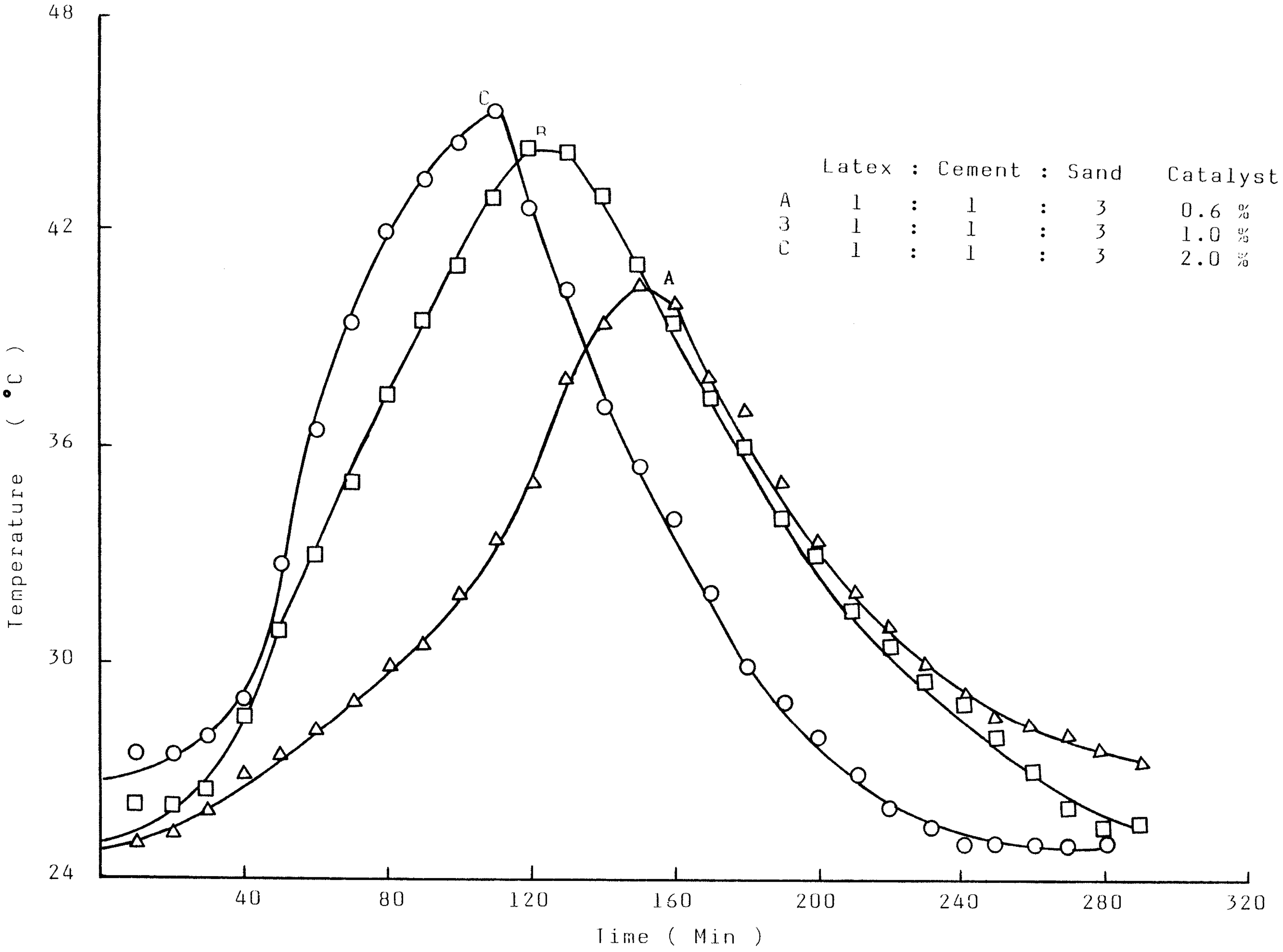


Figure 3. Catalyst Effect On Temperature

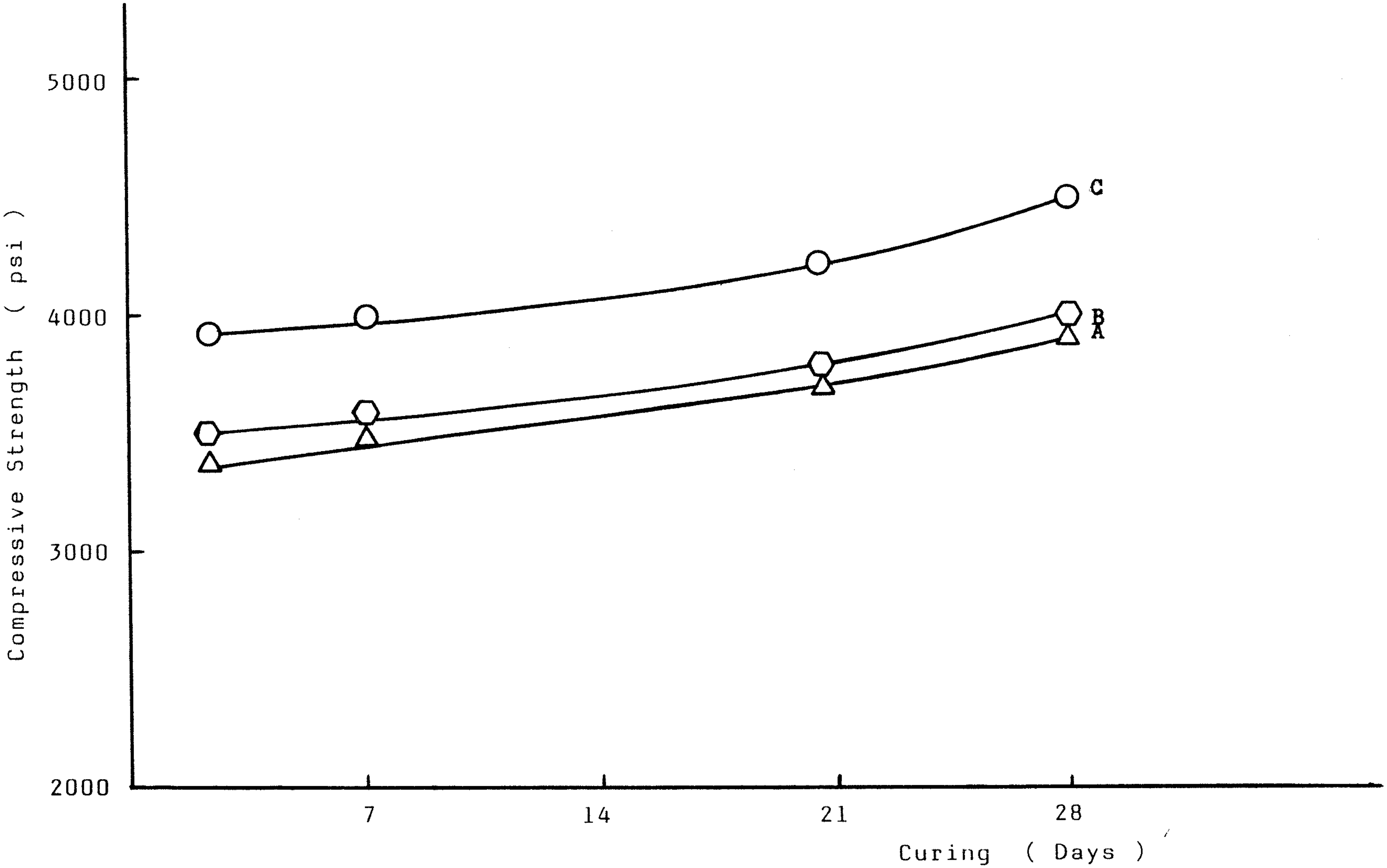


Figure 4. Catalyst Effect On Compressive Strength

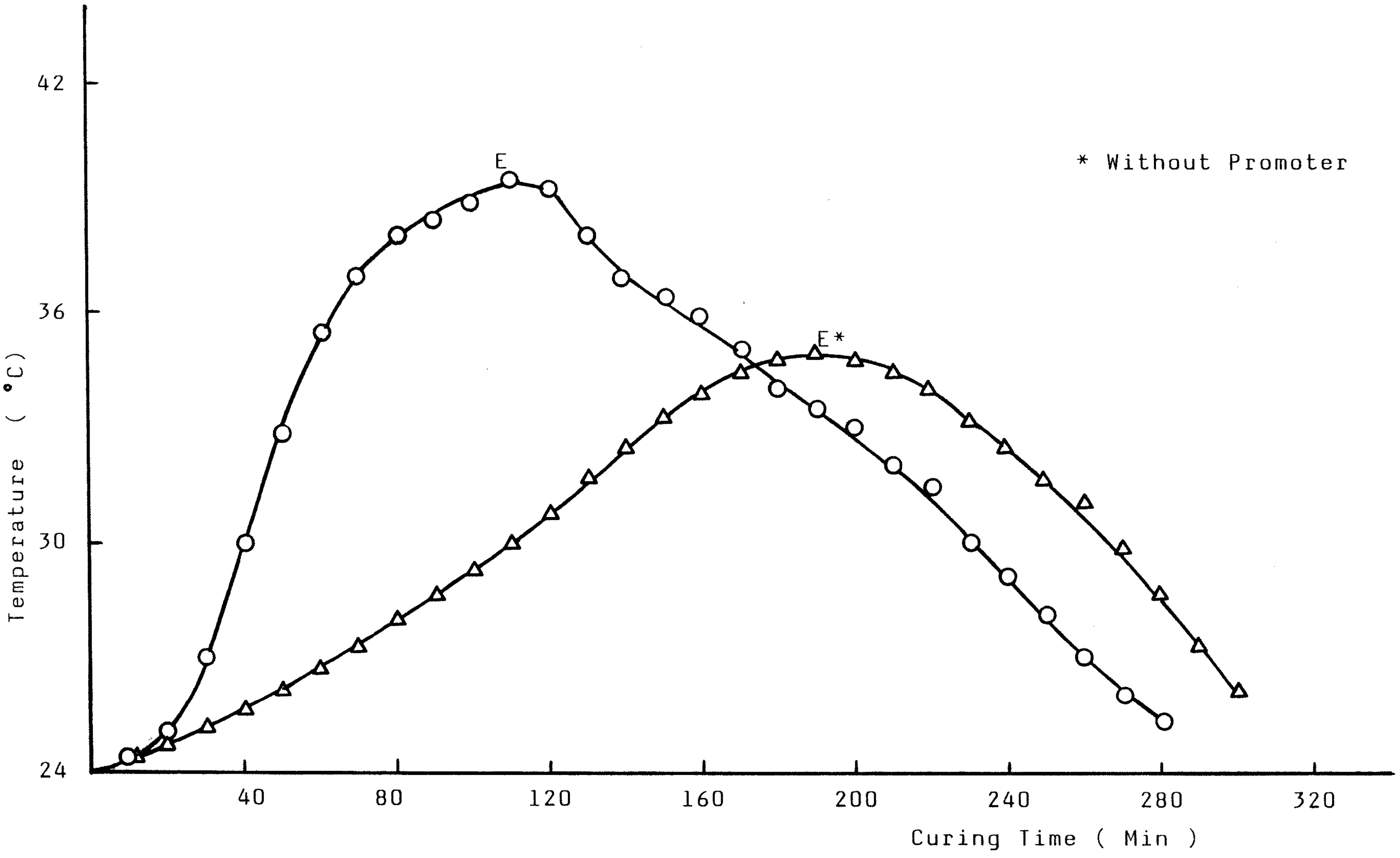


Figure 5. Effect Of Promoter On Temperature

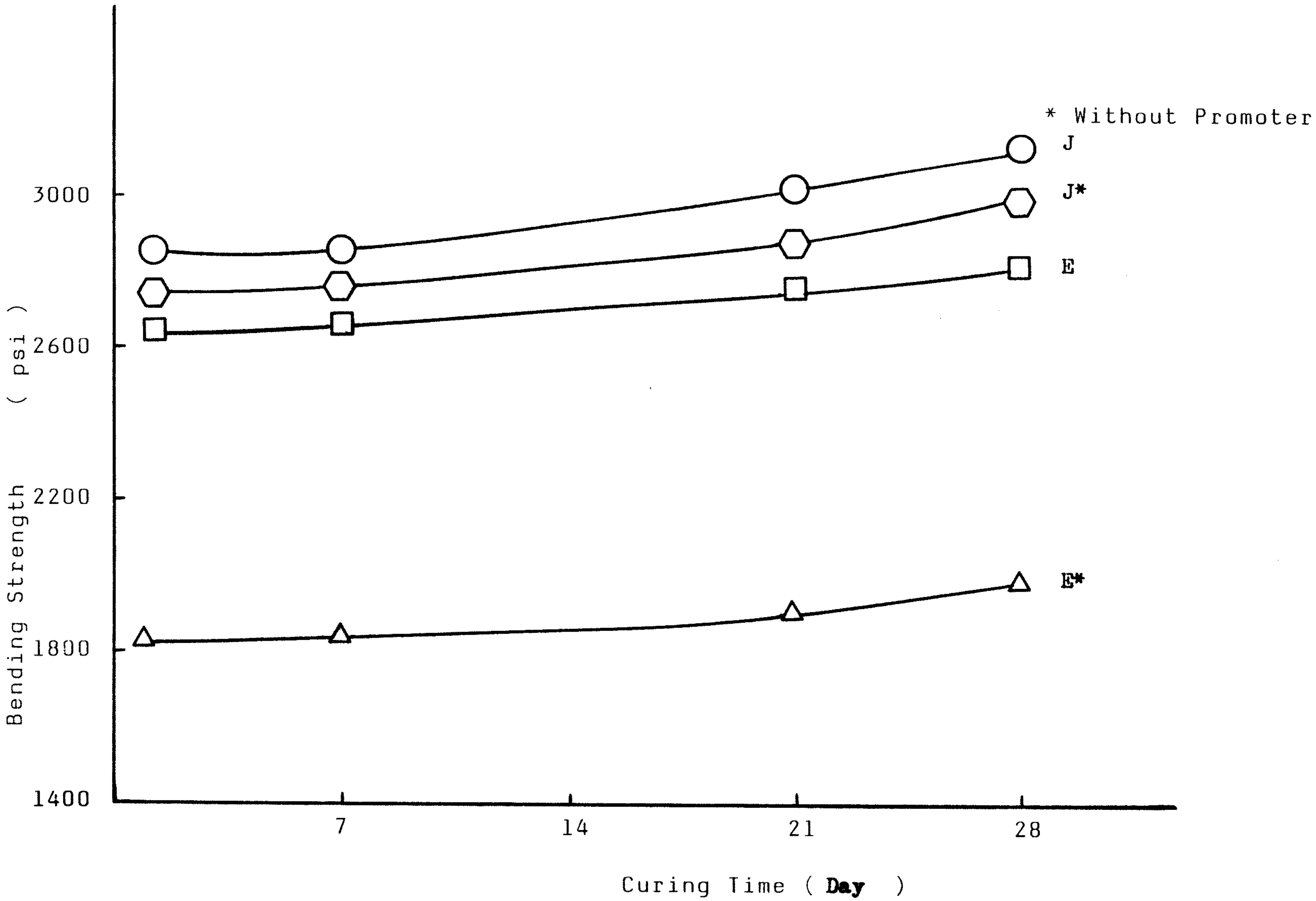
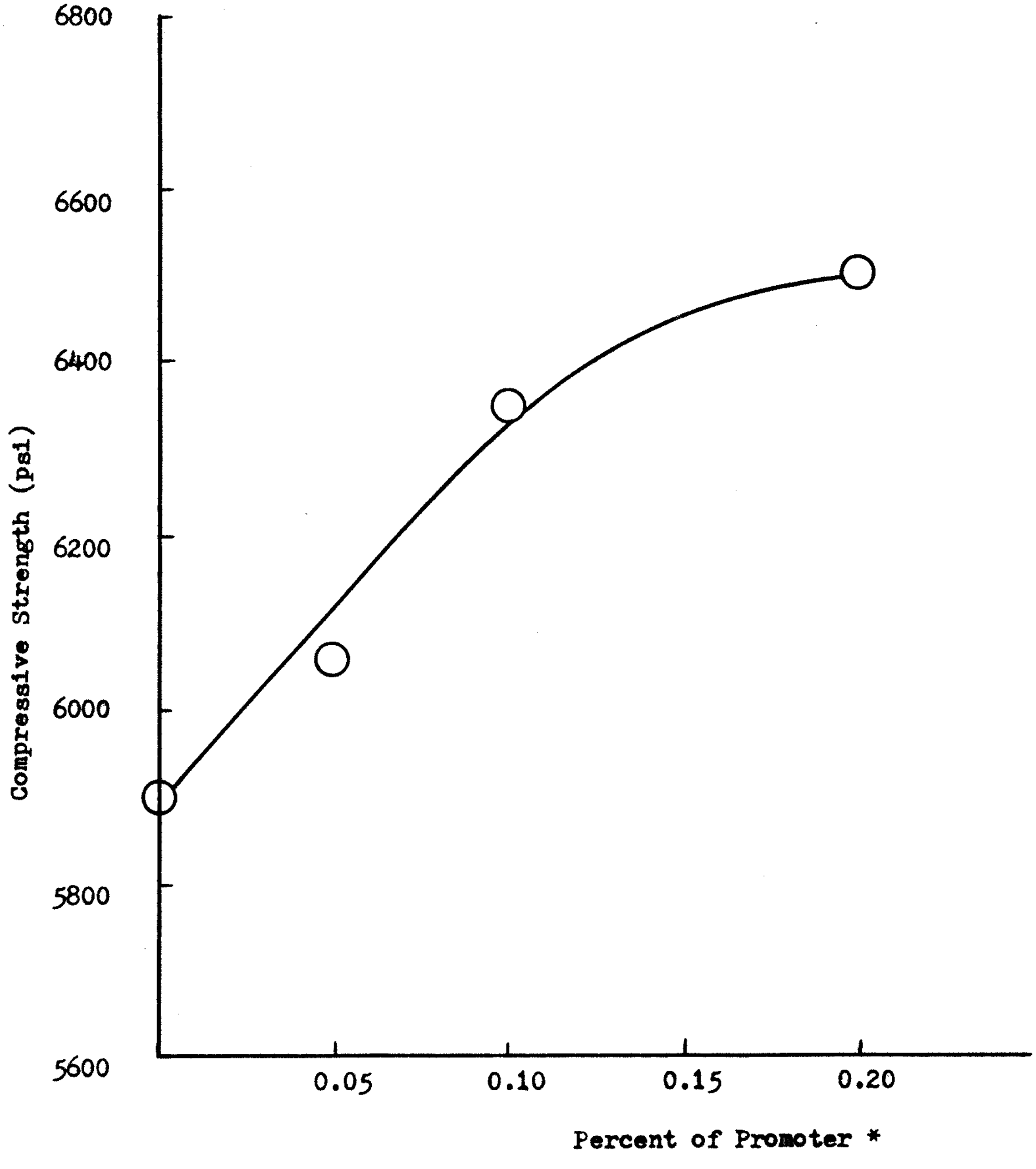


Figure 6. Effect Of Promoter On Bending Strength



* Based on Resin

Fig. 7. Effect of Promoter on Compressive Strength

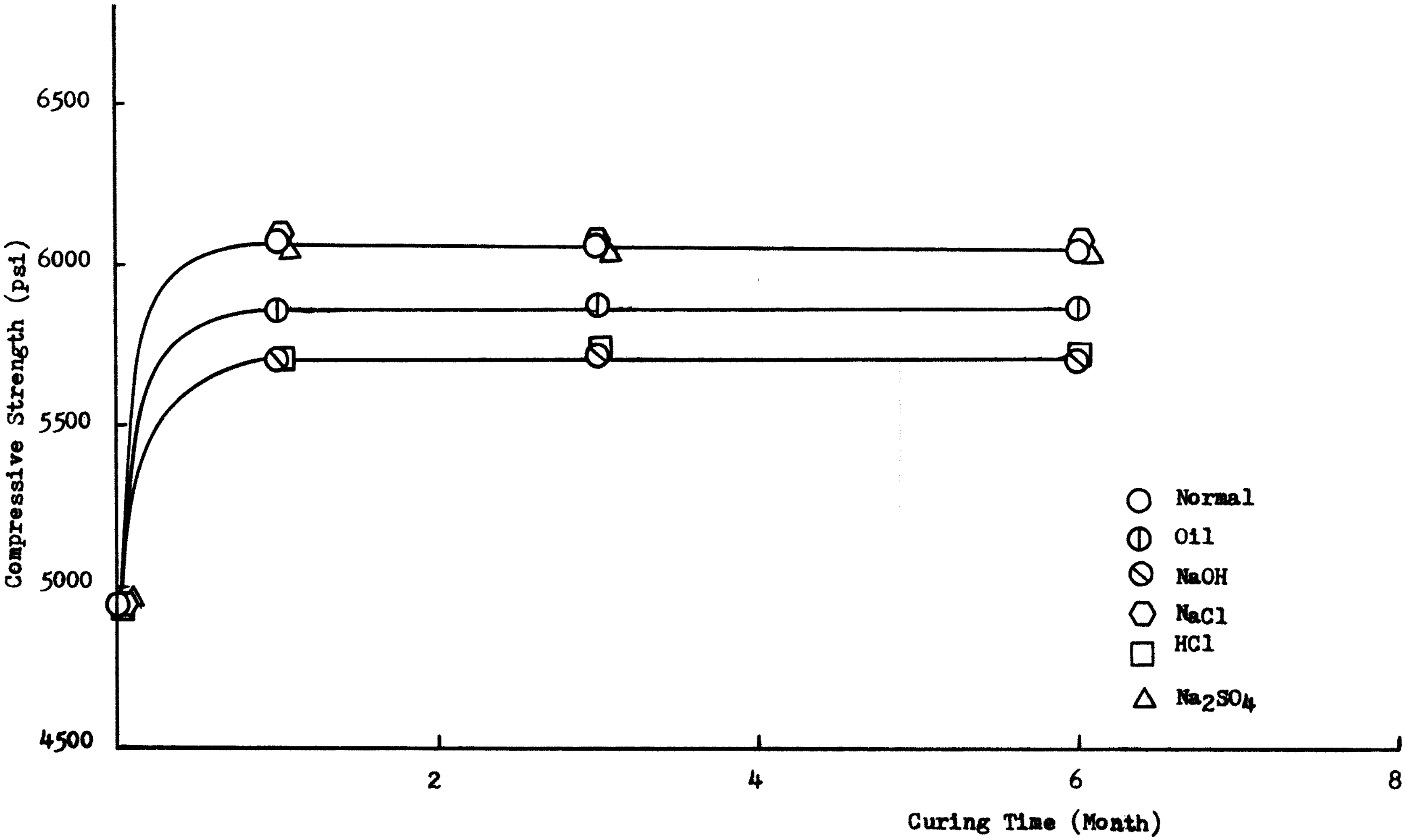


Fig. 8. Effect on strength in Chemical Solution

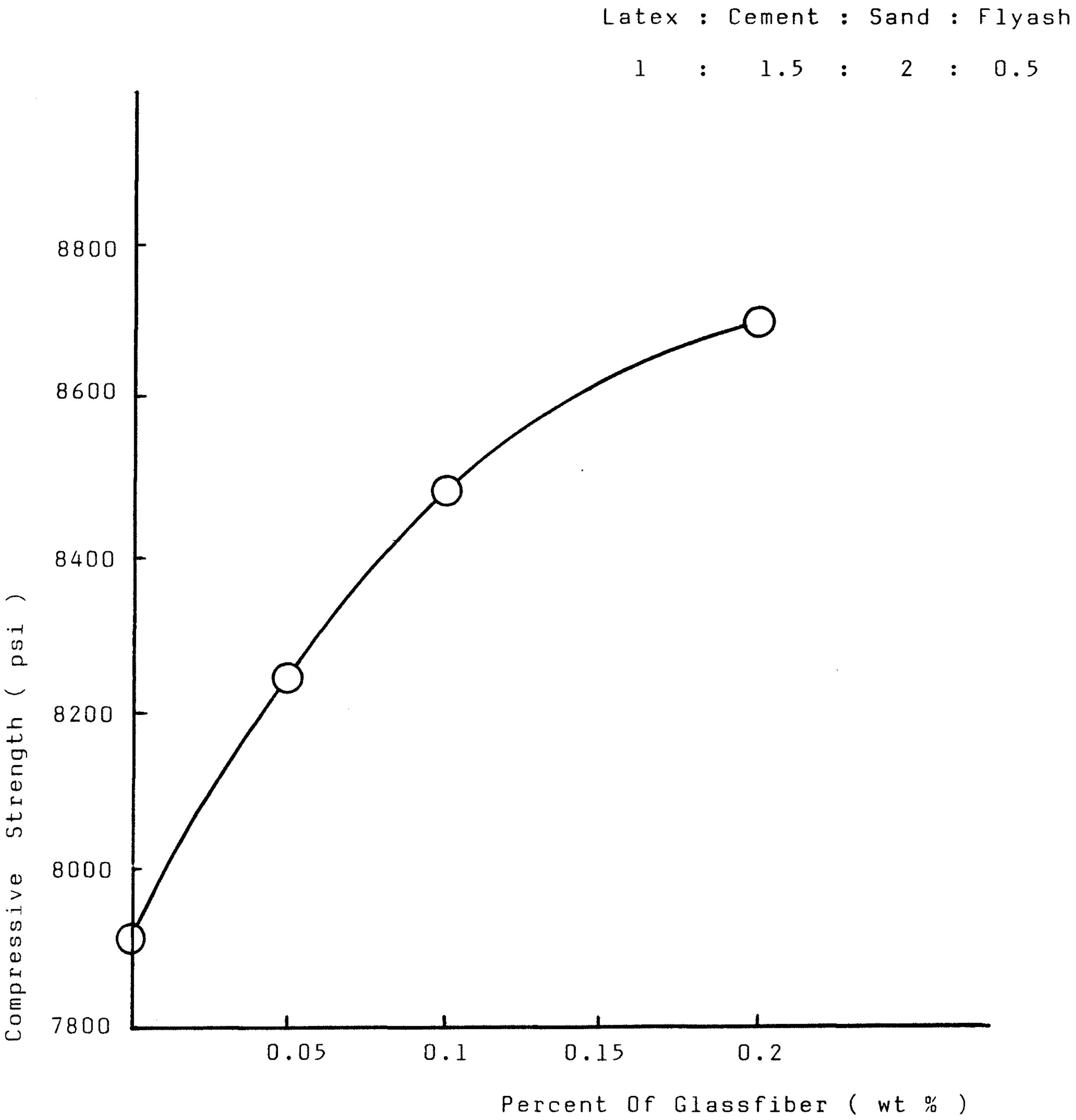
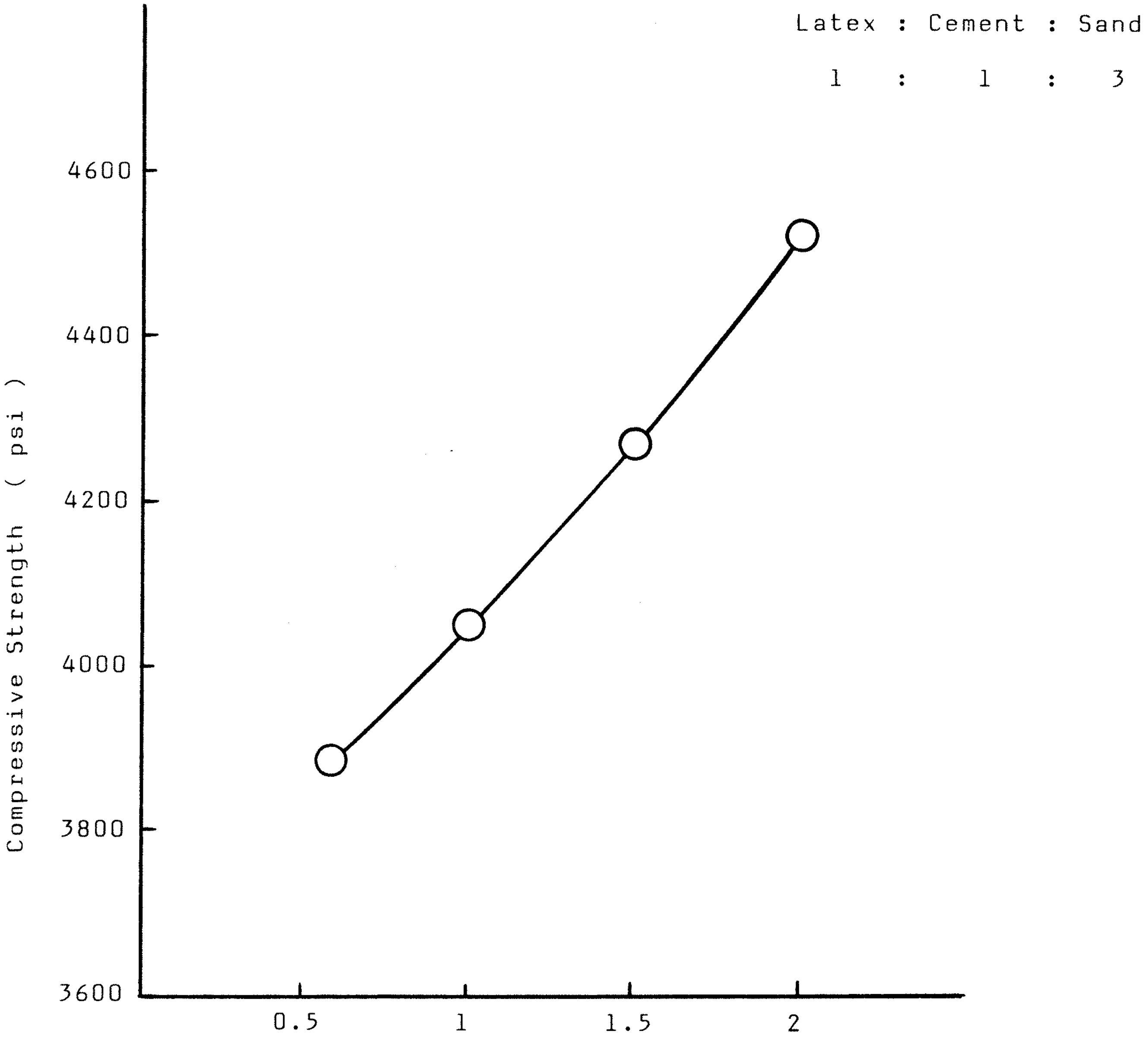


Figure 9. Compressive Strength vs. Fiber Content



* Based on Resin

Figure 10. Compressive Strength vs. Catalyst Content

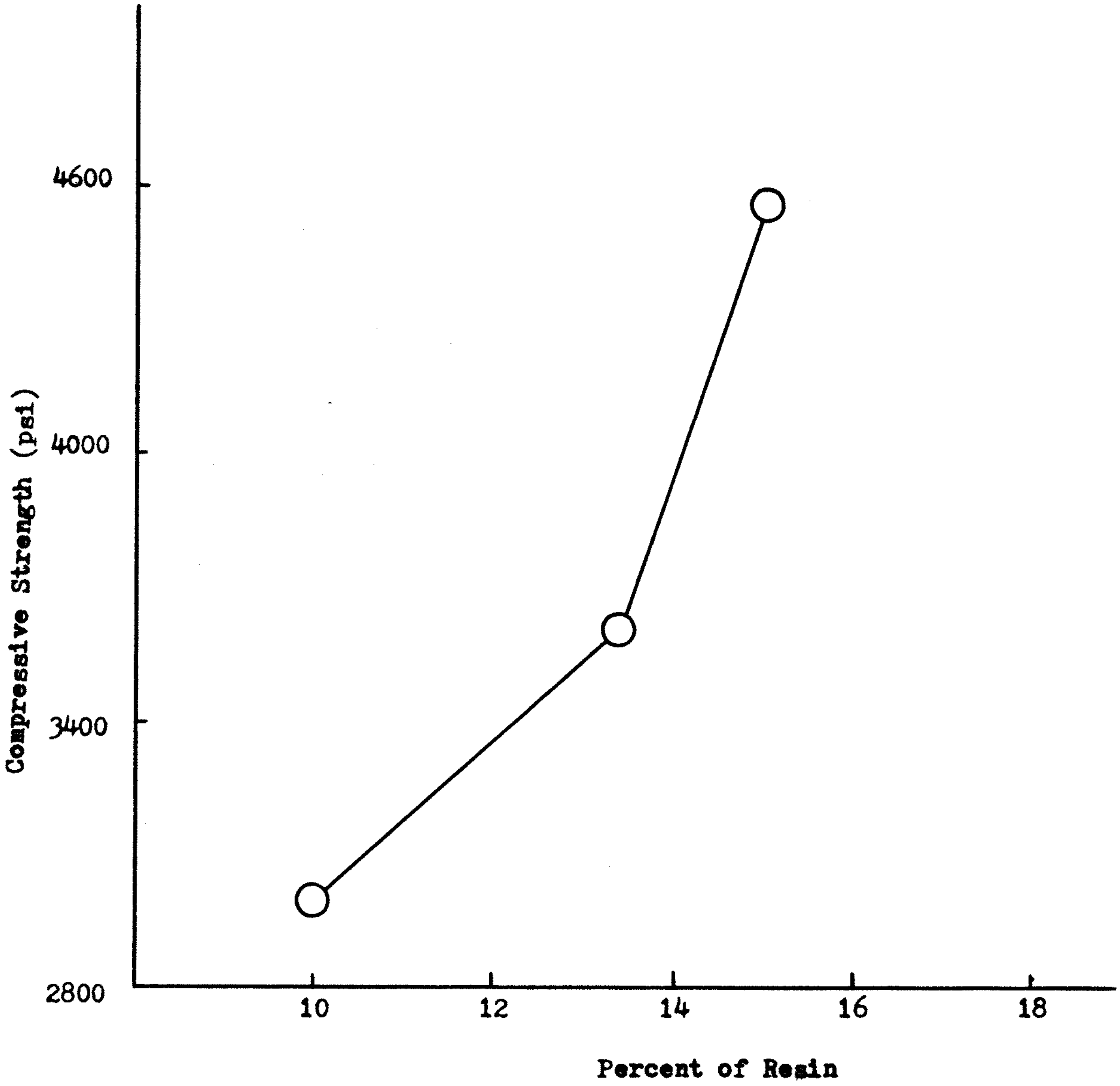


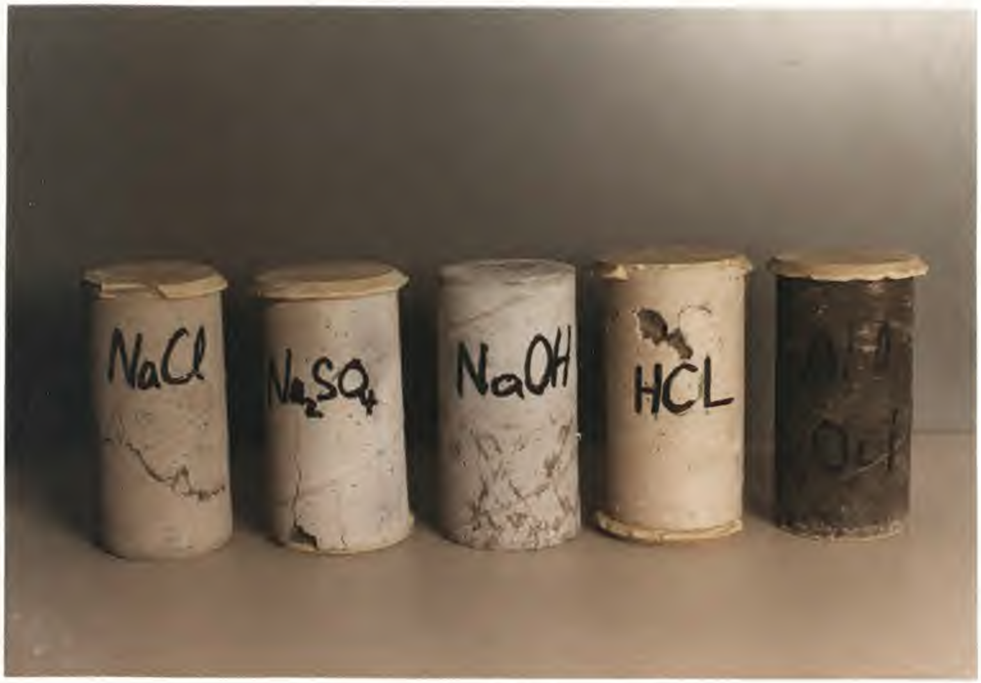
Fig. 11. Compressive strength Vs. Resin Content

(1) Soiltest CT 775 Machine

(2) MTS 810 Material Test System Machine

(3) Testing of Compressive Strength

(4) Testing of Bending Strength



(5) Specimens after Corrosion Test

(6) Beams for Bending Strength

(7) Specimens of Glassfiber Reinforced PC