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390.4

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AS A STRUCTURAL MATERIAL

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Bethlehem, Pennsylvania

May 1973

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USE OF POLYMERS IN HIGHWAY CONCRETE

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ABSTRACT

Polymer Impregnated Concrete (PIC) impregnated with the most common polymers, polymethyl methacrylate and polystyrene shows little ductility. The ultimate strength of these materials are found to be 3 to 4 times higher than that of ordinary concrete, but when the ultimate load of the PIC is reached, the failure comes without warning in a brittle, almost explosive manner.

This investigation was designed to increase the ductility of the PIC so that some plastic yielding may take place before and after the ultimate load is reached. By various percentages of monomer combinations of the methyl methacrylate with an elastomer, n-butylacrylate, this increase in ductility was demonstrated herein by the determination of the entire stress-strain relationship of such co-polymer composite material through the split-tensile and simple compression tests.

It shows from this experiment that the concrete material can be modified to give either a high strength and a little ductility material or a somewhat lower strength and a large ductility material and thus provide potentially tailored material properties to particular structural service requirements.

## 1. INTRODUCTION

Concrete impregnated with a monomer such as Methyl Methacrylate followed by in-situ polymerization (Polymer Impregnated Concrete or PIC) has proved to have 3 to 4-fold improvements in strength, both in compression and in tension than that of ordinary concrete. Also the modulus of elasticity is increased significantly compared to that of ordinary concrete. Other improved properties are resistance to water penetration, abrasion and resistance to various chemical attacks together with improved freeze-thaw resistance (1,2,3,4). Due to these greatly improved structural and durability properties, PIC is expected to find special application in highways, air fields, underground pipes, underwater habitats and other marine structures. Further, due to certain inherent qualities such as negligible creep and reduced weight-to-strength ratio, PIC will find extensive use in precast, prefabricated and prestressed building elements such as floor panels, beams, columns, and walls.

An investigation by Brookhaven National Laboratory (1,2,3,4) indicated that the strength to cost ratio alone was 2:1 in favor of PIC compared to that of ordinary concrete. The potential use of PIC in building construction appears therefore to be very promising.

In its present form, however, PIC is expected to find only limited application as a structural material in building construction. One of the main reasons for this is the brittle behavior of PIC. Even if the ultimate strength is high, no plastic yielding or ductility has been observed before sudden and explosive failure.

This investigation was designed to increase not only the strength but also the ductility of the PIC by various monomer combinations of Methyl Methacrylate (MMA) and Butyl Acrylate (BA) and determine the entire stress-strain relationship through the split-tensile and simple compression tests.

## 2. SCOPE

Sand, coarse aggregate, type of cement, water-cement ratio, and curing age as well as curing conditions were standardized for all the specimens. Also the same impregnation procedures were used for all the specimens. By varying the percentages of monomer combinations of Methyl Methacrylate (MMA) and the Butyl Acrylate (BA) various strength and ductility properties of the composite material were found.

To initiate the polymerization a azobisisobutyronitrile concentration of 0.5% by weight of the monomer was used as catalyst. This azo-compound catalyst has proved to give the best result in an earlier investigation for PIC specimens impregnated with MMA (7). Polymerization was achieved by keeping the specimens submerged in hot water (70-80°C) for 3 hours.

## 3. CONCRETE SPECIMENS

The cement was a high early strength (Type 1) Portland cement. The fine aggregate was a siliceous sand, crushed to a fineness modulus = 2.83 and the coarse aggregate was crushed stone  $\frac{1}{2}$ " in size, both according to ASTM C33-67. The mix consisted of water, cement, sand and coarse aggregate in the proportion 1:2:4.3:4.7 by weight.

Airetraining agent was added to the water and mixed into the fresh concrete.

Table 1 gives the mix of the concrete for preparation of the concrete cylinders for both control and PIC specimens.

Table 1 Concrete Mixture

| W/C Ratio | Water lb | Cement lb | Sand lb | Coarse Aggregate lb | Measured Slump in | Entrained Air % |
|-----------|----------|-----------|---------|---------------------|-------------------|-----------------|
| 0.5       | 24.4     | 48.8      | 104.5   | 113.5               | 5                 | 7               |

The concrete was compacted in 3x6 in. cardboard cylinder molds. After 24 hours the specimens were removed from the molds and cured in a moisture room with 90-100% relative humidity for 28 days, and then stored for 14 days in air, before impregnation.

#### 4. Impregnation Vessel

The vessel was constructed from an 8x15 in. steel pipe capable of impregnating eight 3x6 in. specimens simultaneously. The vessel (Fig. 1) consists of the steel pipe, a top and bottom flange with a lid bolted to the top flange. Two gages: One measuring the vacuum and the other measuring pressure, a safety valve and a valve connected to a hose to suck the monomer into the vessel, were attached to the lid. After the vacuum was applied to evacuate the air from the specimens, the monomer was sucked into the impregnation vessel. Pressure from a nitrogen tube was then applied to complete the penetration of the monomer into the concrete specimens.

## 5. IMPREGNATION PROCEDURE

The specimens were prepared for impregnation first by drying to constant weight at 125°C for 10 hrs., cooled off and placed in the impregnation vessel (Fig. 1) subjected to both vacuum and pressure.

The air was removed from the specimens by a vacuum pump (20 in. of H<sub>g</sub>) for 1 hr., before the monomer containing 0.5% azobisisobutyronitrile was induced into the vessel. To speed up the impregnation, 60 psi pressure was applied from a nitrogen cylinder. Nitrogen was used to eliminate possible fire hazard. The specimens were kept under pressure for 1 hr., removed, and polymerized under hot water (70-80°C) for 3 hrs. This method of polymerization has been proved to be very successful. It is simple to perform and reduces the loss of monomer in the specimens (5,6). Table 2 gives the details of the polymerization procedure.

Table 2 Polymerization Procedure

| No. of Specimens | Polymer        | Drying   |           | Vacuum   |             | Pressure |     |
|------------------|----------------|----------|-----------|----------|-------------|----------|-----|
|                  |                | Time hr. | Temp. °C. | Time hr. | Mercury in. | Time hr. | psi |
| 8                | 100% MMA       | 10       | 125       | 1        | 20          | 1        | 60  |
| 8                | 90% MMA 10% BA | 10       | 125       | 1        | 20          | 1        | 60  |
| 8                | 70% MMA 30% BA | 10       | 125       | 1        | 20          | 1        | 60  |
| 8                | 50% MMA 50% BA | 10       | 125       | 1        | 20          | 1        | 60  |

The polymer loading of the specimens after polymerization was calculated as the increase in weight after polymerization, divided



by the initial dry weight of the specimens. The percentages given in Table 3 are the average values for eight specimens of each type.

Table 3 Polymer Loading

| Specimens         | Polymer Loading<br>% (Average) |
|-------------------|--------------------------------|
| 100% MMA          | 6.8                            |
| 90% MMA 10% BA    | 7.2                            |
| 70% MMA 30% BA    | 7.2                            |
| 50% MMA 50% BA    | 6.9                            |
| Control Specimens | 0                              |

6. TEST SET-UP

The standard split-tensile test (ASTM-C496-66) setup is shown in Fig. 2, with an electrical strain gage glued to the plane bottom surface of the specimen. The strain gage was placed horizontally in the center of the specimen and recorded the lateral strain. Only one gage was used per specimen.

The specimens used in the compression test (ASTM C39-66) were capped using hydrostone as capping material. This was done to achieve two parallel surfaces. Both the split-tensile and the compression tests were performed in a 300 kip hydraulic testing machine. The strain rate was approximately constant in the elastic range.

The compression test setup is shown in Fig. 3 including a closeup of the strain measuring device.

To measure strain in the compression test a frame consisting of two rings that easily could be mounted on the specimen, was designed for this investigation. Two "clip type" extensometers were fixed on

either side of the specimen between the two rings. The setup was designed considering the "explosive", brittle failure of the PIC in compression. At failure the clip gages detach themselves from the rings and are not damaged by the "explosion" and can therefore be reused. The setup was easy to handle, economical, and rather accurate for such tests. Two "clip type" extensometers were fixed on either side of the specimen between the two rings. The load-strain relationships were recorded automatically on a X-Y plotter for both tension and compression tests. The compression test setup can be used repeatedly and satisfactorily even after several "explosive" failures of the PIC specimens.

#### 7. TEST RESULTS

Full impregnation and polymerization of the monomer in the specimens were apparently achieved. Only a slight smell of monomer was released when the specimens were broken.

Figure 4 shows the average load-strain curves for the split-tensile tests and the corresponding compressive stress-strain curves are shown in Fig. 5. Clearly, the modulus of elasticity, ultimate strength, and energy to break of the concrete specimens are dramatically increased by incorporation of MMA as compared to that of control specimens. Further the incorporation of BA results in less increase in strength and modulus but at the considerable gain in ductility as implied by plastic yielding at least for the specimen with 50% MMA and 50% BA. The tensile and compressive properties all tend to be decreased in direct proportion to the amount of increasing proportions of BA.

The load-strain or stress strain curves for the specimens with 100%, 90%, and 70% MMA show an almost linear relationship up to approximately 75% of the ultimate load. For the specimens with 70% MMA and 30% BA, the load-strain or the stress-strain curves show some yielding (unloading) after the ultimate load has been reached.

For 50% MMA and 50% BA the specimens show a remarkable ductile behavior and specimens still carried a higher load than the control concrete's ultimate strength with a strain of  $9000 \text{ in/in} \times 10^{-6}$  in compression (Fig. 5). This is a three times larger strain than the control concrete reached at its failure. Table 4 lists some average ultimate strengths and Young's modulus for the tested specimens.

Table 4 Ultimate Strength

| Specimens        | Tensile Strength<br>ksi | Compressive Strength<br>ksi | Young's Modulus*<br>ksi x $10^3$ |
|------------------|-------------------------|-----------------------------|----------------------------------|
| 100% MMA         | 1.71                    | 17.2                        | 6.7                              |
| 90% MMA 10% BA   | 1.62                    | 15.6                        | 5.4                              |
| 70% MMA 30% BA   | 1.60                    | 15.2                        | 5.0                              |
| 50% MMA 50% BA   | 1.07                    | 10.5                        | 3.5*                             |
| Control Concrete | 0.43                    | 4.4                         | 3.8*                             |

\*Young's modulus for the control and 50% MMA + 50% BA specimens are the "secant modulus" measured at  $\frac{1}{2}$  ultimate strength. The "Tangent modulus" are given for the other specimens.

8. CONCLUSION

(1) The brittle behavior of PIC impregnated with polymethyl methacrylate can be improved by various monomer combinations of MMA with polybutylacrylate. The higher the percentage of BA, the larger the ductility, though, at the expense of a corollary decrease in strength and modulus of elasticity. These results show that a PIC material can be prepared to fit any specified criteria concerning strength vs. ductility and thus providing potentially tailored material properties to fit a particular service requirement as a structural material.

(2) Full penetration of copolymer impregnated concrete specimens can be achieved with the concrete, drying, vacuum, and pressure together with polymerization time and temperature used in this investigation. Little smell of monomer was released when the copolymer specimens were broken, varifying the effectiveness of the catalyst 0.5% azobisiobutyronitrile that was found in the previous investigation using MMA only (7).

(3) The investigation also showed that concrete can be successfully impregnated with the co-polymer system used herein. The impregnation of this system appeared to be just as easy to obtain as impregnation with 100% MMA.

(4) The results proved that such a copolymer system can improve the ductility of the PIC, however, further research is necessary to determine either the optimum percentage combinations of the MMA with BA concentration or a better copolymer system.

9. ACKNOWLEDGMENT

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Dr. John A. Manson of the Materials Research Center was consulted concerning the polymers and Mr. H. C. Mehta helped with the preparation of the specimens.

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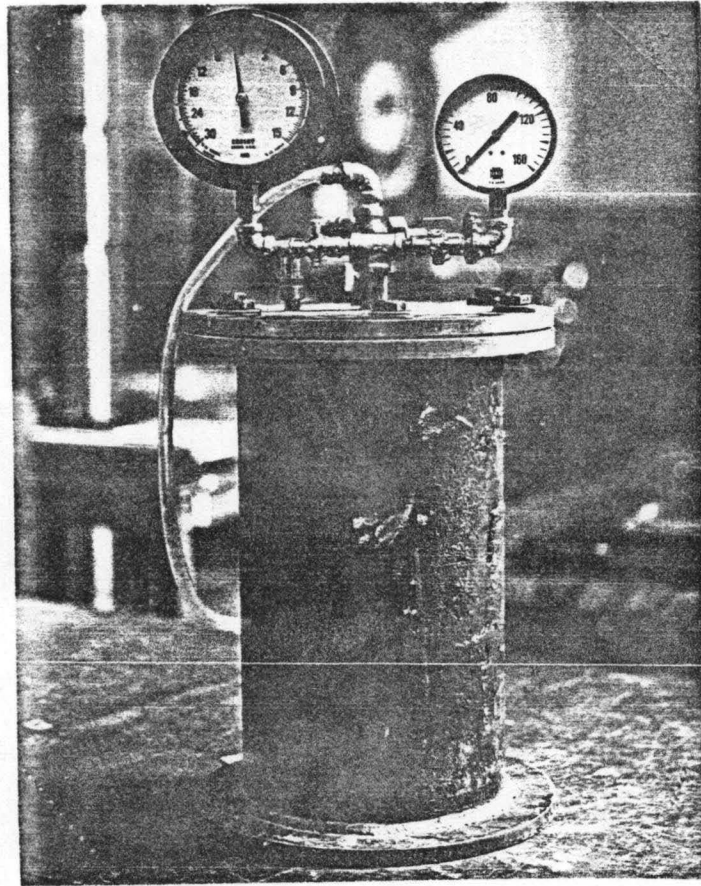


Fig. 1 Impregnation Vessel

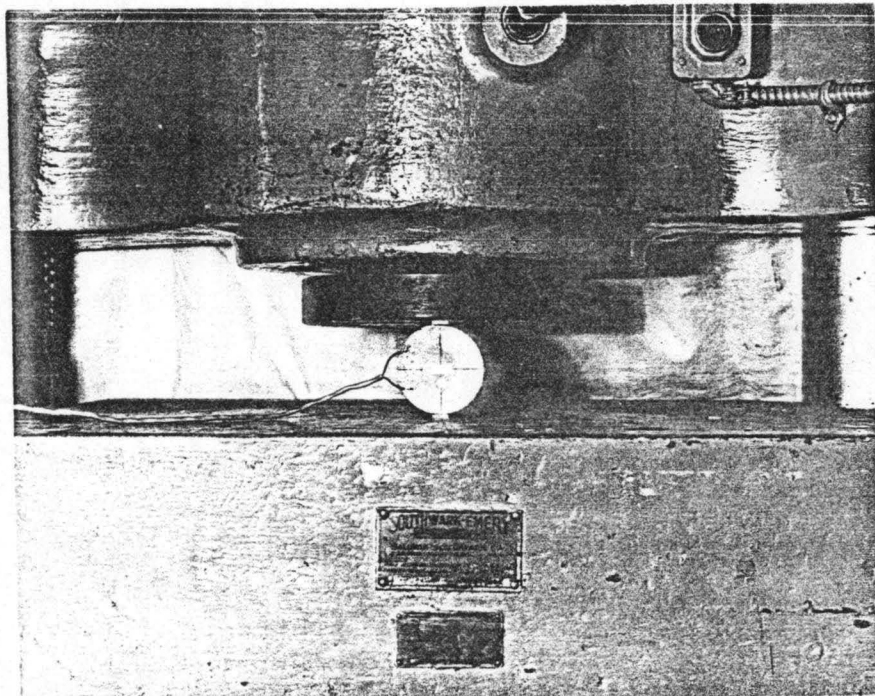


Fig. 2 Split-Tensile Test

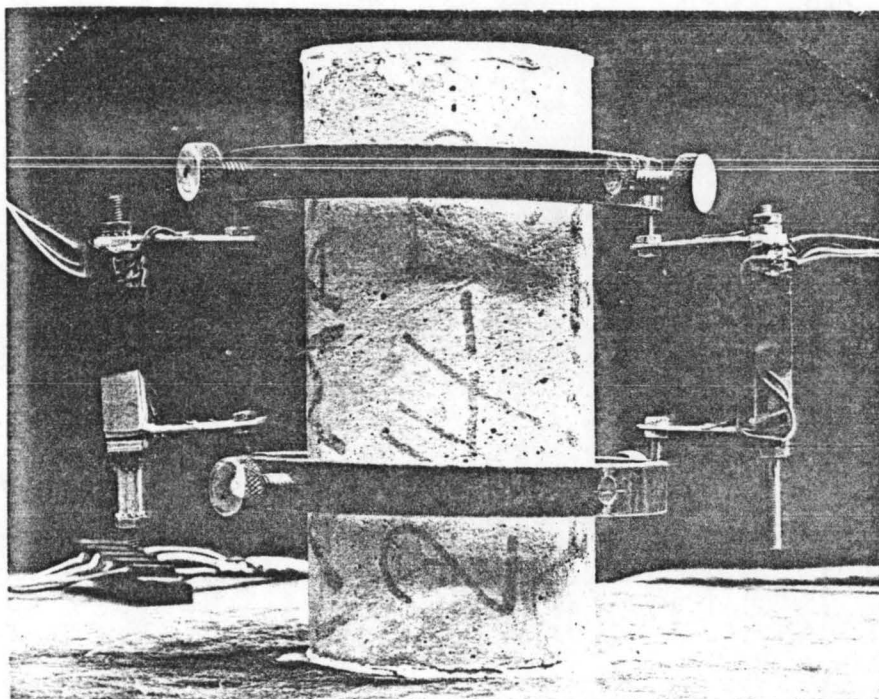
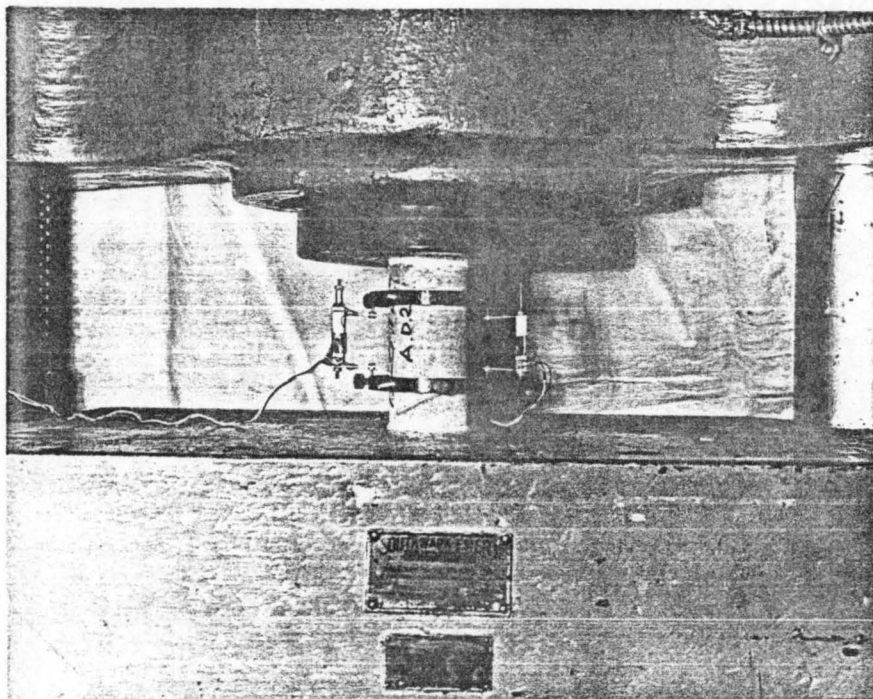


Fig. 3 Compression Test and Strain Measuring Device



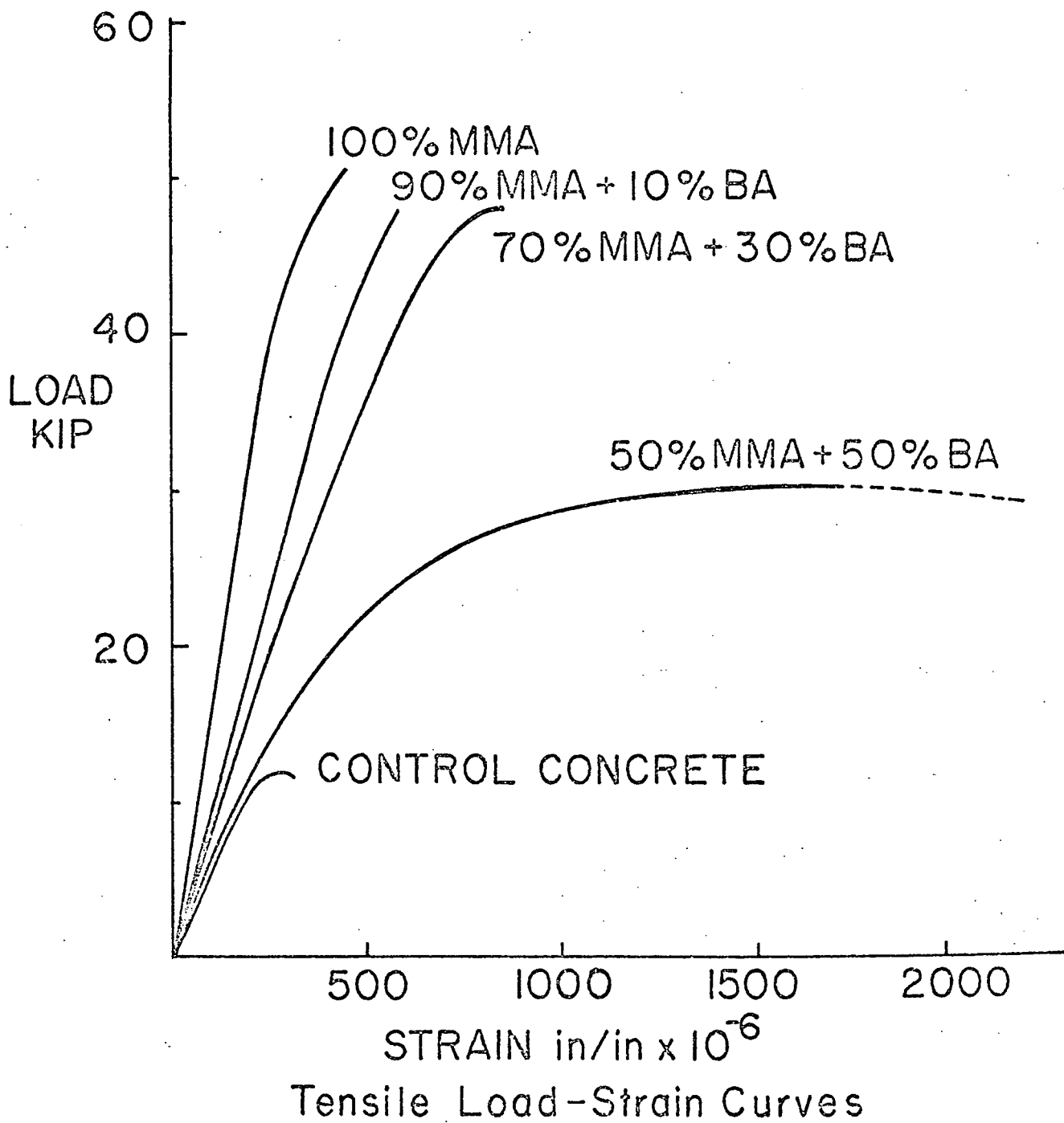


Fig. 4

MMA = Methyl Methacrylate  
BA = Butyl Acrylate

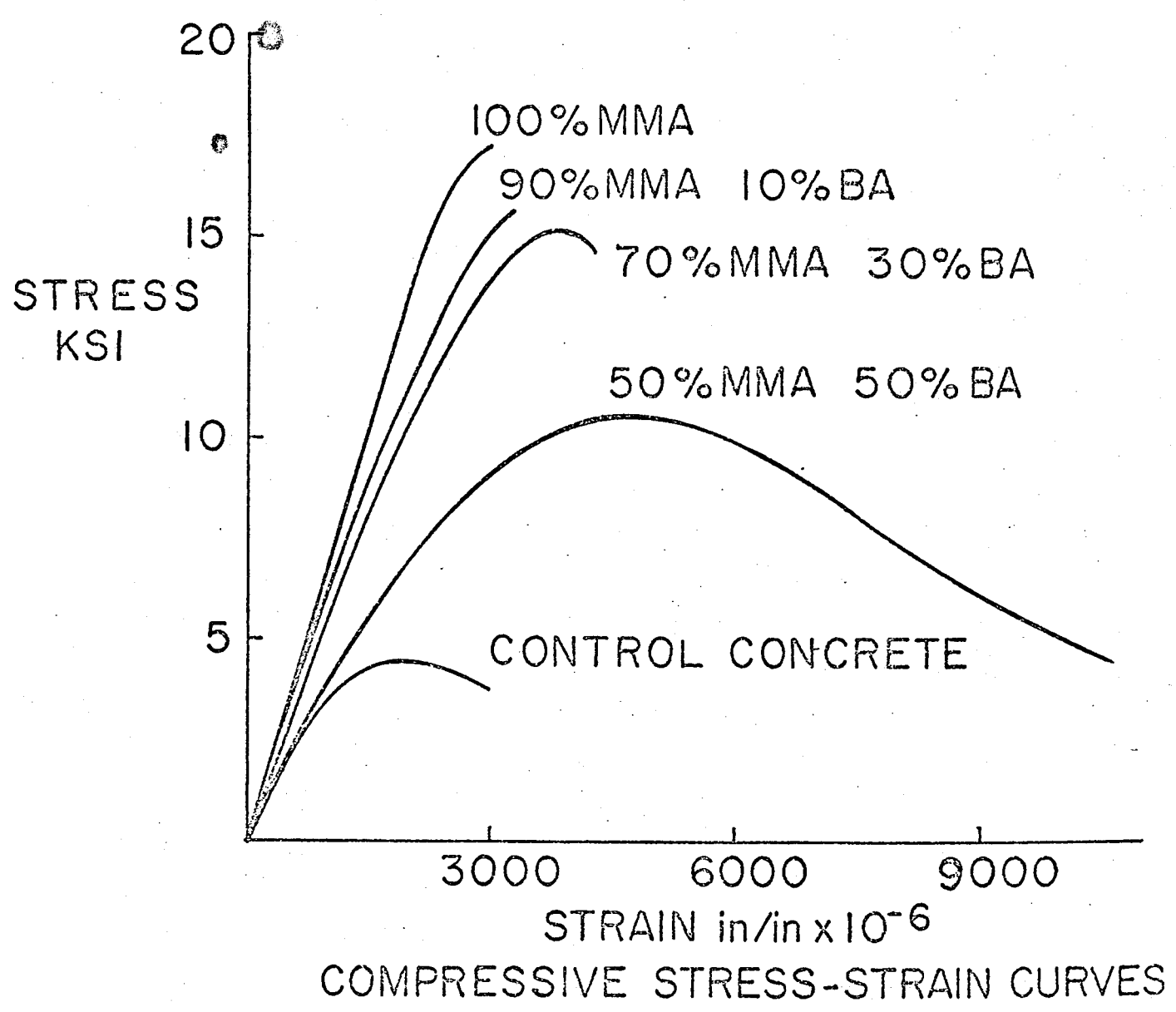


Fig. 5