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Effect of Polymers on the Properties of Portland and Pozzolanic Cement Concrete

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Submitted in partial fulfillment of the
requirements for the degree of
Master of Science in Civil Engineering
Faculty of Graduate Studies
University of Jordan
Amman-Jordan

August, 1991

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TO
MY FAMILY
And
FIANCEE,
HANA

Acknowledgments

Firstly I wish to acknowledge my thesis supervisor, Dr. Raed Samra for his continuous encouragement and useful suggestions throughout the study.

Also I wish to thank all the staff members of the Civil Engineering Department, especially members of the examining Committee, and I wouldn't forget to express my appreciation to the Computer-Center Staff, especially Mr. Hussien Omary for his assistance.

I am grateful to may collegues for their support and encouragement.

Finally, I bow to my parents and family for their endless love and support throughout my career; without their sacrifices, this undertaking could not have been possible.

Abstract

This research aims at incorporating elements of latex into Portland cement concrete and pozzolanic Portland cement concrete and studying the properties of the modified concretes, also a polymer was introduced into well-graded sand and gap-graded aggregate to create what is termed as polymer concrete and to study some of its properties among which are: compressive strength, absorption of water, effect of temperature on strength and effect of cement as filler.

The polymer content in polymer cement concrete (as a ratio by weight of cement) was varied from 0.00 to 0.25 (increment of 0.05),while in polymer concrete, the polymer content (as a ratio by weight of aggregate) was varied from 0.06 to 0.24 (increment of 0.02). For polymer cement concrete, about 200 beams and 200 cubes were prepared and tested, while for polymer concrete, about 85 cylinders and 66 beams were prepared and examined. The test results were tabulated and then they were reproduced into curves.

Polymers being considered include polyester, polyvinylacetate homopolymer and polyvinylacetate copolymer. These polymers seemed to have good effect on some properties of the fresh modified concretes espeically workability and setting time, while some of them improve the strength properties of the hardened modified concertes..

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CHAPTER 1

Introduction

1.1. Synopsis

As we have become more and more concerned with the conservation of energy and materials, interest has grown in improving the strength, toughness, ductility, and durability of portland cement concrete or in finding replacements that exhibit a superior cost-property balance. Thus one approach has been to improve the properties of concrete itself; another -the subject of this research-is to combine the two technologies of concrete; cement concrete and polymer concrete. It should be noted that combinations of silliceous materials with polymers require in many cases lower energy inputs per unit of performace than either component alone.(2,3)

Indeed, significant progress has been made recently in both fundamental and applied research on all kinds of polymer/concrete systems. It is suggested that further progress to achieve sophisticated understanding, design, and materials selection will still require much work in combining the science, technology, and economics involved.(1,5)

1.2. Classification

There are generally three types of concrete materials which utilize polymers to form composite materials.

Polymer-impregnated concrete (PIC) is a hydrated portland cement concrete which has been impregnated with a monomer and subsequently polymerized in situ.(10,11)

Polymer-portland cement concrete (PPCC) is a premixed material in which either a monomer or polymer is added to a fresh concrete mixture in a liquid, powder, or dispersed phase, and subsequently allowed to cure, and if needed, polymerized in place. The term polymer cement concrete (PCC) has also been used to refer to this same material definition.

Polymer concrete (PC) is a composite material formed by polymerizing a monomer and aggregate mixture. The polymerized monomer acts as the binder for the aggregate.(3,7)

For this state-of-the-art review, the incorporation of monomers and polymers is made for the purpose of substantially altering some property of the final hardened concrete material. Small quantities of polymer are sometimes added to modify the properties of fresh concrete. Such materials are more appropriately considered to be admixtures .

1.3 Historical Development of Polymer-Concrete Materials

While several kinds of what are now called PCs and PPCCs (the latter being latex-modified mortars) were in use during the 1950s, major interest in such materials, and in PIC, developed in the middle 1960s. A major thrust was the desire to obtain improved materials for rigorous applications such as desalination process equipment, water and waste-water pipes, and bridge decks. Both research and development activities accelerated as the 1970s approached.

In 1971, the American Concrete Society formed committee 548, " Polymers in Concrete", and by the late 1970s the society had sponsored two symposia on the general topic and a state-of-the art report ; a manual of recommended practice is also in preparation. Interest has by no means been confined to the U.S.A.Thus, for example, the Concrete Society (London) formed a working group on this topic, and numerous other symposia, workshops, and seminars have been sponsored and articles written throughout the world. In particular, it is noteworthy that two major international congresses have been held-the first in London in 1975, and the second in Austin, Texas, in 1978.(1,2,3)

Some polymer-concrete materials have already been in use for many years, some are undergoing their first applications, and some are awaiting acceptance by a justifiably conservative technological world. After about 15 years of research and development, enthusiasm for fascinating new combinations of properties has been tempered with a healthy skepticism about whether or not polymer-concrete materials really have a place in engineering applications. Fortunately, even under the cold and impartial eye of cost-effectiveness, there are indeed applications which appear suitable for the unique properties of such materials. (5,7)

Thus the field appears to have reached a first level of maturity. Older applications are being consolidated into practice and newer ones are being sought. Indeed a major development has been that several major classes of applications have been, or are being, commercialized generally throughout Europe and the Americas. In fact, a reading of Chemical Abstracts reveals that about 150-200 publications on polymer-concrete materials are currently being abstracted each year. Most of them come from a dozen-odd countries, and an increasing number (about one third) are based on patents, thus reflecting a high incidence of tailor-making products for particular applications.

CHAPTER 2

MONOMERS AND POLYMERS

2.1 Definitions

A monomer is a molecular species (usually organic) which is capable of combining chemically with molecules of like kind, or with other monomers, to form a very high molecular weight material known as a polymer. A polymer consists of repeating units derived from the monomers which are linked together in a chain-like structure. The chemical processes through which these linkages occur is known as polymerization. If only one type of monomer molecule is used to form a polymer, the process is called homopolymerization and a homopolymer results.

If more than one chemical species is used as monomers, the chemical process is colled copolymerization.

The polymerization process may take place in a variety of ways depending upon the chemical species used, but in general, only two major processes can be distinguished: addition and condensation polymerizations. (4,9)

An emulsion is an essentially permanent two-phase mixture made up of very fine particles of a solid or a liquid (the dispersed phase) suspended in a nonsolvent liquid (the continuous phase). The suspension is usually stabilized by small amounts of additional substances known as emulsifiers which modify the surface tension of the particles to keep them from coalescing. A latex is an emulsion in which a polymer is the dispersed phase and water is the continuous phase. A latex usually has the appearance of a milk-like fluid.

The properties of polymers depend on the chemical structure and molecular architecture of the polymer chains, and on the interactions between the chains. Linear polymers are composed of long chains held together by weak Van der Waals forces. Such polymers are termed thermoplastics because their properties change reversibly with temperature as thermal motion overcomes the weak intermolecular bonding. These polymers undergo an abrupt change in their physical state , passing from a hard , glassy material at low temperature to a plastic material of much lower viscosity at higher temperatures , then revert back to their original state on cooling . The temperature at which this transition occurs is known as the glass transition temperature (Tg) and marks a pronounced change in physical and mechanical properties. (2,10)

In many cases, condensation polymer chains are crosslinked or interconnected in a random three-dimensional network by the use of monomers that can take part in more than one condensation reaction. Such structures form rigid materials which are called thermosets since they do not show the reversible changes with temperature typical of thermoplastics.(1)

It is possible to link the polymeric chains of vinyl thermoplastics with strong chemical bonds through the use of cross-linking agents. Such agents are difunctional or polyfunctional molecules which have more than one site available for polymerization reactions. The glass transition temperature (Tg) is raised with increasing amounts of cross-linking and eventually a thermoset results. Conversely, plasticizers are used to lower Tg by altering the Van der Waals interactions between polymer chains or by increasing the flexibility of the polymer chain .

2.2. Polymer Impregnated Concrete

2.2.1 Monomers

The selection of suitable monomers for PIC is based upon the impregnation and polymerization characteristics, availability and cost, and the resultant properties of the polymer and the PIC. Most monomer investigations have been with vinyl monomer systems. Properties of some monomer and polymer systems are listed in Tables 2.1 and 2.2. These monomers were investigated for normal temperature applications of PIC. (11,13)

At ambient temperature and pressure, monomers can be either gases (e.g. vinyl chloride), liquids (e.g. methyl methacrylate), or solids (e.g. acrylamide). Liquid type monomers are most adaptable to impregnation of precast concrete, although gaseous monomers have been used.

2.2.2 Viscosity

The rate and degree of monomer penetration through concrete depends on the density and pore structure of the concrete, and on the viscosity of the monomer. Table 2.1 lists some common liquid monomers of low viscosity at ambient temperature, which are suitable for impregnation. Precast concrete can be successfully impregnated with higher viscosity monomers (greater than 20 centipoises or 20 millipascal-seconds), although it is usually advantageous to reduce viscosity by suitable blends with low viscosity comonomers, e.g. methacrylate polymers.The viscosity may be increased by dissolving a polymer in the monomer. The viscosity of methacrylate (MMA) solutions can be varied greatly in this manner. (5,6,9)

Table 2.1. Physical Properties of Common Monomers Used in PIC and PC (11,13)

Monomer	Viscosity	Density	Vapor Pressure		B.P.
Solubility	(Centipoise)[7]	gm/cc[8]	(mm Hg)[9]	(oC)	in water (%)
Acrylonitrile	0.343	0.81	852	77	7.43
Diallyl Phthalate	12.02	-	2.546	300	Inso
Methyl Methacrylate	0.573	0.94	352	100	1.54
Monochlorostyrene	1.043	1.11	0.682	180	0.00643
Styrene	0.762	0.91	2.92	135	0.0703
Tert-butylstyrene	1.463	0.88	1.05	218	0.00053
Vinyl Acetate	0.432	0.93	1153	73	2.52
Vinyl Chloride	0.281	0.91	16602	-13.9	Slight
Vinylidene Chloride	–	1.21	5993	32	Insol

(1) - 20oC (2) 20oC (3) 25oC (4) 30oC (5) 46oC (6) 150oC

(7) Centipoise= millipascal-second (8) gm/cc = 1000 Kg/m^3 (9) mm Hg (at 0°C) = 133 Pa

2.2.3.Vapor pressure

In the selection of a monomer for impregnating precast concrete, consideration must be given to its volatility (see Table 2.1) for safety and processability. The high vapor pressure of vinyl chloride, for example, requires special precautions in handling. Considerations must also be given to the effect of curing temperature on vapor pressures, since monomer depletion on the surface of the specimen may occur due to evaporation. Low viscosity monomers tend to have low boiling points while high boiling monomers are more viscous. (3,5)

2.2.4 Chemical Stability

Monomers are generally supplied containing an inhibitor. Inhibitors are chemical compounds which react with free radicals and oxidation products to prevent premature polymerization and to maintain the purity of the monomer. Over a period of time, the inhibitor is consumed and its concentration gradually decreases. The rate of inhibitor consumption also depends on the storage temperature and cleanliness of the storage facility. Stored monomer should be tested regularly for inhibitor content, and inhibitors should be added if the level drops appreciably below the original level. Concentrations of inhibitor can be determined by various methods. During polymerization of the monomer, an induction period is observed, which represents the period during which the inhibitor is consumed. (4,10)

2.2.5. Polymers

2.2.5.1. Thermal Properties

One of the most important performance characteristics of polymers is the marked dependence of their properties on temperature within their useful temperature range. Thermoplastics retain their useful properties at temperatures below Tg, but lose them at higher temperatures. Generally at somewhat higher temperatures, the polymers begin to thermally decompose. Thermoset polymers do not exhibit a Tg and retain their structural properties up to the thermal decomposition temperature. The thermal decomposition temperature of some typical vinyl polymers ranges from about 110°C for (poly vinyl chloride) (PVC) to 260°C for (poly methyl methacrylate) (PMMA), but is genrally about 200°C (see Table 2.2). (11,12,13)

The useful temperature range of a thermoplastic may be raised with the addition of a suitable crosslinking monomer or comonomer having a higher Tg. Table 2.3 lists Tg for several MMA and styrene comonomer systems. It should be noted, however, that these systems may not be stable under all exposure conditions; for example, it has been observed that the 90-10- MMA-dialylphthalate (DAP) and 70-30 MMA- trimethylolpropane trimethacrylate (TMPTMA) systems fail under prolonged exposure to moisture at elevated temperatures, whereas under the same conditions the 60-40 styrene- TMPTMA system is stable. (5,8)

2.2.5.2. Mechanical Properties

The tensile strength of polymers is relatively high at temperatures well below Tg. Most glassy, vinyl polymers have a tensile strength in the range of 5,000 to 10,000 psi (34.5 to 68.9MPa); the compressive strength is greater , ranging from about 11,000 to 19,000 psi (75.8 to 131.0 MPa). Below Tg, where the polymers

Table 2.2. Properties of Some Polymers Used in PIC, PPCC and PC. (1,3)

	PS[3]	PMMA[4]	PVAC[5]	PVC[6]
Physical Properties				
Specific Gravity	1.05	1.18	1.19	1.38
Glass Transition Temp.(°C)	93	100	70	80
Decomposition Temp.(°C)	250	260	200	110
Water Adsorption (%)	0.03-0.05	0.3-0.4	3-6	----
Mechanical Properties				
Compressive Strength (ksi)[1]	11.5-16	11-19	----	10
Tensile Strength (ksi)	5-12	8-11	2-4	
Flexural Strength (ksi)	8.7-14	12-17	----	----
Modulus of Elasticity (ksi)	400-500	400-500	40	30-60
Poisson's Ratio	0.33	0.33	-----	0.38
Impact Strength (ft. 1b/in. of width)[2]	0.25-0.4	0.4-0.5	-----	------

(1) Ksi=6.9 megapascal
(2) ft. 1b/in. =53.4 joule/metre of width
(3) PS = Polystyrene
(4) PMMA = Polymethyl methacrylate
(5) PVAC= Polyvinyl acetate
(6) PVC=Polyvinyl Chloride

are hard, brittle materials, the modulus of elasticity is relatively constant (~ 100ksi or 690 MPa). Above Tg, the modulus drops to relatively low value (> 100 psi, 0.7 MPa) and the materials exhibit plastic behavior. The same is true for the shear modulus. Other deformation characteristics (e.g. coefficient of thermal expansion and creep strains) are significantly increased above Tg. (1,3)

A reduction in volume occurs during the polymerization of a monomer. This shrinkage from polymerization may cause detrimental effects on the mechanical properties of the polymer and consequently has been the subject of some speculation on adverse affects on the properties of PIC; however, no such adverse effects are known to have been reported. The potential effects of polymerization shrinkage on PIC would include residual shrinkage stresses in the polymer, shrinkage of the overall PIC member, poor bonding between the polymer and substrate, and leaving voids in PIC which would tend to lower the durability somewhat below that which would be obtained if all voids were filled. Residual stresses and strains in thermoplastic polymers may be relieved by annealing at a temperature close to Tg. (1,3)

2.2.5.3 Chemical Properties

Generally, polymers are inert materials, unaffected by most reagents. They may, however, be attacked by oxidizing agents or aromatic or chlorinated organic solvents. Absorption of UV radiation may lead to eventual degradation of some polymers. Stress cracking is often a problem with many polymers.

2.2.6. Additives and Modifiers

The various physical and chemical properties of polymers have been discussed in the preceding sections. Various comonomers and other additives to the monomer system are frequently used to modify or produce desired changes in the properties of the polymer. (4)

2.2.6.1 Plasticizers

Plasticizers are commonly added to momomers to improve the flexibility of inherently brittle polymers such as poly (methylmethacrylate) and polystyrene (PS). Specific examples are the addition of " internal plasticizer" like vinylstearate, butyl acrylate (BA) or dibutylphthalate which co-polymerize with monomer. (6)

2.2.6.2 Cross-linking Agents

Cross-linking by means of the addition of an appropriate bi-functional or poly-functional monomer increases the rigidity of the polymer, increases its resistance to the action of solvents, and increases its softening point. The amount of change depends on the cross-linking density in the polymer. The cross-linking agent most commonly used in PIC is TMPTMA which is a tri-functional acrylic monomer which can be homo-polymerized or co-polymerized with other vinyl monomers such as MMA or styrene.(7,9)

2.2.6.3. Flame Retardants

All polymers will burn, pyrolyze, or char in contact with a flame source. It is known, however, that compounds containing certain elements such as chlorine, bromine, phosphorous, antimony, boron, and nitrogen will retard or inhibit combustion. The degree of flame retardancy depends mainly on the amount of the flame-retarding elements in the composition. Flame retardants are divided into two general classes: reactive additives which become part of the polymer structure, and inert additives. There is no significant difference in efficiency between the two types, the dominant factor being the content of flame retarding element. Convenience, availability cost and degree of flame retardancy are factors that determine the most advantageous type. The physical properties of polymers may change significantly as a result of dilution and plasticization of the polymer. Flame retardants are blended with the monomer prior to polymerization in proportions depending upon the desired degree of flame retardancy. The flame retardants react to provide either inert, non-combustible gases (antimony, bromine, nitrogen) or to promote the formation of protective chars (boron, chlorine, phosphorous). Toxic gases may often be generated from flame retardants under these conditions.

2.2.6.4. Silane Coupling Agents

Silane coupling agents are monomeric, silicon chemicals used to chemically bond organic polymers to inorganic materials such as sand, rock, glass and metals. They have the general formula $(HO)_3$ SiR where R is an organic group compatible with thermoplastic or thermosetting resins. Coupling agents have been used occasionally in PIC, and more commonly in PC for improvements in strength and for retention of aggregate bond in long term exposure to moisture. (3,5)

2.2.7. Polymerization

There are three commonly used methods for free radical initiated polymerization.

2.2.7.1 Thermal-catalytic

The simplest method of polymerization is throught the addition of small amounts of a compound which will generate free radicals on heating. These compounds are generally called catalysts or initiators. (1,2)

These compounds are not strictly catalysts in the pure chemical sense, since they are consumed during the reaction. The term catalysts is commonly used, however, as only very small amounts of materials are used. The following commercially available compounds have been used in forming PIC: benzoyl peroxide (BzP), azobis (isobutyronitrile), a-tert-butyl-azoisobutyronitrile, azoiso-butyronitrile, tert-butylperbenzoate and methylethylketone perozide. These compounds decompose at different rates over a range of temperatures to generate free radicals. The selection of type and concentration of initiator, and the optimum polymerization temperature, are important in the production of a uniformly good quality PIC. BzP catalyst is well suited for most vinyl monomers, such as methyl methacrylate and styrene, because it decomposes well below their boiling points. However, there is some controversy over the use of BzP in PIC. Some investigators have reported difficulties in achieving a uniform polymerization. BzP is also susceptible to induced chemical decomposition, which increases the risk of an accidental bulk polymerization if the catalyzed monomer is stored. These problems have not been encountered with azonitrile compounds, and some prefer these compounds for PIC. A higher temperature catalyst such as tert-butyl perbenzoate is more effective with higher boiling point monomers like diallyl ph thalate. (5,6)

It should be noted that organic peroxides are shock sensitive, highly reactive, and may decompose explosively. Special precaution must therefore be taken when dealing with large amounts of monomer-peroxide mixtures. The use and handling of chemical catalysts should be in accordance with procedures recommended by the manufacturer.(9)

2.2.7.2. Promoted-Catalytic

Decomposition of organic peroxide catalysts can be initiated by promoters or accelerators instead of temperature.

These compounds are reducing agents which induce the decomposition of the peroxides. Thus, polymerization reactions can take place at ambient temperature. Several promoters which are commonly used are methyl anilines, dimethyl-p-toluidine, cobalt napthenate and mercaptans. Promoted-catalyst systems can induce polymerization at a temperature of 5 °C or lower, and are well suited for PC. (4,6)

However, because polymerization begins immediately on adding a promoter to the monomer-catalyst system, its use in PIC would be restricted to shallow impregnations. (1)

2.2.7.3. Radiation

The production of free radicals during initiated polymerization can also be achieved by the use of ionizing radiation such as gamma rays emitted by cobalt-60. Absorption of the radiation energy by the monomer results in secondary processes including the production of free radicals. The rate of polymerization varies with the different monomers under constant radiation and temperature conditions. The polymerization rate is dependent upon the square root of the intensity, but at very high radiation intensities it reaches a limiting value. An important advantage of radiation curing is that chain reactions can be initiated at room temperatures or lower. Lower temperature polymerization increases the chain length of the polymer and tends to reduce the amount of monomer lost by evaporation before complete polymerization takes place, particularly when momoners of high vapor pressures are used. Since catalysts and promoters are not required for this process, the inhibited monomer can be used directly as it comes from the manufacturer. However, some monomers require high radiation doses and polymerize slowly. (6)

2.3. Polymer Portland Cement Concrete

PPCC has been prepared with both pre-mix polymerized and post-mix polymerized materials. The pre-mix polymerized materials include latexes and polymer solutions or dispersions. The post-mix polymerized PPCC has been made with a number of resins and monomers. (2,6,7)

2.3.1 Polymer Latexes

A latex consists of very small (0.05-1.0 μm diameter) spherical particles of polymers held in suspension by the use of surface-active agents. The polymer latex is usually formed directly by emulsion polymerization of the monomer and typically contains about 50 percent solids by weight. Polymer latexes are generally copolymer systems of at least two or more monomers with a possible addition of a plasticizer and other modifiers. Examples of polymers used in latexes are poly (vinyl acetate) (PVAc), polystyrene, polyvinyl chloride, natural rubber, and polybutadiene. Some general characteristics of latexes are shown in Table 2.4. Latex modified concretes are the oldest type of concrete composites which contain polymer and , at present , represent the large majority of commercial applications of polymer modified concrete in the United States. Their commercial success is most likely due to the fact that they can markedly improve the properties of ordinary concrete and mortar without requiring any significant changes in process technology. (1,2)

The variability of the polymer latex formulations makes comparisons between PPCC's difficult. Many investigators have not reported the exact polymer formulations, probably because this information was not available to them in most cases. The importance of the emulsification agent incorporated in the latex during its manufacture has usually not been considered. Nevertheless, a number of suitable latex formulations have been developed for commercial applications and are finding increasing use because they greatly improve the shear bond, tensile and flexural strength of cements and mortars compared to unmodified controls. [2]

2.3.2. Thermoplastics used as latexes

Polyvinyl esters were among the first polymer types to be evaluated for use in PPCC, but are susceptible to rapid alkaline degradation, forming acetic acid, carboxylic acids, and polyvinyl alcohol. The resulting PPCC, while possessing improved flexural and shear bond strength when dry, rapidly loses strength when wet because of the water solubility of polyvinyl alcohol. Polyacrylics are superior to polyvinyl esters in this respect. However, slow alkaline degradation necessitates dry curing and limited exposure to moist conditions in practical applications. Both polyvinyl esters and polyacrylics can show improved performace by the use of suitable copolymer formulations. [4,5]

Table 2.3

Glass Transition Temperature (Tg°C), of Co-Polymers

Co-Polymers	Tg°C	Co-Polymer	Tg°C
100% MMA	100	100% PS	93
90%MMA-10% DAP	185	60% PS-40% TMPTMA	213
70% MMA-30% TMPTMA	160	60% PS-40% Poly (acrylonitrile)	110

Table 2.4(1,2)

Typical Properties of Polymer Latexes for PPCC

Polymer Type	Poyvinyl Acetate	Styrene Butadiene	Acrylic	Poly (vinylidiene chloride)-PVC Copolymer (Saran)	Neoprene
Percent solids	50%	48%	46%	50%	42%
Stabilizer type	Nonionic	Nonionic	Nonionic	Nonionic	Nonionic
Specific gravity (25°C)	1.09	1.01	1.05	1.23	1.10
Weight per gallon (pounds &25°C)	9.21	8.4	8.8	10.25	9.3
PH	2.5	10.5	9.5	2.0	9.0
Particle size (°A)	N.A.	2.000[2]	N.A.	1.400	N.A.
Surface tension (dynes/cm^2 & 25°C)	N.A.	32[3]	40	33	40
Shelf life	N.A.	> 2 years	Excellent	6 months	N.A.
Freeze thaw stability (-15°C to 25°C)	N.A	5 cycles	5 cycles	None	N.A.
Viscosity (cps & 20°C)	17[4]	24	~ 250	~15	10

---

(1) 1b/gal = 119.8 Kg/m3 (2) °A =.1 nanometre (3) dyne/cm2 =.1 pascal

(4) Centipoise = millipascal - second

N.A. = Not Available

Polyvinyl chlorides have been evaluated. A specially formulated polyvinylidene chloride-PVC copolymer is commercially available.

Polystyrene does not appear to have been commonly used in PPCC as a homopolymer (synthetic elastomers). However, a thermoplastic styrene-butadiene latex promulation that affords improved durability and moisture resistance is commercially availalbe. (2,5)

2.3.3. Elastomeric latexes

Natural rubber latexes were one of the first polymers used to modify Portland systems. The relatively poor mechanical properties, however, have led to the development of PPCC Synthetic elastomers, such as acrylonitrile- butadiene, neoprene and styrene-butadiene. Synthetic rubber PPCC is more flexible, but has somewhat lower strength than thermoplastic PPCC. (5,6)

2.3.4 Polymer Solutions

Both thermosetting and thermoplastic water-soluble polymers of various kinds have been added to fresh concrete. The thermosetting polymers include epoxies, amino resins, polyesters, and formaldehyde derivatives. The thermoplastics include polyvinyl alcohol and polyacrylamides.

Work has been done in the USSR with water soluble polyorgano-siloxanes to improve strength and water-tightness of concrete. Water soluble polyelectrolytes such as polyacrylamide, polyacrylonitrile, polymethacrylic acid, polyvinyl acetate-maleic anhydride and polyisobutylene-maleic anhydride have been used to induce flocculation of the cement paste to improve reheological properties. Cellulose ethers and starch ethers have long been used in grouts, mortars, and concretes for improved water retention and cohesiveness during placing of the material. Such materials are more properly considered as admixtures. (3,9)

2.3.5 Monomers

Attempts to prepare PPCC by adding vinyl monomers directly to the wet mix, followed by a subsequent polymerization during or after the curing of the portland cement, have in general not been very successful . Some problems have been encountered in uniformly dispersing the monomers throughout the mix, as the organic monomers are essentially insoluble in water. Furthermore, these organic compounds frequently interfere with the hydration of cement and may also suffer slow alkaline degradation. Thus adequate strength is not obtained after polymerization. Extensive alkaline degradation has been found with MMA, A acrylamide, vinyl acetate and, to lesser extent zinc acrylate. Acrylontrile and styrene appear to be alkaline resistant and give improvements over unmodified controls.(13)

Furfuryl alcohol PPCC has been reported as promising in the Soviet Union, but it is reported as requiring up to 45 days of curing to develop full strength. This system has also been under limited study in the U.S.

2.3.6. Thermosetting Resins

A polyester formulation has been used in England to produce " Estercrete". A polymer/cement ratio of 0.3 or higher was used together with a water-soluble catalyst for the condensation reaction. When the system is mixed with water the catalyst is activated, polymerization occurs and cement hydrates. Such systems are very rapid setting, but with the high polymer loadings the system can be regarded as polyester filled with hydrated portland cement as well as hydrated portland cement paste filled with polyester.

The use of epoxy in concrete has been the subject of more recent research and develpment in several countries. Water-soluble epoxy resins have been developed in the USSR, while water- dispersible epxoy resins have been patented in Japan and have recently been developed in the United States. The recommended loading of 10-20 percent by weight of cement and partial replacement of epoxy by other thermosetting resins, such as phenolics, is possible.

Polyurethanes have been investigated for use in portland cement concrete and formulations have recently been patented, but not yet developed commercially. Phenol-formaldehyde and Urea-formaldehyde resins have been investigated by Russian workers, primarily as plasticizers.(12)

2.4 Polymer Concrete

2.4.1. Monomers and Resins

Most of the work on PC has been chiefly with polyester-styrene resin systems, and to a lesser extent with furan and epoxy and vinyl ester resin systems. The polyester resins are attractive because of moderate cost, availability of a great variety of formulations, and moderately good PC properties. The furan resins have been investigated in Europe, and are low cost, and highly resistant to chemical attack. The epoxy resins are generally somewhat higher in cost, but may offer some advantages such as adhesion to wet surfaces with specially formulated epoxies. Polyurethane concretes have been developed in Engand and are sold under the brand name " Ucrete". (1,2)

Low viscosity monomers, such as MMA and styrene, have been also investigated. They are easily mixed with aggregates, giving a mix which can be readily compacted into a dense PC of low porosity and relatively low polymer content. The low viscosity monomers also penetrate fractures and voids in the aggregate particles. PC made with an MMA-TMPTMA monomer system appears to have structural properties comparable to PIC and superior durability. (11,13)

2.4.2. Additives and Modifiers

2.4.2.1. Plasticizers.

PC has a greater ductility than either PIC or conventional concrete. Nevertheless, efforts have been made to further increase the ductility of PC through the addition of a plasticizer to the monomer. An example is the co-polymerization of methyl methacrylate with butyl acrylate as a plasticizer.

2.4.2.2. Flame Retardants.

Since a relatively small amount of polymer is actually present in PC, the composite is nonburning or self-extinguishing by standard flamability tests. It is probable that the loss of structural intgegrity in PC exposed to fire conditions may be more important than questions concerning the flamability of the material . PC appears to be essentially self-charring and flame retardants probably are not necessary, but nevertheless can be used as in the case of PIC. (11)

2.4.2.3. Coupling Agents

One of the most beneficial modifications to PC is the addition of silane coupling agents to the monomer system. The coupling agent serves to increase the interfacial bond between polymer and aggregate and hence increase the strength of the composite. Several techniques have been used for applying silane coupling agents to PC composites. The most practical technique is to add the compound directly to the monomer system prior to mixing, but the greatest strength is obtained when the aggregate is pretreated with the coupling agent. (12)

2.4.3. Polymerization

Most of the monomer and resin systems for PC are polymerized at room temperatures. The vinyl monomer systems can be polymerized with a variety of catalysts, but are most commonly polymerized using benzoyl peroxide with an amine promoter. The polyester-styrene systems likewise are polymerized with a similar variety of promoter-catalyst systems. The most common system is methylethyl ketone peroxide with cobalt napthanate promoter. These systems polymerize satisfactorily at room temperatures and the application of heat is not essential ; however, a final heat treatment may be used to ensure that the highest degree of conversion is obtained. Other room temperature systems include amine curing agents for epoxy resins. (6,13)

Gamma radiation from a cobalt-60 source also can be used for polymerization, as in PIC; but this method is less likely to find favor because of the availability and initial cost of radiation sources and the hazards involved in field applications.

CHAPTER 3

PROCESS TECHNOLOGY

3.1 Polymer Portland Cement Concrete (PPCC)

The process technology associated with PPCC is very similar to that of conventional portland cement concrete. Organic materials in either a powdery or dispersed form are added to the mixture during mixing. Because most organic polymers and their monomers are incompatible with a mixture of Portland cement, water, and aggregate, a review of PPCC process technology is in large measure an examination of how these basic incompatibilities are overcome. Extensive field experience has been gained with pre-mix polymerization (polymer Latex) but the problems anticipated for post-mix polymerization systems should be of a similar nature. (10,12)

3.1.1 Latex Modified Concretes

3.1.1.1 Materials.

The mix design of latex PPCC will vary in much the same way as do normal concretes and mortars, depending on the ends use application. The

materialsused in PPCC are the same materialsused in regular concrete except with the addition of the latexes. However,in no case, should air - entrained portland

cement, or air-entraining agents be used because polymer latexes entrain considerable amounts of air. In fact, anti-foaming agents are generally recommended to control excessive air entrainment . (9,12,13)

3.1.1.2 Mix Design Proportions

Standard concrete mix designs are normally employed when using polymeric latex systems . Normally the latexes are more effective in richer mixes containing over 500 1bs. of portland cement per cubic yard (297 kg/m^3) of concrete. Several typical mix designs for mortars and concretes which contain latexes are shown in Table 3.2 .

Polymer latexes generally act as water reducing agents , and the water content of the mix is reducing on a volume basis by the volume of the polymer.

3.1.1.3 Mixing and casting

Latex PPCC is prepared by the same method used for portland cement concrete . Experience has shown that very good mold release agents should be used. Care should be taken not to over vibrate the PPCC to prevent bringing excess water to the surface .(1,9)

3.1.1.4 Curing

The optimum curing of latex PPCC is different than that of ordinary concrete. In normal concrete, maximum properties are obtained by moist curing the concrete for as long a period of time as possible up to 28 days. This is detrimental in latex portland cement systems. By the incorporation of latexes in these systems, a material is added which requires a different curing mechanism, which is best achieved under the environment of less than 100 percent relative humidity. The optimum properties in latex -modified portland cement systems are obtained by moist curing the resulting concrete from 1 to 3 days followed by dry curing of the concrete at ambient conditions. The curing of latex PPCC may be accelerated by the use of heat. However, steam heat has been found to be detrimental to the gain in strength properties of these systems. The use of moist curing until after final set, followed by accelerated curing with dry heat, has proven to be an advantageous way of obtaining early strength properties . (1,9,10)

3.1.1.5 Toxicological Considerations

In general, latexes are not considered to be toxic materials. They are safe materials to handle and require only normal precautions in their use . In portland cement systems, the hazards of handling the portland cement itself are far more severe than those involved in the handling of the latexes. If latexes accidentally come in contact with the eyes, the eyes should be flushed with copious amounts of water for 15 minutes. It is then advisable to consult a physician. Repeated exposure of latex PPCC to the skin can cause mild irritation in much the same manner as conventional portland cement systems. Materials should be washed off the skin with water before they have set. Clothing contaminated with latex or post-latex polymer cement concrete should be washed prior to rewearing.

3.1.2 Water-Soluble Polymers

As the name implies, these polymers are added to the mixture in the form of a water solution during the mixing operation. Normal mixture proportion and batching procedures can be followed. The mechanism of combination of the water-soluble polyelectrolytes and liquid resins with cement differs from that described for latexes in that most of these polymers are thermosetting.The exception is polyvinyl alcohol which is a thermoplastic. Curing for the concrete usually involves some period of standard moist curing followed by curing at elevated temperatures. This can be achieved by hot air, hot water, or steam at either low or high pressures. (5)

The cellulose ethers and starch ethers form solutions with water that are very viscous, and the viscosity persists when the solutions are used to hydrate hydraulic cements. The viscosity is controlled within a range of 4 to 150 poises (0.4 to 15 Pa.s) by the selection of the appropriate polymer and by adjusting its concentration. The polymer is added to the mixture while in solution and normal mixing procedures are followed. No special curing is necessary. (5,7)

3.2 Polymer Concrete (PC)

The batching, mixing, and placing techniques for producing PC are largely based on adaptation of existing equipment and methods for producing portland cement concrete. A knowledge of polymer chemistry is helpful, but not absolutely essential, as directions for curing mixes are readily available from the resin manufacturers and from the published literature. Although the monomers are toxic and flammable, the use of well established safety procedures allows them to be used without undue difficulty. (5,6)

3.2.1 Monomer Resin Systems

Most of the work on PC has been with epoxy, polyester, and furan resins and more recently with MMA and styrene monomer systems. However, It is conceivable that many other resins could be used as well as many polymers through the use of solvent or fusion molding techniques. The important considerations in choice of the resin system include low cost, durability under anticipated exposure conditions, adhesion to aggregate, handling properties, and ease of curing.

3.2.2 Mix Design

The design of a PC mix to optimize the propeties of the resultant material is largely accomplished by aggregate gradation to give a void volume which will require minimal amounts of monomer or resin to fill the voids and to give good workability. In general, the aggregate should be dried to less than 2 percent moisture prior to use, although some epoxy resins are less affected by moisture and, therefore, the drying conditions are less stringent .

The major mix variables are maximum particle size, gradation, and composition. Crushed stone and natural sand and gravel aggregates are generally used, but finely divided materials, such as portland cement, powdered chalk, clay, fly ash, and silica flour, have also been incorporated as fillers and to improve workability of the mix. Test results indicate that aggregate type and composition do not signficantly influence the strength properties of the mix, but do affect the durability .(13)

Aggregate gradation and maximum particle size influence the amount of resin required to coat the filler particles and to fill the voids. Tests have indicated that for a well-graded aggregate, larger maximum particle sizes require less resin; also gap grading tends to reduce the amount of resin required. Conversely, smaller maximum particle sizes produce higher strength mixes. An aggregate size distribution developed at the USBR (US Bureau of Reclamation), which when mixed with 7 to 8 percent MMA produced specimens with compressive strength of ~19.000 psi (131.0 MPa) is given in Table 3.3. Dense binder mixes of the type used in asphalt concrete will produce composites with a strength of 13, 000 psi (89.6MPa) when mixed with 9 percent MMA. (13)

The monomer content of the mix, a dependent variable, is the minimum necessary to coat the aggregate and to fill the voids. Excess monomer will bleed to the surface due to the low density relative to the density of the aggregate .

Monomer concentrations ranging from 5 to 30 weight percent , depending on void volumes, have been reported. The lowest loading were obtained in pipe when a compaction method which involved pressure, vibration, and centrifugal force was used in conjunction with a graded aggregate and filler . (11,13)

3.2.3 Fabrication Methods

Conventional mixing equipment may be used for PC. The use of some resin systems, such as polyesters and epoxies, may present some cleaning problems that do not exist with MMA, which is an exellent solvent and will tend to evaporate before it will polymerize in the mixer. However, volatile and potentially explosive monomers, such as MMA, will require nonsparking and explosion-proof equipment. Mixing should be done in a closed system or outdoors in a well-ventilated area. Some of the chemicals may be irritants or toxic and should be handled in accordance with recognized safe practices.

The PC mix is cast into forms or molds in a manner similar to conventional concrete. Wood, steel, glass, and paper molds have all been used successfully. A great variety of mold-releasing agents have also been used , such as silicone gels, vegetable oils. automobile wax , and paraffins .

After placing, the mix should be consolidated by external vibration, rodding, mechanical pressure, or application of vacuum to remove entrapped air.

The harshness of some mixes may prohibit the use of internal vibrators, in some cases, but in other cases with well-graded mixes, internal vibrators work very well. (1,11)

Curing of the PC may be performed by radiation, thermal-catalytic, or catalyst-promoter methods. Catalysts and promoters are added to the monomer prior to mixing with the aggregate. Curing times may be varied between a few minutes and several hours. Full strength is attained when polymerization is completed . (1,11,13)

Table 3.1

Typical Mix Designs for latex Modified Mortars and Concretes (1,9)

Mortar

	Resurfacing Mortar	Underlayment mortar
Sand	250-350 pounds[1]	200-250 pounds
Portland cement	1 bag (94 pounds)	1bag(94pounds)
Latex solids[2]	10-20 pounds	10 pounds
Water[3]	50-40 pounds	40-50 pounds
Concrete		
Stone m 3/4-inch maximum	2,240 pounds	1,960 pounds
Sand	1,160 pounds	840 pounds
Portland cement	580 pounds	825 pounds
Latex solids (5-15%)[2]	30-90 pounds	40-125 pounds
water[3]	250-200 pounds	380-300 pounds

(1) pound = 0.454 kg

(2) The latex should be formulated with an antifoamer prior to adding it to the mix .

(3) Total water including the water in the latex and the sand .

Table 3.2

Aggregate Gradation for PC (1,3)

Sieve size	Percent retained
Pan	15.2
100	5.8
50	8.8
30	9.2
16	5.5
8	5.5
4 to 3/8-in .[1]	20
3/8 to 3/4	30

(1) in = 25.4 mm

CHAPTER 4

Experimental Program

4.1 Introduction

The availability of durable and economic construction materials is a serious problem in the development and growing of the world. In an attempt to solve this problem, a research program to develop strong, durable and economic building materials has been in progress at many interested institutes and committees. The goals of the program were studied very carefully in order to determine the most accurate and shortest way of research.

In this program many materials were tested and studied among which are polymers regardless of their chemical compounds or origin;i.e: organic or inorganic. Using those materials (Polymers) in producing our target of durable and economic building materials seems to be not so easy, especially if we don't know how to optimize their composition to get the best results.

Our program was to study the effect of some polymers on ordinary portland cement concrete and pozzolanic cement concrete; also to investigate a relatively new building or repairing material ; that is polymer concrete.

4.2. Polymer Concrete (PC)

4.2.1. General

Polymer concrete (PC) is produced by using polymer as a binder for the aggregate instead of cement. A wide range of aggregates and monomers may be used although the cost and properties of the PC may be strongly influenced by the gradation of aggregate and monomer type. The significant advantages of rapid setting and high strength have resulted in the use of this material for repair of bridge decks, highways, pipe lines and structures under various temperature and loading conditions.

4.2.2. Materials Tested

- Unsaturated polyester.
- Styrene.
- Benzoyl Peroxide
- Sweileh Sand.
- Aggregate of 4.75mm size.

4.2.3.Methodology

Two types of polymer concrete (PC) were created and tested using the same polymer (unsaturated polyester and styrene) and two types of aggregate (well-graded and gap-graded aggregates). The two types were prepared as follows:

1- Sweileh sand whose maximum particle size is about 1.18 mm , was used to prepare polymer concrete with well-graded aggregate, while crushed limestone aggregate whose maximum size is 4.75 mm was added to Sweileh sand in order to get gap- graded aggregate.

2. Special trays of dimensions 400 * 200 * 30 mm and cylinders of 40-mm diameter and 80-mm height were used as molds.
3. Aggregate and polymer were hand -mixed untill all aggregate particles are very well coated by polymer.
4. Mold-releasing agents are of great importance in order to prevent adhesion of polymer to the molds and to make demolding much easier, so aluminum foil was used for that purpose.
5. Polymer concrete was then molded and compacted by the compression machine up to 0.8 MPa.
6. Molded polymer concrete is then cured by relative high temperature (100°C) for about five hours.
7. For flexural test, small beam specimens of 100 * 20 * 20 mm were cut off from the specimen molded in the tray and tested by a special testing machine while, the cylindrical specimens were used for the compressive test.
8. The quantity of Benzoyl Peroxide added was 3% by the weight of polyester.

4.2.4 Tests Performed

In fact many tests were performed on polymer concrete; namely:

1. Flexural Test.
2. Compressive Test. (neither water nor cement is added)
3. Effect of moisture content on the compressive strength of polymer concrete.
4. Effect of cement content on the compressive strength of polymer concrete.
5. Absorption of water by polymer concrete with varying polymer content.
6. Effect of temperature on the strength of polymer concrete.

4.3. Polymer Portland cement concrete (PPCC)

4.3.1 General

PPCC has been of considerable interest to researchers and users because of the similarity to current concrete technology. PPCC is prepared by adding one of the monomers or polymers to the fresh conventional concrete mix.

Many types of monomers and polymers are used successfully with PPCC among which are: polymer latexes, elastomeric latexes, thermosetting resins, epoxies, ...etc.

Latex modified concrete (PPCC in which polymer is latex) has been developed and used for many years for overlaying deteriorated bridge decks. It is also used for producing prefabricated brick panels which have sufficient strength for handling.

4.3.2. Materials Tested:

- Polyvinylacetate homopolymer
- Polyvinylacetate copolymer
- Conventional portland cement concrete.

4.3.3. Methodology

Two types of polymer Portland Cement concrete were produced and tested; those are:

- Conventional Portland cement concrete with polyvinylacetate homopolymer.
- Conventional Portland cement concrete with polyvinylacetate copolymer.

Both of the two types of (PPCC) were produced and tested in the same manner with varying type of polymer:

1- The selected polymer was added to a fresh mix of ordinary portland cement Conrete.

2- The used concrete mix was of :

  - W/C = 0.55
  - Cement : Fine aggregate : Coarse aggregate = 1 : 2 : 4 (by weight).

3. Molds used were :

   a. Beams of 750 * 150 mm* 150 mm; for flexural test.

   b. Cubes of 150 mm side ; for compressive test.

4. Specimens were then moist-cured for three days before curing in the air.
5. All specimens were then tested following ASTM Standards.
6. Different polymer contents were considered as ratios with respect of cement contents (P/C).

4.3.4. Mix Design

The fresh concrete mix was perpared conventionally :

1. Cement content was 30 Kg for eash mix .
2. Absorption of water by the used aggregates was found to be 6.5% by weight of the aggregate .
3. A quantity of water equals that absorped by the aggergate was added to compensate the concrete mix for the amount absorped .
4. Maintaining a constant liquid/ cement ratio when adding the polymer was achieved by considering the additional water content in the polymer (50% of the polymer is water) ; the liquid is the total amount of water and polymer emulsion (Table 4.1) .

4.3.5. Tests Performed

Only the main two tests were performed; those are :

1. Flexural Test.
2. Compressive Test.

4.4. Polymer Pozzolanic Portland Cement Concrete (PPPCC)

Polyvinylacetate homopolymer was added to the conventional pozzolanic portland cement concrete in different quantities, then it was tested the same as (PPCC).

4.5 Standards:

In fact, no specific standards are to be followed when testing polymer concrete because the subjects still on test, while ASTM standards were followed when dealing with PPCC or PPPCC especially in mixing and testing. Curing can be considered as variable to be optimized; in other words, curing can be done in various methods and then the best method will be recommended.

ASTM Standards were considered when calculating modulus of rupture for PPCC, PPPCC and PC. These standards state that;

$$M = PL / bd^2$$

where:

M: Modulus of rupture (MPa)

P : Strength (N)

L : Length of beam tested (mm)

b: Width of beam tested (mm)

d: Depth of beam tested (mm)

4.6. Specimens Tested

4.6.1. Polymer Pozzolanic Portland Cement concrete (PPPCC)

Six P/C ratios were considered when testing PPPCC for both the compressive strength and the modulus of rupture (from 0.00 to 0.25), also the tests were performed at three different ages (14,21 and 28 days); three specimens for each P/C ratio (for both the compressive strength and the modulus of rupture) were examined at the same age, then the average of the results of the three specimens was considered:

- Compressive Test :

  54 Cubes of 150 mm side.

- Flexural Test :

  54 beams of 750 * 150 * 150 mm.

4.6.2. Polymer Portland Cement concrete (PPCC)

The same technique of PPPCC was followed when testing PPCC (with PVAh and PVAc) taking into consideration that it was (PPCC) tested at four different ages (7,14,28 and 56 days) :

- Compressive strength:

  72 cubes of 150 mm side.

- Modulus of rupture:

  72 beams of 750 * 150 * 150 mm.

(The same number of specimens were prepared for both PPCC with PVAh and that with PVAc).

4.6.3. Polymer concrete (PC)

The polymer content in PC (P/A) was varied ten times (from 0,06 to 0.24) for both PC's with well-graded sand and gap-praded aggregate; three specimens were prepared at each P/A ratio (for both the compressive strength and the modulus of rupture), then the average of the results of the three specimes was considered. PC with gap- graded aggregate was not workable at P/A = 0.06 and so nine values of P/A were considered in this type of PC.

- Compressive strength

  57 Cylinders of 80 - mm height and 40-mm diameter.

- Modulus of rupture

  57 Beams of 100 * 20 * 20 mm

- Effect of temperature

  9 Cylinders 9 Beams

- Absorption of water

  5 Cylinders

- Effect of water content

  6 Cylinders

- Effect of cement content

  8 Cylinders

(All cylinders are of the same dimensions)

Table 4.1 Mix Design of PPPCC and PPCC

P/C	Cement Content Kg	Polymer Content Kg	water in polymer Kg	Total amount of water Kg	W/C
0.00	30	0.0	0.00	16.5	0.550
0.05	30	1.5	0.75	15.75	0.525
0.10	30	3.0	1.50	15.00	0.500
0.15	30	4.5	2.25	14.25	0.475
0.20	30	6.0	3.00	13.50	0.450
0.25	30	7.5	3.75	12.75	0.425

N.B :

An additional amount of water that was absorbed by the aggregate (11.7 Kg) was added to each mix in addition to the above mentioned amounts .

CHAPTER 5

Analysis of Results

5.1 Introduction

The main objective of this study was to optimize the polymer content to be incorporated into conventional concrete to get modified concrete which possesses higher structural strength and better quality. Also the objective of the experiments was to optimize the conditions of the concrete which is of great importance and is useful especially for repairing purposes.

5.2. Polymer Pozzolanic Portland Cement Concrete (PPPCC)

In order to understand the behavior of PPPCC, it is important to vary P/C ratio (Polymer content by weight of cement) and study the properties of PPPCC for each P/C ratio while keeping all other conditions constant. By so doing, it is possible to optimize P/C ratio which yields the best results.

5.2.1. Workability

Workability was measured by the slump for each P/C ratio (Table 5.1). It was found that the polymer increases workability of modified concrete in a linear manner (Figure 5.1) although water was progressively replaced by the polymer while maintaining a constant (liquid/cement) ratio. The liquid is the total amount of water and polymer emulsion.

5.2.2 Compressive Strength

In the study of latex systems of polyvinyl acetate homopolymer (PVAh), it was found that the presence of PVAh results in a significant decrease in the compressive strength of PPPCC (Figure 5.8), while the rate of gaining that strength by age was not affected by polymer (Figures 5.2, 5.3, 5.4, 5.5, 5.6 and 5.7).

Decrease in compressive strength can be explained by inteferrence between hydraiion of cement and PVAh which is degraded by alkalines in cement.

5.2.3. Modulus of Rupture

It was also noted that the modulus of rupture of PPPCC decreased as a result of incorporation of PVAh into' conventional pozzolanic concrete mix (Tables 5.9, 5.10,5.11, 5.12 and 5.13). A general function for that decrease (Figure 5.9) can't be easily determined. It is also possible to say that the rate of gaining of flexural strength as represented by the modulus of rupture was not significantly influenced by introducing PVAh into the concrete mix (Figures 5.2, 5.3, 5.4, 5.5, 5.6 and 5.7).

5.3. Polymer Portland Cement Concrete (PPCC)

Polymer Portland cement concrete has been prepared with both polyvinylacetate homopolymer (PVAh) and polyvinylacetate-veova copolymer (PVAc). The general behavior of PPCC with PVAh is similar to that of PPPCC taking into consideration the differences between ordinary Portland cement concrete and pozzolanic Portland cement concrete; e.g: setting time, rate of gaining strength, ...etc. (Figures 5.10 to 5.15).

From (Figure 5.17), it is noted that the relationship between modulus of rupture of PPCC with PVAh and P/C seems to be linear and the effect of polymer decreases by age (same points at P/C = 0.20).

PPCC with PVAc was noted to behave in different manner for both compressive strength and modulus of rupture:

5.3.1. Compressive Strength

Compressive strength of PPCC seems to have an optimum value of 35.1 MPa where P/C is 0.15 at age of 56 days, while the compressive strength is 26.3 MPa at P/C = 0.00 at the same age , which means that there is an increase in strength of a bout 33% due to introducing PVAc into conventional concrete by 15% of the cement weight.

The general behavior of PPCC with varying PVAc content is unchanged throughout different ages; the curves are nearly parallel (Figure 5.24).

5.3.2 Modulus of rupture

(Figure 5.25) gives an idea about the relationship between the modulus of rupture and P/C; modulus of rupture has an optimum value of 8.2 MPa at P/C= 0.20 (at age of 56 days) while it is (modulus of rupture) 4.8 MPa at P/C = 0.00 ; in other words, adding PVAc to conventional concrete mix by about 20% of cement weight yields an increase in the moulus of rupture by about 71%.

Also it was found that the increase in modulus of rupture is a function of polymer content, while rate of agining of that modulus is not affected by polymer (Figures 5.18 to 5.23).

Workability of PPCC with PVAc was also noted to be the same as that of PPCC with PVAh ; latex whose continuous phase is water was found to have the same effect upon workability regardless of its chemical compound.

5.4 Polymer concrete (PC)

In PC, the crosslinked polymer; polyester-styrene, was to replace portland cement as the binder in a concrete mix. Since the polymer constitutes the continuous phase, behavior of polymer concrete will clearly be determined by the polymer whose properties are dependent on time and temperature.

5.4.1 Compressive Strength

5.4.1.1 PC made with well-graded sand

Polymer content by weight of aggregate (P/A) was varied for the same type of aggregate (Sweileh sand) in order to determine the quantity of resin required to coat all the particles of sand and get workable concrete. That enough quantity can be determined as shown in Figure 5.26 ; it is clear that the maximum compressive strength of 40.9 MPa is obtained at P/A = 0.12, while after that limit of 0.12, the compressive strength starts to decrease gradually because the excess resin causes a concrete mix with high water content.

5.4.1.2. PC made with gap-graded aggregate

When using gap-graded aggregate or aggregate of large particle size, two points are to be considered;

1. Volume of voids is greater than that of well-graded aggregate.
2. Particle size is larger which means that a larger quantity of resin is required to coat all the particles.

With reference to Figure 5.27, it is evident that the compressive strength has an optimum value of 33.1 MPa at P/A = 0.18. The peak compressive strength required a larger quantity of resin although its value is less than that of concrete made with well-graded sand.

The rate of increase in the compressive strength by increasing P/A (before reaching the optimum value) seems to be the same for both concretes made with well-graded sand and gap-graded aggregate.

5.4.2. Modulus of Rupture

5.4.2.1. PC made with well-graded Sand

The rate of increase in the modulus of rupture by increasing the polymer content (P/A) is less than that of increase in compressive strength, while modulus of rupture is more affected by resin.

Also modulus of rupture has a peak value of 13.4 MPa at P/A= 0.14 (Figure 5.26) (which is less than that of the optimum compressive strength), in other words PC reaches its optimum modulus of rupture before that of compressive strength.

5.4.2.2 PC Made with gap-graded aggregate.

That type of PC has an optimum modulus of rupture of 12.5 MPa at P/A = 0.16

(Figure 5.27). Which is less than that of PC made with well graded sand.

5.5. Tests Performed on PC made with well-graded sand

5.5.1. Effect of water content

Many samples of PC were prepared by varying the water content (from 0 to 5% by weight of sand) while keeping polymer content constant at 10%, then those samples were examined for compressive strength (Table5.43).

Figure (5.28) shows that increasing the water content by 1%, decreases the compressive strength of PC by about 20%; this is because water dilutes the resin and causes weaker bonds.

5.5.2 Effect of cement as filler

The results tabulated in Table (5.44) indicate that using cement as a portion of filler used will yield an increase in the compressive strength to a certain limit, then any increase in the quantity of cement will cause a derease in the compressive strength.

The optimum cement content as shown in Figure (5.29) was found to be 0.08 (cement/sand ratio); the increase in the compressive strength is due to hydration of cement by a certain portion of the water in the polymer, also cement added will fill the voids between sand particles which makes it much easier for resin to cover all the particles of sand.

5.5.3. Absorption of water

Absorbtion of water was measured after one day of soaking the samples in water. The results show that the relationship between absorption of water and polymer content is inversely proportional (Figure 5.30).

5.5.4. Effect of Temperature

Both the compressive strength and the modulus of rupture are affected by temperature. A test was performed to study that effect by varying temperature and then measuring the compressive strength and the modulus of rupture (Table 5.46). It seems that both of the properties behave in the same manner by increasing temperature (Figure 5.32).

Each polymer has a certain temperature of degradation, and so increasing the temperature may cause polymer degradation which finally destroys the links between monomers and get that polymer out of use as a resin; viscosity of that polymer decreases.

This test was performed after the complete polymerization is assured; the polymerization was achieved by thermal curing (at 100 °C for about five hours) . The specimens were heated in special ovens for about three hours and then they were tested directly before cooling .

Table 5.1:Workability of PPCC (measured by slump) as a function of polymer content .

Polymer content by weight of Cement (%)	Slump (mm)
0	15
5	18
10	19
15	21
20	23
25	27

Table 5.2 : Compressive strength of pozzolanic Portland cement concrete as a function of age .

Type of Cement Type of Polymer P/C	Pozzolanic Portland Polyvinyl acetate-homopolymer 0.000

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av.Comp. strength (MPa)	Standard deviation (σ)
14	1 2 3	474 482 466	21.1 21.4 20.7	21.1	0.35
21	1 2 3	496 513 504	22.1 22.8 22.4	22.4	0.35
28	1 2 3	540 536 547	24.0 23.8 24.3	24.1	0.25
–	–	–	–	–	–

Table 5.3 : Compressive strength of PPPCC made with PVAh as a function of age (P/C=0.05)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.05

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av.Comp. strength (MPa)	Standard deviation (σ)
	1	390	17.3		
14	2	404	18.0	17.9	0.51
	3	411	18.3		
	1	450	20.0		
21	2	433	19.3	19.4	0.51
	3	427	19.0		
	1	473	21.2		
28	2	462	20.5	21.0	0.40
	3	479	21.3		
–	–	–	–	–	–

Table 5.4 : Compressive strength of PPPCC made with PVAh as a function of age (P/C=0.10)

Type of Cement Type of Polymer P/C	Pozzolanic Portland Polyvinyl acetate-homopolymer 0.10

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av.Comp. strength (MPa)	Standard deviation (σ)
14	1	350	15.6	15.0	0.57
	2	333	14.8		
	3	327	14.5		
21	1	363	16.1	16.7	0.57
	2	381	16.9		
	3	386	17.2		
28	1	391	17.4	17.9	0.46
	2	417	18.5		
	3	401	17.8		
–	–	–	–	–	–

Table 5.5 : Compressive strength of PPPCC made with PVAh as afunction of age (P/C=0.15)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.15

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av.Comp. strength (MPa)	Standard deviation (σ)
14	1	251	11.2	10.8	0.45
	2	244	10.8		
	3	232	10.3		
21	1	278	12.4	12.3	0.60
	2	289	12.9		
	3	263	11.7		
28	1	318	14.1	14.4	0.36
	2	321	14.3		
	3	332	14.8		
–	–	–	–	–	–

Table 5.6 : Compressive strength of PPPCC made with PVAh as a function of age P/C=0.20)

Type of Cement Type of Polymer P/C	Pozzolanic Portland Polyvinyl acetate-homopolymer 0.20

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av.Comp. strength (MPa)	Standard deviation (σ)
14	1	197	8.8	8.5	0.36
	2	191	8.5		
	3	181	8.1		
21	1	227	10.1	9.6	0.48
	2	212	9.4		
	3	206	9.2		
28	1	267	11.9	11.8	0.26
	2	270	12.0		
	3	259	11.5		
–	–	–	–	–	–

Table 5.7 : Compressive strength of PPPCC made with PVAh as a function of age (P/C=0.25)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.25

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av.Comp. strength (MPa)	Standard deviation (σ)
14	1	158	7.0	6.6	0.36
	2	142	6.3		
	3	146	6.5		
21	1	184	8.2	8.6	0.38
	2	197	8.8		
	3	199	8.9		
28	1	216	9.6	10.0	0.48
	2	221	9.8		
	3	237	10.0		
–	–	–	–	–	–

Table 5.8 : Modulus of rupture of Pozzolanic portland Cement Concrete as a function of age.

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.00

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av Mod. of rupture (MPa)	Standard deviation (σ)
14	1 2 3	16.4 16.9 17.6	3.4 3.5 3.7	3.5	0.15
21	1 2 3	20.3 21.2 19.4	4.2 4.4 4.1	4.2	0.15
28	1 2 3	20.7 20.1 21.6	4.3 4.2 4.5	4.3	0.15
–	–	–	–	–	–

Table 5.9 : Modulus of rupture of PPPCC made with PVAh as a function of age (P/C = 0.05)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.05

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av Mod. of rupture (MPa)	Standard deviation (σ)
14	1	13.9	2.9	2.9	0.06
	2	14.3	3.0		
	3	14.0	2.9		
21	1	14.7	3.1	3.0	0.12
	2	14.1	2.9		
	3	14.0	2.9		
28	1	14.9	3.1	3.1	0.10
	2	14.3	3.0		
	3	15.2	3.2		
–	–	–	–	–	–

Table 5.10 : Modulus of rupture of PPPCC made with PVAh as a function of age (P/C = 0.10)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.10

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
14	1	13.9	2.9	3.0	0.10
	2	14.4	3.0		
	3	14.9	3.1		
21	1	14.9	3.1	3.1	0.06
	2	14.4	3.0		
	3	14.8	3.1		
28	1	15.3	3.2	3.2	0.10
	2	15.8	3.3		
	3	14.7	3.1		
–	–	–	–	–	–

Table 5.11 : **Modulus of rupture of PPPCC made with PVAh as a function of age (P/C = 0.15)**

Type of Cement Type of Polymer P/C	Pozzolanic Portland Polyvinyl acetate-homopolymer 0.15

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
14	1	9.4	1.9	2.1	0.15
	2	9.9	2.1		
	3	10.4	2.2		
21	1	11.1	2.3	2.3	0.10
	2	11.7	2.4		
	3	10.6	2.2		
28	1	12.0	2.5	2.3	0.15
	2	11.2	2.3		
	3	10.7	2.2		
–	–	–	–	–	–

Table 5.12 : Modulus of rupture of PPPCC made with PVAh as a function of age (P/C = 0.20)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.20

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av Mod. of rupture (MPa)	Standard deviation (σ)
14	1	8.0	1.7	1.7	0.06
	2	8.4	1.8		
	3	8.1	1.7		
21	1	9.1	1.9	2.0	0.10
	2	9.6	2.0		
	3	9.9	2.1		
28	1	9.4	2.0	2.1	0.18
	2	9.7	2.1		
	3	10.3	2.2		
–	–	–	–	–	–

Table 5.13 : **Modulus of rupture of PPPCC made with PVAh as a function of age (P/C = 0.25)**

Type of Cement Type of Polymer P/C	Pozzolanic Portland Polyvinyl acetate-homopolymer 0.25

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av Mod. of rupture (MPa)	Standard deviation (σ)
14	1	6.7	1.4	1.4	0.10
	2	6.1	1.3		
	3	7.1	1.5		
21	1	7.6	1.6	1.6	0.10
	2	8.2	1.7		
	3	7.2	1.5		
28	1	8.3	1.7	1.6	0.06
	2	7.8	1.6		
	3	7.4	1.6		
–	–	–	–	–	–

Table 5.14: Compressive strength of Portland cement concrete as a function of age .

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.00

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
7	1	364	16.2	15.7	0.42
	2	351	15.6		
	3	346	15.4		
14	1	477	21.2	21.6	0.35
	2	491	21.8		
	3	490	21.8		
28	1	553	24.6	24.5	0.50
	2	541	24.0		
	3	562	25.0		
56	1	592	26.3	26.3	0.35
	2	601	26.7		
	3	584	26.0		

Table 5.15: Compressive strength of PPCC made with PVAh as a function of age (P/C = 0.05)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.05

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
7	1	301	13.4	13.8	0.35
	2	311	13.8		
	3	317	14.1		
14	1	410	18.2	18.2	0.35
	2	401	17.8		
	3	417	18.5		
28	1	443	19.7	20.2	0.46
	2	457	20.3		
	3	463	20.6		
56	1	457	20.3	20.3	0.46
	2	466	20.7		
	3	446	19.8		

Table 5.16: Compressive strength of PPCC made with PVAh as a function of age (P/C=0.10)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.10

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
7	1	238	10.6	10.2	0.48
	2	229	10.2		
	3	217	9.7		
14	1	351	15.6	16.1	0.46
	2	372	16.5		
	3	346	16.2		
28	1	414	18.4	18.4	0.35
	2	406	18.0		
	3	421	18.7		
56	1	432	19.2	19.3	0.35
	2	444	19.7		
	3	427	19.0		

Table 5.17: Compressive strength of PPCC made with PVAh as a function of age (P/C = 0.15)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.15

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
7	1	160	7.1	6.7	0.35
	2	151	6.7		
	3	144	6.4		
14	1	257	11.4	11.3	0.42
	2	242	10.8		
	3	262	11.6		
28	1	340	15.1	14.7	0.41
	2	331	14.7		
	3	321	14.3		
56	1	385	17.1	17.0	0.46
	2	392	17.4		
	3	371	16.5		

Table 5.18: Compressive strength of PPCC made with PVAh as a function of age (P/C = 0.20)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.20

Age (Days)	Cube no.	Strength (kN) P	Comp. Strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
7	1	115	5.1	5.1	0.26
	2	107	4.8		
	3	119	5.3		
14	1	209	9.3	9.5	0.21
	2	217	9.6		
	3	219	9.7		
28	1	272	12.1	12.1	0.48
	2	264	11.7		
	3	283	12.6		
56	1	295	13.1	13.4	0.30
	2	301	13.4		
	3	306	13.7		

Table 5.19: Compressive strength of PPCC made with PVAh as a function of age (P/C = 0.25)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.25

Age (Days)	cube no.	Strength (kN) P	Comp. Strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
7	1	104	4.6	4.6	0.26
	2	109	4.9		
	3	98	4.4		
14	1	140	6.2	6.6	0.41
	2	151	6.7		
	3	157	7.0		
28	1	250	11.1	11.1	0.30
	2	256	11.4		
	3	244	10.8		
56	1	275	12.2	12.5	0.36
	2	282	12.5		
	3	291	12.9		

Table 5.20 : Modulus of rupture of Portland cement concrete as a function of age .

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.00

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. mod. of rupture (MPa)	Standard deviation (σ)
7	1	10.1	2.1	2.1	0.16
	2	9.6	2.0		
	3	11.1	2.3		
14	1	16.4	3.4	3.6	0.15
	2	17.1	3.6		
	3	17.6	3.7		
28	1	21.2	4.4	4.4	0.15
	2	20.6	4.3		
	3	22.1	4.6		
56	1	23.1	4.8	4.8	0.10
	2	23.7	4.9		
	3	22.9	4.7		

Table 5.21: Modulus of rupture of PPCC made with PVAh as a function of age (P/C = 0.05)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.05

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
7	1	7.7	1.6	1.8	0.16
	2	8.9	1.8		
	3	9.2	1.9		
14	1	14.0	2.9	2.9	0.06
	2	14.6	3.0		
	3	13.8	2.9		
28	1	17.4	3.6	3.8	0.15
	2	18.1	3.8		
	3	18.7	3.9		
56	1	19.3	4.0	4.1	0.10
	2	20.1	4.2		
	3	19.6	4.1		

Table 5.22: Modulus of rupture of PPCC made with PVAh as a function of age (P/C = 0.10)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.10

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
7	1	7.2	1.5	1.7	0.21
	2	8.8	1.8		
	3	9.2	1.9		
14	1	12.5	2.6	2.6	0.10
	2	13.1	2.7		
	3	12.2	2.5		
28	1	15.4	3.2	3.0	0.21
	2	14.1	2.9		
	3	13.6	2.8		
56	1	14.9	3.1	3.2	0.16
	2	15.7	3.3		
	3	16.2	3.4		

Table 5.23: Modulus of rupture of PPCC made with PVAh as a function of age (P/C = 0.15)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.15

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
7	1	6.3	1.3	1.5	0.16
	2	7.1	1.5		
	3	7.5	1.6		
14	1	11.1	2.3	2.3	0.15
	2	11.9	2.5		
	3	10.6	2.2		
28	1	12.1	2.5	2.5	0.10
	2	11.8	2.4		
	3	12.5	2.6		
56	1	12.1	2.5	2.6	0.10
	2	12.9	2.7		
	3	12.6	2.6		

Table 5.24: Modulus of rupture of PPCC made with PVAh as a function of age (P/C = 0.20)

Type of Cement Type of Polymer P/C	Pozzolanic Portland Polyvinyl acetate-homopolymer 0.20

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
7	1	5.8	1.2	1.3	0.11
	2	6.9	1.4		
	3	6.7	1.4		
14	1	8.7	1.8	2.0	0.15
	2	9.6	2.0		
	3	10.2	2.1		
28	1	10.1	2.1	2.1	0.06
	2	10.7	2.2		
	3	10.1	2.1		
56	1	10.1	2.1	2.1	0.16
	2	11.0	2.3		
	3	9.7	2.0		

Table 5.25: Modulus of rupture of PPCC made with PVAh as a function of age (P/C = 0.25)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.25

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
7	1	5.8	1.2	1.3	0.10
	2	6.3	1.3		
	3	6.6	1.4		
14	1	7.2	1.5	1.5	0.10
	2	7.7	1.6		
	3	6.6	1.4		
28	1	7.7	1.6	1.7	0.10
	2	8.1	1.7		
	3	18.5	3.9		
56	1	8.2	1.7	1.8	0.10
	2	8.8	1.8		
	3	9.1	1.9		

Table 5.26 : Compressive strength of PPCC made with PVAc as a function of age (P/C= 0.05)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.05

Age (Days)	Cube no.	Strength (kN) P	Comp. strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
7	1	396	17.6	17.6	0.71
	2	411	18.3		
	3	381	16.9		
14	1	556	24.7	24.6	0.69
	2	541	24.0		
	3	572	25.4		
28	1	635	28.2	28.5	0.36
	2	641	28.5		
	3	650	28.9		
56	1	684	30.4	30.3	0.51
	2	692	30.8		
	3	671	29.8		

Table 5.27 : Compressive strength of PPCC made with PVAc as a function of age (P/C= 0.10)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.10

Age (Days)	Cube no.	Strength (kN) P	Comp. strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
7	1	428	180	19.0	0.36
	2	437	19.4		
	3	421	18.7		
14	1	599	26.6	26.6	0.41
	2	607	27.0		
	3	597	26.4		
28	1	684	30.4	30.4	0.51
	2	672	29.9		
	3	650	28.9		
56	1	727	32.3	32.4	0.37
	2	739	32.8		
	3	722	32.1		

Table 5.28 : Compressive strength of PPCC made with PVAh as a function of age (P/C= 0.15)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.15

Age (Days)	Cube no.	Strength (kN) P	Comp. strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
	1	466	20.7		
7	2	462	20.5	20.7	0.20
	3	471	20.9		
	1	648	28.8		
14 2		655	29.1	28.7	0.36
	3	640	28.4		
	1	738	32.8		
28	2	727	32.3	32.9	0.65
	3	751	33.4		
	1	788	35.0		
56	2	775	34.4	35.1	0.66
	3	804	35.7		

Table 5.29 : Compressive strength of PPCC made with PVAc as a function age (P/C=0.20)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.20

Age (Days)	Cube no.	Strength (kN) P	Comp. strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
7	1	432	19.2	19.3	0.46
	2	443	19.7		
	3	423	18.8		
14 2	1	594	26.4	26.5	0.51
		607	27.0		
	3	585	26.0		
28	1	700	31.1	31.2	0.82
	2	684	30.4		
	3	719	32.0		
56	1	736	32.7	32.0	1.21
	2	751	33.4		
	3	722	32.1		

Table 5.30 : Compressive strength of PPCC made with PVAc as a function of age (P/C = 0.25)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.25

Age (Days)	Cube no.	Strength (kN) P	Comp. strength (MPa)	Av. Comp. Strength (MPa)	Standard deviation (σ)
7	1	416	18.5	18.6	0.17
	2	422	18.8		
	3	417	18.5		
14	1	569	25.3	25.2	0.41
	2	577	25.6		
	3	558	24.8		
28	1	655	29.1	29.0	0.27
	2	646	28.7		
	3	657	29.2		
56	1	702	31.2	31.3	0.46
	2	716	31.8		
	3	691	30.7		

Table 5.31 : Modulus of rupture of PPCC made with PVAc as a function of age (P/C=0.05)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.05

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
7	1	10.1	2.1	2.5	0.36
	2	12.1	2.5		
	3	13.5	2.8		
14	1	20.7	4.3	4.5	0.57
	2	24.6	5.1		
	3	19.3	4.0		
28	1	28.9	6.0	5.3	0.66
	2	25.6	5.3		
	3	22.7	4.7		
56	1	27.0	5.6	5.6	0.26
	2	28.5	5.9		
	3	26.0	5.4		

Table 5.32 : Modulus of rupture of PPCC made with PVAc as a function of age (P/C=0.10)

Type of Cement Type of Polymer P/C	Pozzolanic Portland Polyvinyl acetate-homopolymer 0.10

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
7	1	14.5	3.0	3.0	0.16
	2	13.5	2.8		
	3	15.0	3.1		
14	1	23.6	4.9	4.7	0.15
	2	22.7	4.7		
	3	22.2	4.6		
28	1	28.0	5.8	5.8	0.46
	2	26.0	5.4		
	3	30.4	6.3		
56	1	29.9	6.2	6.3	0.57
	2	33.3	6.9		
	3	28.0	5.8		

Table 5.33 : Modulus of rupture of PPCC made with PVAc as a function of age (P/C=0.15)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.15

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
7	1	14.0	2.9	3.1	0.15
	2	15.4	3.2		
	3	14.5	3.0		
14	1	26.0	5.4	5.5	0.51
	2	24.1	5.0		
	3	28.9	6.0		
28	1	31.3	6.5	6.6	0.52
	2	29.4	6.1		
	3	34.2	7.1		
56	1	34.2	7.1	7.3	0.83
	2	39.5	8.2		
	3	31.8	6.6		

Table 5.34 : Modulus of rupture of PPCC made with PVAc as a function of age (P/C=0.20)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.20

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
7	1	15.9	3.3	3.4	0.36
	2	15.0	3.1		
	3	18.3	3.8		
14	1	30.4	6.3	5.8	0.46
	2	28.0	5.8		
	3	26.0	5.4		
28	1	32.3	6.7	7.1	0.36
	2	34.2	7.1		
	3	35.7	7.4		
56	1	38.1	7.9	8.2	0.37
	2	39.1	8.1		
	3	41.5	8.6		

Table 5.35 : Modulus of rupture of PPCC made with PVAc as a function of age (P/C=0.25)

Type of Cement	Pozzolanic Portland
Type of Polymer	Polyvinyl acetate-homopolymer
P/C	0.25

Age (Days)	Beam no.	Strength (kN) P	Modulus of rupture (MPa)	Av. Mod. of rupture (MPa)	Standard deviation (σ)
7	1	14.0	2.9	2.9	0.20
	2	13.0	2.7		
	3	15.0	3.1		
14	1	22.2	4.6	5.2	0.67
	2	24.1	5.0		
	3	28.5	5.9		
28	1	32.8	6.8	6.3	0.41
	2	28.9	6.0		
	3	29.9	6.2		
56	1	37.1	7.7	6.9	0.82
	2	32.8	6.8		
	3	29.4	6.1		

Table 5.36 : Properties of PPCC made with PVAh as a function of age and polymer content .

P/C	Age (Days)	Av . Comp. strength (MPa)	Av . Mod of rupture (MPa)
0.00	14 21 28	21.1 22.4 24.1	3.5 4.2 4.3
0.05	14 21 28	17.9 19.4 21.0	2.9 3.0 3.1
0.10	14 21 28	15.0 16.7 17.9	3.0 3.1 3.2
0.15	14 21 28	10.8 12.3 14.4	2.1 2.3 2.3
0.20	14 21 28	8.5 9.6 11.8	1.7 2.0 2.1
0.25	14 21 28	6.6 8.6 10.0	1.4 1.6 1.6

Table 5.37 : Properties of PPCC made with PVAh as a function of age and polymer content.

P/C	Age (Days)	Av . Comp. strength (MPa)	Av . Mod of rupture (MPa)
0.00	7	15.7	2.1
	14	21.6	3.6
	28	24.5	4.4
	56	26.3	4.8
0.05	7	17.6	2.5
	14	24.6	4.5
	28	28.5	5.3
	56	30.3	5.6
0.10	7	19.0	3.0
	14	26.6	4.7
	28	30.4	5.8
	56	32.4	6.3
0.15	7	20.7	3.1
	14	28.7	5.5
	28	32.9	6.6
	56	35.1	7.3
0.20	7	19.3	3.4
	14	26.5	5.8
	28	31.2	7.1
	56	32.0	8.2
0.25	7	18.6	2.9
	14	25.2	5.2
	28	29.0	6.3
	56	31.3	6.9

Table 5.38 : Properties of PPCC made with Pvah as a function of age and polymer content.

P/C	Age (Days)	Av. Comp. strength (MPa)	Av. Mod of rupture (MPa)
0.00	7	15.7	2.1
	14	21.6	3.6
	28	24.5	4.4
	56	26.3	4.8
0.05	7	13.8	1.8
	14	18.2	2.9
	28	20.2	3.8
	56	20.3	4.1
0.10	7	10.2	1.7
	14	16.1	2.6
	28	18.4	3.0
	56	18.3	3.2
0.15	7	6.7	1.5
	14	11.3	2.3
	28	14.7	2.5
	56	17.0	2.6
0.20	7	5.1	1.3
	14	9.5	2.0
	28	12.1	2.1
	56	13.4	2.1
0.25	7	4.6	1.3
	14	6.6	1.5
	28	11.1	1.7
	56	12.5	1.8

Table 5.39 : Compressive strength of PC made with well - graded aggregate as a function of polymer content .

Type of aggregate	Sweileh sand
Type of polymer	Unsaturated polyester
Type of hardner	Benzoyl Peroxide

P/A	Cylinder no	Strength (kN)	Comp. Strength (MPa)	Av. Comp Strength (MPa)	Srandard deviation (σ)
0.06	1 2 3	27.1 23.2 21.6	21.6 18.5 17.2	19.1	2.26
0.08	1 2 3	31.7 29.4 33.6	25.2 23.4 26.7	25.1	1.65
0.10	1 2 3	39.0 41.1 36.6	31.0 32.7 29.1	30.9	1.79
0.12	1 2 3	51.6 55.1 47.4	41.1 43.8 37.7	40.9	3.05
0.14	1 2 3	49.3 47.1 48.0	39.2 37.5 38.2	38.3	0.85

Table 5.39 : (Cont.)

Type of aggregate Type of polymer Type of hardner	Sweileh sand Unsaturated polyester Benzoyl Peroxide

P/A	Cylinder no	Strength (kN)	Comp. Strength (MPa)	Av. Comp. Strength (MPa)	Srandard deviation (σ)
0.16	1	47.0	37.4	35.4	2.34
	2	45.1	35.9		
	3	41.2	32.8		
0.18	1	42.2	33.6	33.1	1.76
	2	43.4	34.5		
	3	39.1	31.1		
0.20	1	39.2	31.2	28.6	2.81
	2	36.6	29.1		
	3	32.1	25.6		
0.22	1	36.6	29.1	28.5	3.37
	2	39.7	31.6		
	3	31.3	24.9		
0.24	1	34.7	27.6	25.5	1.96
	2	29.8	23.7		
	3	31.7	25.2		

Table 5.40: **Modulus of rupture of PC made with well - graded aggregate as a function of polymer content .**

Type of aggregate	Sweileh sand
Type of polymer	Unsaturated polyester
Type of hardner	Benzoyl Peroxide

P/A	Cylinder no	Strength (kN)	Comp. Strength (MPa)	Av. Comp Strength (MPa)	Srandard deviation (σ)
0.06	1	0.575	9.7	9.8	0.60
	2	0.616	10.4		
	3	0.545	9.2		
0.08	1	0.628	10.6	11.0	0.40
	2	0.646	10.9		
	3	0.676	11.4		
0.10	1	0.705	11.9	11.9	0.84
	2	0.759	12.8		
	3	0.656	11.1		
0.12	1	0.705	11.9	12.6	0.60
	2	0.735	12.4		
	3	0.800	13.5		
0.14	1	0.794	13.4	13.4	0.74
	2	0.747	12.6		
	3	0.836	14.1		

Table 5.40 : (Cont.).

Type of aggregate Type of polymer Type of hardner	Sweileh sand Unsaturated polyester Benzoyl Peroxide

P/A	Cylinder no	Strength (kN)	Comp. Strength (MPa)	Av. Comp Strength (MPa)	Srandard deviation (σ)
0.16	1	0.764	12.9	12.9	0.74
	2	0.717	12.1		
	3	0.806	13.6		
0.18	1	0.717	12.1	12.2	0.90
	2	0.676	11.4		
	3	0.782	13.2		
0.20	1	0.687	11.6	12.0	0.35
	2	0.729	12.3		
	3	0.711	12.0		
0.22	1	0.693	11.7	11.7	0.31
	2	0.670	11.3		
	3	0.705	11.9		
0.24	1	0.658	11.1	11.2	1.05
	2	0.729	12.3		
	3	0.604	10.2		

Table 5.41 : Compressive strength of PC made with gap - graded aggregate as a function of polymer content .

Type of aggregate Type of polymer Type of hardner	Sweileh sand Unsaturated polyester Benzoyl Peroxide

P/A	Cylinder no	Strength (kN)	Comp. Strength (MPa)	Av. Comp Strength (MPa)	Srandard deviation (σ)
0.06	Polymer content is not enough				
0.08	1	28.0	22.3	22.4	0.76
	2	29.1	23.2		
	3	27.3	21.7		
0.10	1	34.7	27.6	27.3	1.56
	2	36.1	28.7		
	3	32.2	25.6		
0.12	1	39.1	31.1	31.1	1.29
	2	37.4	29.8		
	3	40.7	32.4		
0.14	1	42.3	33.7	32.0	1.51
	2	39.6	31.5		
	3	38.7	30.8		

Table 5.41 : (Cont .)

Type of aggregate	Sweileh sand
Type of polymer	Unsaturated polyester
Type of hardner	Benzoyl Peroxide

P/A	Cylinder no	Strength (kN)	Comp. Strength (MPa)	Av. Comp. Strength (MPa)	Srandard deviation (σ)
0.16	1 2 3	44.5 41.7 47.6	35.4 33.2 37.9	35.5	2.34
0.18	1 2 3	46.6 48.8 50.2	37.1 38.8 39.9	38.6	1.40
0.20	1 2 3	44.1 47.6 45.2	35.1 37.9 36.0	36.3	1.43
0.22	1 2 3	39.2 40.7 41.9	31.2 32.4 33.3	32.3	1.05
0.24	1 2 3	39.2 40.7 41.9	31.2 32.4 33.3	32.3	1.05

Table 5.42 : Modulus of rupture of PC made with gap - graded aggregate as a function of polymer content .

Type of aggregate Type of polymer Type of hardner	Sweileh sand Unsaturated polyester Benzoyl Peroxide

P/A	Cylinder no	Strength (kN)	Comp. Strength (MPa)	Av. Comp Strength (MPa)	Srandard deviation (σ)
0.06	Polymer ccontent is not enough				
0.08	1	0.580	9.8	9.7	0.46
	2	0.545	9.2		
	3	0.598	10.1		
0.10	1	0.610	10.3	10.4	0.73
	2	0.663	11.2		
	3	0.569	9.6		
0.12	1	0.646	10.9	11.0	1.05
	2	0.717	12.1		
	3	0.569	9.6		
0.14	1	0.687	11.6	12.3	0.76
	2	0.723	12.2		
	3	0.776	13.1		

Table 5 . 42 (Cont)

Type of aggregate	Sweileh sand
Type of polymer	Unsaturated polyester
Type of hardner	Benzoyl Peroxide

P/A	Cylinder no	Strength (kN)	Comp. Strength (MPa)	Av. Comp Strength (MPa)	Srandard deviation (σ)
0.16	1 2 3	0.735 0.782 0.705	12.4 11.2 11.9	12.5	0.66
0.18	1 2 3	0.711 0.663 0.693	12.0 11.2 11.7	11.7	0.40
0.20	1 2 3	0.711 0.640 0.734	12.0 10.8 12.4	11.7	0.83
0.22	1 2 3	0.700 0.717 0.62	11.8 12.1 10.6	11.5	0.79
0.24	1 2 3	0.687 0.634 0.711	11.6 10.7 12.0	11.4	0.67

Table 5.43 :Compressive strength of PC as a function of water content (Polymer content is10%)

Water content by weight of sand (%)	Comp. strength (MPa)
0	30.9
1	24.6
2	21.2
3	17.7
4	14.1
5	12.0

Table 5.44 : Compressive strength of PC as a function of water content /sand ratio(Polymer content is 10%)

Water content by weight of sand (%)	Comp. strength (MPa)
0.00	30.9
0.02	34.1
0.04	40.7
0.06	45.1
0.08	47.4
0.10	37.3
0.12	31.1
0.14	27.6

Table 5.45 : Absorption of water by PC as a function of water content

Polymer content by weight of aggregate (%)	Absorption of water (%)
16	1.6
18	1.3
20	1.1
22	1.0
24	0.8

Table 5.46 : Strength of PC made with well- graded aggregate as a function of temperature with varying polymer content .

P/A	Termperature °(C)	Comp. strength (MPa)	mod. of rupture (MPa)
14	22 80 120	38.3 32.6 25.1	13.4 10.6 8.7
16	22 80 120	35.4 30.2 23.6	12.9 10.1 8.2
18	22 80 120	33.1 28.4 21.1	12.2 9.6 8.1

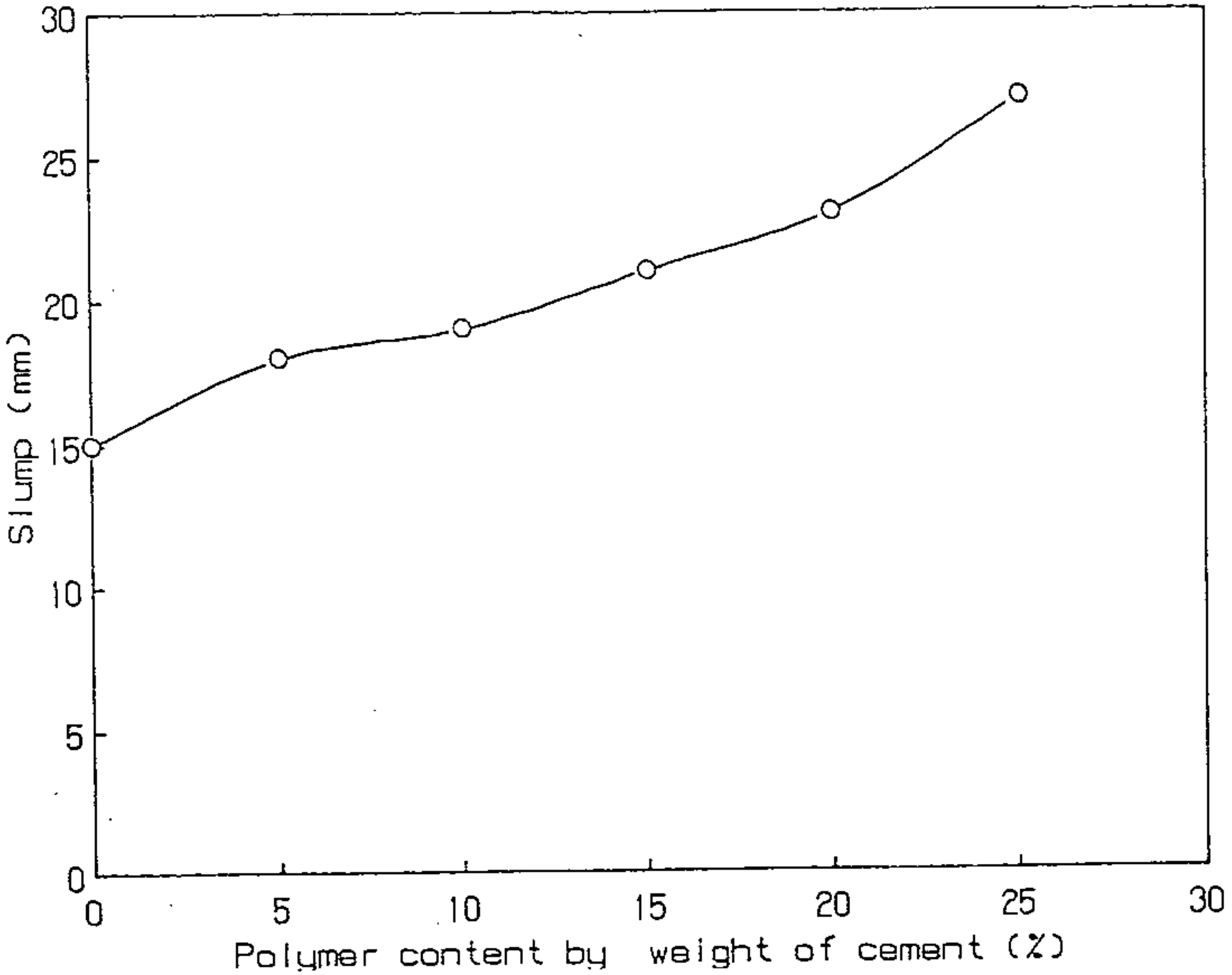

Figure 5.1: Workability of PPCC (measured by slump) as a function of polymer content.

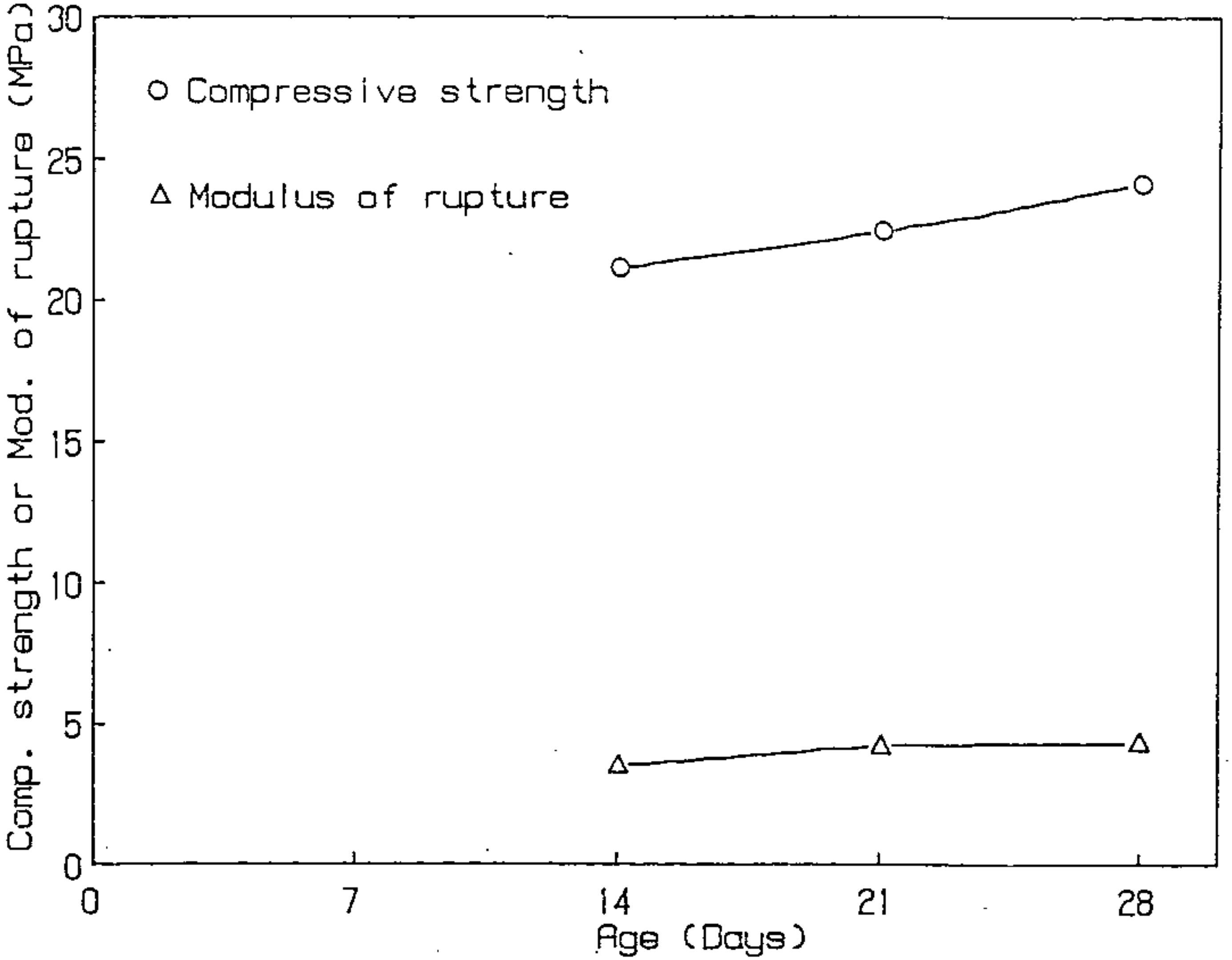

Figure 5.2: Relationship between properties of PPPCC with PVAh and age at P/C=0.00

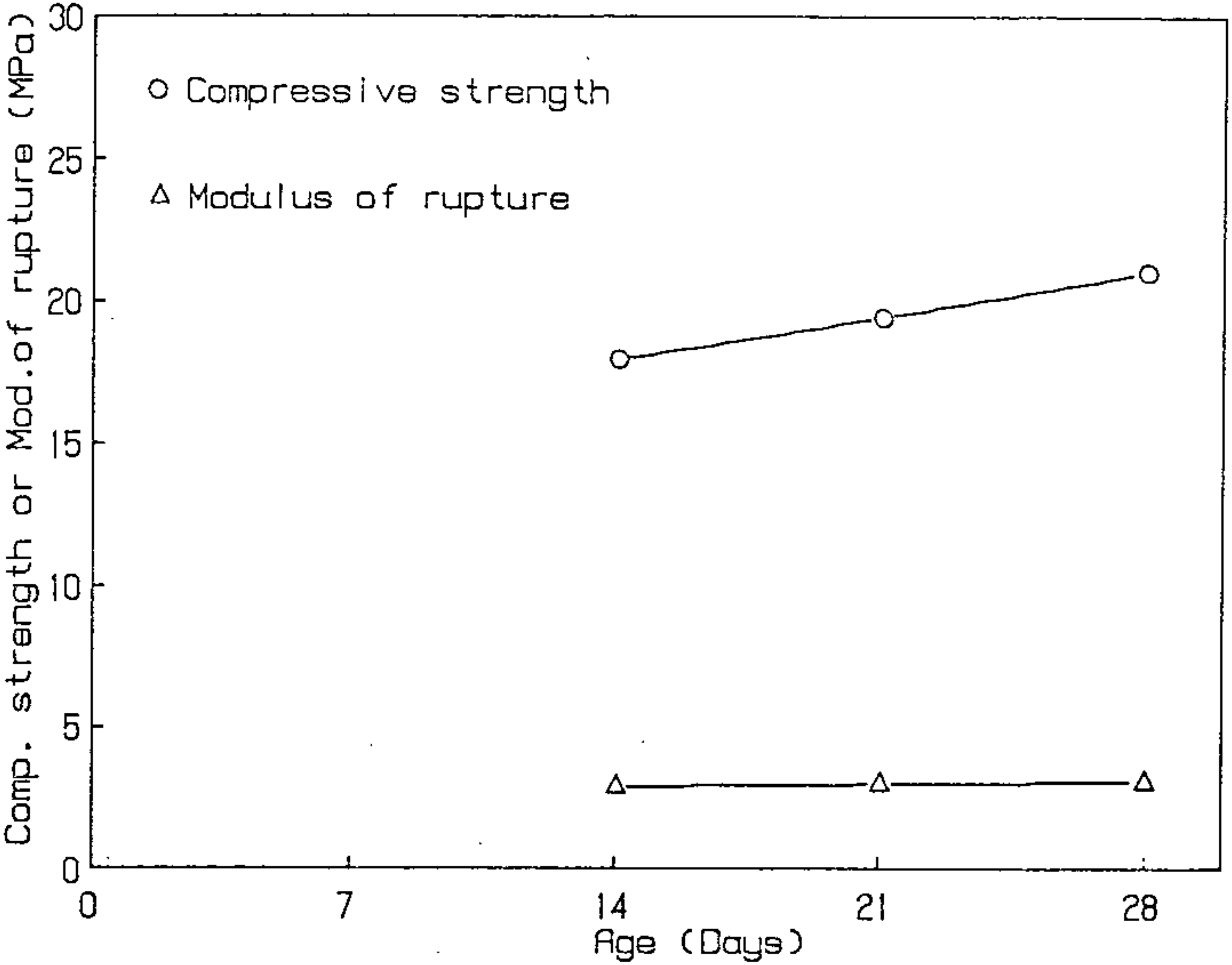

Figure 5.3 : Relationship between properties of PPPCC with PVAh and age at P/C=0.05

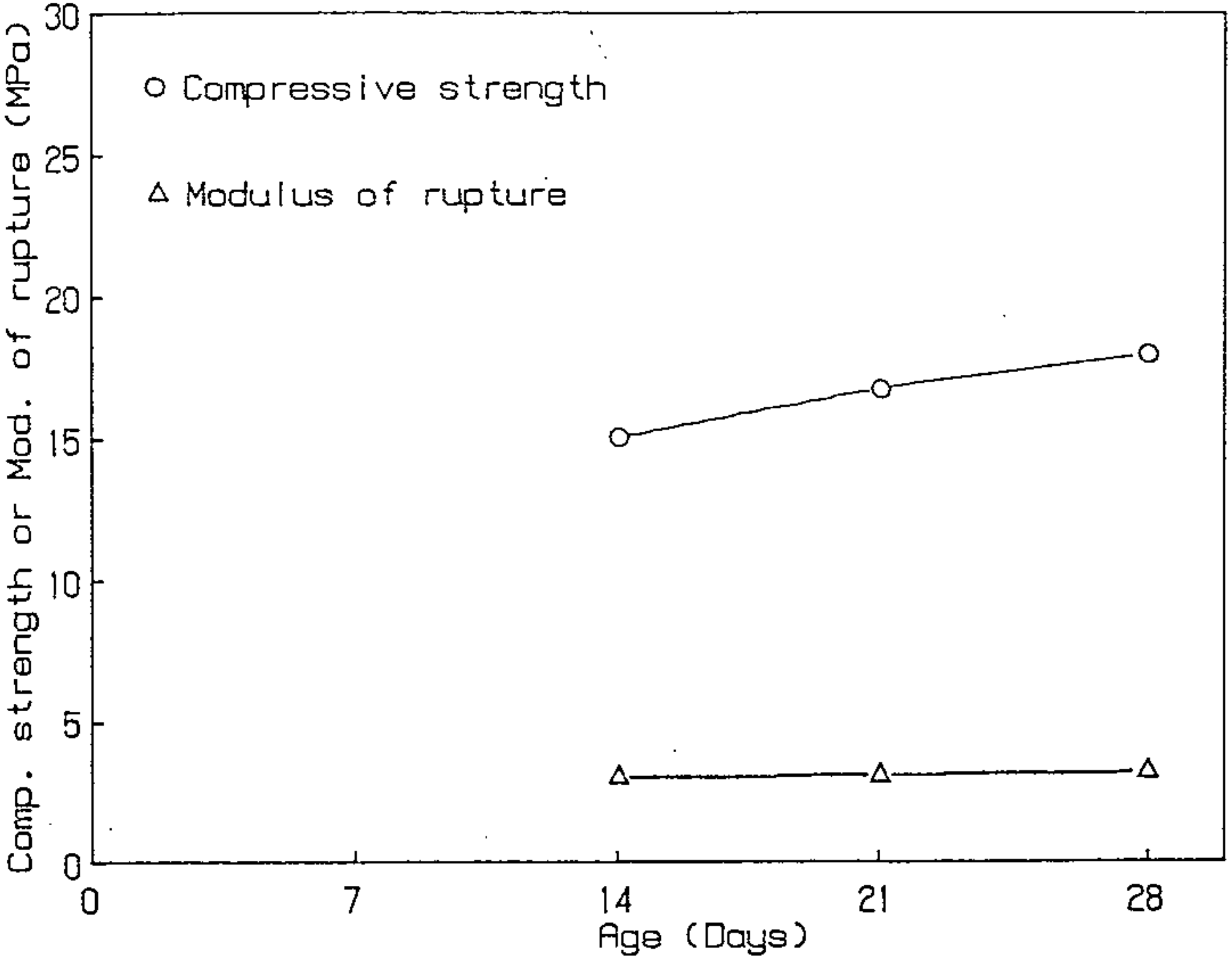

Figure 5.4 : Relationship between properties of PPPCC with PVAh and age at P/C=0.10

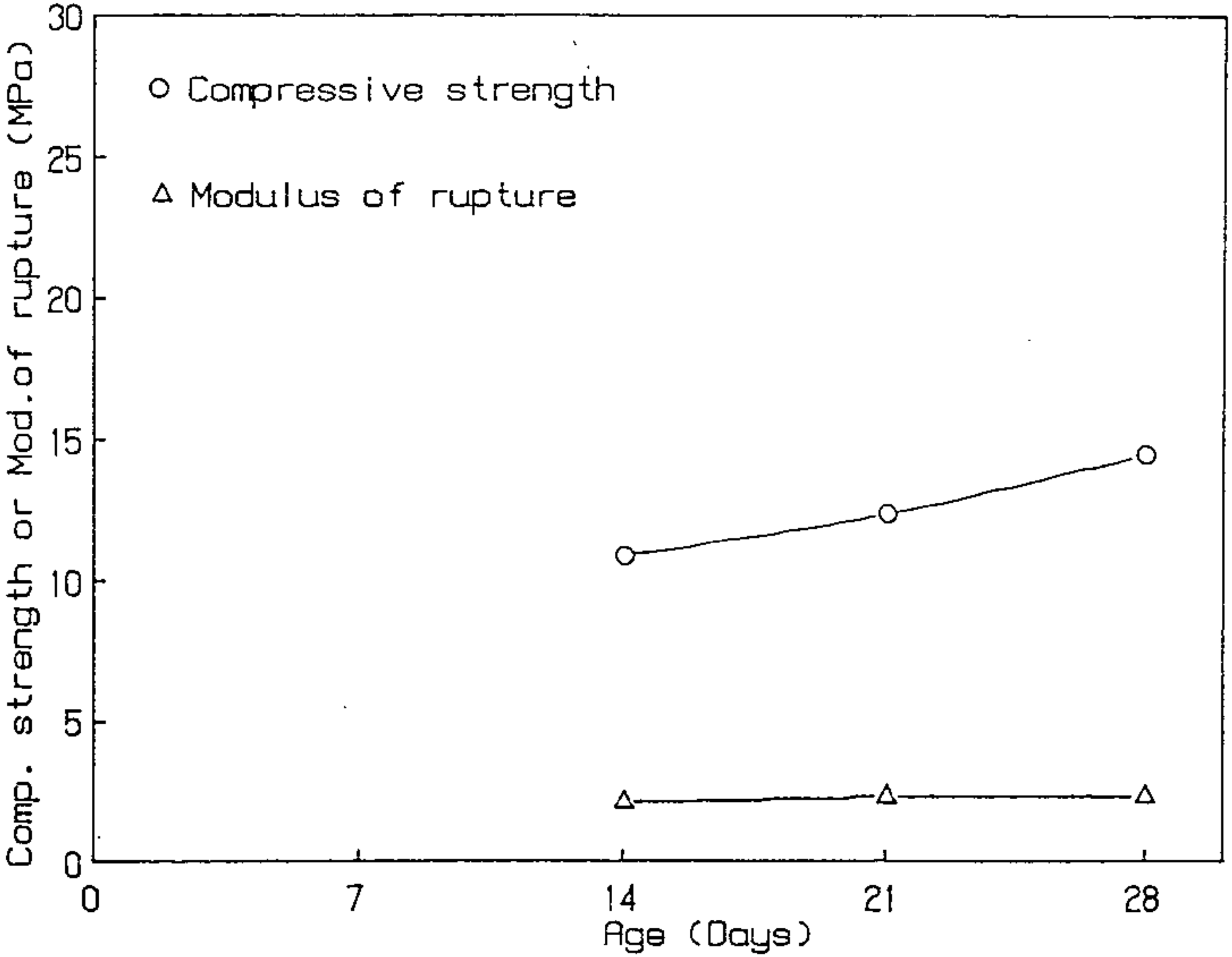

Figure 5.5 : Relationship between properties of PPPCC with PVAh and age at P/C=0.15

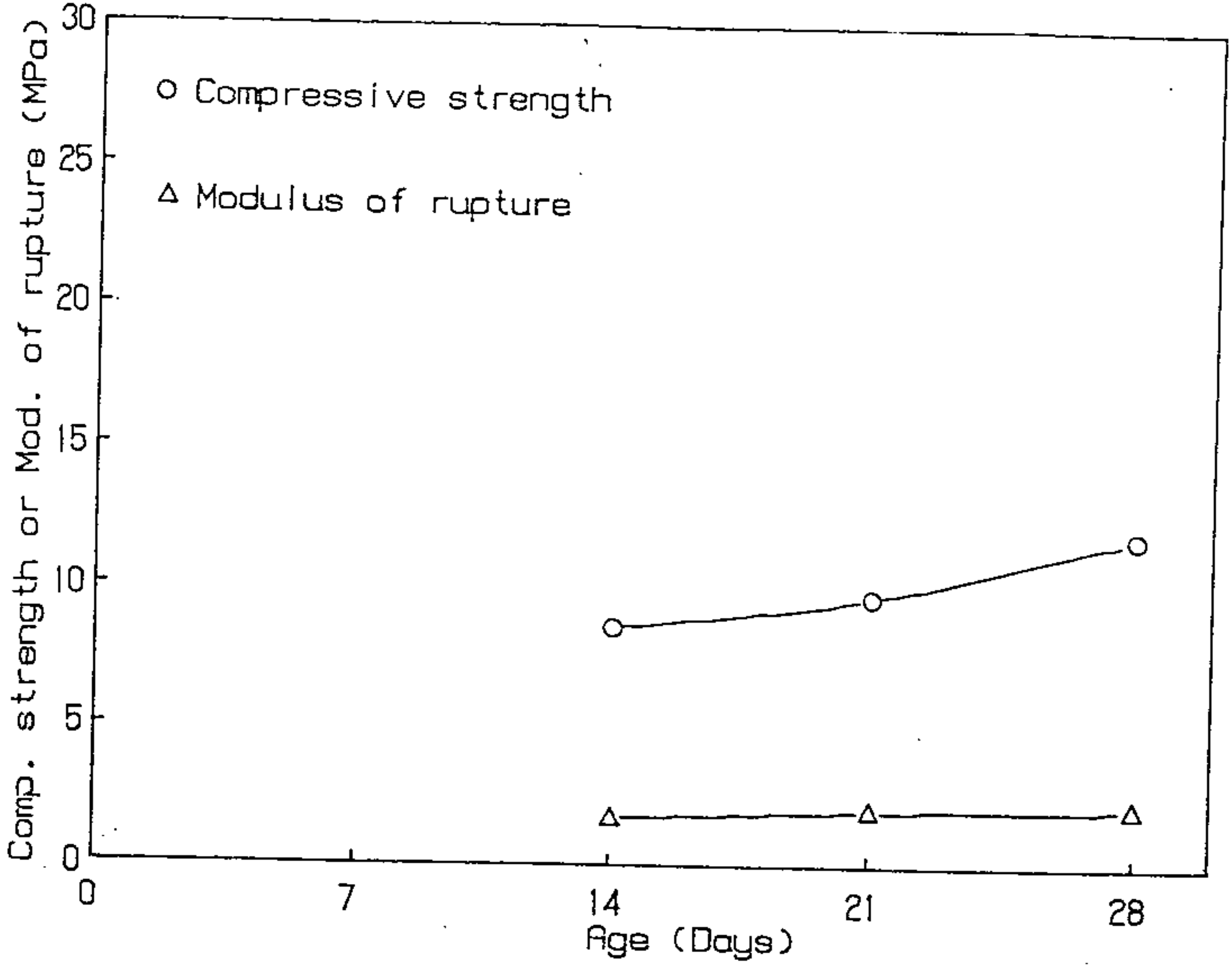

Figure 5.6: Relationship between properties of PPPCC with PVAh and age at P/C=0.20

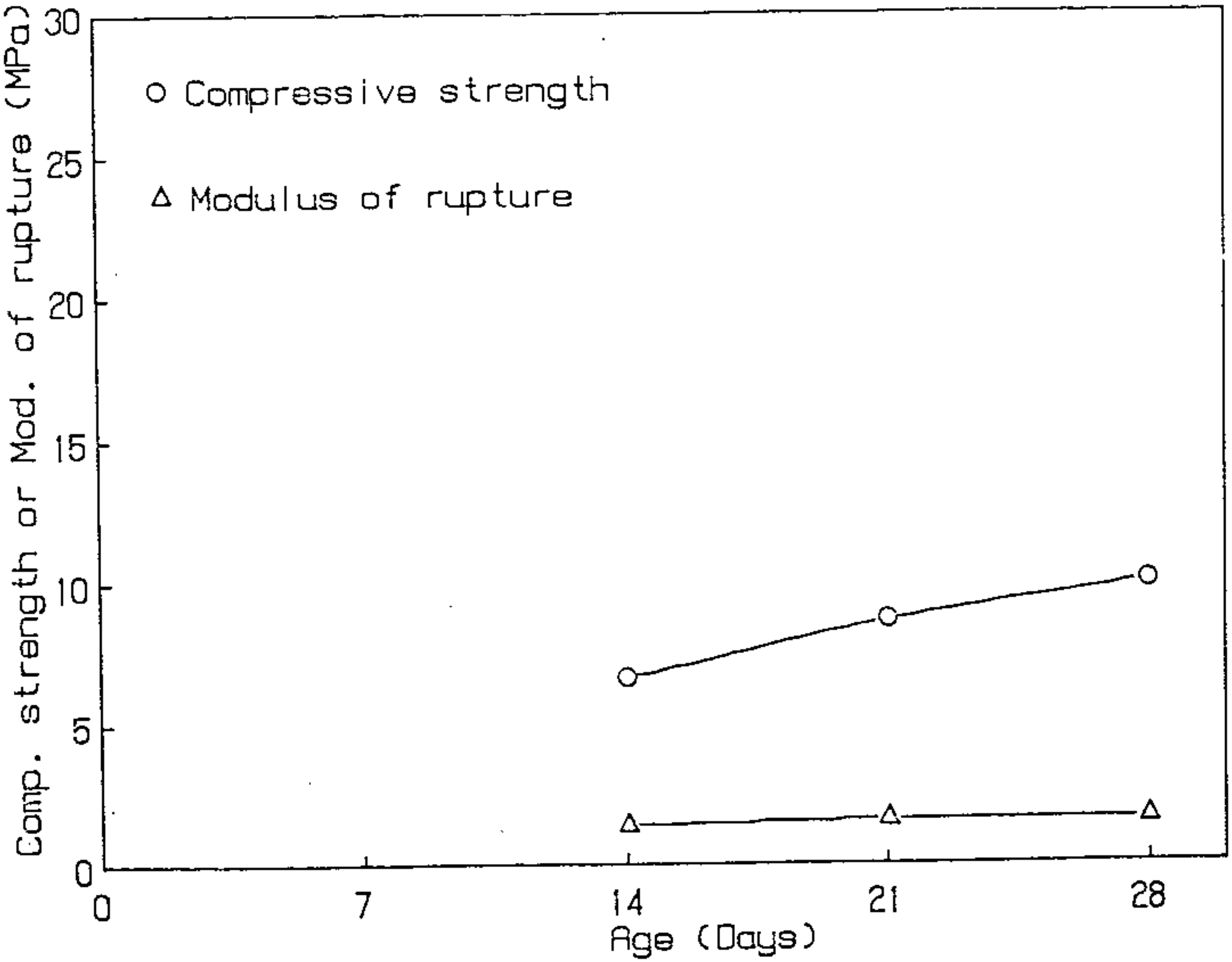

Figure 5.7: Relationship between properties of PPPCC with PVAh and age at P/C=0.25

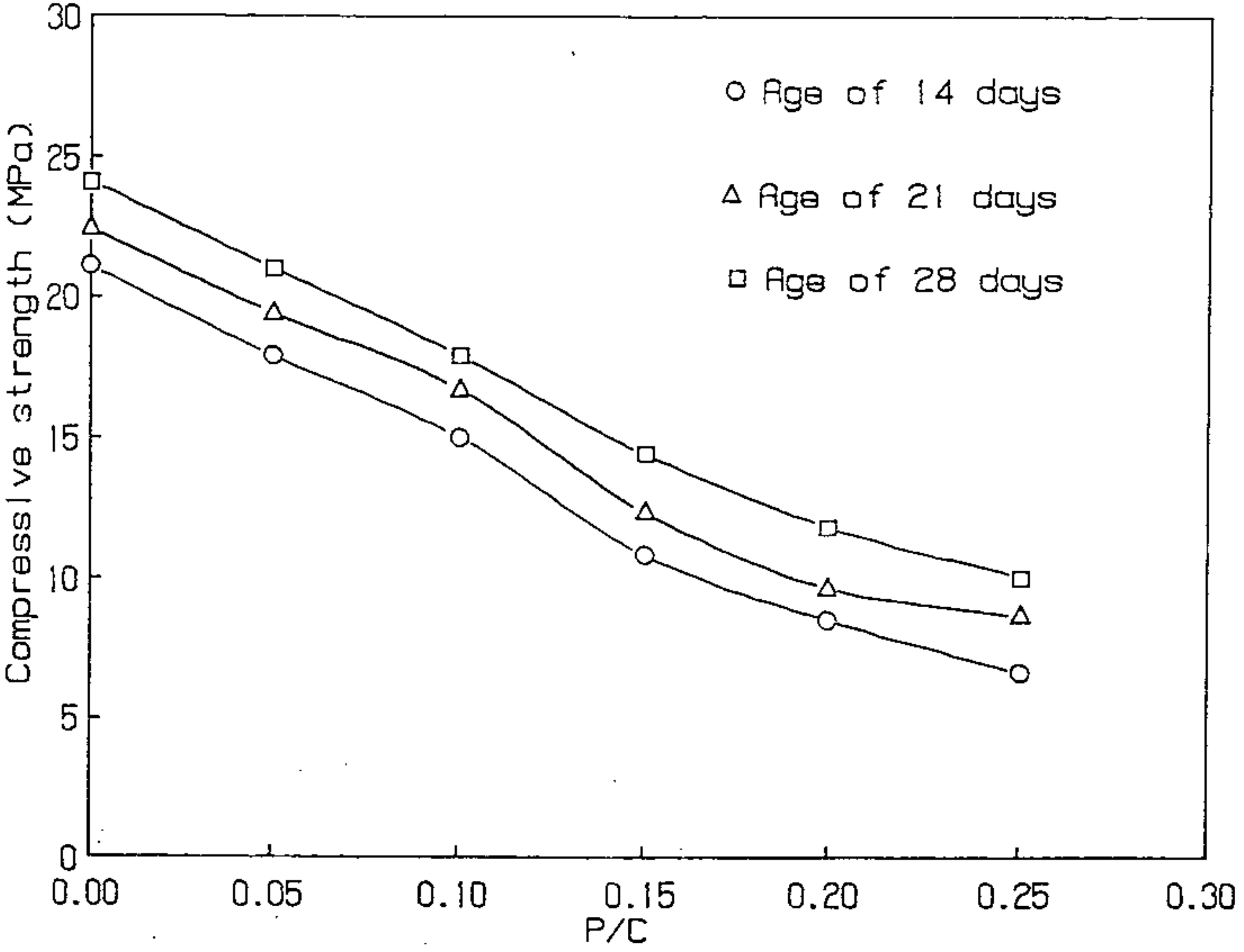

Figure 5.8 : Relationship between compressive strength of PPPCC with PVAh and P/C at different ages

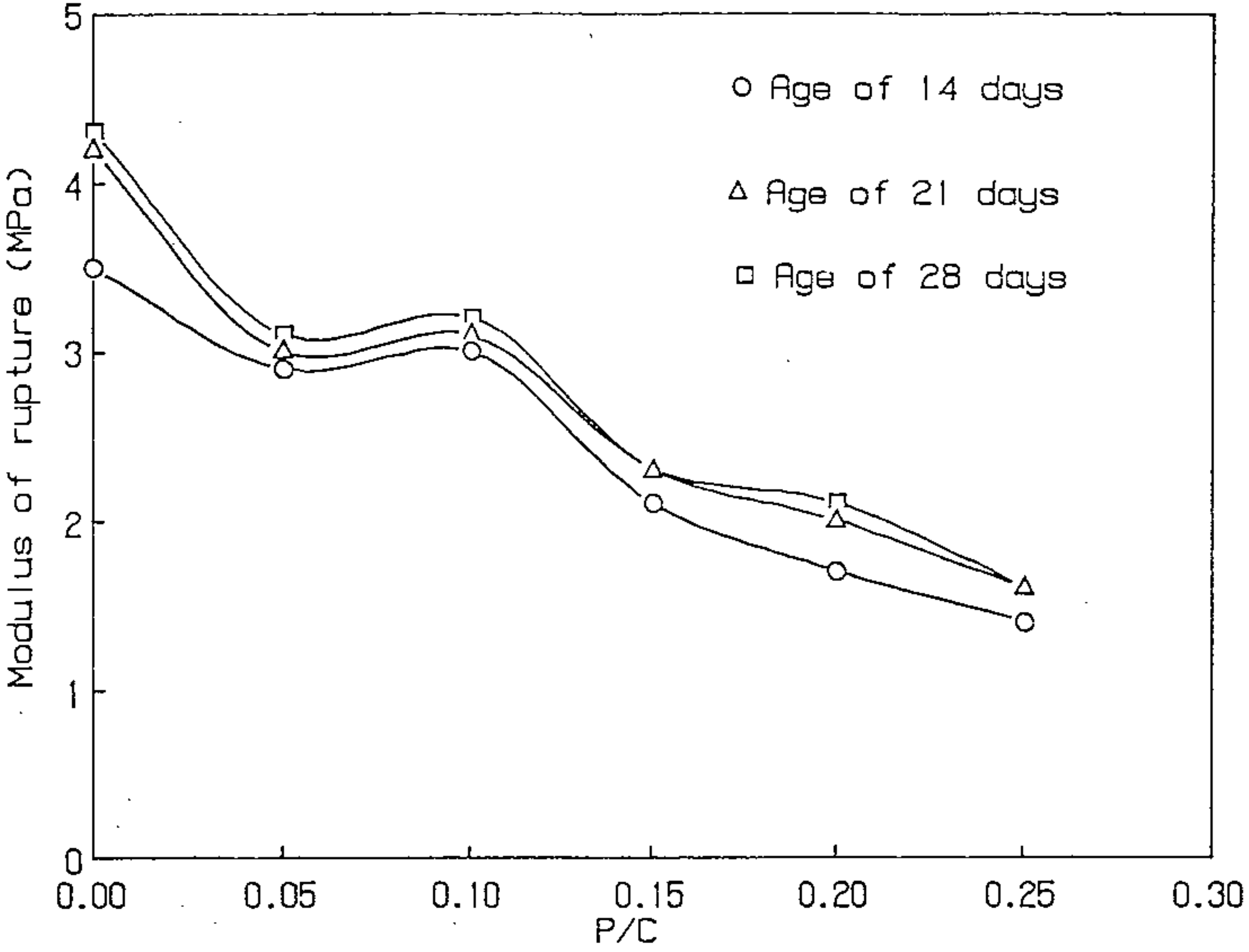

Figure 5.9: Relationship between modulus of rupture of PPPCC with PVAh and P/C at different ages

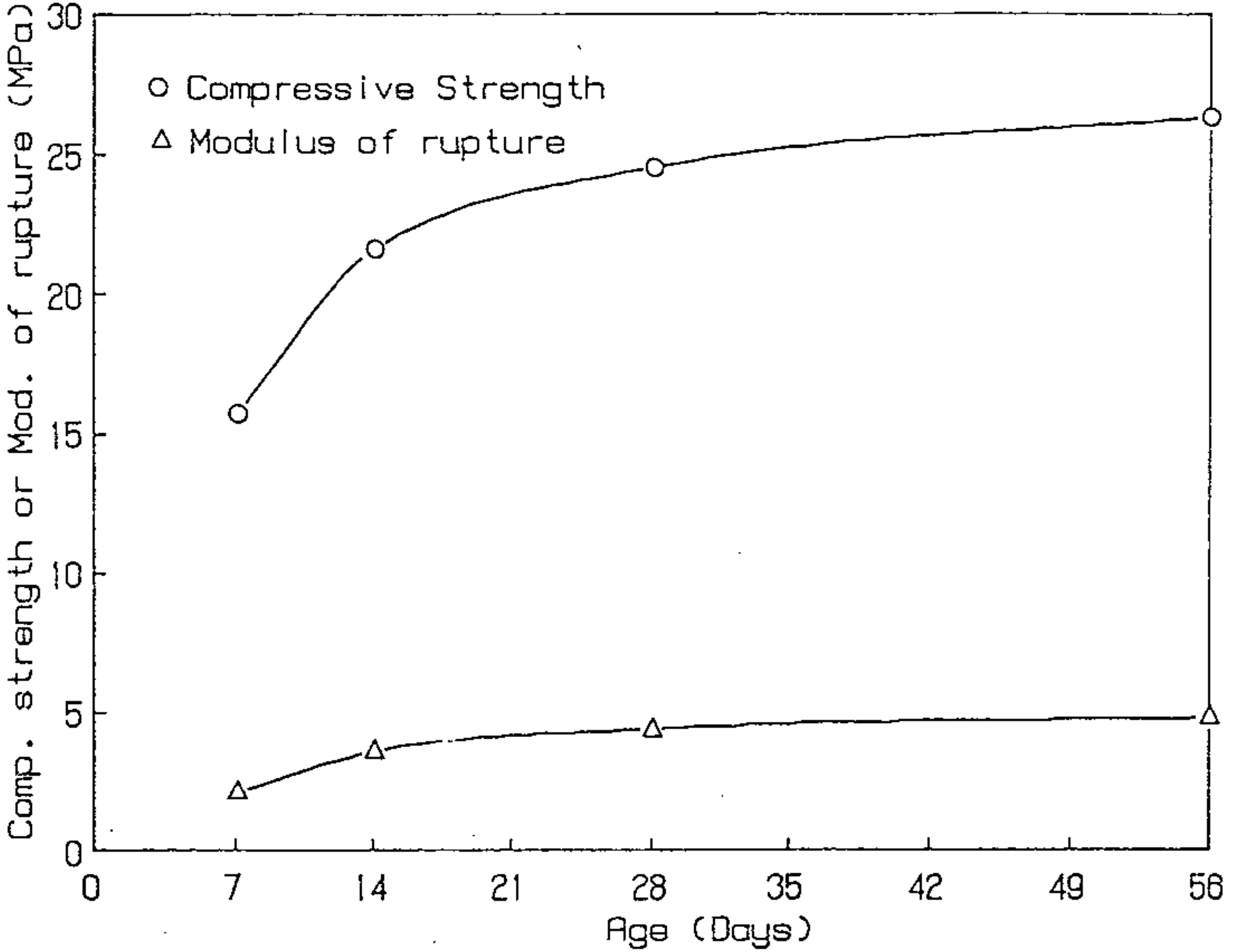

Figure 5.10 :Relationship between properties of PPCC with PVAh and age at P/C=0.00

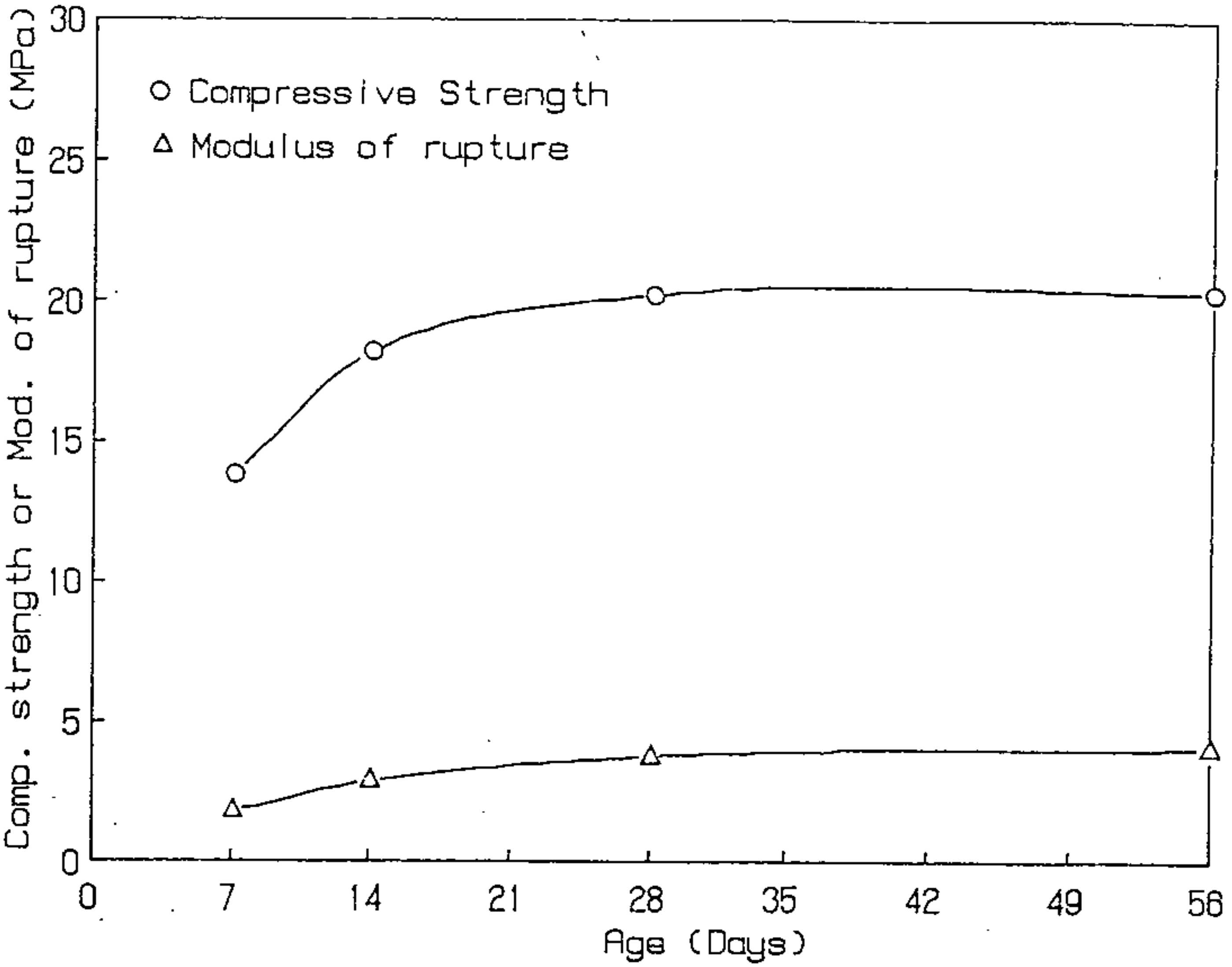

Figure 5.11: Relationship between properties of PPCC with PVAh and age at P/C=0.05

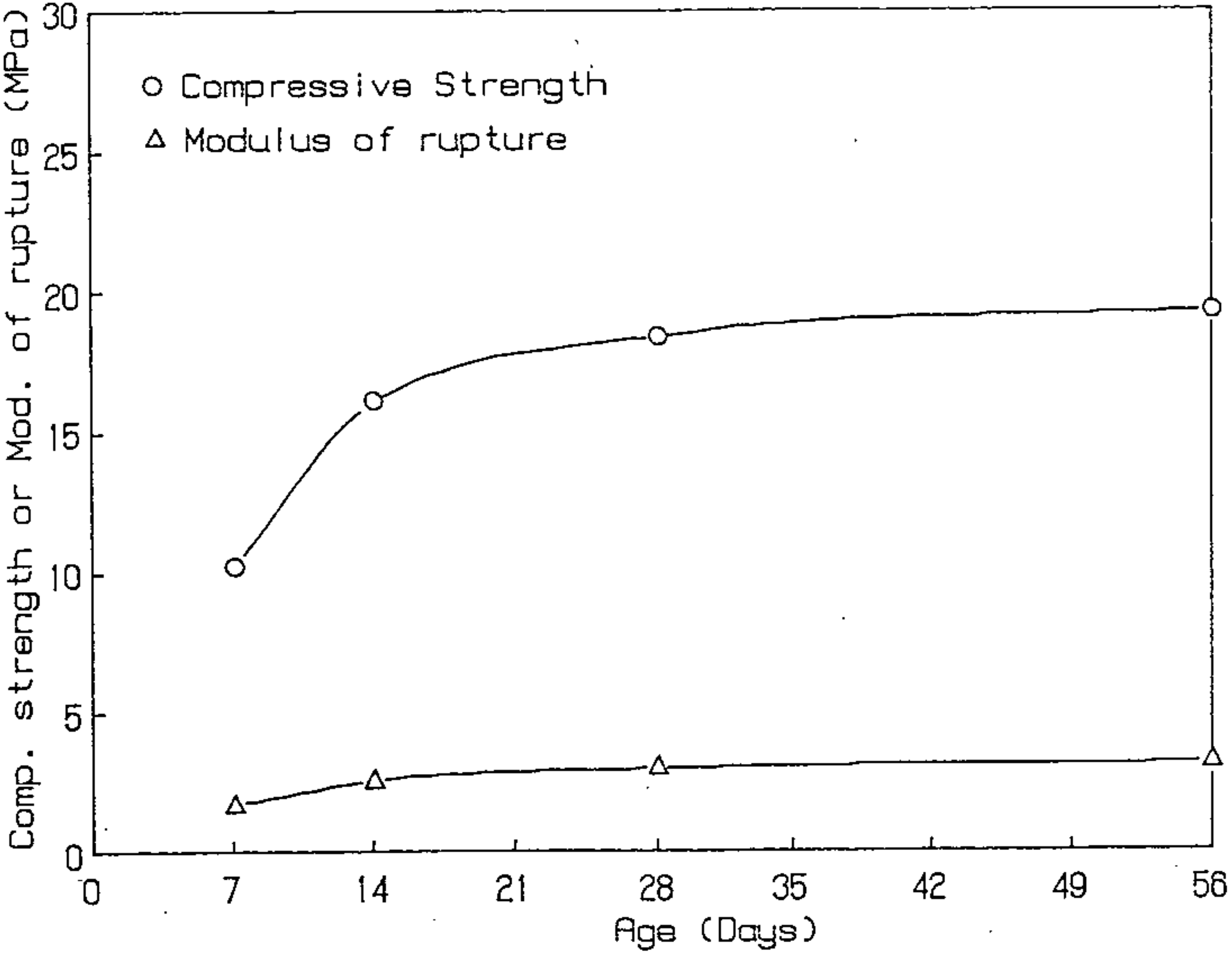

Figure 5.12: Relationship between properties of PPCC with PVAh and age at P/C=0.10

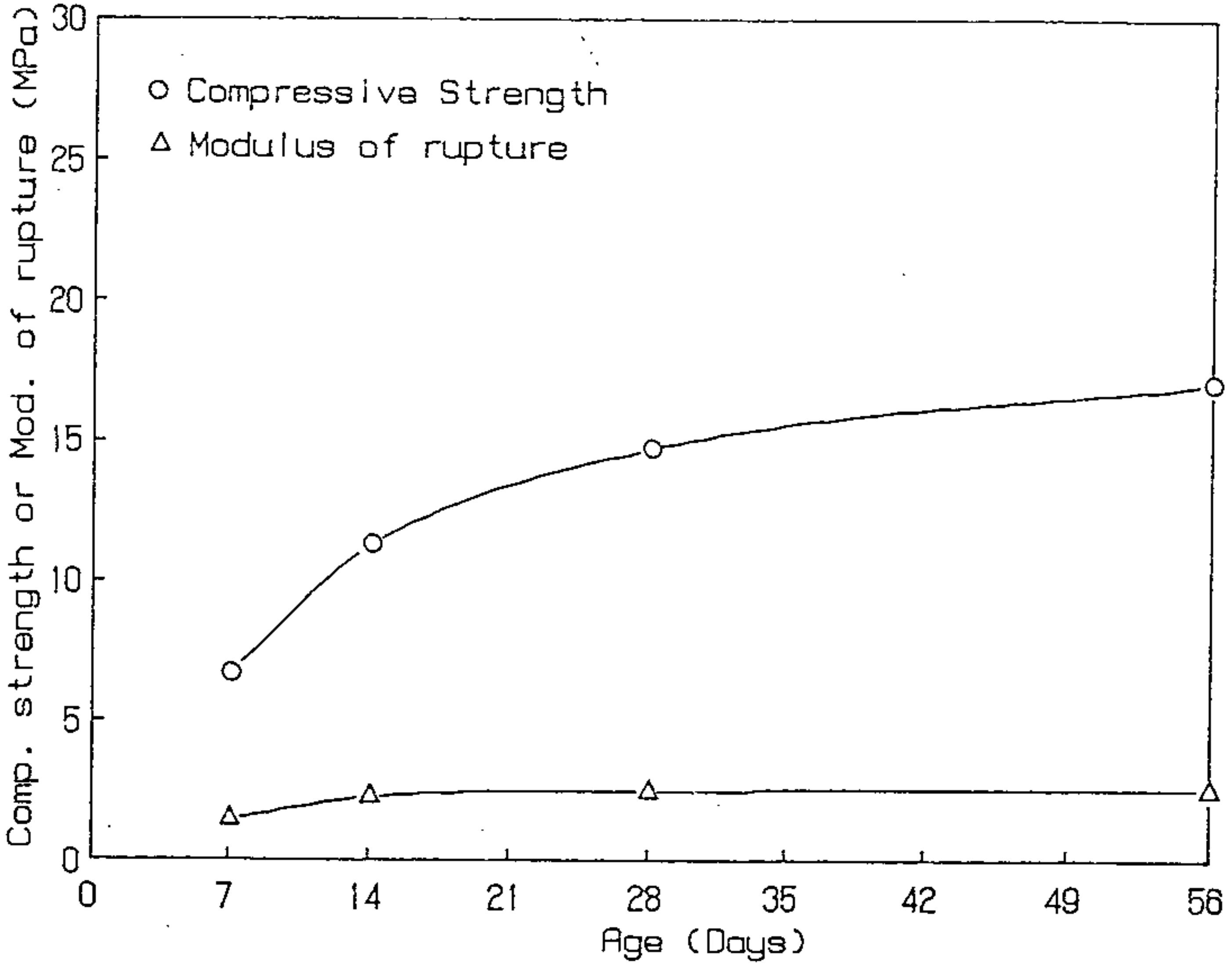

Figure 5.13: Relationship between properties of PPCC with PVAh and age at P/C=0.15

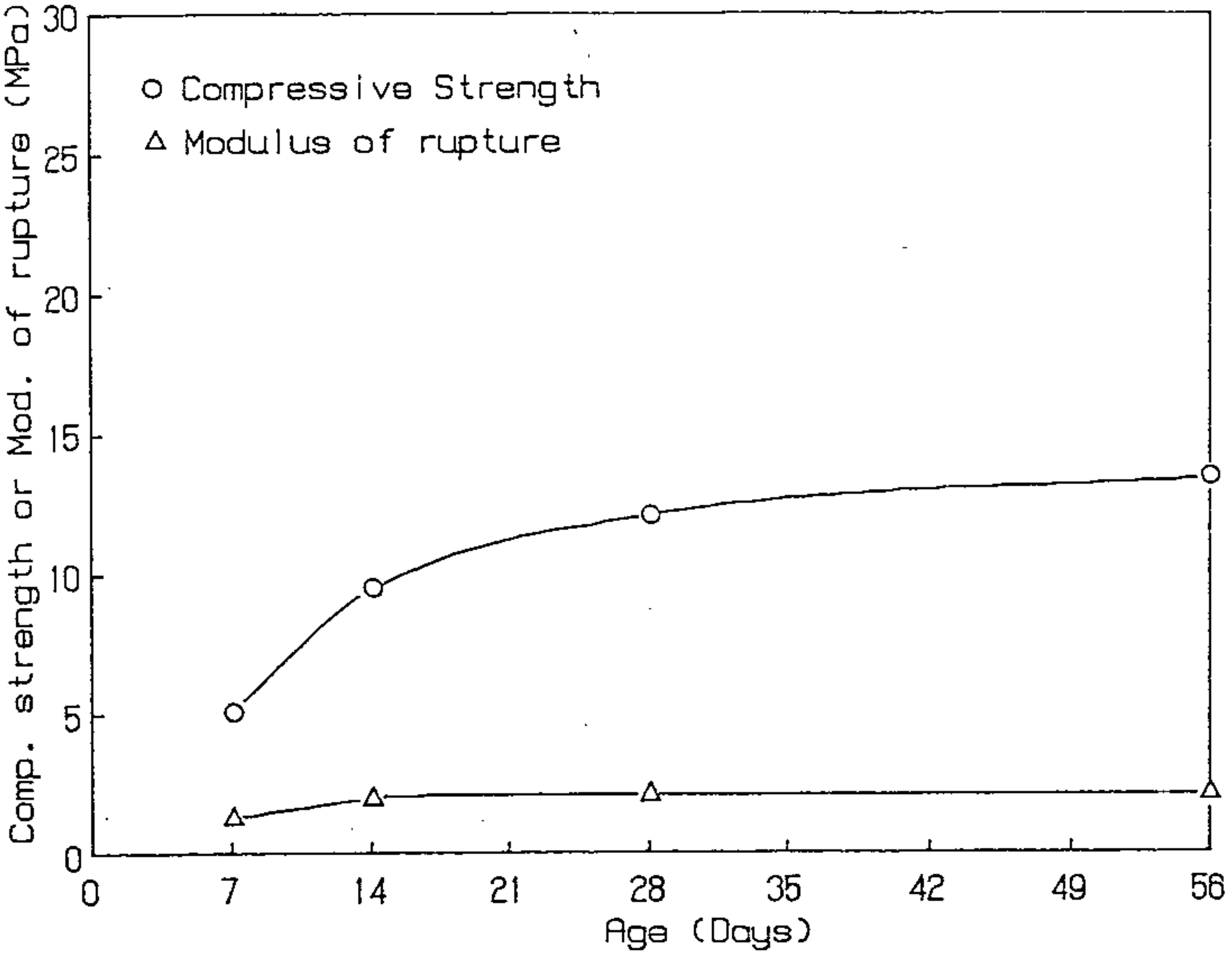

Figure 5.14: Relationship between properties of PPCC with PVAh and age at P/C=0.20

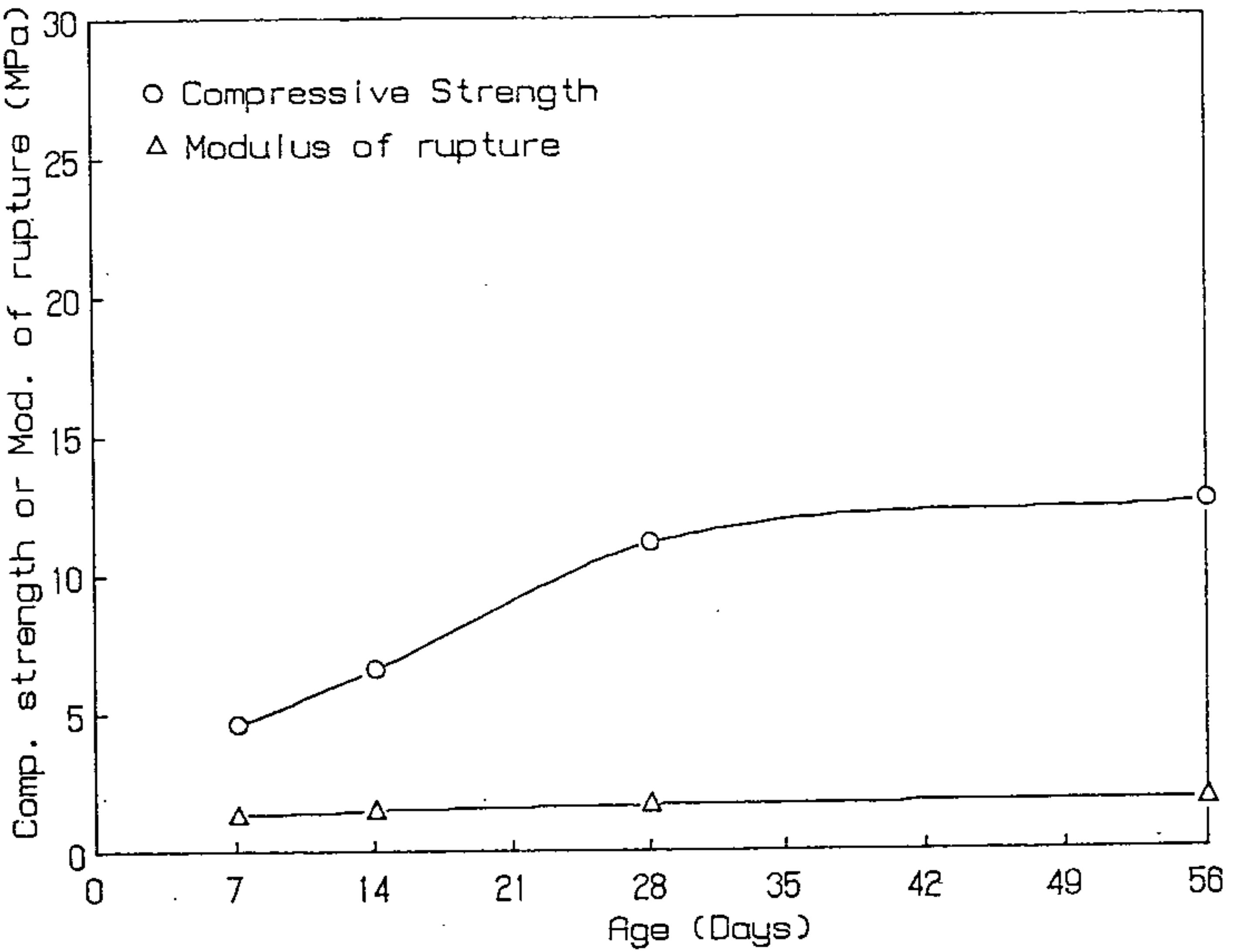

Figure 5.15 :Relationship between properties of PPCC with PVAh and age at P/C=0.25

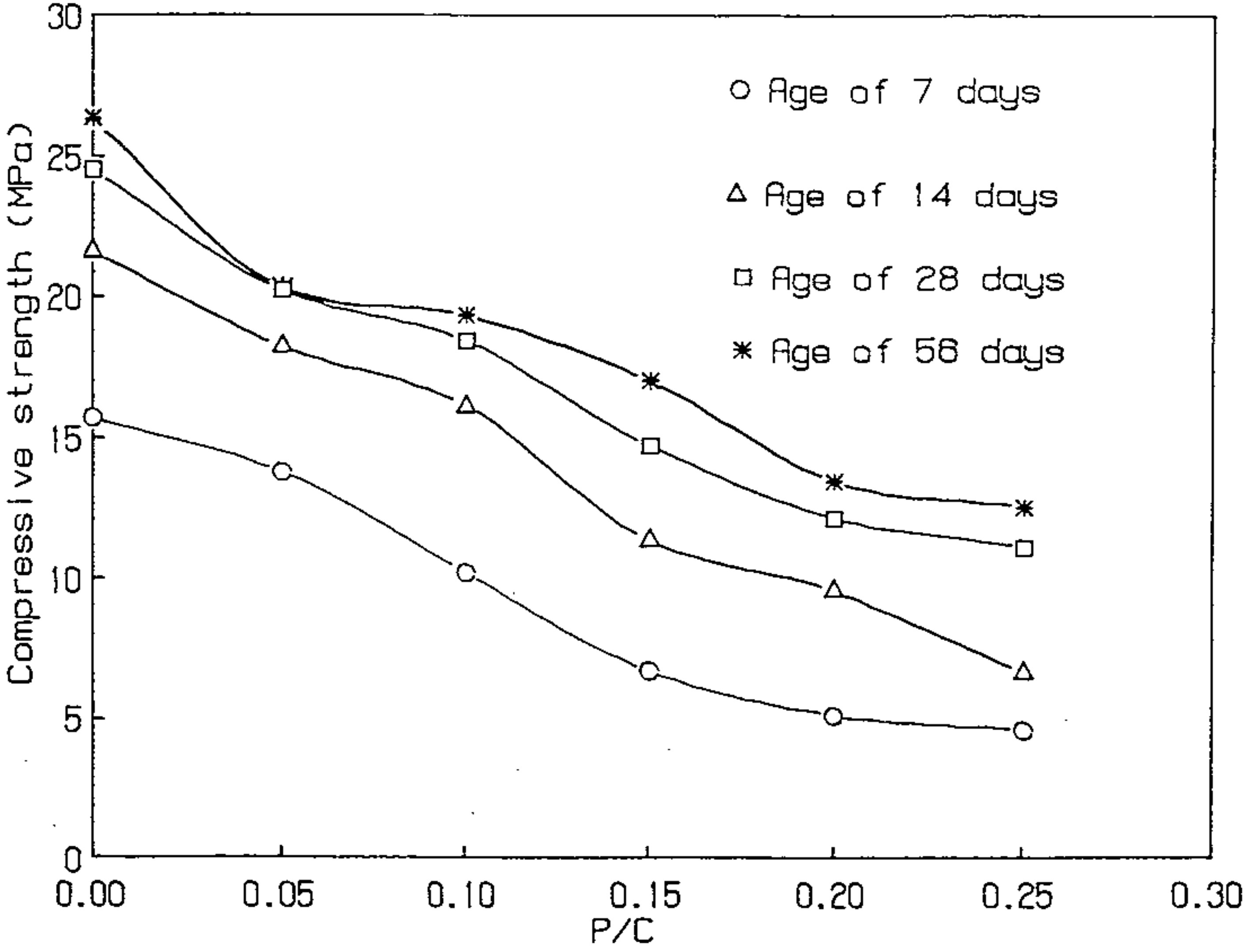

Figure 5.16: Relationship between compressive strength of PPCC with PVAh and P/C at different ages

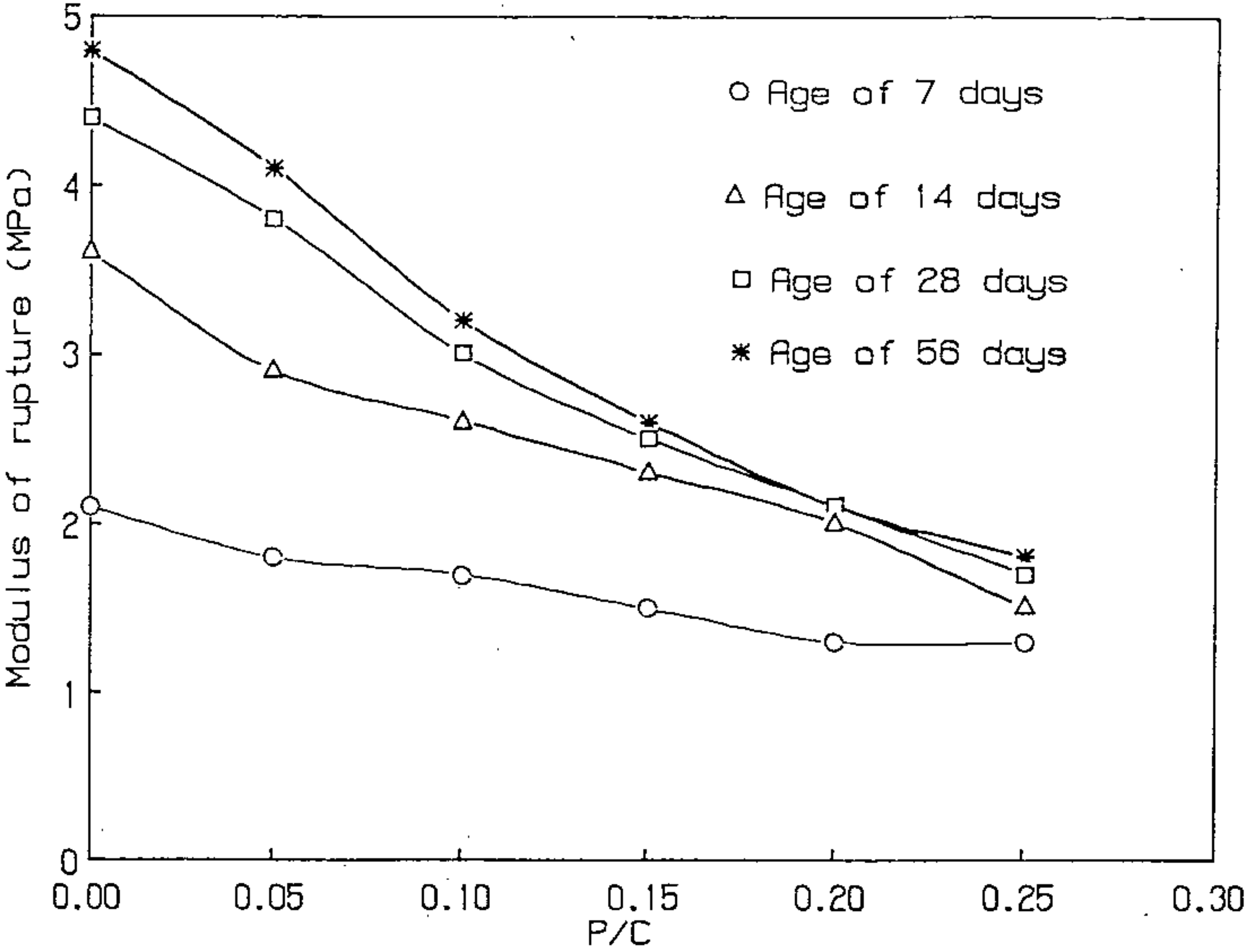

Figure 5.17: Relationship between modulus of rupture of PPCC with PVAh and P/C at different ages

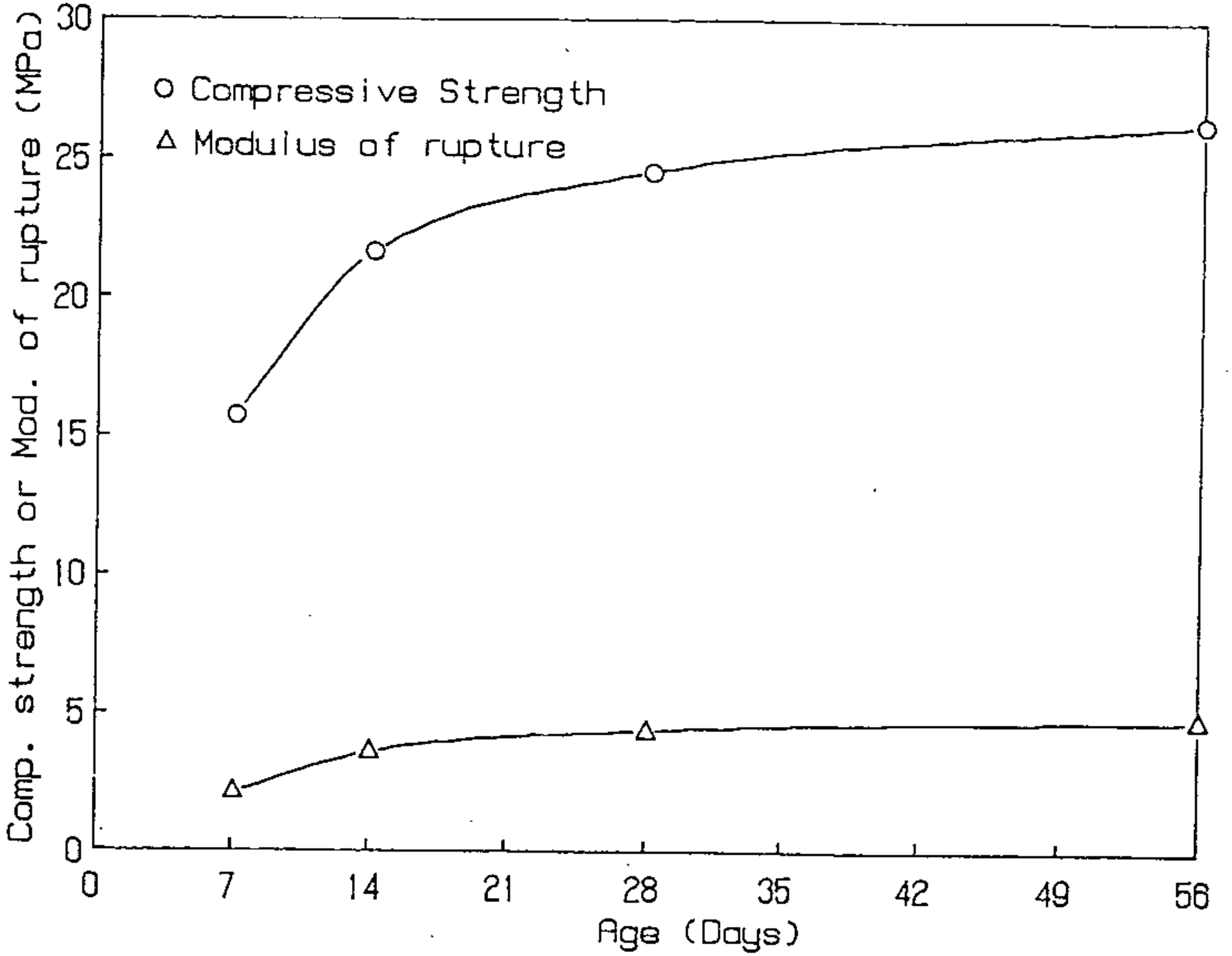

Figure 5.18: Relationship between properties of PPCC with PVAc and age at P/C=0.00

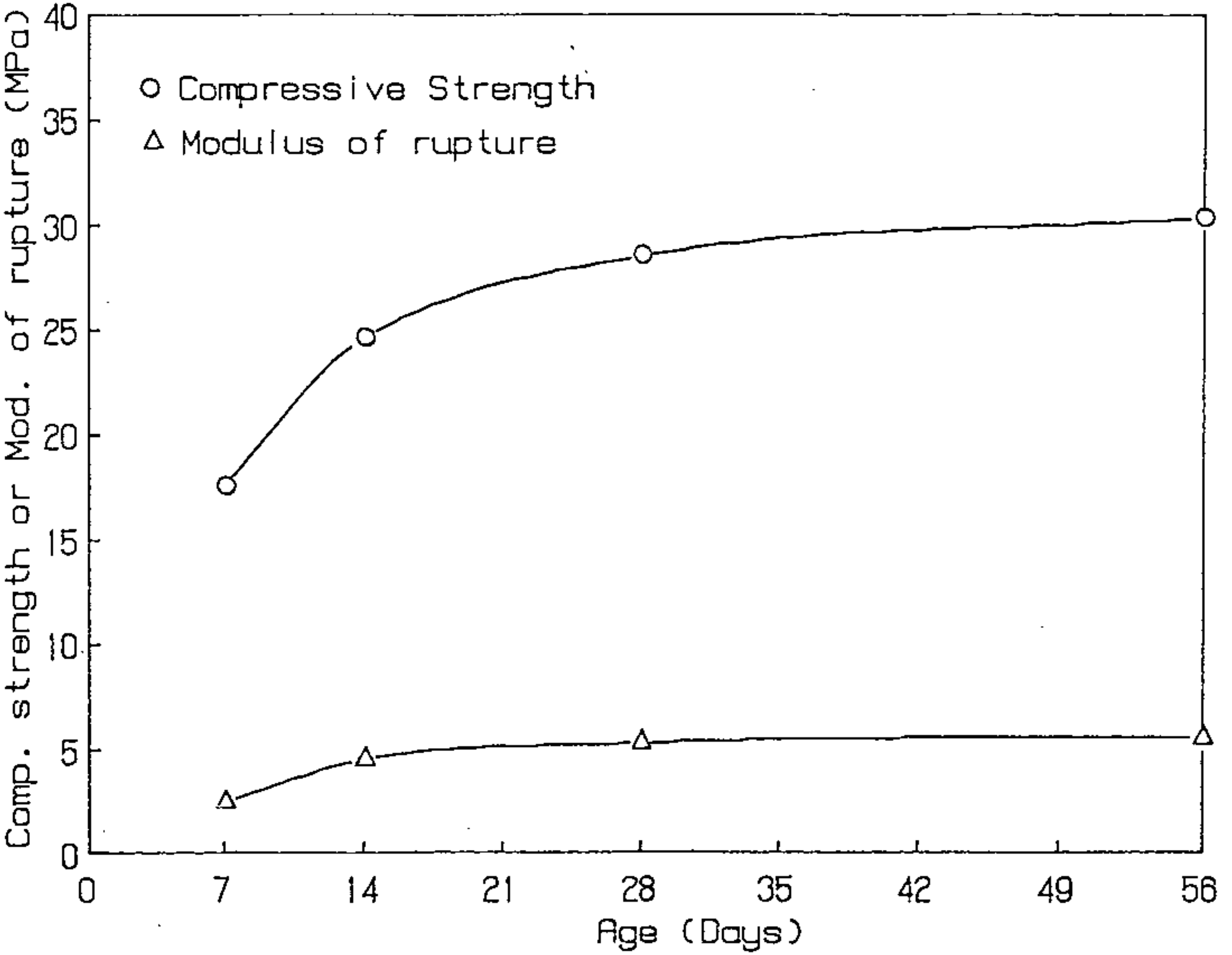

Figure 5.19: Relationship between properties of PPCC with PVAc and age at P/C=0.05

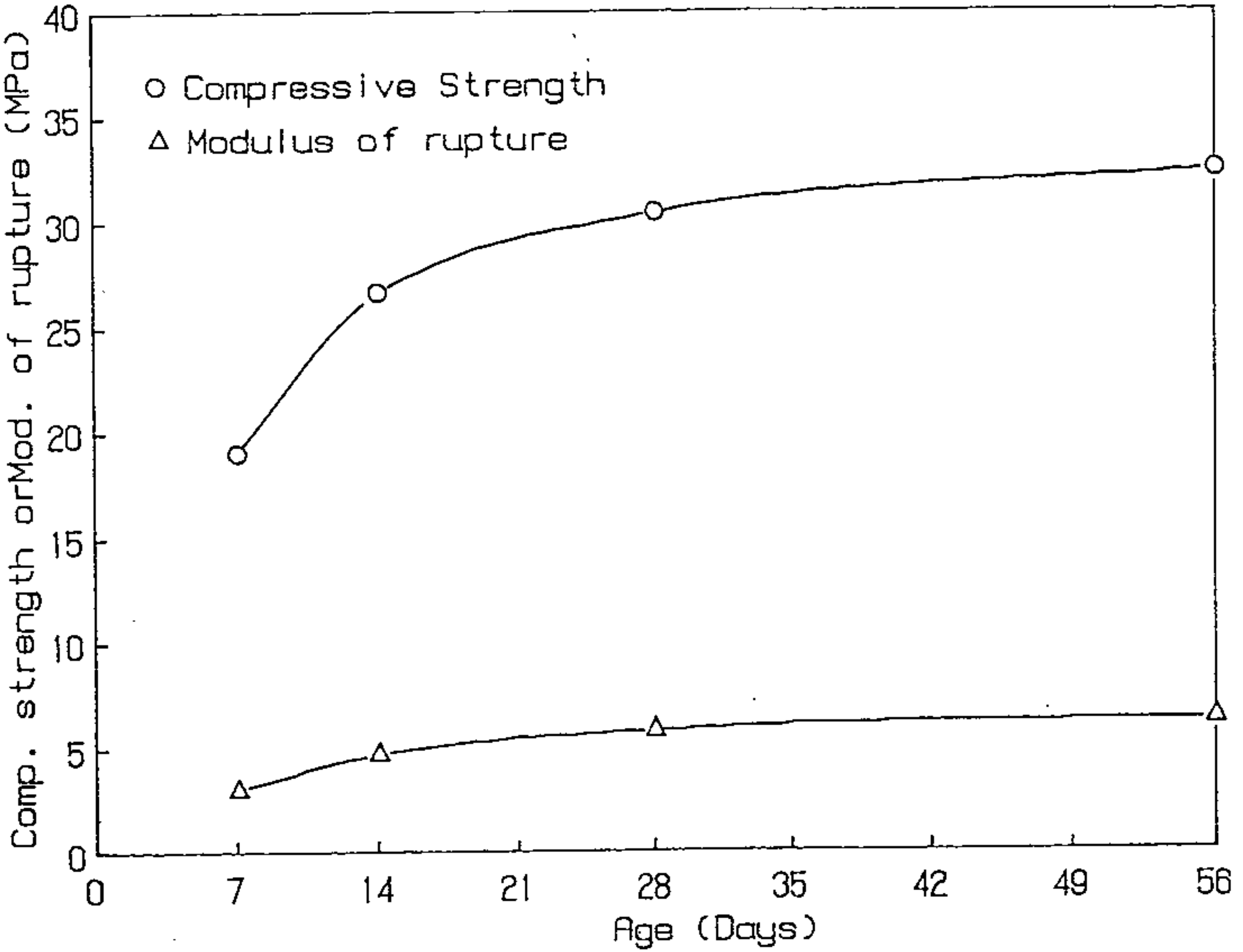

Figure 5.20: Relationship between properties of PPCC with PVAc and age at P/C=0.10

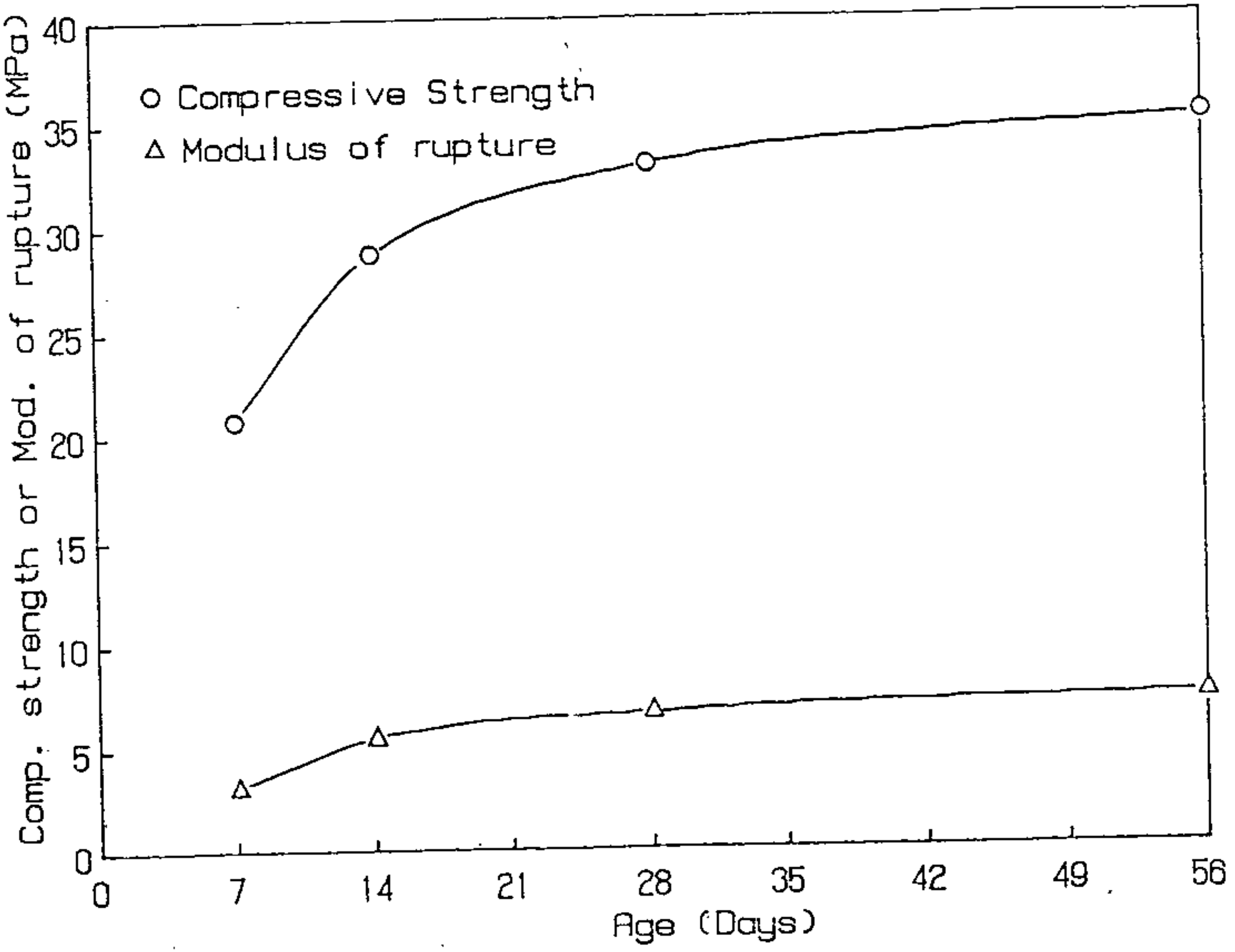

Figure 5.21: Relationship between properties of PPCC with PVAc and age at P/C=0.15

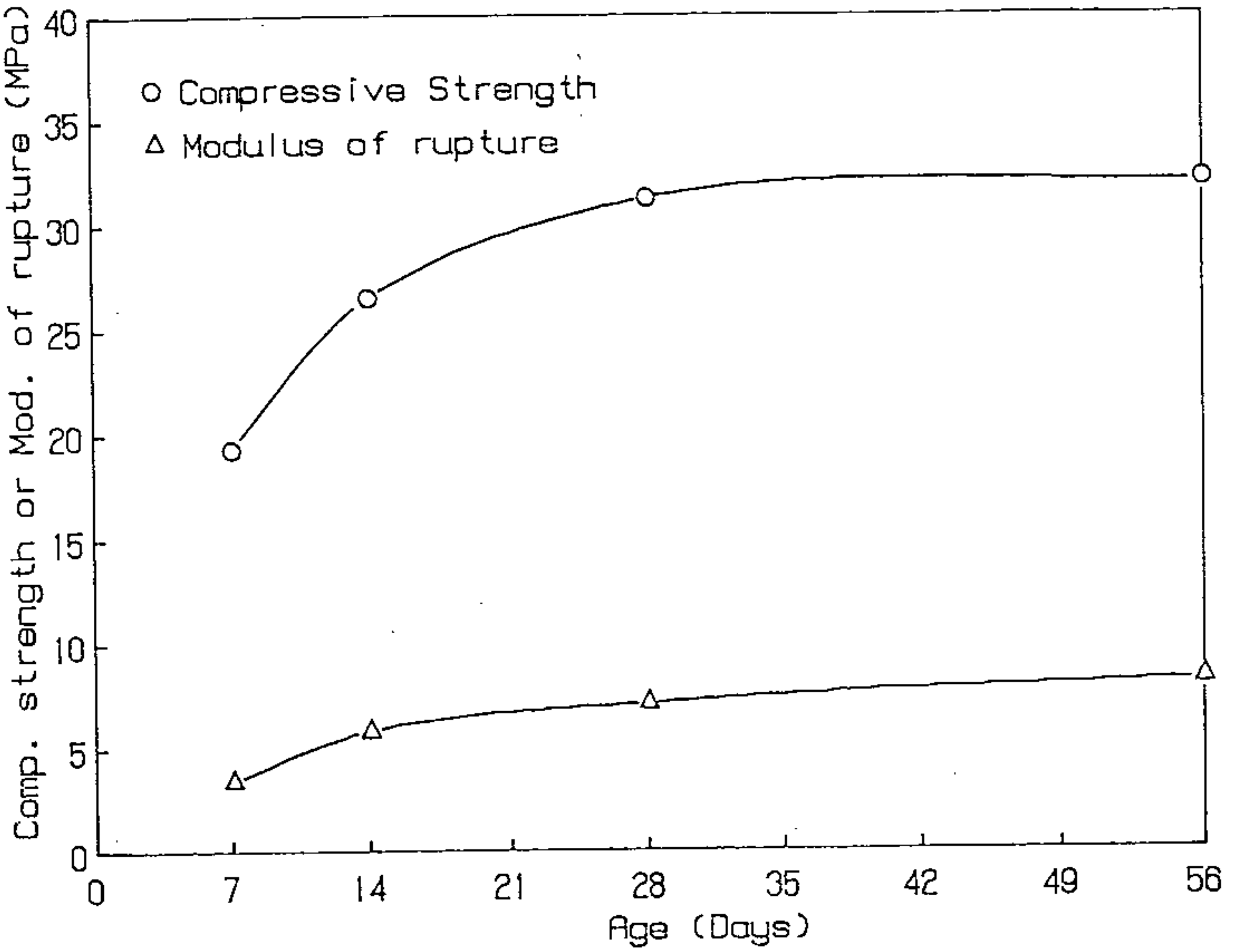

Figure 5.22: Relationship between properties of PPCC with PVAc and age at P/C=0.20

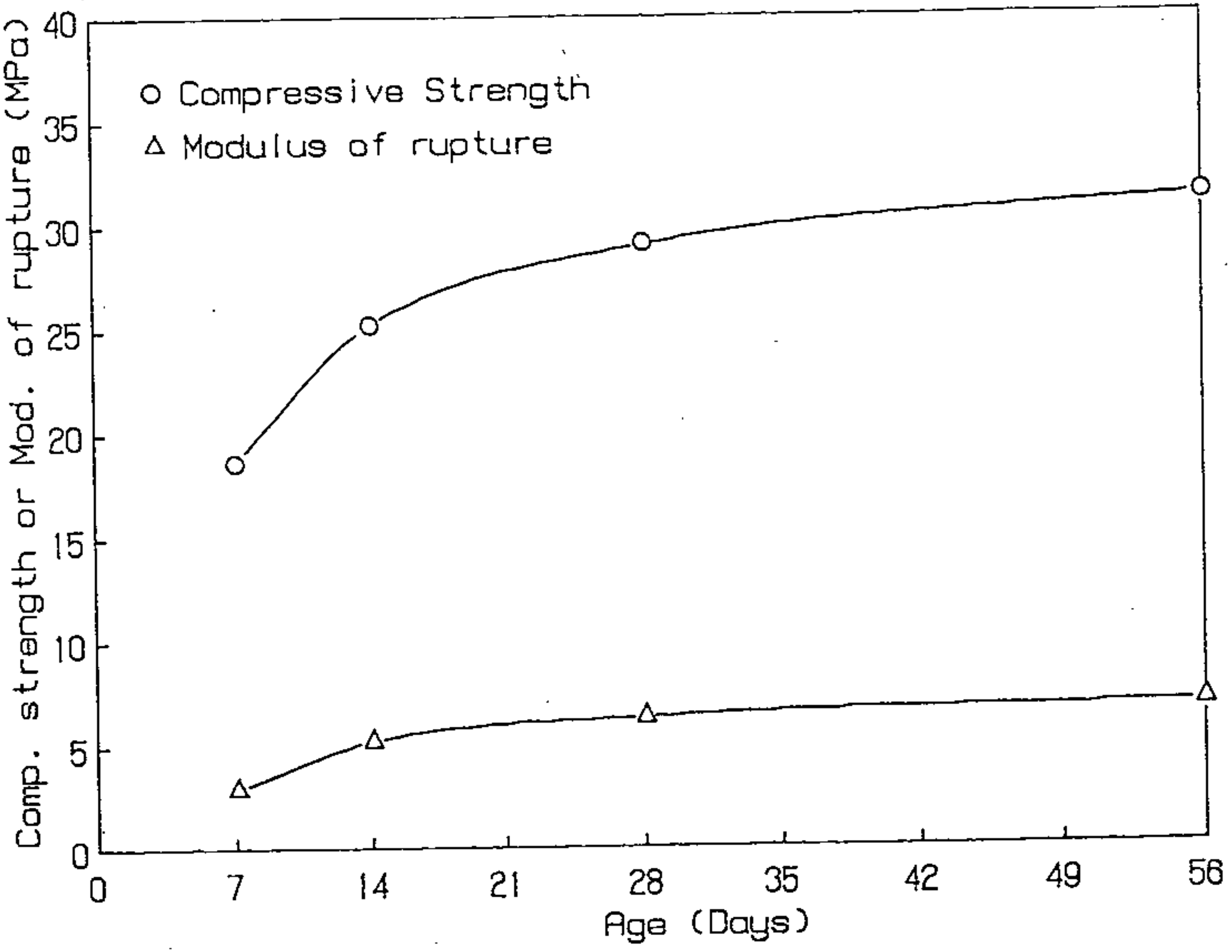

Figure 5.23: Relationship between properties of PPCC with PVAc and age at P/C=0.25

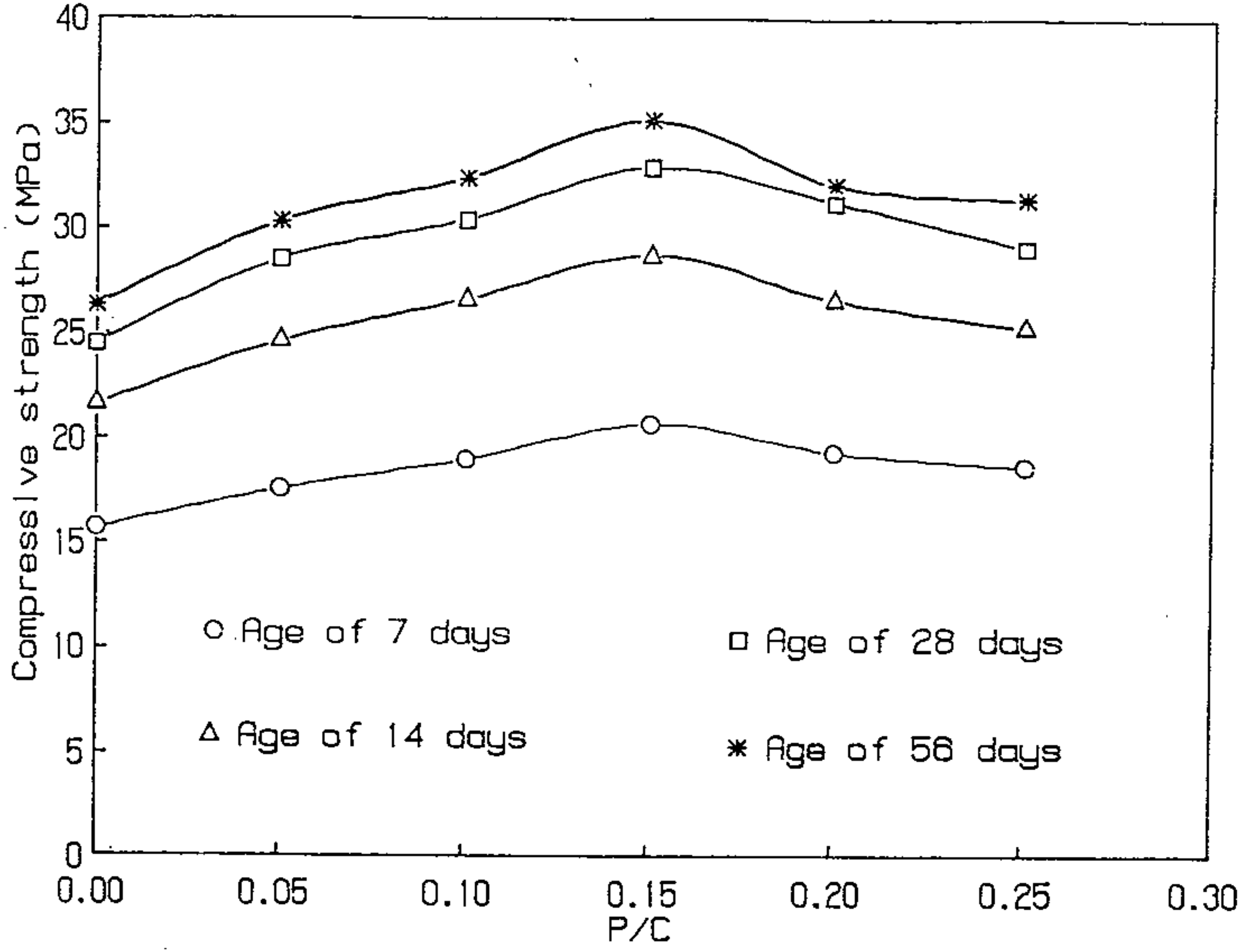

Figure 5.24: Relationship between compressive strength of PPCC with PVAc and P/C at different ages

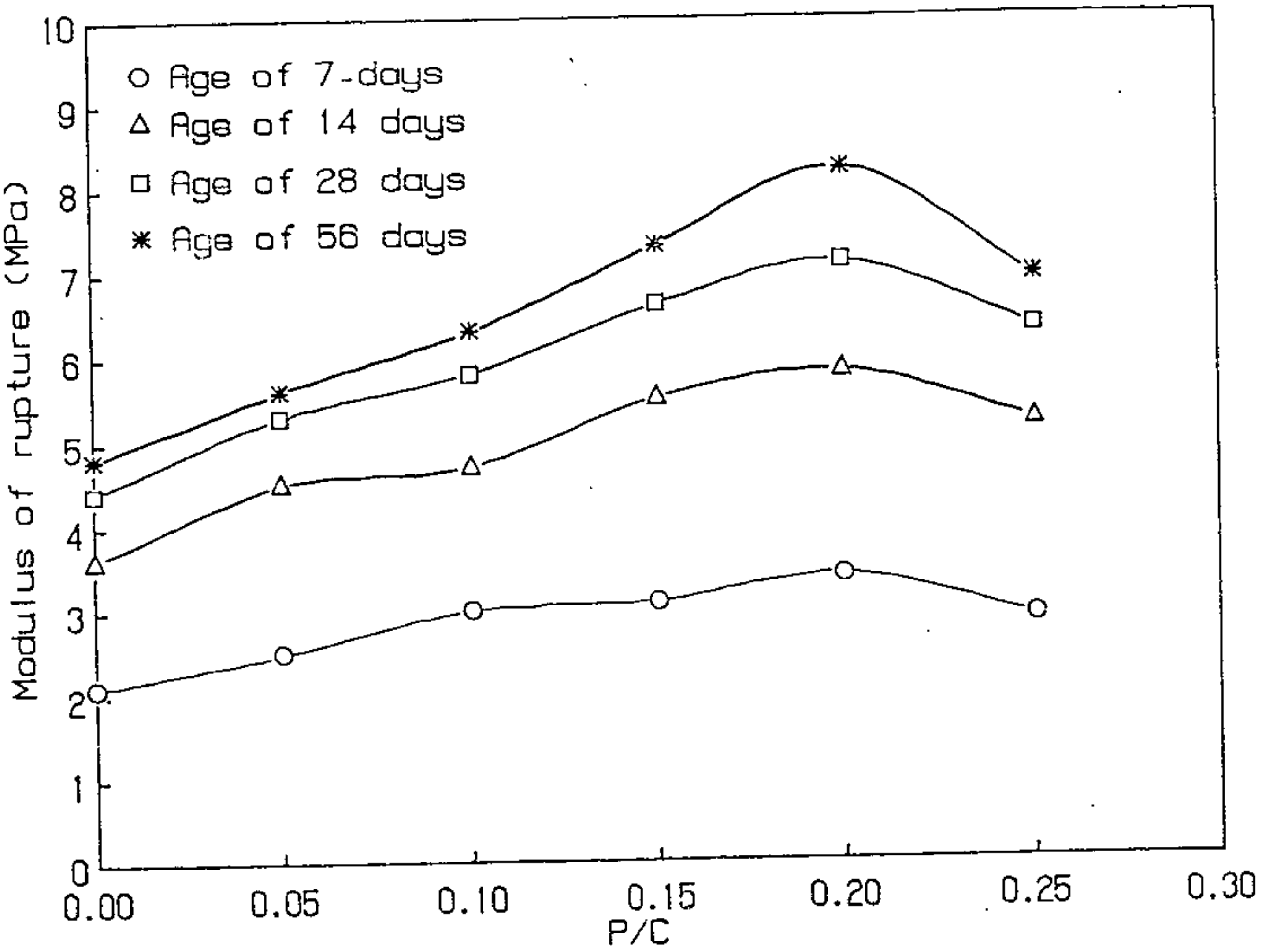

Figure 5.25: Relationship between modulus of rupture of PPCC with PVAc and P/C at different ages

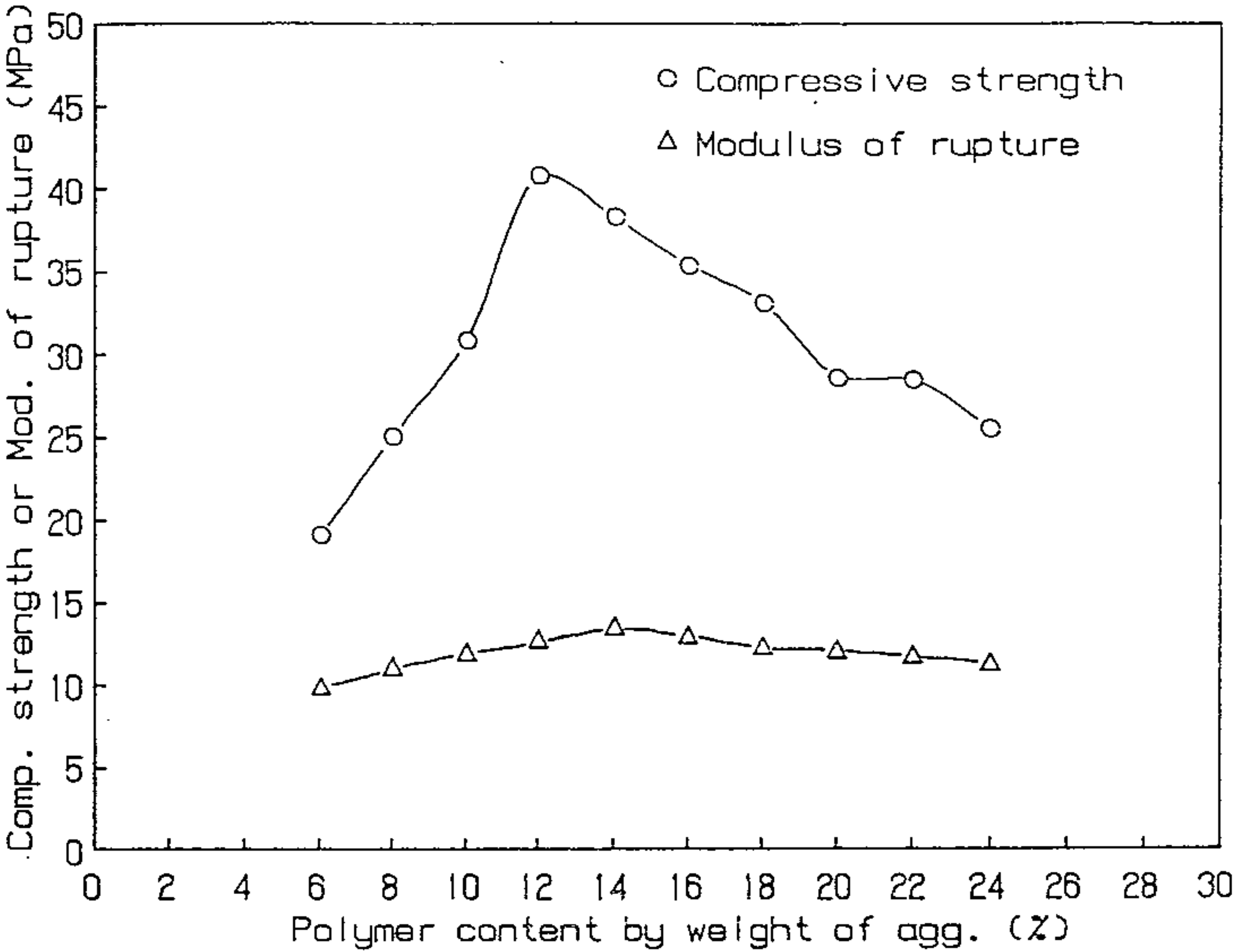

Figure 5.26: Properties of polymer concrete made of unsaturated polyster and well-graded aggregate with varying polymer content.

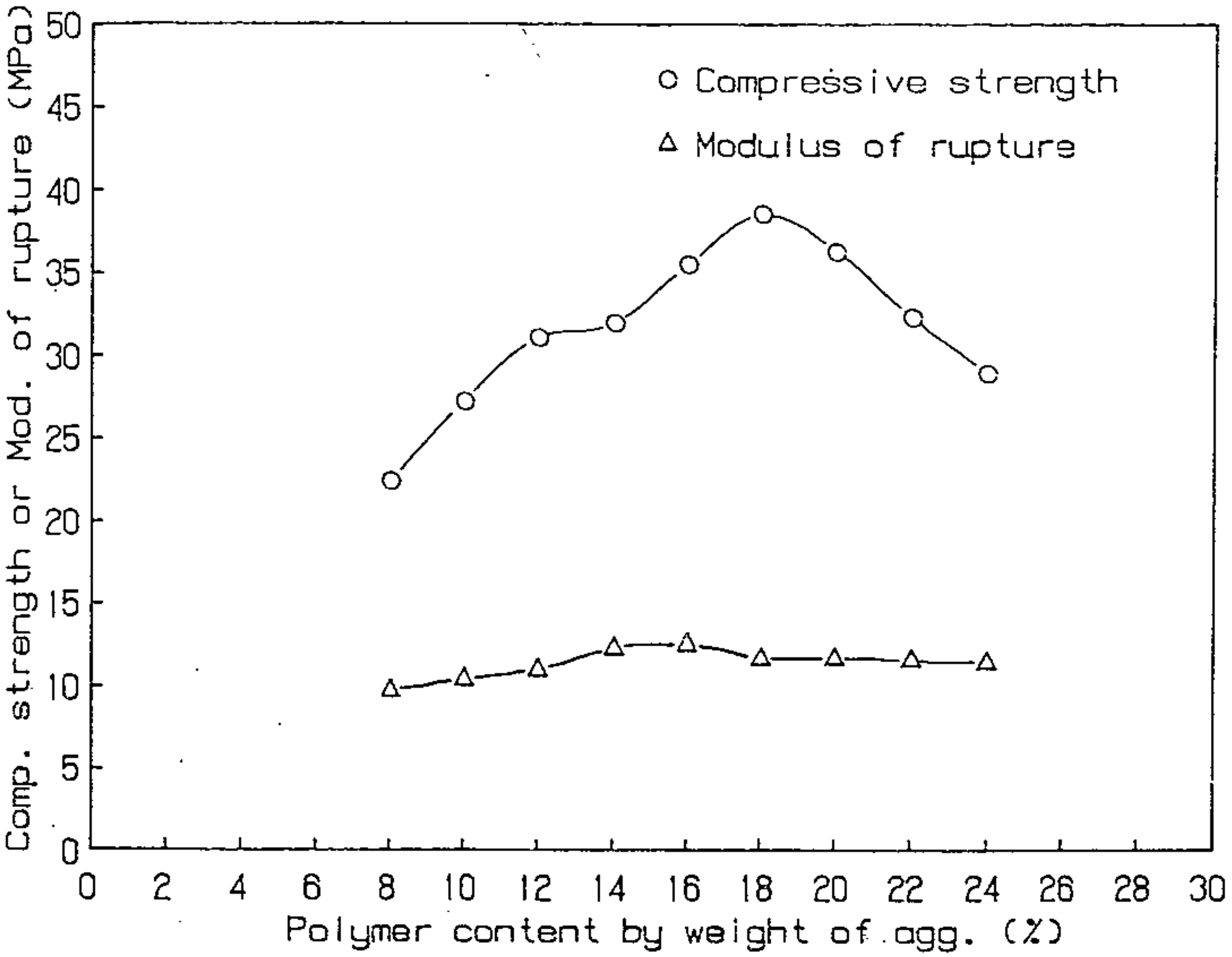

Figure 5.27: properties of polymer concrete made of unsaturated polyster and gap-graded aggregate with varying polymer content.

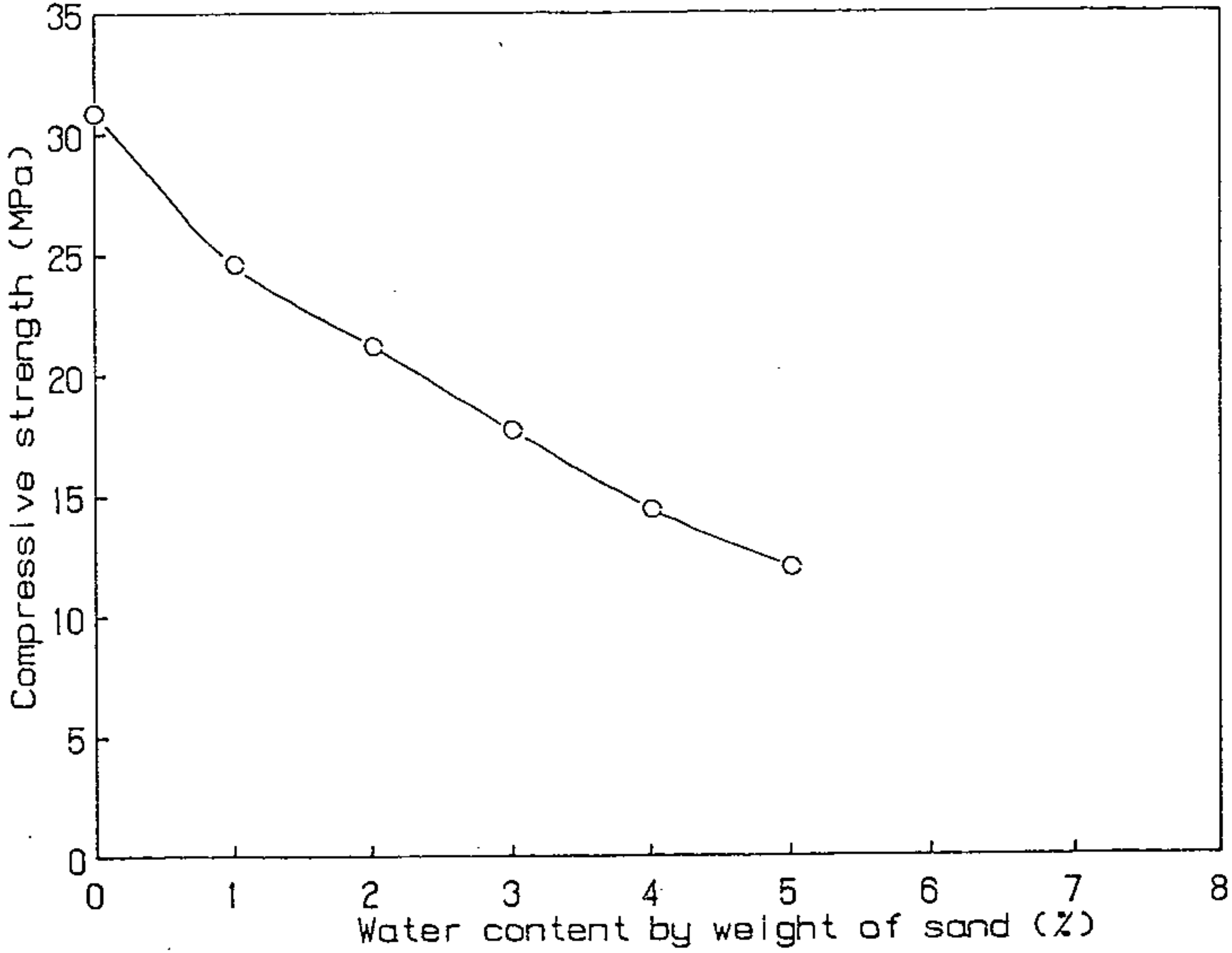

Figure 5.28: Compressive strength of PC as a function of water content (polymer content is 10%)

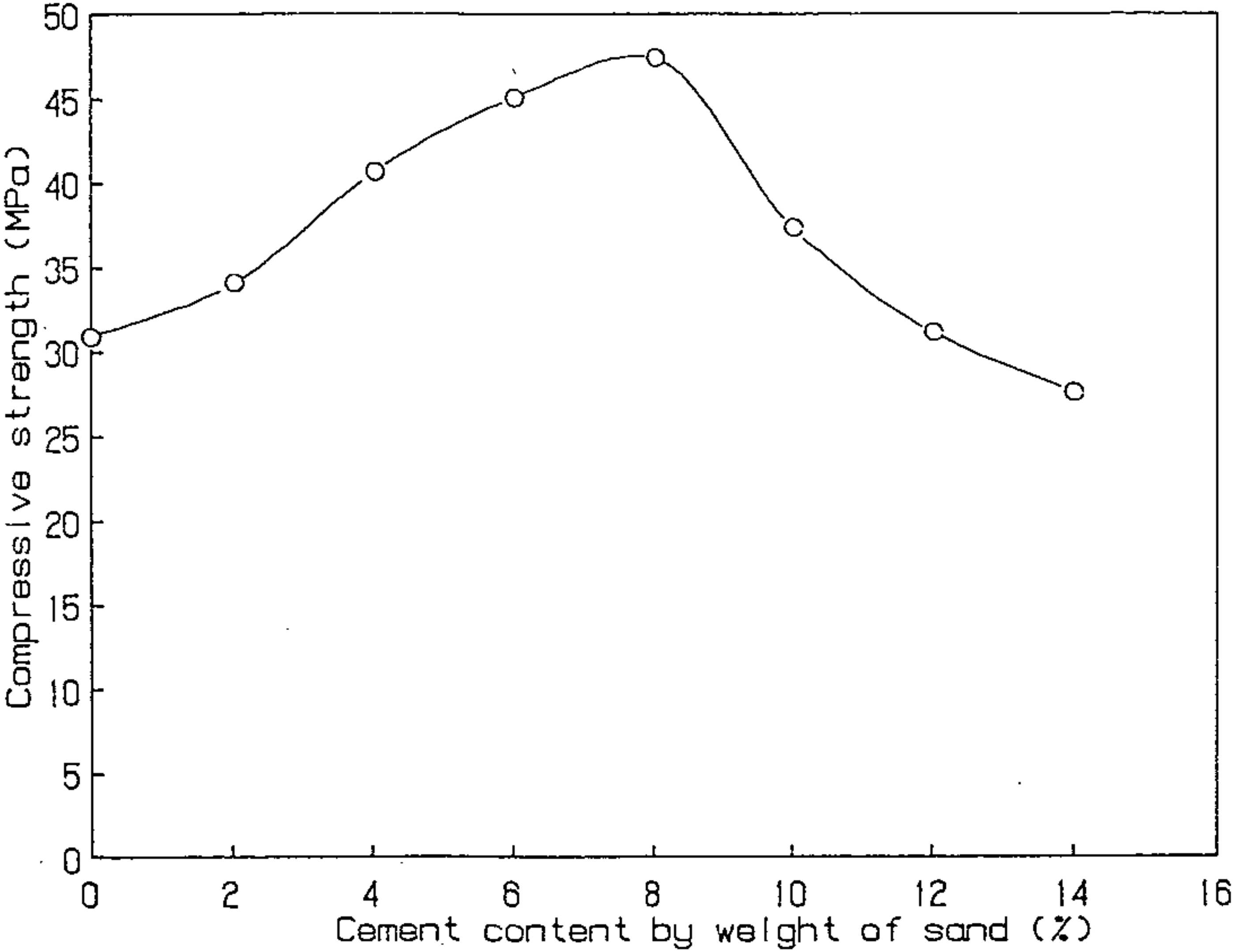

Figure 5.29: Compressive strength of PC as a function of cement content (polymer content is 10%)

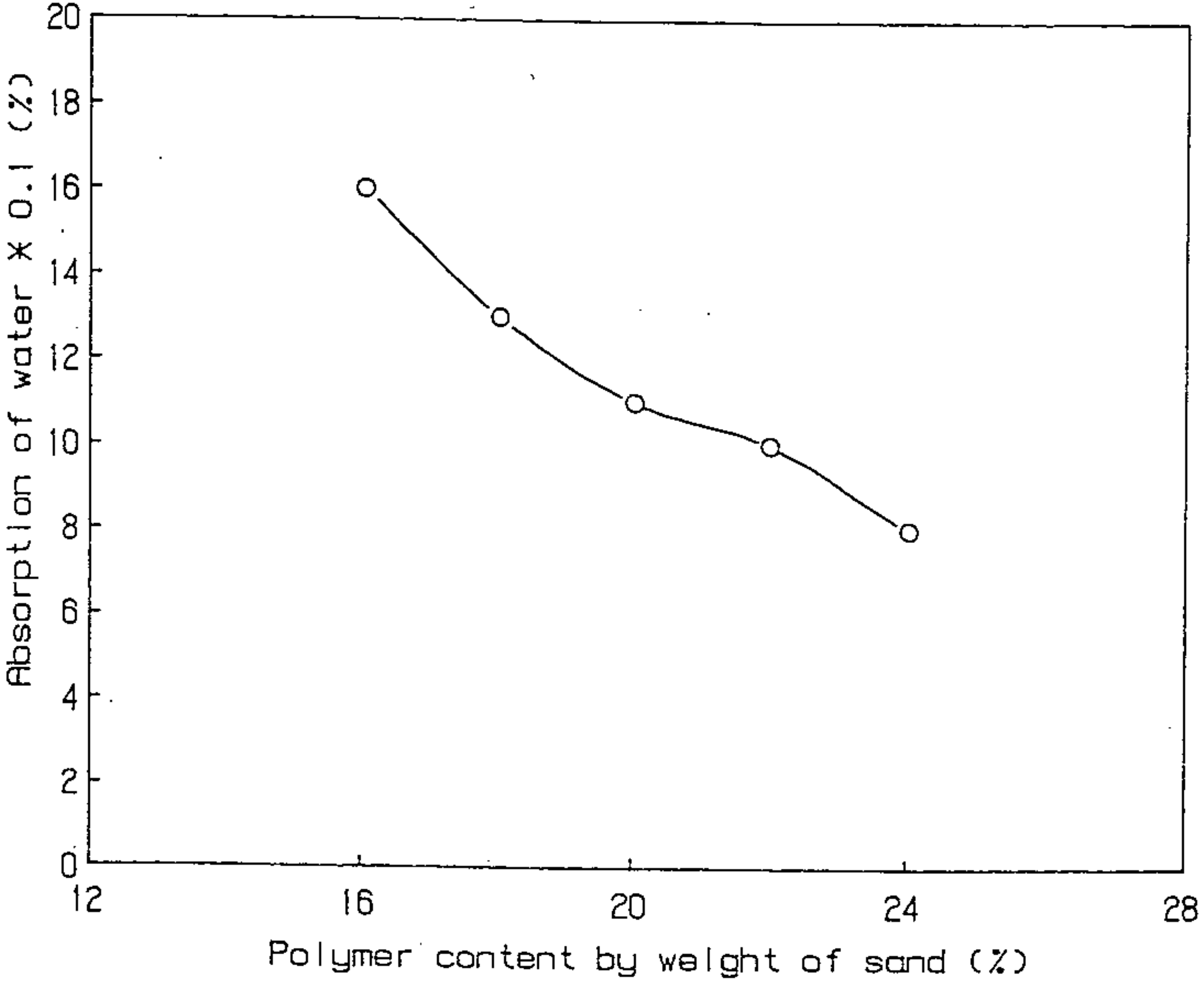

Figure 5.30: Absorption of water by PC as a function of polymer content

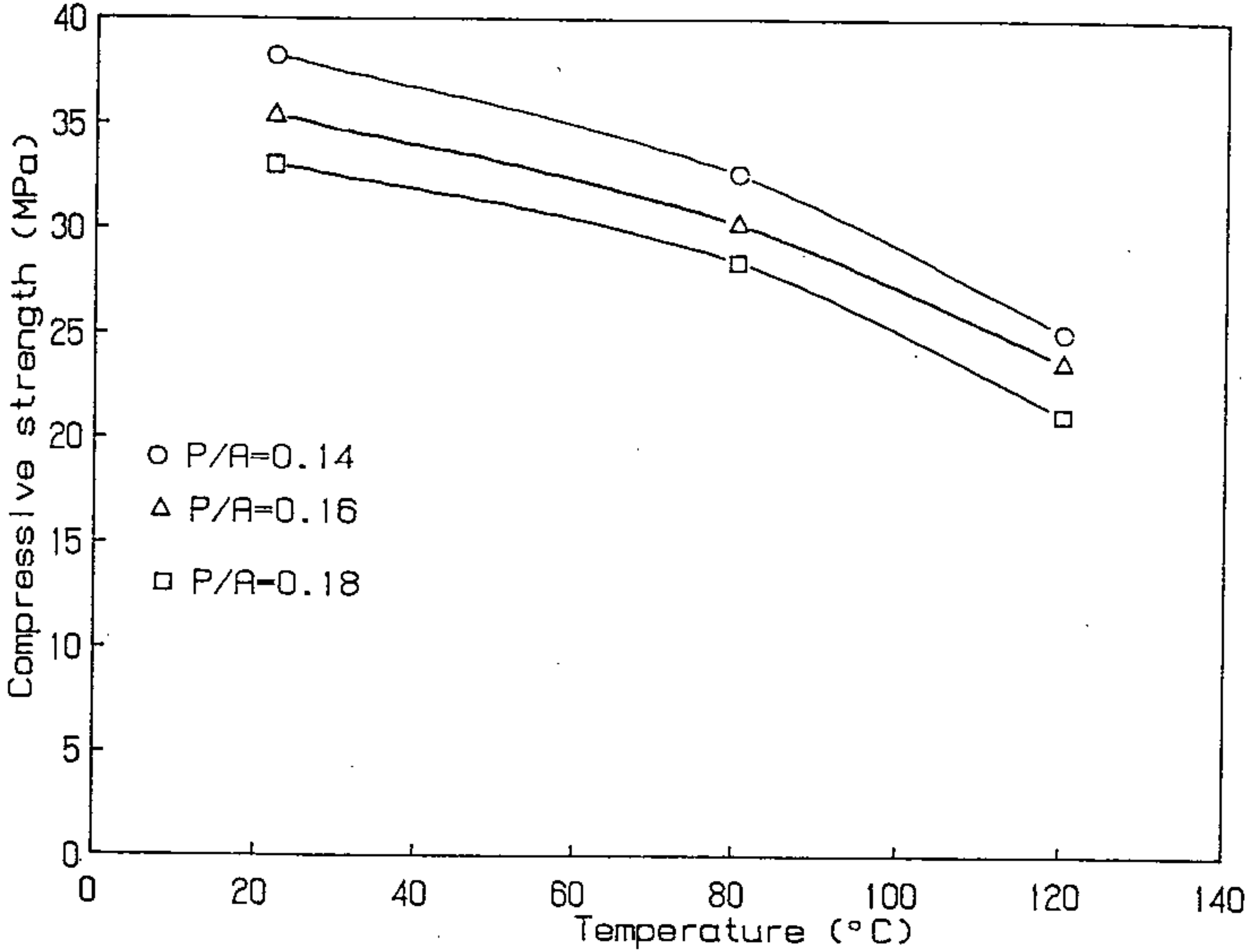

Figure 5.31: Compressive strength of PC made with well-graded aggregate as a function of temperature with varying polymer content

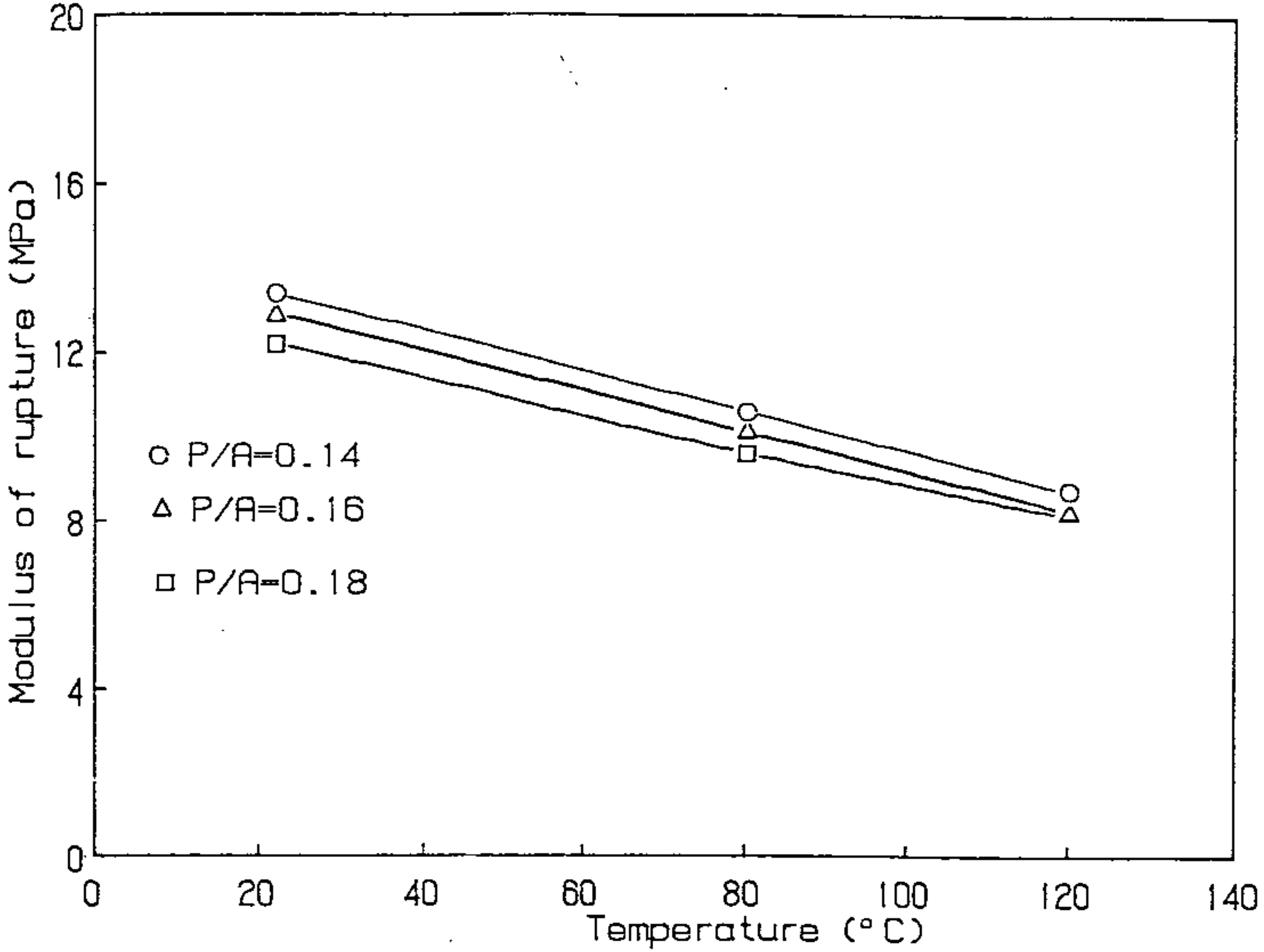

Figure 5.32: Modulus of rupture of PC made with well-graded aggregate as a function of temperature with varying polymer content

CHAPTER 6

Conclusions and Recommendations

6.1 Conclusions

6.1.1 Polymer Cement Concrete (PPCC , PPPCC)

Based on this study, the following conclusions can be advanced:

1. Polyvinylacetate homopolymer (PVAh) has an inverse effect on the strength of both PPCC and PPPCC.
2. PVAh modifies the behavior of fresh concrete; delays the setting of concrete and improves the workability.
3. PVAh has the same effect on the strength properties of polymer cement concrete regardless of the type of cement; whether it is ordinary Portland or Pozzolanic.
4. Polymers are water-reducing agents.
5. Air-entraining agents are not to be used in polymer cement concrete, on the contrary anti-foaming agents should be used.
6. The effect of the polymer content (PVAh) on the compressive strength is nearly the same as that on the modulus of rupture; increasing the polymer content (PVAh) causes a decrease in the strength properties (compressive strength and modulus of rupture) in the same manner.
7. Polyvinylacetate-Veova copolymer (PVAc) affects the properties of fresh

cement concrete (workability and setting time) in the same way that PVAh does.

8. PVAc results in a considerable increase in the strength of PPCC.
9. It is preferred for polymer cement concrete to be moist-cured for three days and then to dry cure it .
10. The three types of polymer cement concrete show excellent adhesive properties.
11. A serious disadvantage of the LMC (Latex modified concrete) has been their tendency to lose strength when immersed in water or exposed to high humidities, and so dry curing was preferred for LMC.

6.1.2 Polymer concrete (PC)

1. The lowest polymer content at which the strength and modulus are maximum represents the optimum polymer content for the polymer concrete.
2. An increase in temprerature decreases the compressive strength and the modulus of rupture of polymer concrete. The effect of temperature on the optimum polymer content is negligible although the maximum strength decreases at high temperatures.
3. The presence of excess water in the aggregate reduces the strength of polymer concrete.
4. Polymer concrete made with well-graded aggregate has better properties (strength, absorption of water and workability) than those of polymer

concrete made with gap-graded aggregate. Also the smaller the sizes of sand particles are , the better are the properties of PC.

5. The absorption of water by PC is reduced by increasing the polymer content because solids of the polymer fill the voids between the particles of the sand used.
6. Using cement as a portion of the sand used in PC results in a significant increase in the strength of PC until an optimum cement content is reached at which incorporating more cement yields a significant decrease in the strength of PC .
7. The properties of PC are determined by the type of polymer and type of aggregate used.
8. The polymer was polymerized at about (100°C) using Benzoyl Peroxide.

6.2 Recommendations

6.2.1 Polymer Cement Concrete (PPCC, PPPCC)

Concrete-polymer materials are relatively new in the construction industry. The composites that offer very good mechanical and durability properties should be determined by tests :

1. Monomers and polymers (PVAh) added to the fresh concrete to form polymer cement concrete are soluble in water, generally interfere with the hydration of cement, and are subject to slow alkaline degradation. Strength of PPPCC and PPCC was found to be reduced in the hardened concrete. There are

many polymers that appear to be alkaline resistant such as styrene which provide improvements in the properties compared to unmodified concretes, and so PVAh is not recommended as modifier for cement conerete , while PVAc appears to be good modifier .

2. Latex modified concrete (polymers PVAh and PVAc are latexes) is prepared and placed in the way that conventional concrete is placed. However , adding the polymer while mixing is recommended in order to get homogeneous mix .
3. Excessive vibration or compaction should be avoided to prevent excess polymer from collecting on the surface; if that occurs (polymer collect on the surface) , the mix should be remixed by hand or any tool .
4. Curing of latex modified concrete is much shorter than that of conventional concrete, latex modified concrete is usually moist-cured for no more than three days. Steam heat is not recommended because high temperature results in degradation of bond and of the latex it self.
5. The water content of the mix should be reduced by an amount equal to water in the polymer (maintining a constant liquid / cement ratio) unless solid polymers are used for which an extra amount of water should be added considering the polymer as a portion of the cement used .
6. Copolymers (of two or more monomers) with alkaline-resistant material such as polyvinylacetate-veova copolymer worked well when added to the fresh concrete. In other words, alkaline - resistant polymers (such as PVAc) are

recommended to produce polymer modified concretes.

7. Polymer latexes don't cost that much compared with the other polymer systems such as epoxies.

6.2.2 Polymer Concrete (PC)

The significant advantages of rapid setting and high strength have resulted in the use of this material for repair of bridge decks, highways, pipe lines and structures under various temperatures and loading conditions. To get the best results and based on the experimental study, the following should be noted :

1. The properties of PC are strongly affected by the behavior of the polymer. The response of most polymers used in PC is a function of time and temperature and the structural system of that polymer. To get a good PC, a good polymer system should be used.
2. Aggregate should be sound, free of dirt, asphalt and other organic materials. The aggregate should be dry to insure adequate bond to the polymer. Also the gradation of the aggregate in PC should provide a relatively low void volume and have sufficient fines to provide workability.

   The coated aggregate (coated with polymer by immersing in monomer) would provide a better surface for bonding to the polymer in addition to preventing moisture from being absorped by the aggregate.
3. compaction of PC is preferable to vibration because the last method causes the excess polymer to accumulate on the surface which in turn delays the

setting of PC; as a solution additional fine aggregate should be added to the surface of PC.

4. Some monomers (especially the light ones) may evaporate if they are exposed to high temperatures for a long time, so when using such monomers in repairing in hot weathers, the surface should be covered by some membranes to minimize evaporation.
5. Modifiers can be used in PC, such as styrene which was used to improve the adhesive properties of polymer concrete.
6. Polymer concrete made with sand of small particles seems to have better properties than those of PC made with aggregates of large particles, and so fine aggregate is recommended to create polymer concrete for repairing purposes.

REFERENCES

1. American Concrete Institute, Polymers in Concrete, State-of-the-Art Report 1976.
2. Synthetic Resins in Building Construction, RILEM Symposium, Paris, 1967.
3. Flexural Behaviour of Reinforced PPCC Beams Abdel-Halim, M. A. Pennsylvania State Univ. 1979.
4. Polymer Modified Concrete, Mohammed A. H. Abdel-Halim. Yarmouk Univ. Jordan, 1985 .
5. Polymer Cement Concrete and Polymer concrete Solomatov, V.I, U.S.A.E.C
6. Polymer-concrete trials and tribulations, Proc. 2nd int. Congr. polymers in concrete, 1978 Jenkins, J.C, Beecorft, G.W and Quinn, W.J University of Texas at Austin.
7. Polymers in Concrete,The concrete society (London), 1975.
8. Selected Bibliography on polymer concrete, Y. Ohama, Nihon University, Koriyama, Japan, 1978.
9. Polymers in Concrete, Proc. 2nd int. Congr. polymers in concrete, 1978. Dikeou, J.T, University of Texasat Austin.
10. An evaluation of a polymer-cement Composite, Composites. Vol.1, No. 4, 1970.
11. Applications of polymer concrete, ACI Publication, SP-69, Detroit, 1978 .
12. Polymers in Concrete, American Concrete Institute, SP-40, 1973, American Concrete Institute, SP-4-,1973, Detroit, Michigan, U.S.A.
13. Polymer Adititives for cement composite, a review composites, Vol.5, No.1: June 1974.
14. Polymers in concrete, American concrete Institute, SP-58,1978 Detroit, U.S.A.

ملخص

ان هدف هذا البحث هو دراسة خواص خرسانة الاسمنت البورتلاندي والبوزولاني المحسنه باضافة بعض عناصر البلمره ، كذلك خلق نوع جديد من الخرسانه والمعروفه باسم خرسانه البلمره والمنتجه باعتماد البلمره كمادة رابطه للركام بدلا من الاسمنت ، حيث استعمل في هذا النوع من الخرسانه نوعين من الركام هما الرمل المتدرج (الاحجام) بشكل جيد والركام المتفاوت التدرج ، ومن ثم درست بعض خواص (خرسانة البلمره) مثل قوى التحمل ، امتصاص الماء ، تاثير الحراره على القوه كذلك تأثير الاسمنت كجزء من الركام .

وفي البرنامج العملي تم اعتماد نسب مختلفة لمادة البلمره مقاسه بالنسبه لمحتوى الاسمنت في خرسانه الاسمنت البورتلاندي والبوزولاني ، ومقاسه بالنسبه لمحتوى الركام في خرسانة البلمره ، حيث فحصت اعداد من الجسور باحجام مختلفه كذلك فحصت اعداد من المكعبات في النوع الاول بينما اعتمدت الاسطوانات في النوع الثاني من الخرسانه (خرسانه البلمره) ، وفي نهاية البحث العملي تمت دراسة النتائج للوصول الى بعض الاستنتاجات وبالتالي اعطاء بعض التوصيات .

وقد تبين ان عناصر البلمره التي درست تحسن خصائص الخرسانه الطرية في حين ان بعضها فقط يحسن خصائص القوى للخرسانه الجافه وهذا يتفق مع نتائج بعض الدراسات في هذا الميدان .