



## Nomenclature

- **polymer concrete (PC)**: formed by polymerizing a mixture of a monomer and aggregate (no other bonding material)
- **latex-modified concrete (LMC)**: also known as polymer Portland cement concrete. Conventional concrete made by replacing part of mixing water with a latex.
- **polymer-impregnated concrete (PIC)**: produced by impregnating or infiltrating a hardened concrete with a monomer and subsequently polymerizing the monomer in situ.



## Significance

- Both PC and LMC have been in commercial use since the 1950s;
- PIC was developed and has been in use since the 1970s.
- Depending on the materials employed, PC can develop compressive strengths of the order of 140 MPa (20,000 psi) within hours or even minutes and is therefore suitable for emergency concreting jobs in mines, tunnels, and highways.



## Significance -- LMC

- LMC possess excellent bonding ability to old concrete, and high durability to aggressive solutions; it has therefore been used mainly for overlays in industrial floors, and for rehabilitation of deteriorated bridge decks.



## Significance -- PIC

- In the case of PIC, by effectively sealing the microcracks and capillary pores, it is possible to produce a virtually impermeable product which gives an ultimate strength of the same order as that of PC. PIC has been used for the production of high-strength precast products and for improving the durability of bridge deck surfaces.



## **Polymer Concrete**

- Polymer concrete (PC) is a mixture of aggregates with a polymer as the sole binder. To minimize the amount of the expensive binder, it is very important to achieve the maximum possible dry-packed density of the aggregate.



# Polymer

- Commercial products are available with a variety of formulations, some capable of hardening to 105 MPa (15,000 psi) within a few minutes without thermal treatment.
- Epoxy resins are higher in cost but offer advantages such as adhesion to wet surfaces.
- Styrene monomer, and methyl methacrylate (MMA) with benzoyl peroxide catalyst and an amine promoter are often used.
- Products with increased strength have been obtained by adding to the PC monomer system a silane coupling agent, which increases the interfacial bond between the polymer and aggregate.

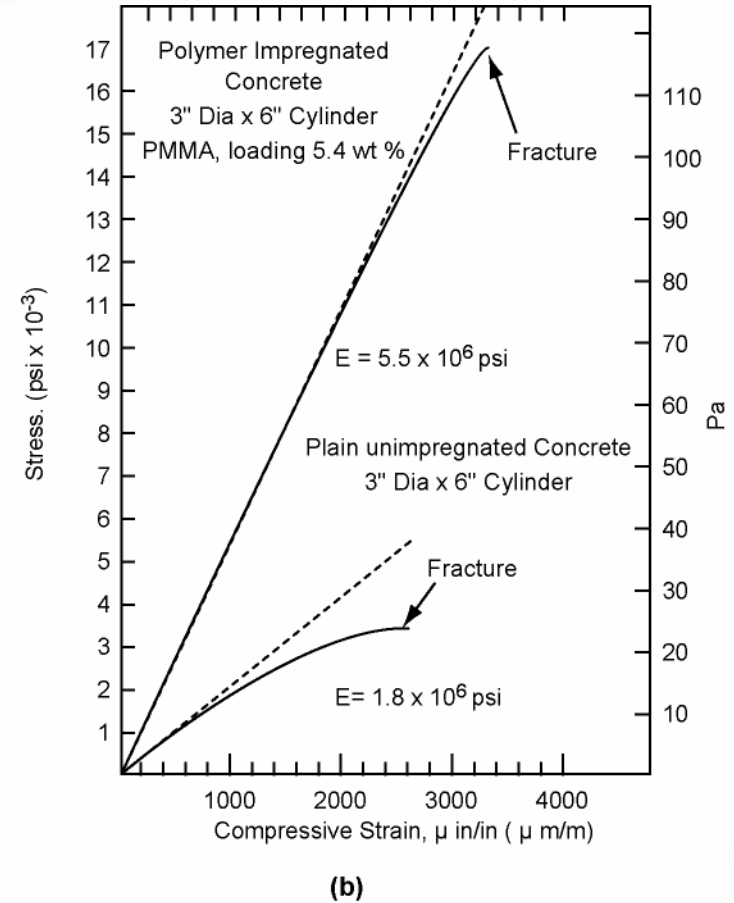
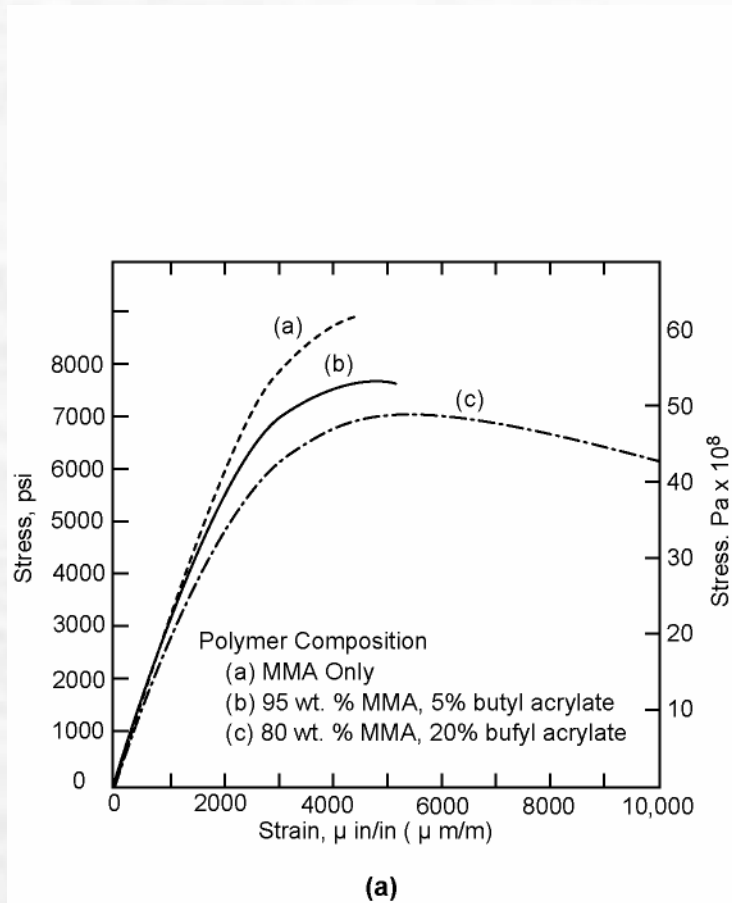


## Properties

- The properties of PC are largely dependent on the amount and properties of polymer in the concrete.
- PC made with MMA is a brittle material that shows a nearly linear stress-strain relationship with high ultimate strength, but the addition of butyl acrylate produces a more ductile material



# Stress-Strain Diagram





## Properties

- Due to good chemical resistance and high initial strength and modulus of elasticity, industrial use of PC has been mainly in overlays and repair jobs.
- Thermal and creep characteristics of the material are usually not favorable for structural applications of PC.
- Polyester concretes are viscoelastic and will fail under a sustained compressive loading at stress levels greater than 50 percent of the ultimate strength. Sustained loadings at a stress level of 25 percent did not reduce ultimate strength capacity for a loading period of 1000 hr.



## **Latex-Modified Concrete**

- The materials and the production technology for concrete in LMC are the same as those used in normal portland cement concrete except that latex, which is a colloidal suspension of polymer in water, is used as an admixture.



## Latex-Modified Concrete

- Earlier latexes were based on polyvinyl acetate or polyvinylidene chloride, but these are seldom used now because of the risk of corrosion of steel in concrete in the latter case, and low wet strengths in the former.
- Elastomeric or rubberlike polymers based on styrenebutadiene and polyacrylate copolymers are more commonly used now.



## Latex

- A latex generally contains about 50 % by weight of spherical and very small (0.01 to 1  $\mu$ m in diameter) polymer particles held in suspension in water by surface-active agents.
- The presence of surface-active agents in the latex tends to incorporate large amounts of entrained air in concrete; therefore, air detrainning agents are usually added to commercial latexes.



## Latex

- 10 to 25 percent polymer (solid basis) by weight of cement is used in typical LMC formulations,
- the addition of latex provides a large quantity of the needed mixing water in concrete.
- The application of LMC is limited to overlays where durability to severe environmental conditions is of primary concern.
- LMC is made with as low an addition of extra mixing water as possible; the spherical polymer molecules and the entrained air associated with the latex usually provide excellent workability.



## Concrete Mix

- Typically, water-cement ratios are in the range 0.40 to 0.45, and cement contents are on the order of 650 to 700 lb/yd<sup>3</sup> (390 to 420 kg/m<sup>3</sup>).



## Curing

- The hardening of a latex takes place by drying or loss of water.
- Dry curing is mandatory for LMC; the material cured in air is believed to form a continuous and coherent polymer film which coats the cement hydration products, aggregate particles, and even the capillary pores.



## Properties

- The most impressive characteristics of LMC are its ability to bond strongly with old concrete, and to resist the entry of water and aggressive solutions.
- It is believed that the polymer film lining the capillary pores and microcracks does an excellent job in impeding the fluid flow in LMC.
- These characteristics have made the LMC a popular material for rehabilitation of deteriorated floors, pavements, and bridge decks.



## Polymer-Impregnated Concrete

- The concept underlying PIC is that if voids are responsible for low strength as well as poor durability of concrete in severe environments, then eliminating them by filling with a polymer should improve the characteristics of the material.



## Polymer-Impregnated Concrete

- It is difficult for a liquid to penetrate it if the viscosity of the liquid is high and the voids in concrete are not empty (they contain water and air). Therefore, for producing PIC, it is essential not only to select a low-viscosity liquid for penetration but also to dry and evacuate the concrete before subjecting it to the penetration process.



## Polymer-Impregnated Concrete

- Monomers such as methyl methacrylate (MMA) and styrene are commonly used for penetration because of relatively low viscosity, high boiling point (less loss due to volatilization), and low cost.



## Polymer-Impregnated Concrete

- After penetration, the monomer has to be polymerized in situ. This can be accomplished in one of three ways.
- A combination of promoter chemical and catalysts can be used for room-temperature polymerization; but it is not favored because the process is slow and less controllable.
- Gamma radiation can also induce polymerization at room temperature, but the health hazard associated with it discourages the wide acceptance of this process in field practice.
- The third method, which is generally employed, consists of using a monomer-catalyst mixture for penetration, and subsequently polymerizing the monomer by heating the concrete to 70 C with steam, hot water, or infrared heaters.



## Sequence of operation

- **Casting conventional concrete elements:**  
Since the quality of concrete before penetration is not important from the standpoint of properties of the end product, no special care is needed in the selection of materials and proportioning of concrete mixtures.
- Section thickness is generally limited to a maximum of about 150 mm, since it is difficult to fully penetrate thick sections.



## Sequence of operation

- **Curing the elements**
- Following the removal of elements from forms, at ambient temperatures conventional moist curing for 28 days or even 7 days is adequate because the ultimate properties of PIC do not depend on the prepenetration concrete quality.
- For fast production schedules, thermal curing techniques may be adopted.



## Sequence of operation

- **Drying and evacuation:**
- The time and temperature needed for removal of free water from the capillary pores of moist-cured products depend on the thickness of the elements.
- At the drying temperatures ordinarily used (i.e., 105 C), it may require 3 to 7 days before free water has been completely removed from a 150-by 300-mm concrete cylinder.
- Temperatures on the order of 150 C can accelerate the drying process so that it is complete in 1 to 2 days.



## Sequence of operation

- **Soaking the dried concrete in a monomer**
- The in situ penetration of concrete in the field may be achieved by surface ponding, but precast elements are directly immersed in the monomer-catalyst mixture.
- Commercial monomers contain inhibitors that prevent premature polymerization during storage; the catalyst serves to overcome the effect of the inhibitor.



## Sequence of operation

- **Sealing the monomer**
- To prevent loss of monomer by evaporation during handling and polymerization, the impregnated elements must be effectively sealed in steel containers or several layers of aluminum foil;
- in the rehabilitation of bridge decks this has been achieved by covering the surface with sand.



## Sequence of operation

- **Polymerizing the monomer**
- Thermal-catalytical polymerization is the preferred technique.
- The time for complete polymerization of the monomer in the sealed elements exposed to steam, hot water or air, or infrared heat at 70 to C may vary from a few to several hours.
- In the case of a MMA-benzoyl peroxide mixture, no differences in strength were found between specimens polymerized at C with hot air for 16 hr or with hot water for 4 hr.