Report on Polymer-Modified Concrete

Reported by ACI Committee 548



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Report on Polymer-Modified Concrete

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Report on Polymer-Modified Concrete

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This report addresses concrete made with organic polymers combined with hydraulic cement and discusses the polymer systems used to produce polymer-modified concrete, including their composition and physical properties. It explains the principle of polymer modification and reviews the factors involved in selecting appropriate polymer systems. The report also discusses mixture proportioning and construction techniques for different polymer systems and summarizes the properties of fresh and hardened polymer-modified concrete and common applications.

Keywords: abrasion; acrylic resins; admixtures; bridge deck; construction; corrosion; curing; durability; epoxy resins; latex; mixture proportioning; mortar; pavements (concrete); plastic; polymer; polymer-cement concrete; repair; resin; resistance to chemical attack; resistance to freezing and thawing; test.

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PREFACE

Polymer-modified concrete (PMC) is developed by mixing a polymer material to portland-cement concrete with the interest of enhancing the concrete durability and bond strength. PMC, also known as polymer portland-cement concrete (PPCC) or latex-modified concrete (LMC), was originally developed during the 1950 and 1960s. The material quickly found its way to awaiting industry to make use of its unique properties and became a common material in bridge deck slab overlays, industrial floors and as repair material with enhanced tensile and bond strength. Extensive research and numerous publications on the behavior of PMC were produced from the late 1970s up to the early 1990s. These publications constitute most of our current knowledge on PMC and polymer-modified mortars (PMM). While the development of PMC has significantly slowed down in the last decade, this document is designed to provide a major source of collective information for the public about PMC. The intent is to provide insight on most up-to-date standards, current practices, and the state of the art on research developments on PMC.

The International Congress on Polymers in Concrete (ICPIC) served during the last four decades as the international forum for research and development (R&D) on all types of polymer concrete including PMC. Proceedings of the ICPIC reflected the state of R&D on PMC and the issues of current interest for both academia and industry. The first ICPIC was held in London (UK) in 1975, and the most recent ICPIC was held in Chuncheon (South Korea) in 2007. For the last three decades, the ICPIC forum has served to connect interested specialists in PMC while providing insight on new technologies and future development trends.

Research on PMC continues to date with little addition to the main body of knowledge that was generated in the last 20 years of the twentieth century. Research developments in the 1980s and 1990s explained the principles of polymer modification of cement hydration (Ohama 1987) and provided the basis for selecting the suitable polymer type for PMC. Today, styrene butadiene rubber (SBR) and styreneacrylic (S-A) copolymer represent the most usable polymers in PMC. It is therefore evident that PMC production and use has reached a high level of maturity and most research investigations in the last two decades were applications directed to further establish the procedures and standards for the material's use in the field. Within the past few years, the most interesting developments in PMC are the development of new very-earlystrength LMC (Sprinkel 2005) and the use of chopped glass and carbon fibers as additives to reduce LMC plastic shrinkage cracking (Issa et al. 2007). Both developments have found their way to bridge deck slab overlays for their ability to provide fast construction and reduce plastic shrinkage cracking. The recent work by Ohama and Demura (2001) and Ohama (2007a) on self-repair epoxy-modified mortars is definitely worth noting.

CHAPTER 1—INTRODUCTION AND SCOPE 1.1—Introduction

Polymer-modified cementitious mixtures (PMCs), also called polymer portland-cement concrete (PPCC) and latexmodified concrete (LMC), are defined as hydraulic cement combined at the time of mixing with organic polymers that are dispersed or redispersed in water, with or without aggregates. An organic polymer is a substance composed of thousands of simple molecules combined into large molecules. The simple molecules are known as monomers, and the reaction that combines them is called polymerization. The polymer may be a homopolymer if it is made by the polymerization of one monomer, or a copolymer when two or more monomers are polymerized. The organic polymer is supplied in three forms: as a dispersion in water that is called latex; as a redispersible powder; or as a liquid that is dispersible or soluble in water. Dispersions of polymers in water and redispersible polymer powders have been in use for many years as admixtures to hydraulic-cement mixtures. These admixtures are called polymer modifiers. The dispersions of these polymer modifiers are called latexes, sometimes incorrectly referred to as emulsions.

In this report, the use of the general term "polymer-modified cementitious mixture" includes polymer-modified cementitious slurry, mortar, and concrete. Where specific slurry, mortar, or concrete mixtures are referenced, specific terms are used, such as LMC and latex-modified mortar (LMM). Several other terms used in this report are defined in ACI 548.1R.

The improvements from adding polymer modifiers to concrete include increased bond strength, flexural and tensile strengths, split strength, and reduced elastic modulus. These lead to improved physical resistance such as impact resistance and abrasion resistance (Shaker et al. 1997; Wong et al. 2003; Colak 2005). A reduced elastic modulus might be particularly helpful when LMC is applied as a bridge deck overlay or repair surface. The reduced elastic modulus results in a reduction of the stresses developed due to differential shrinkage and thermal strains that would reduce the tendency of the material to crack. PMC can also improve corrosion resistance, resistance to chemical attack and severe environment (such as sulfuric acid attack, penetration by water and dissolved salts, and freezing-and-thawing resistance), and it reduces need for sustained moist curing. These improvements are largely due to reduced water permeability in PMC (Shaker et al. 1997; Ohama 1995b). The improvements are measurably reduced when PMC is tested in the wet state (Popovics 1987: Soroushian et al. 1993). The specific property improvement to the modified cementitious mixture varies with the type of polymer modifier used.

The proportioning of ingredients and mixing procedures are similar to those for unmodified mixtures. Curing of modified mixtures, however, differs in that only 1 to 2 days of moist curing are required, followed by air curing. Applications of these materials include tile adhesive and grout, floor leveling concrete, water tanks, swimming pools, roof deck, concrete patches, bridge deck overlays, and ship decks (Su et al. 1991; Kardon 1997; Pinelle 1995; Cabrera and Al-Hasen 1997; Gerharz 1999; Hare 1999; Jingang et al. 2005).

1.2—History

The use of polymers as an additive to construction material is not new. In Babylonia in 4000 B.C. and in Indus Valley in 3000 B.C., clay brick walls were produced by using natural polymers such as albumen and rice paste (Chandra and Ohama 1994; Kardon 1997). More recently, in 1923, the first patent of a polymer-hydraulic-cement system, issued to Cresson (1923), refers to paving materials with natural rubber latexes where cement was used as filler. The first patent of the modern concept of a polymer-modified system was granted to Lefebure in 1924 (Lefebure 1924). Lefebure appears to be the first worker who intended to produce a PMC using natural rubber latexes by proportioning latex on the basis of cement content; Cresson, in contrast, based his mixture on the polymer content. In 1925, Kirkpatrick patented a similar idea (Kirkpatrick 1925). Throughout the 1920s and 1930s, LMM and concrete using natural rubber latexes were developed. Bond's patent in 1932 (Bond 1932) suggested the use of synthetic rubber latexes, and Rodwell's patent in 1939 (Rodwell 1939) first claimed to use synthetic resin latexes, including polyvinyl acetate latexes, to produce polymer-modified systems.

In the 1940s, patents on polymer-modified systems with synthetic latexes, such as polychloroprene rubber latexes (Neoprene) (Cooke 1941) and polyacrylic ester latexes (Jaenicke et al. 1943) were published. Also, polyvinyl acetate-modified mortar and concrete were actively developed for practical applications. Since the late 1940s, polymermodified mixtures have been used in various applications such as deck coverings for ships and bridges, paving, floorings, anticorrosives, and adhesives. In the United Kingdom, feasibility studies on the applications of natural rubber-modified systems were conducted by Stevens (1948) and Griffiths (1951). Also, a strong interest was focused on the use of synthetic latexes in the polymer-modified systems. Geist et al. (1953) reported a detailed fundamental study on polyvinyl acetate-modified mortar and provided a number of valuable suggestions for later research and development of polymermodified systems. The first use of epoxy resins to modify hydraulic cement was reported by Lezy and Paillere (1967).

Research efforts in the 1970s, 80s, and 90s were focused on examining the properties of LMC and selecting the most suitable polymer latex for modifying cement in polymermodified mortar (PMM) and PMC (Popovics and Tamas 1978; Lavelle 1988; Ohama 1995b; Okba et al. 1997). A major milestone during that time period was revealing the principles of latex modification of the cement hydration and identifying the mechanism of polymer-cement co-matrix formation (Ohama 1987; Su et al. 1991, 1996; Puterman and Malorny 1998; Jenni et al. 2006). Later efforts examined the long-term behavior of PMC with focus on durability and deterioration resistance aspects as a main characteristic of PMC (Ohama et al. 1985; Shaker et al. 1997; Mirza et al. 2002) and on controlling the rheological properties of LMC (Barluenga and Hernández-Olivares 2004).

Recently, researchers developed and examined veryearly-strength LMC using rapid hardening cement (Sprinkel 1999, 2005). The use of the new very-early-strength LMC proved efficient for replacing bridge deck overlays. Moreover, the use of fiber-reinforced LMC has been recently promoted (Cao and Chung 2001; Issa et al. 2007). The use of glass and carbon fiber-reinforced LMC provides a watertight microstructure of LMC with very low permeability and the ability of the chopped fibers to limit plastic shrinkage cracking. Such combined benefits make fiber-reinforced LMC an excellent alternative for bridge deck slabs (Issa et al. 2007). Finally, a bibliography developed and updated by Ohama (2007b) represents an excellent source of information on historical and recent developments of PMC.

1.3—Scope

This report reflects the current state of knowledge of PMC and intends to provide the reader with a credible source of knowledge on PMC reflecting the maturity of that technology and highlighting R&D efforts taking place in the last few years. It is not the intention of this document to cover all research efforts on PMC but rather to highlight the significant efforts that helped shape the current state of knowledge of that material.

CHAPTER 2—ACRONYMS AND DEFINITIONS 2.1—Acronyms

ASTM—ASTM International FHWA—Federal Highway Administration ICPIC—International Congress on Polymers in Concrete ICRI—International Concrete Repair Institute LMC—latex-modified concrete LMM—latex-modified mortar MFFT—minimum film-forming temperature PAE—acrylic polymer and copolymer PMC—polymer-modified cementitious mixture PMM—polymer-modified mortar PPCC—polymer portland-cement concrete PVA—polyvinyl acetate homopolymer R&D-Research & Development RH—relative humidity S-A—styrene-acrylic copolymer S-B-styrene-butadiene copolymer SBR-styrene-butadiene rubber VAC-vinyl acetate copolymer VAE—vinyl acetate ethylene copolymer VA-VEOVA-vinyl acetate-vinyl ester of versatic acid copolymer

VEOVA—vinyl acetate-vinyl ester of versatic acid copolymer UV—ultraviolet