ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

PROPERTIES OF POLYMER MODIFIED MORTARS AND EFFECTS OF FLY ASH AND SLAG INCORPORATION

M.Sc. THESIS

Hakan Erdoğan ÖZMEN

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POLİMER MODİFİYE HARÇLARIN ÖZELLİKLERİ VE UÇUCU KÜL VE CÜRUF KATKISININ ETKİSİ

YÜKSEK LİSANS TEZİ

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OCAK 2015

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FOREWORD

I would like to express my deep appreciation to my thesis advisor Prof. Dr. Hulusi ÖZKUL, for his valuable help, guidance and motivation during my laboratory studies and during preparation of my thesis.

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December 2014

Hakan Erdoğan ÖZMEN
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ABBREVIATIONS

ASTM	: American Society for Testing and Materials
$Ca(OH)_2$	: Calcium hydroxide
CaO	: Calcium oxide
CO_2	: Carbon dioxide
CS	: Crushed Stone
CSH	: Calcium Silicate Hydrate
EVA	: Ethylene-Vinyl Acetate
FA	: Fly Ash
GGBFS	: Ground Granulated Blast Furnace Slag
SBR	: Styrene-Butadiene Rubber
SCM	: Supplementary Cementing Material
SL	: Ground Granulated Blast Furnace Slag
SN	: Sand

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PROPERTIES OF POLYMER MODIFIED MORTARS AND EFFECTS OF FLY ASH AND SLAG INCORPORATION

SUMMARY

In this study, polymer modified mortars, which are composites of portland cement, aggregate and polymer admixture, are described and change of properties of polymer modified mortars with respect to curing conditions, type of polymer admixture and supplementary cementing material incorporation is investigated.

Matrix phase of polymer modified mortars consists of cement hydrates and polymer film formation intermingled with each other. Properties of cement mortars could be improved by incorporation of polymer admixtures. However, properties of polymer modified mortars depend on various parameters such as type of polymer, polymer/cement ratio, water/cement ratio and curing conditions.

The study is divided into two phases as preliminary and comparative. In the preliminary phase, the objective is to determine favorable curing condition for polymer modified mortar. In the comparative phase of the study, effects of polymer type on properties of polymer modified mortars and optimum polymer content was investigated. Three different brands and two different types of polymers were used. Polymers were labelled as Polymer-A (SBR), Polymer-B (SBR) and Polymer-C (EVA) respectively.

Hardened and durability properties of polymer modified specimens become different with respect to curing conditions. Polymer modified mortars require water during curing for hydration of cement and air for polymer film formation. For this reason, the favorable curing regime for polymer modified mortars should be consisted of both curing regimes.

In order to determine the favorable curing conditions for polymer modified mortars, specimens with SBR polymer admixture (Polymer A) were prepared with 5%, 15%, 25% polymer / binder ratios and five different curing regimens were applied for a total of 28 days. Curing regimes were numbered from #0 to #4. Curing regimes were grouped as water curing (#0), air curing (#1), water and high humidity curing (#2), high humidity and air curing (#3) and water and air curing (#4).

Preliminary strength tests were performed related specimens after 28 days of curing. According to results of preliminary tests, favorable curing condition for polymer modified mortars was selected and comparative tests were carried out using SBR (Polymer B) and EVA (Polymer C) polymer admixture.

In addition, effects of fly ash and ground granulated blast furnace slag incorporation to properties of polymer modified mortars were also studied. For this purpose, fly ash and slag was incorporated to mixtures separately or together with 10%, 30% and 50% of cement amount of unmodified specimens. Properties of supplementary

cementing material (SCM) incorporated specimens were compared to those of polymer modified specimens under same curing conditions.

Workability of polymer modified mortars were determined by flow test. Hardened properties after 28 days curing were evaluated by flexural and compressive strength tests. For each label 3 rectangular blocks of mortar with dimension of 40x40x160mm were prepared. 3 ea flexural strength tests were performed on specimens. As a result of flexural strength tests, specimens were divided in two parts and a total of 6 pieces were obtained. Compressive tests were performed on divided pieces. In total 4 ea compressive strength tests were performed. Sorptivity tests were performed on remaining two pieces.

Results of preliminary tests showed that workability of mortars are increased with respect to polymer admixtures addition. For this reason, change of properties of specimens for similar workability as polymer modified specimens was added to study. Water/binder ratios of several specimens were changed in order to obtain similar workability as polymer modified mortar. These specimens were labelled as "W".

Favorable curing conditions for polymer modified mortars was chosen as curing regime #4 (3 days immersed in water + 25 days curing at room environment), which allowed cement hydration and polymer film formation. Strength and sorptivity of specimens differed with respect to type of polymer and curing condition.

It was observed that polymer admixture incorporation increased flexural strength values, but mainly decreased compressive strength values. The decrease in compressive strength has been attributed to void-like behavior of soft polymer inside matrix. In addition, lower sorptivity values could be obtained with polymer incorporation. Overall, EVA polymer showed higher strength values, whereas SBR polymer showed lower sorptivity values.

POLİMER MODİFİYE HARÇLARIN ÖZELLİKLERİ VE UÇUCU KÜL VE CÜRUF KATKISININ ETKİSİ

ÖZET

Bu çalışmada, portland çimentosu, agrega ve polimer katkının birlikte kullanılması ile elde edilen polimer modifiye harçların özellikleri tanımlanmıştır. Kür koşullarının, katkı olarak kullanılan polimer türünün, uçucu kül ve cüruf gibi mineral katkıların polimer modifiye harçların özellikleri üzerine etkileri incelenmiştir. Ayrıca, aynı kür koşulları uygulanan polimer modifiye harçlar ile modifiye edilmemiş harçlar arasındaki mekanik ve durabilite özellikleri karşılaştırılmıştır.

Polimer katkılı harçlarda çimento ve polimer katkının bir arada kullanılması ile normal harçlara göre farklı özellikler elde edilebilmektedir. Polimer modifiye harçların matris fazında hidrate olmuş çimento ile polimer katkının oluşturduğu film iç içe bulunmaktadır: Çimento hamuru agregalar arasındaki boşlukları doldururken, polimer fazı da kılcal boşlukları doldurur. Polimer modifiye harçların özellikleri polimer türü, polimer/çimento oranı, su/çimento oranı, kür koşulları gibi farklı parametrelere bağlıdır.

Çalışma iki aşamadan oluşmaktadır. İlk aşamadaki amaç polimer modifiye harçlar için en uygun kür koşulunun bulunmasıdır. İkinci aşamadaki amaç ise en uygun kür koşulu uygulanarak polimer türleri arasındaki farklılıkların incelenmesi ve optimum polimer oranının belirlenmesidir. Çalışma sırasında üç farklı marka, iki farklı tip (iki adet SBR polimer katkı, bir adet EVA polimer katkı) polimer katkı kullanılmıştır. Polimerler, Polimer-A (SBR), Polimer-B (SBR) ve Polimer-C (EVA) olarak isimlendirilmiştir.

Polimer modifiye harçların mekanik ve dayanıklılık özellikleri kür koşullarına göre farklılık göstermektedir. Harcın bileşimde bulunan çimentonun hidratasyonu için su kürüne; polimer katkının harç içerisinde film oluşturulabilmesi için de hava kürüne ihtiyaç duyulmaktadır. Bu nedenle, polimer modifiye harçlara uygulanacak kür koşulunun hem su, hem de hava kürünü içermesi gerekmektedir.

Polimer modifiye harçlar için en uygun kür ortamının belirlenmesi amacıyla, 5%, 15% ve 25% SBR polimer katkı (Polimer A)/bağlayıcı oranında numuneler hazırlanmış ve numunelere beş farklı kür koşulunda toplam 28 gün kür uygulanmıştır. Kür koşulları #0 ~ #4 arasında numaralandırılmıştır. Kür koşulları sadece su kürü (#0), sadece hava kürü (#1), su ve buhar kürü (#2), buhar ve hava kürü (#3) ve su ve hava kürü (#4) olarak gruplandırılmıştır.

Polimer-A kullanılarak üretilen polimer modifiye harçlar üzerinde ilk aşama deneyleri yapılmıştır. İlk aşama test sonuçlarına göre, polimer modifiye harçlar için en uygun kür koşulu belirlenmiş ve SBR polimer (Polimer B) ile EVA polimer (Polimer C) katkılar kullanılarak ikinci aşama karşılaştırmalı deneylere geçilmiştir.

Çalışma için üretilen harçların etiketlendirilmesinde polimer modifiyesini, polimer tipini, polimer oranını, uygulanan kür koşulu ve mineral katkı durumunu gösteren bir etiketleme sistemi kullanılmıştır.

Çalışma için üretilen tüm harçların işlenebilirliği yayılma tablası deneyi ile değerlendirilmiştir. Sertleşmiş beton özelliklerinin belirlenmesi için numuneler farklı kür koşullarına göre gruplandırılmış; toplam 28 gün kür uygulanan numunelere basınç ve eğilme dayanımı testleri uygulanmıştır. Her bir etiket için 3 adet 40x40x160mm boyutlarında dikdörtgen prizma harç üretilmiştir. Her bir etiket için 3 adet eğilme testi yapılmıştır. Eğilme testi sonucunda ikiye ayrılan prizmanın parçaları basınç testleri için kullanılmıştır. Eğilme testi sonucunda toplam 6 adet parça elde edilmiştir. Her bir etiket için toplam 4 adet basınç testi yapılmıştır. Geriye kalan iki parça durabilite özelliklerinin belirlenmesi için kullanılmıştır. Numunelerin durabilite özelliklerinin belirlenmesi için numuneler 60℃ sıcaklıktaki etüvde 48 saat bırakılmış ve numuneler soğuduktan sonra 24 saatlik kılcal su emme deneyleri yapılmıştır.

Aynı çalışmada, uçucu kül ve cüruf katkısının polimer modifiye harçların özelliklerine etkisi de incelenmiştir. Bu amaçla, yalnız uçucu kül, yalnız cüruf veya uçucu kül ile cüruf karışımı, modifiye edilmemiş harçların toplam çimento miktarının %10'u, %30'u ve %50'si oranında karışımlara eklenmiştir. Mineral katkılı harçlar ve mineral katkılı polimer modifiye harçlar için de polimer katkılı harçlar ile aynı kür koşulları uygulanmış ve numunelerin özellikleri karşılaştırılmıştır.

Birinci aşama testler sırasında, polimer katkının harçların işlenebilirliğini iyileştirdiği ve su ihtiyacını azalttığı gözlemlenmiştir. Bu nedenle, polimer modifiye harçlar ile aynı işlenebilirliği elde etmek amacıyla bazı numunelerin su/çimento oranı arttırılmıştır. Su/çimento oranı değiştirilen harçlar, polimer modifiye harçlar ile aynı kür koşullarında tutulmuş ve harçların özellikleri polimer modifiye harçların özellikleri ile karşılaştırılmıştır. Su/çimento oranı değiştirilen numuneler için "W" harfi kullanılmış ve bu numuneler de etiketleme sistemine dahil edilmiştir.

Birinci aşama testler sonucunda, polimer modifiye harçlar için en uygun kür koşulunun, hem çimentonun hidratasyonunu ve hem de polimer film oluşumunu mümkün kılan 4'üncü kür koşulu (3 gün su + 25 gün oda ortamında kür) olduğu belirlenmiştir. Fakat aynı kür koşulları ve aynı polimer oranı kullanılmasına rağmen, farklı polimerle üretilmiş numunelerin dayanım ve kılcallık özelliklerinin aynı olmadığı belirlenmiştir. Bu sayede, harç özelliklerinin polimer katkısının tipine ve kür koşullarına göre değişiklik gösterdiği tespit edilmiştir.

Polimer katkıların eğilme dayanımı arttırdığı gözlenmiştir. Eğilme dayanımındaki artışın nedeni olarak, polimer film tabakasının harç tabakasını güçlendirmesi önerilmiştir. Aynı zamanda, polimer katkıların basınç dayanımında düşmeye neden olduğu belirlenmiştir. Basınç dayanımındaki azalmanın nedeni olarak da harç içinde bulunan yumuşak polimerin davranışının beton içindeki boşlukların davranışına benzer olduğu önerilmiş ve bu davranış, basınç dayanımındaki azalmanın nedeni olarak gösterilmiştir.

Polimer katkı kullanılmasının harçların durabilite özelliklerini iyileştirdiği belirlenmiştir. Numunelerinin kılcallığının polimer katkı kullanıldığı zaman azaldığı görülmüştür. Fakat dayanım özelliklerindeki duruma benzer şekilde, polimer modifiye harçların durabilite özelliklerinin polimer oranına, kür koşuluna ve polimer tipine bağlı olduğu gözlenmiştir.

Genel olarak, EVA polimer ile hazırlanan numunelerin daha yüksek dayanıma; fakat SBR ile hazırlanan numunelerin de daha iyi kılcallık özelliklerine sahip olduğu belirlenmiştir. Bu durumun, farklı polimer katkıların hidratasyon kinetiği ve hidrat morfolojisi üzerindeki farklı etkilerinden dolayı ortaya çıktığı önerilebilir.

Mineral katkının polimer modifiye harçların durabilite özellikleri üzerinde dikkate değer bir iyileştirme yapmadığı; aksine mineral katkının artan oranda karışıma katılmasının kılcallığı arttırdığı gözlemlenmiştir.

İşlenebilirliğinin, polimer modifiye harçlarının işlenebilirliğine benzer olması için su/çimento oranı arttırılan numunelerin dayanım ve durabilite özellikleri incelenmiştir. Su/çimento oranı arttırılmış numuneler polimer modifiye harçlar ile karşılaştırıldığında aynı kür koşulları altında eğilme dayanımında %23 oranında azalma, basınç dayanımında %38 oranında azalma ve kılcallıkta ise yaklaşık 5 kat artış gözlemlenmiştir. Aradaki büyük farkın nedeni ise, su/çimento oranı arttırılan numunelerdeki artan kılcal boşlukların numune özellikleri üzerine etkileri olarak belirtilmiştir.

1. INTRODUCTION

Among construction materials used worldwide, concrete is by far the most widely used construction material due to its well-known advantages such as low cost, general availability and wide applicability [1].

Concrete consists of cement, aggregates (fine and coarse) and water. Cementing materials have played a vital role and were used widely in the ancient world. The Egyptians used calcined gypsum as a cement and the Greeks and Romans used lime made by heating limestone and added sand to make mortar, with coarser stones for concrete. The Renaissance and Age of Enlightenment brought new ways of thinking which led to the industrial revolution. In eighteenth century Britain, with the need to build lighthouses on exposed rocks to prevent shipping losses, drove cement technology forwards. Joseph Aspdin took out a patent in 1824 for "Portland Cement," a material was produced by firing finely-ground clay and limestone until the limestone was calcined. It was called Portland Cement because the concrete made from it looked like Portland stone, a widely-used building stone in England. A few years later, in 1845, Isaac Johnson made the first modern Portland Cement by firing a mixture of chalk and clay at much higher temperatures, similar to those used today [2].

However, due to high amounts of energy required to produce Portland cement and the large quantities of CO2 released into the atmosphere in the process, various efforts have been made in order to improve environmental friendliness of concrete [1]. The use of suitable substitutes for Portland cement, especially byproducts of industrial processes, has been most successful in this regard [1].

Incorporation of mineral admixtures or supplementary cementing materials such as fly ash or slag into concrete mix design as portland cement substitutes not only reduces cost and energy savings, also increases the performance and durability of concrete in most applications [3].

However, even though concrete is widely used and SCM is incorporated into mixtures, there are still some setbacks. Concrete has high compressive strength but relatively weak in tension and adhesion and its porosity can lead to physical and chemical deterioration. Polymers, on the other hand, are weaker in compression but can have higher tensile capacities and provide good adhesion to other materials as well as chemical and physical attacks. Therefore, combination of these two materials that can exploit the useful properties of both materials was evaluated [4].

Polymer has a long history in the construction industry with the usage of natural polymer asphalt in the mortar of the clay brick walls of Babylonia back in the fourth millennium B.C. [4]. However, incorporation of synthetic polymer in portland cement mortars and concrete started in the 1950s [4]. Polymer-based admixture is one of the materials added into the mortar or concrete in order to modify or improve its properties such as strength, deformability, adhesion, waterproofness and durability [5]. Polymer modified mortar or concrete is something named as "concrete-polymer composite" and depending on the principles of their process technology, concrete-polymer composites are generally classified into three types as polymer-modified mortar (or concrete), polymer mortar (or concrete) and polymer-impregnated mortar (or concrete) [6]. Concrete-polymer composites are mostly used for finish and repair work, bridge and deck overlays and patching works [6].

2. LITERATURE

2.1 Portland Cement

2.1.1 Definition

Portland cement is the most common type of cement in general use around the world, used as a basic ingredient of concrete, mortar, stucco, and most non-specialty grout. It developed from other types of hydraulic lime in England in the mid 19th century and usually originates from limestone. It is a fine powder produced by heating materials in a kiln to form what is called clinker, grinding the clinker, and adding small amounts of other materials [7].

2.2 Fly Ash

2.2.1 Definition

Fly ash is the finely dinely divided residue rof coal combustion, which is carried from combustion chamber of a furnace by exhaust gases. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants [8, 9].

Depending on CaO content, fly ash is classified as Type F and Type C. The primary difference between Class C and Class F fly ash is the chemical composition of the ash itself. While Class F fly ash is highly pozzolanic, Class C fly ash is pozzolanic and also can be self cementing. ASTM C618[1] requires that Class F fly ash contain at least 70% pozzolanic compounds (silica oxide, alumina oxide, and iron oxide), while Class C fly ashes have between 50% and 70% of these compounds. Typically, Class C fly ash also contains significant amounts of calcium oxide - over 20%. Most Class F fly ash contains little calcium oxide; however, some Class F fly ash sources may contain intermediate levels (8% to 16%) of calcium oxide [9].

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[1] ASTM C618 - Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

2.2.2 Properties of fly ash

2.2.2.1 Physical properties

Fly ash consists of fine, powdery particles predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature, which are between 1 ~150 μm in diameter. The colour of fly ash can vary from tan to gray to black, depending on the amount of unburned carbon in the ash.

2.2.2.2 Chemical properties

The chemical properties of fly ash are influenced to a great extent by the properties of the coal being burned and the techniques used for handling and storage. There are basically four types, or ranks, of coal, each vary in heating value, chemical composition, ash content, and geological origin. The four types (ranks) of coal are anthracite, bituminous, sub-bituminous, and lignite. In addition to being handled in a dry, conditioned, or wet form, fly ash is also sometimes classified according to the type of coal from which the ash was derived.

The principal components of bituminous coal fly ash are silica, alumina, iron oxide, and calcium, with varying amounts of carbon. Lignite and sub-bituminous coal fly ash is characterized by higher concentrations of calcium and magnesium oxide and reduced percentages of silica and iron oxide, as well as lower carbon content, compared with bituminous coal fly ash. Very little anthracite coal is burned in utility boilers, so there are only small amounts of anthracite coal fly ash [9].

2.2.3 Effects of fly ash on concrete properties

Incorporation of fly ash as a replacement for portland cement effects fresh concrete properties, mechanical properties and durability characterictics as described in Table 2.1 [3].

2.3 Ground Granulated Blast Furnace Slag

2.3.1 Definition

Ground, granulated blast-furnace slag (GGBFS) is a nonmetallic product consisting essentially of silicates and aluminosilicates of calcium and other bases, that is developed in a molten condition simultaneously with iron in a blast furnace, then water chilled rapidly to form glassy granular particles, and then ground to cement fineness or finer [10].

2.3.2 Physical properties of GGBFS

2.3.2.1 Fineness

GGBFS is ground to a desired particle size or surface area, depending on the degree of activation needed and economic considerations (Figure 2.1). The fineness of GGBFS is a very important parameter, which influences the reactivity of GGBFS inconcrete, early strength development of concrete and water requirement. It is reported that slag particles < 10 μm contribute to early strength development (up to 28-day); particles in the 10-45 μm range continue to hydrate beyond 28 days and contribute to later-age strength; and particles above 45 μm generally show little or no activity.

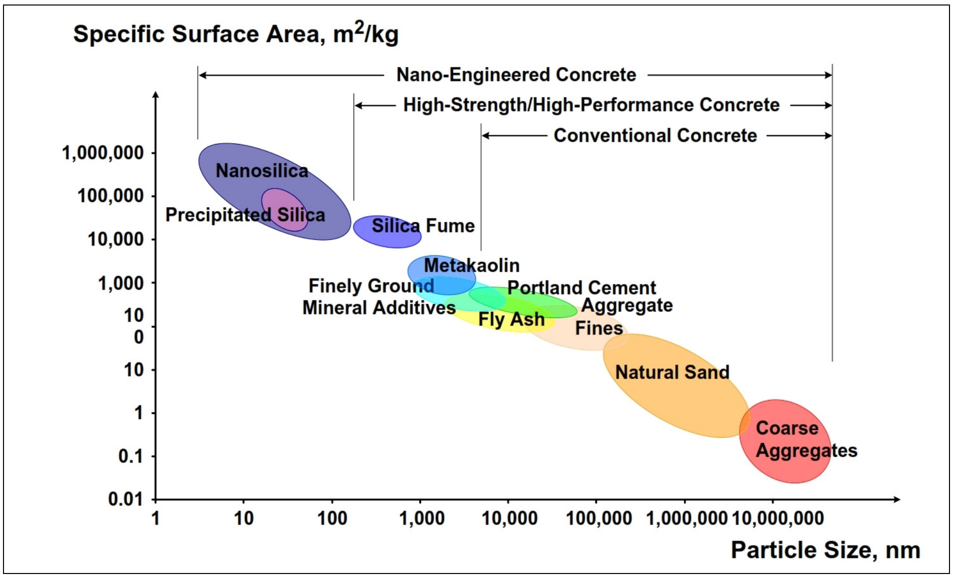

Figure 2.1 : Particle size and specific surface area related to concrete materials [11].

2.3.2.2 Mineralogical composition

Mineralogical analyses of GGBFS samples show glass contents ranging from 80 to 100%. The reactivity of GGBFS is strongly dependent on the glass content.

2.3.3 Effects of GGBFS on concrete properties

Incorporation of ground granulated blast furnace slag as a replacement for portland cement effects fresh concrete properties, mechanical properties and durability characterictics as described in Table 2.1.

Table 2.1: Summary of General Effects of Fly Ash and GGBFS on Concrete Properties [3].

PROPERTY	FLY ASH	GGBFS	Comments
FRESH PROPERTIES			
Water demand	↘	↘~	Fly ash: the water reduction decreases with increasing fineness and carbon content of fly ash. GGBFS: does not have a strong effect on water demand.
Workability	↗	↗~	Fly ash: the spherical particle shape of fly ash assists in improving workability. GGBFS: does not have a strong effect on slump, but increases the pumpability.
Bleeding	↘	~	Fly ash: bleeding and segregation are in general reduced and pumpability is improved. However, the low bleed water may increase the risk of plastic shrinkage cracking. GGBFS: does not have a strong effect on bleeding.
Setting times	↗	↗	Fly ash: longer setting times compared to normal concrete which may affect the finishing schedule. Cold weather conditions may further slow setting times. GGBFS: its effect on setting times is less than that of fly
Autogenous temperature rise	↘	↘	Fly ash: generally reduces the risk of thermal stress and cracking (especially type F and CI). GGBFS: may reduce the risk of thermal cracking if at least 50% is used and the Blaine fineness is lower than 6000 cm^2/g, and if at least 65% is used in warm weather.
MECHANICAL PROPERTIES			
Compressive strength	↘ ↗	↘ ↗	Fly ash: Decreases the mechanical properties at early ages (especially at 1-d and in cold weather). The long-term mechanical properties such as compressive and flexural strengths, and the modulus of elasticity of fly ash concrete are typically superior to those of portland cement concrete of similar 28-day compressive strength.
Flexural strength	↘ ↗	↘ ↗	GGBFS: similar behavior to fly ash concrete, except that slag concrete has higher early-age mechanical properties and lower long-term mechanical properties compared to fly ash concrete with similar contents.
Modulus of elasticity	↘ ↗	↘ ↗	
Drying shrinkage	~↘	~	Fly ash: the long-term drying shrinkage and creep of fly ash concrete will be similar to, or lower than that of portland cement concrete of similar 28-day compressive strength.
Creep	~↘	~↘	GGBFS: appears to reduce creep and has no significant effect on drying shrinkage.
DURABILITY			
Permeability	↘	↘	Fly ash: reduces water and chloride-ion permeability, especially at later ages, if well cured. GGBFS: similar to fly ash
Corrosion resistance	↗	↗	Fly ash: increases the protection of reinforcing steel from corrosion if well cured. GGBFS: similar to fly ash
Sulphate resistance	↗	↗	Fly ash: the use of low calcium fly ash (CSA Class F and CI with CaO content < 20%) increases resistance to sulphate attack. Fly ashes with more than 20% CaO should be investigated for sulphate resistance (rarely used in Canada). GGBFS: the content required should be investigated (usually more than 35% is

↘: decreases; ↗: increases; ~: no significant effect

2.4 Polymer

2.4.1 Definition

A polymer is chemical compound where molecules are bonded together in long repeating chains. Polymers are categorized with respect to how they are obtained, their chemical compositions and structures, physical properties [12].

2.4.2 Use of polymers as construction material

As a concept, use of polymer as construction material has considered as 1920s, as the first patent of paving materials with natural rubber latex has been issued to Cresson in 1923. Concept of polymer latex modified systems by a mix proportioning method has been patented in 1924 by Lefebure.

In 1940s, polymer modified mortar and concrete have been used as deck covering for ships and bridges, paving, flooring, anticorrosive and adhesive.

By 1960s, reasearch and development of polymer-modified mortar and conrete for practical uses have been considerable advanced in various counteries.

In recent years, polymer modified mortars and concretes using various polymer latexes, redispersible polymer powders, water-soluble resins, epoxy resins have been widely used in the world. In paralel with usage, various standards and guides for polymer modified mortars and concretes have been published in USA, Germany, Japan [12].

2.4.3 Concrete-polymer composites

2.4.3.1 Use of polymers as concrete admixture

Use of polymers as concrete admixture, or in other words, polymer modification of concrete, has been investigated in order to improve properties of concrete: Concrete has high conpressive strength, but has relatively weak tension and adhesion strength, whereas polymers are weaker in compression but they have much better tensile and adhesive properties. In addition, resistance of polymers to physical (such as abrasion, erosion, impact) and chemical attacks are betters than concrete [4].

Although there are many types and formulations of polymer admxtures manufactured, only those specificially for use in portland cement are suitable in mortar and concrete applications [13].

Polymers are incorporated into mixture in various ways: Polymer-modified concrete (PMC), polymer-impregnated concrete (PIC) and polymer concrete (PC).

Polymer-modified concrete

Polymer-modified concrete (PMC) is normal portland cement incorporating polymer admixture [4]. They are made by partially replacing the cement hydrate binder of cement mortar and conrete with polymers, thereby strengthening the binders with polymers [12]. Resultant modified concrete is a composite material consisting of two solid phasses: aggregates which are discontinuously dispersed through the material and the binder, which consists of cementirious phase and polymer phase [14]. It is reported that PMC exceeds ordinary cement mortar in its adhesive properties and crack resistibility [15]. In addition, it is also documented that water tigthness of PMC is superior to that of conventional conrete [16].

Polymer-impregnated concrete

Polymer-impregnated concrete (PIC) is obtained by injecting low-viscocity monomers into the pores of hardened concrete and then polymerizing by radiation or thermal catalytic techniques [17]. Polymer form a second matrix if the pores are interconnected through-out the material [14].

Polymer concrete

Polymer concrete (PC) consists of aggregate with a polymer binder and does not contain any portland cement or water [17].

2.4.3.2 Classification of polymer-based admixtures

In general, polymer based admixtures are classified into four main types by Ohama [12]: polymer latex dispersion, redispersible polymer powder, water-soluble polymer and liquid polymer (Figure 2.2).

Polymer latexes (or dispersions)

Polymer latexes (or dispersions) are made of very small (0,05-5 μm) polymer particles which are dispersed in water. They are also sub-classified by the kind of electrical charges on polymer particles, which is determined by the type of surfactants used in the production: cationic (positively charged), anionic (negatively charged), non-ionic (uncharged).

Redispersible polymer powders

Redispesible powder powders are manufactured by spray-drying of polymer latexes. Generally, resdispersible polymer powders are dry blended with cement and aggregate mixtures, followed by wet mixing with water.

Water-soluble polymers

Water-soluble polymers are added in the form of powders or aqueous solutions to cement mortar or concrete during mixing, mainly in order to improve workability.

Liquid polymers

Liquid polymers are viscous polymeric liquid such as epoxy resin and unsaturated polyester resin, which are added to mortar or concrete during mixing. However, liquid polymers are not used as widely as other types of polymer admixtures.

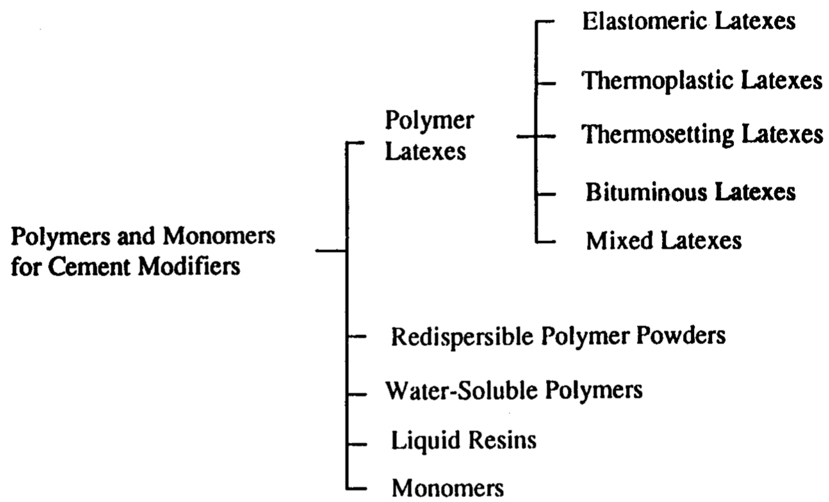

Figure 2.2 : Polymers and monomers for cement modifiers [12].

2.4.4 Principles of polymer modification

Polymer modification generates an interpenetrating network of polymer film and cement hydrates in which the aggregates are embedded. The effect of the polymer modification on the properties of the hardened concrete is in part a result of the formation of this three dimensional polymer network in the hardened cement paste [18].

The most general and commonly used model for polymer-cement co-matrix is suggested by Ohama. Ohama summarises the model into three steps [12] (Figure 2.3).

During the first step, cement gel is gradually formed by cement hydration and polymer particles partially deposit on the surfaces of cement gel and unhydrated cement particles. In the second step, the polymer particles are gradually confined in the capillary pores. As the cement hydration proceeds and consequently the capillary water is reduced, the polymer particles flocculate to form a continuous close-packed layer on the surface of the unhydrated cement particles and cement gel mixture as well as between the aggregate and the cement paste. Ultimately, in the third step, with water withdrawing due to further hydration, the closely packed polymer particles on the cement hydrates coalesce into a continuous film and a network is formed in which the polymer phase and the cement hydrate phase interpenetrate into each other.

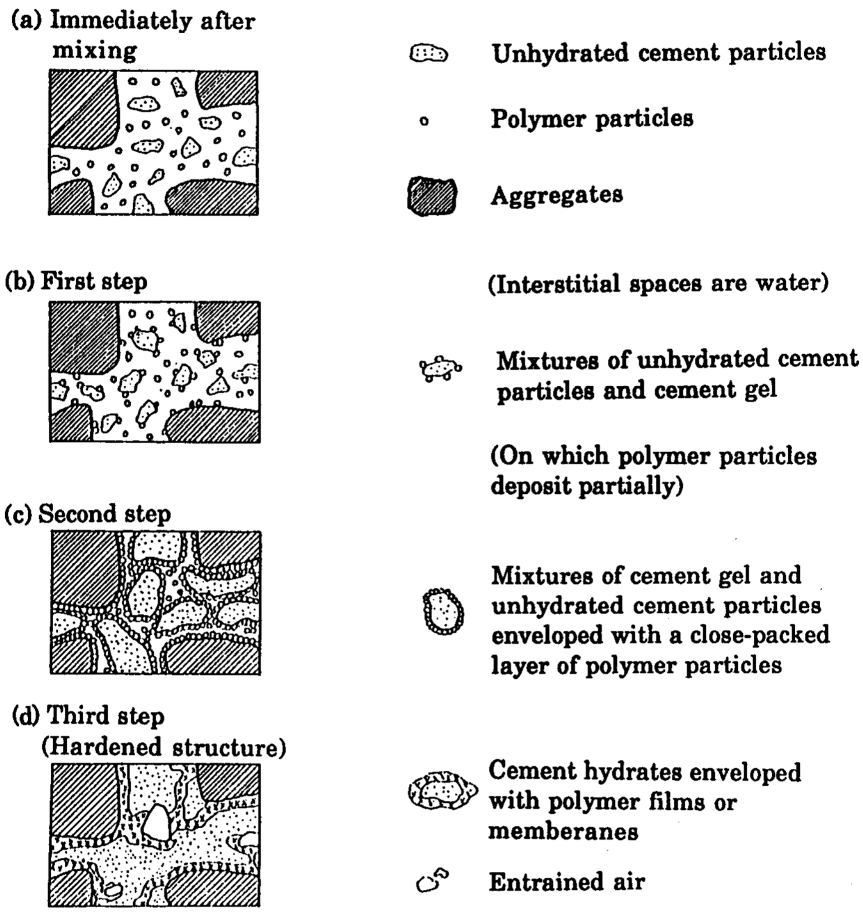

Figure 2.3 : Simplified model of formation of polymer-cement co-matrix [12].

2.4.5 Influence of polymer modification

Properties of fresh and hardened ordinary cement mortar and concrete are generally improved to a great extent by latex modification [12].

Depending on the type of polymer admixture, it has been reported that polymer incorporated fresh mixture provides a reduction in mixing water requirements, a higher air entrainment, improved workability and a retardation effect on the hydration of the cement particles [18].

The polymer modification of hardened concrete, attributed to polymer film formation causes the improved adhesion, improved flexural and tensile strength, a blocking of the pores that restricts the movement of water and reduces permeability, bridging of microfractures and improved toughness [18]. The sealing effect due to polymer films or membranes formed in the microstructure an decrease in the total porosity or pore volume also provide a considerable increase in waterproofness or water-tightness, resistance to chloride ion penetration, moisture transmission, carbonation and oxygen diffusion, chemical resistance and freeze-thaw durability [12].

3. EXPERIMENTAL

The change in workability, mechanical properties and durability of mortars modified with polymer admixtures under different curing regimens were investigated. In addition, same properties were compared with unmodified mortars and mortars incorporation fly ash, slag and a combination of fly ash and slag.

Considering the fact that not all polymer mixtures are compatible to be used as admixture, experiments were divided in two parts as preliminary study and comparative study [15].

3.1 Materials

3.1.1 Portland cement

AKÇANSA portland cement CEM I 42,5R, which complies with TS EN 197-1, was used for preparation of mortar specimens.

Physical and chemical properties of cement which are presented by the manufacturer are given in Table 3.1.

3.1.2 Aggregate

Ideal Fullers grading curve, which is described by below equation, was used for maximum density gradation of aggregates.

$$P = \left(\frac{d}{D}\right)^{0,5} * 100 \qquad \textbf{(3.1)}$$

A maximum denisty gradation involves particle arrangement where smaller particles are packed between the larger particles, by which reducing void spaces between aggregates is possible.

Two types of aggregates were used for maximum density gradation: Crushed stone and natural sand. Sieve analysis of aggrates, Fuller cuve and maximum density

Table 3.1: Properties of portland cement.

Property / Component & Unit	Value
Specific gravity (gr/cm³)	3,15
Soundness (Le Chatelier) (mm)	0,5
Surface area (Blaine) (cm²/gr)	3490
Initial setting time (min)	150
Final setting time (min)	180
SiO_2 (%)	20,14
Al_2O_3 (%)	5,04
Fe_2O_3 (%)	3,78
CaO (%)	63,92
MgO (%)	1,35
SO_3 (%)	2,84
Cl (%)	0,0407
Na_2O / K_2O (%)	0,23 / 0,84
C_3S (%)	54,23
C_2S (%)	16,91
C_3A (%)	6,97
C_4AF (%)	11,5
Loss on ignition (%)	1,35

gradation obtained by proportional mixing of aggregates are demonstrated in Figure 3.1, Table 3.2, Table 3.3 respectively.

Table 3.2 : Sieve analysis table.

Sieve size	4	2	1,41	1	0,5	0,177	0,09
Natural sand	100	100	100	99,7	99,1	2	1
Crushed stone	94,6	53	40,89	28,54	16,5	3,47	1,82
Fuller Curve	100,00	70,71	59,37	50,00	35,36	21,04	15,00

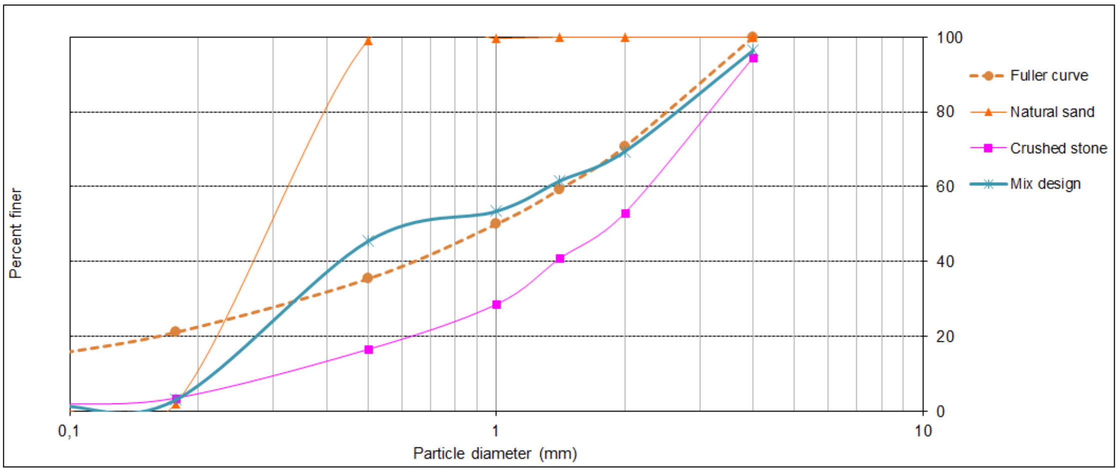

Figure 3.1 : Gradation curve of aggregate and mix design.

Table 3.3 : Proportions of aggregates in order to obtain Fuller curve.

Aggregate	Percentage
Natural sand	35 %
Crushed stone	65 %

3.1.3 Fly ash

Type F fly ash, which was obtained from Çatalağzı thermal power plant, was used as supplementary cementing material (SCM) in this study. Properties of fly ash provided by supplier are presented in Table 3.4.

Table 3.4 : Properties of Type F fly ash.

Component	Percentage (%)
H2O	0,2
SiO2	58,5
Al2O3	23,4
Fe2O3	6,97
CaO	1,55
MgO	2,76
SO3	0,45
Na2O	0,46
K2O	4,11
Cl	0,0319
Loss on ignition %	0,2
Free lime (%) 0,15 0,15	0,15
Specific Gravity(gr/cm3)	2,12

3.1.4 Ground granulated blast-furnace slag (GGBFS)

Ground granulated blast-furnace slag (GGBFS), which was obtained from AkçanSA Karçimsa factory, was used as SCM in this study. Chemical and physical properties provided by supplier are presented in Table 3.5.

3.1.5 Polymer admixtures

Commercially available polymer admixtures were used during experiments as described in Table 3.6.

Table 3.5 : Properties of GGBFS.

Component	Percentage (%)
Ca CO3 + Mg CO3 -	-
H_2O	1,1
Residue	-
Si O_2	38,88
Al_2O_3	10,87
Fe_2O_3	2,78
CaO	34,01
MgO	9,09
S O_3	2,654
Na_2O	0,35
K_2O	1,31
Klorür (Cl^-)	0,0227
Loss on ignition	0
Specific gravity (gr/cm³)	2,88
Soundness (Le Chatelier) (mm)	1
Surface area (Blaine) (cm²/gr)	4340

Table 3.6 : Polymer admixtures used during experiments.

Polymer Admixture	Type	Abbrevation	Solid content
Polymer A	Stytrene-budaine rubber latex	SBR	37 %
Polymer B	Stytrene-budaine rubber latex	SBR	37 %
Polymer C	Poly (ethylene-vinyl acetate) latex	EVA	37 %

3.2 Mixing Proportions

Specimens were prepared with varying proportions of portland cement, fly ash, slag and polymer. Specimens were categorised in accordance with their binder (cement+pozzolan) composition. Specimens in fly ash category incorporated only fly ash between 10%-50% of total binder amount. Specimes in slag category incorporated only slag between 10%-50% of total binder amount. Specimens in fly ash + slag category incorporated between 5% fly ash + 5 percent fly ash – 25% fly ash + 25% slag of total binder amount. Specimens in polymer category incorporated polymer admixtures between 5%-25% for preliminary tests and 5%-15% for comparative tests.

Mixing proportions with respect to total binder amount are summarised in Table 3.7

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Table 3.7 : Summary of mix proportions used during experiments.

Component	Min. Proportion	Max. Proportion
Portland cement	50%	100%
Fly ash	0%	25%
Slag	0%	25%
Polymer	0%	25%

3.3 Specimen Preparation: Preliminary Study

In order to determine best curing condition for polymer modified specimens and to obtain data for comparative study, preliminary tests were performed using Polymer A.

For preliminary tests, five different curing conditions were selected (Table 3.8).

Table 3.8 : Curing regimens for preliminary study.

Curing label	Curing condition
0	28 days immersed in water
1	28 days at room environment
2	3 days immersed in water + 25 days in high humidity
3	3 day in high humidity + 25 days at room environment
4	3 days immersed in water + 25 days at room environment

Mortar specimens were prepared in accordance with TS EN 196-1, with different polymer / binder ratio (p/c) 0%, 5%, 10%, 15%, 20%, 25% respectively.

Diffent polymer modified mix designs with the same water/binder ratios or unmodified mix designs with similar workability (different water / binder ratio) were prepared. After prepartion of each mixture, flow test were performed in order to determine consistency of mortars.

During prepartion of unmodified specimens with similar workability, water / binder ratio was modified in order to obtain similar flow diameter.

Details of mixtures prepared for preliminary tests are described below:

Unmodified mixture – Cement (specimens #1 - #3) (Table A.1)

Unmodified mixture – Cement + Fly Ash (specimens #4 - #12)(Table A.1)

Unmodified mixture – Cement + Slag (specimens #13 - #15) (Table A.1)

Unmodified mixture – Cement + Fly Ash + Slag (specimens #16 - #18) (Table A.1)

Unmodified mixture – Mixtures with similar workability with polymer modified mortars (different water / binder ratio) (specimens #19 - #38) (Table A.2)

Polymer modified mixture – Cement + Polymer A admixture (#39 - # 50) (Table A.3)

Polymer modified mixture – Cement + Fly Ash + Polymer A admixture (#51 - # 86) (Table A.3)

Polymer modified mixture – Cement + Slag + Polymer A admixture (#87 - # 122) (Table A.3)

Polymer modified mixture – Cement + Fly Ash + Slag + Polymer A admixture (#123 - # 158) (Table A.3)

3.4 Specimen Preparation: Comparative Study

Mortar specimens were prepared in accordance with TS EN 196-1, with different polymer / binder ratio (*p/c*) 0%, 5%, 10%, 15%, 20%, 25% respectively.

Duing prepartion of polymer modified specimens with fixed w/binder ratios, the water of polymer emulsion was taken into account to calculate water/binder ratio. Fixed w/binder ratio was used in order to aim a similar state of hydration for the cement matrix [19]

Details of mixtures preperaped for comparative study are described as follows:

Polymer modified mixture – Cement + Polymer B admixture (specimens #159 - #162) (Table A.4)

Polymer modified mixture – Cement + Polymer C admixture (specimens #163 - #166) (Table A.4)

Polymer modified mixture – Cement + Fly Ash + Polymer B admixture (specimens #167 - #178) (Table A.5)

Polymer modified mixture – Cement + Fly Ash + Polymer C admixture (specimens #179 - #190) (Table A.6)

In accordance with the data obtained from preliminary study, curing conditions for comparative tests were selected as below (Table 3.9):

Table 3.9 : Curing regimens for comparative study.

Curing label	Curing condition
1	28 days at room environment
4	3 days immersed in water + 25 days at room environment

3.5 Testing Methods

3.5.1 Bending test

Standart prisms, 40x40x160 mm, were prepared in accordance with TS-EN 196-1 and labelled. Different curing conditions as described previously have been applied. Flexural tests were performed after 28 days of curing using three point bending test set-up, in accordance with TS-EN-196-1. As a result of bending test, 40x40x160 mm prisms had been divided in two pieces.

Flexural strength of specimens were calculated according to following equation (Equation 3.2), where *Rf* is the flexural strength (MPa), *Ff* is the load applied to fracture the specimen (N), *l* is the distance between the supports (mm) and *b* is the width of the square cross-section (mm).

$$Rf = \frac{1{,}5 * Ff * l}{b^3} \qquad \textbf{(3.2)}$$

Bending tests were performed using three specimens for each label.

3.5.2 Compression test

Compression tests were carried on 40x40x80 mm samples, which were acquired after bending tests, in accordance with TS-EN-196-1.

Compressive strength of specimens were calculated according to equation 3.3, where *Rc* is the compressive strength (MPa), *Fc* is the load applied to fracture the specimen (N) and 1600 is the testing area (40x40 mm).

$$Rc = \frac{Fc}{1600} \qquad \textbf{(3.3)}$$

Compressive tests were performed using four specimens for each label.

3.5.3 Capillary rise (sorptivity) test

Capillary rise tests were performed using two 40x40x80 mm samples for each label, which were acquired after bending test.

Specimens were placed in the drying oven at 60℃ for 48 hours. On removal of specimens from the oven, specimens were cooled and paraffin wax was applied on four side of the specimen, which were going to be immersed in water. Only bottom surface area of the specimens were directly exposed to water. Dry wieght of specimens were measured, specimens were partially immersed in water and periodically, weight of specimens were recorded. Test was terminated after 24 hours.

4. RESULTS

4.1 Specimen Labelling

Specimens were labelled with respect to mix design. Specimen labelling has been detailed in Figure 4.1, Figure 4.2, Figure 4.3.

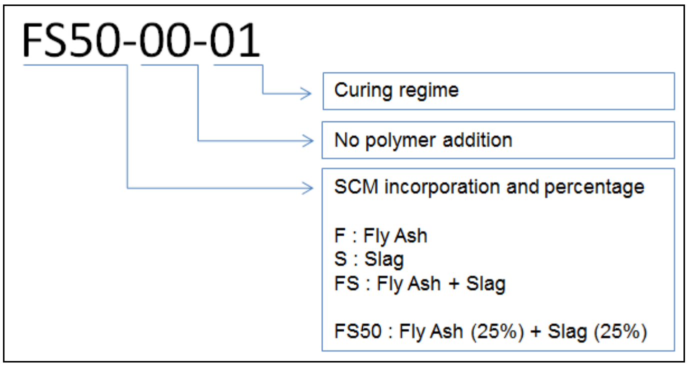


Figure 4.1 : Labelling of unmodified specimens.

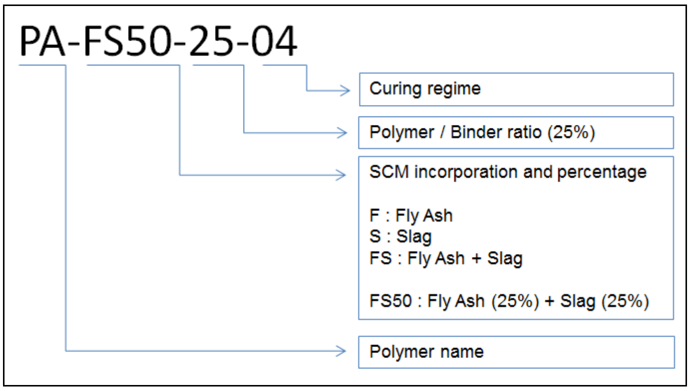


Figure 4.2 : Labelling of polymer modified specimens.

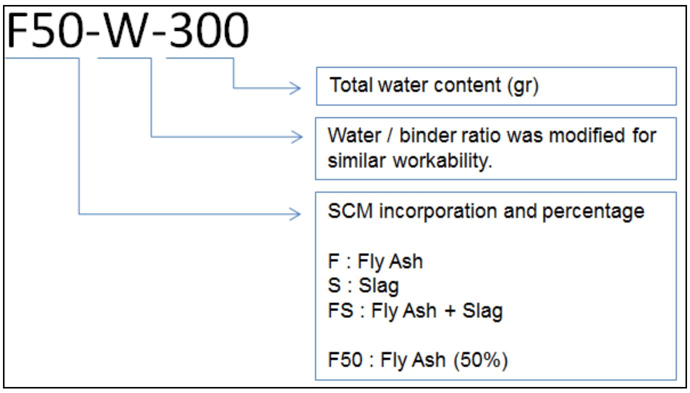


Figure 4.3 : Labelling of specimens prepared for similar workability.

4.2 Fresh Properties

4.2.1 Unmodified mixture

Workability of unmodified mixtures increases up to 30% fly ash or fly ash and slag incorporation as can be seen in Figure 4.4. With respct to increasing incorporation ratio of SCM, workability decreases.

Specimen labelled 00-00-00 describes that specimen is prepared only with cement. Labels F, FS and S describes fly ash, fly ash and slag, slag incorporation respectively.

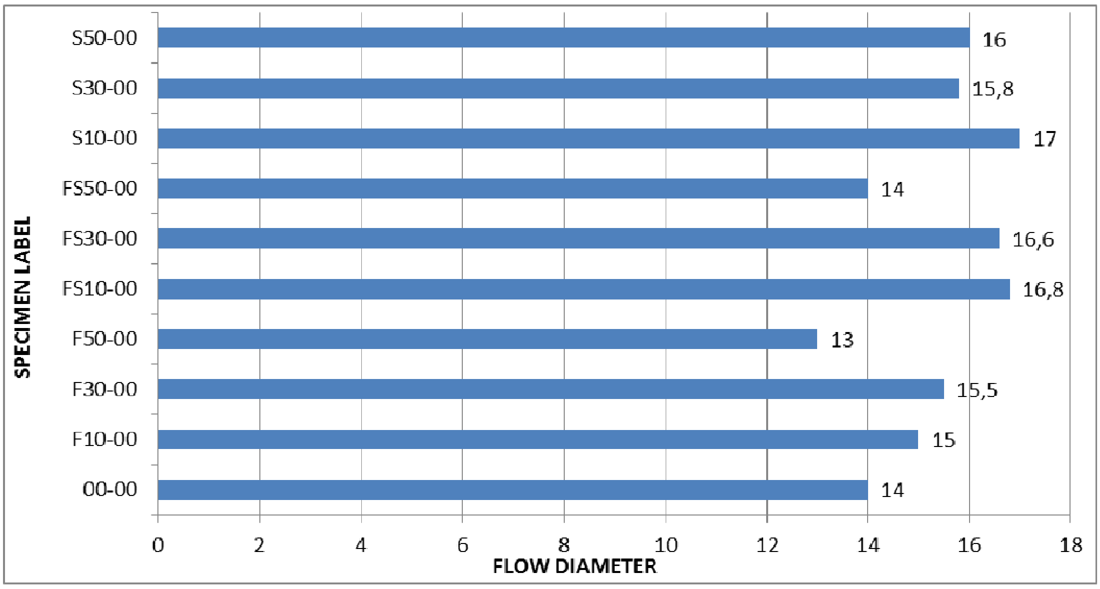


Figure 4.4 : Workability of unmodified specimens.

4.2.2 Polymer modified mixture

Workability of polymer modified mixtures usually increases with respect to polymer admixture ratio of mixtures as shown in Figure 4.5. It has been reported that due to water-reducing propeties of polymers, the use of a superplasticizer is not necessary for polymer modified specimens [20]. However, for low polymer addition levels no change or decrease of workability was also observed as documented [21].

4.2.3 Mixtures with similar workability

Water / binder ratio of specimens has been modified in order to achieve similar workability as polymer modified specimens. Specimens, for which water / binder ratio has been modified, are labelled as “W” and total water amount has been

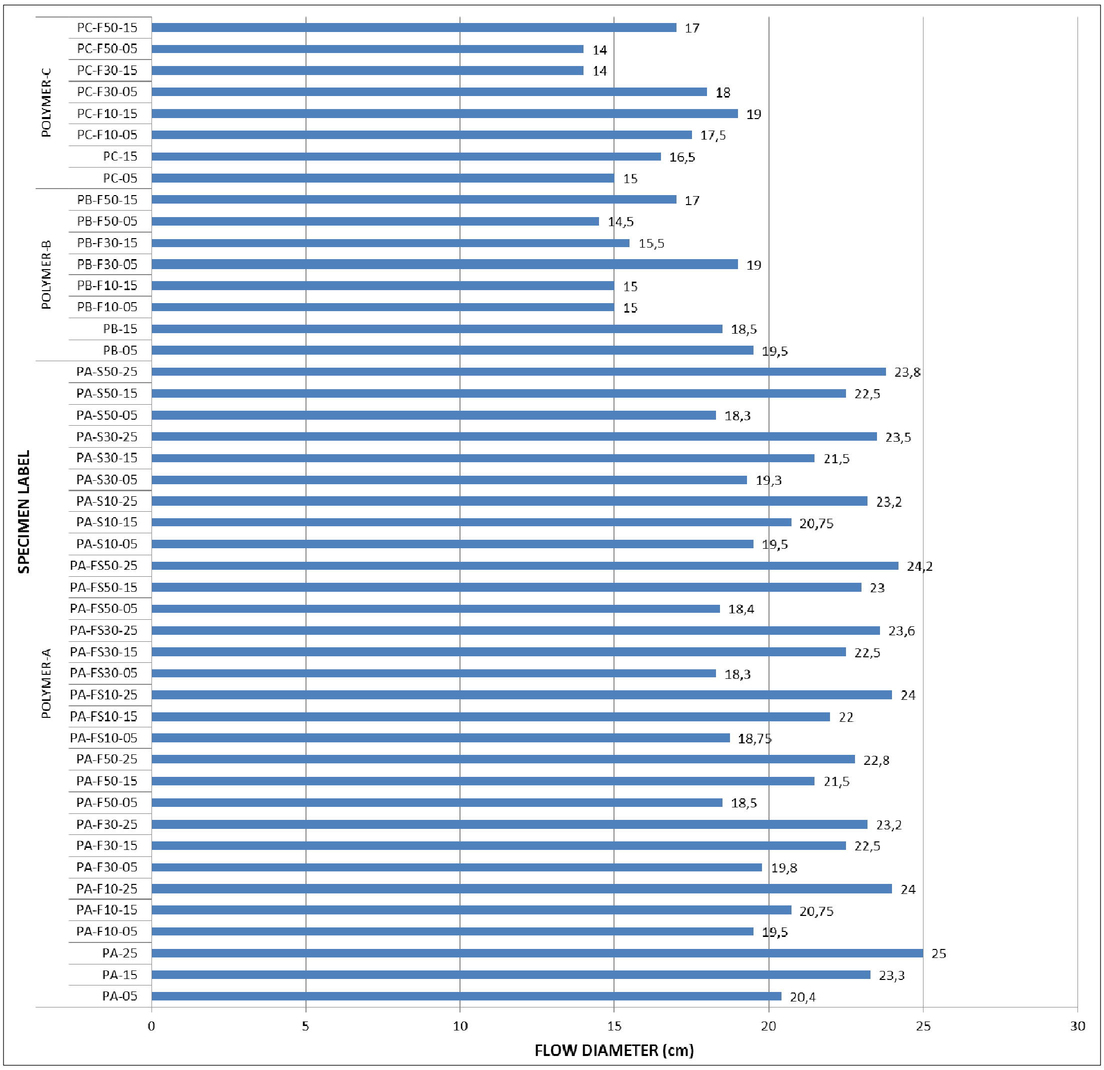


Figure 4.5 : Workability of polymer modified specimens.

described in the label. For example, in order to achieve same workability with 25% polymer incorporated specimen (PA-00-25), water amount of unmodified specimen has been increased to 325 gr from 250 gr (Figure 4.6).

4.3 Hardened Properties

Curing conditions play an important role on hardened properties of polymer modified concrete. For this reason, test results for hardened properties of specimens after 28 days of curing under different conditions are going to be evaluated in order to determine favorable curing condition and optimum polymer admixture ratio.

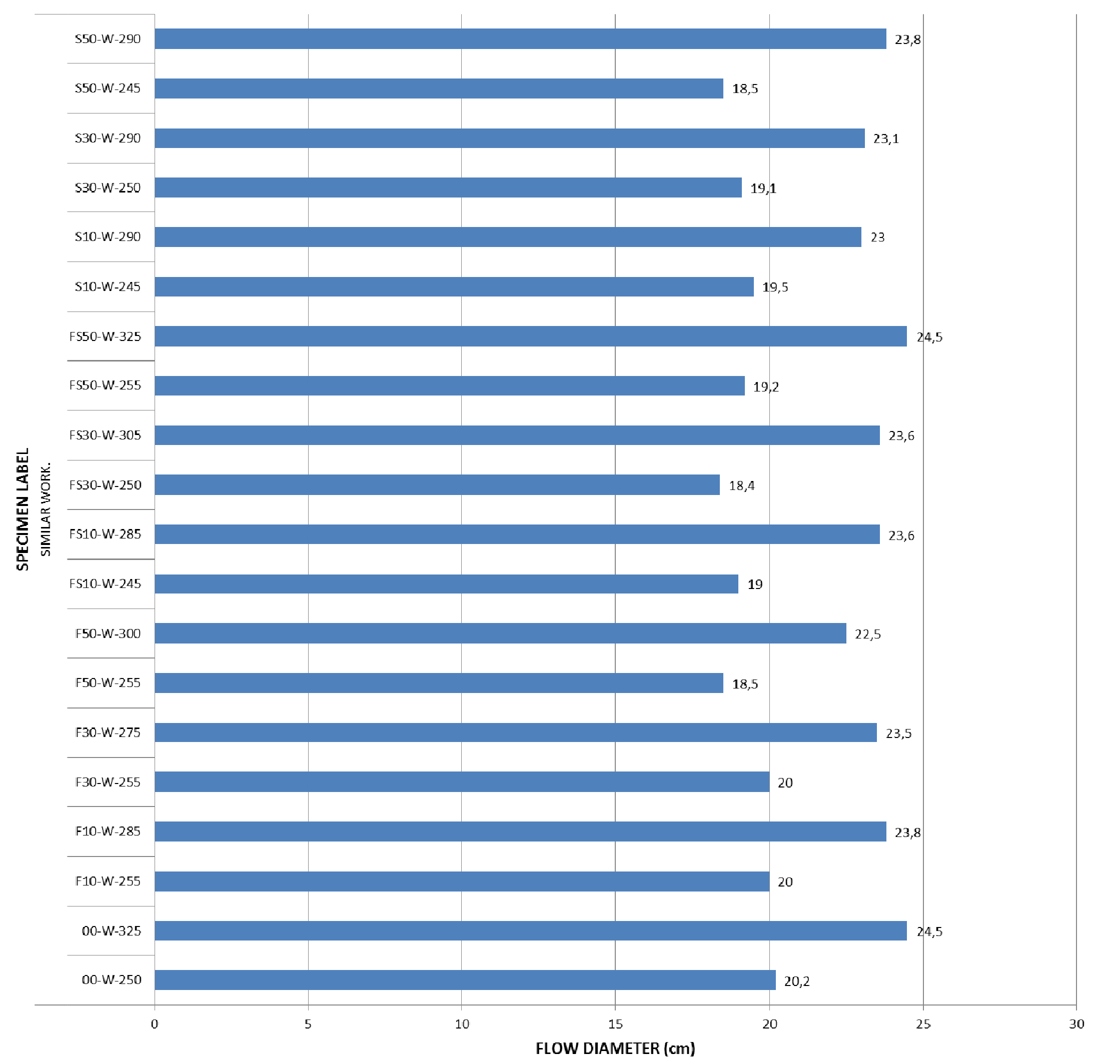


Figure 4.6 : Workability of specimens with similar workability.

4.3.1 Preliminary test results

4.3.1.1 Unmodified specimens

It was observed that for unmodified specimens, both compressive and flexural strength slightly decreased with respect to increasing amounts of fly and slag incorporation as can be seen in Figure 4.7. Lowest values were observed for specimens which incorporated fly ash and slag together.

4.3.1.2 Polymer modified specimens: cement

In order to determine best curing conditions for polymer modified specimens, preliminary test were performed on specimens prepared with Polymer A admixture.

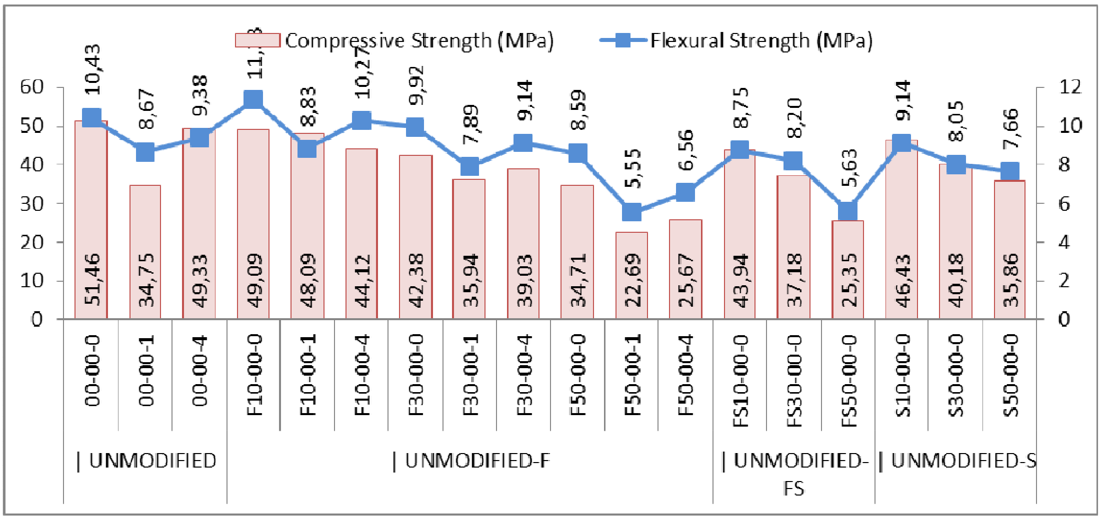


Figure 4.7 : Hardened properties of unmodified specimens.

It was observed that compressive strength of specimens prepared using polymer admixture decreased regardless of curing regimens as reported ([22], [23]) (Figure 4.8).

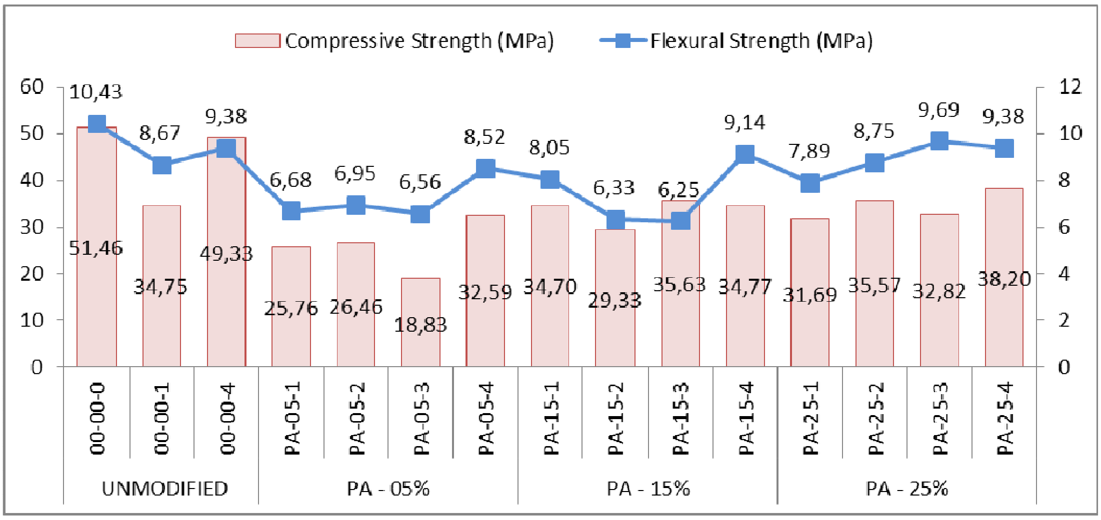


Figure 4.8 : Pre. – Hardened properties of Cement + Polymer A (5%-25%) specimens.

Although flexural strength also descreased when compred to unmodified specimens, curing regime #1 and curing regime #4 provided better strength values. In addition, results for 15% polymer admixture were better when compared to other specimens and there was no significant difference between specimens prepared with 15% polymer admixure and 25% polymer admixture. This data supports result of the study about optimum polymer / binder ratio which enables full development of interpenetraing polymer structure ([24], [25]).

4.3.1.3 Polymer modified specimens: cement + fly ash

It was observed that compressive strength of specimens prepared using polymer admixture was decreased regardless of curing regimens. It was found that the results of specimens prepared with 15% polymer admixture were better when compared to other mixtures (Figure 4.9, Figure 4.10, Figure 4.11).

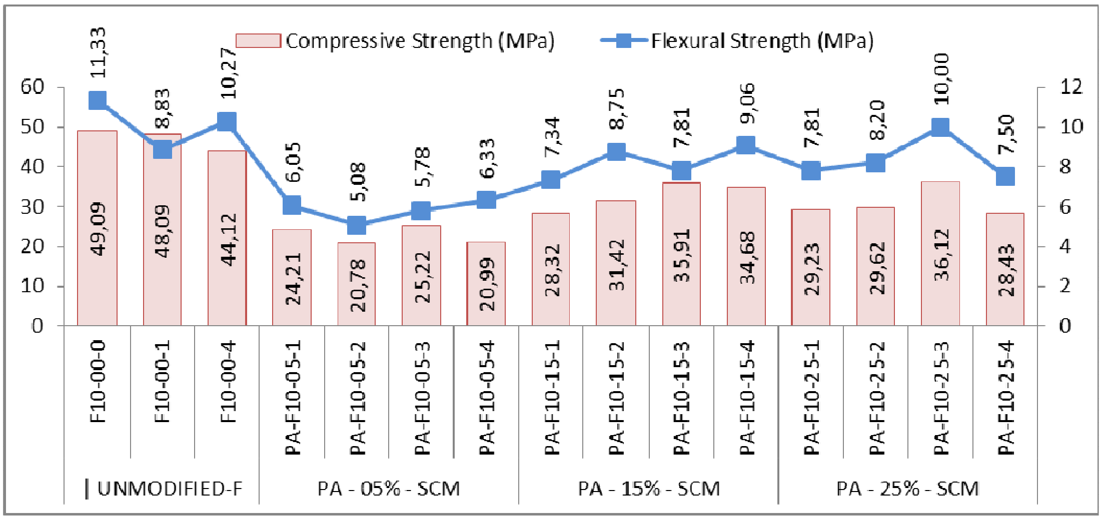


Figure 4.9 : Pre. – Hardened properties of Cement + Fly Ash (10%) + Polymer A (5%-25%) specimens.

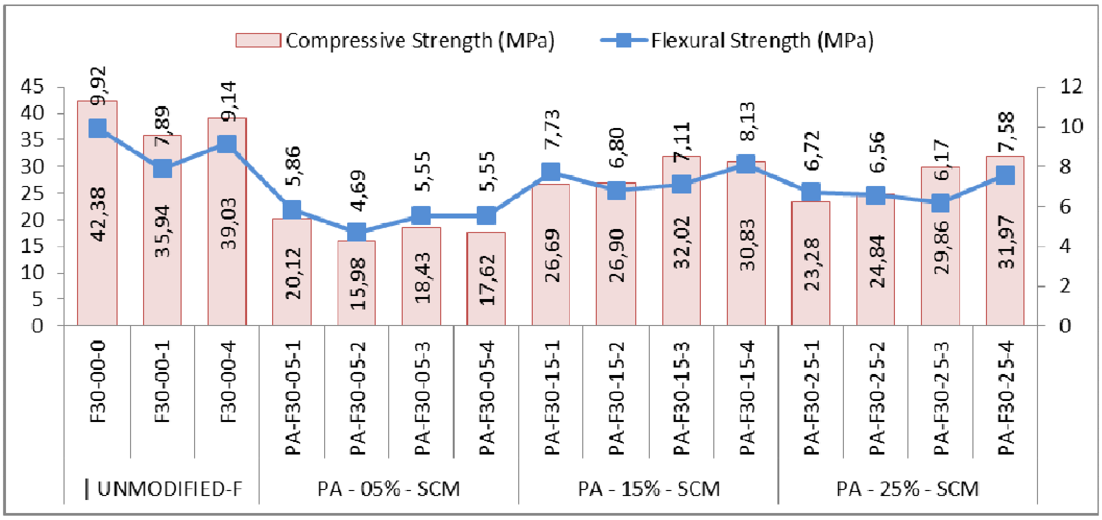


Figure 4.10 : Pre. – Hardened properties of Cement + Fly Ash (30%) + Polymer A (5%-25%) specimens.

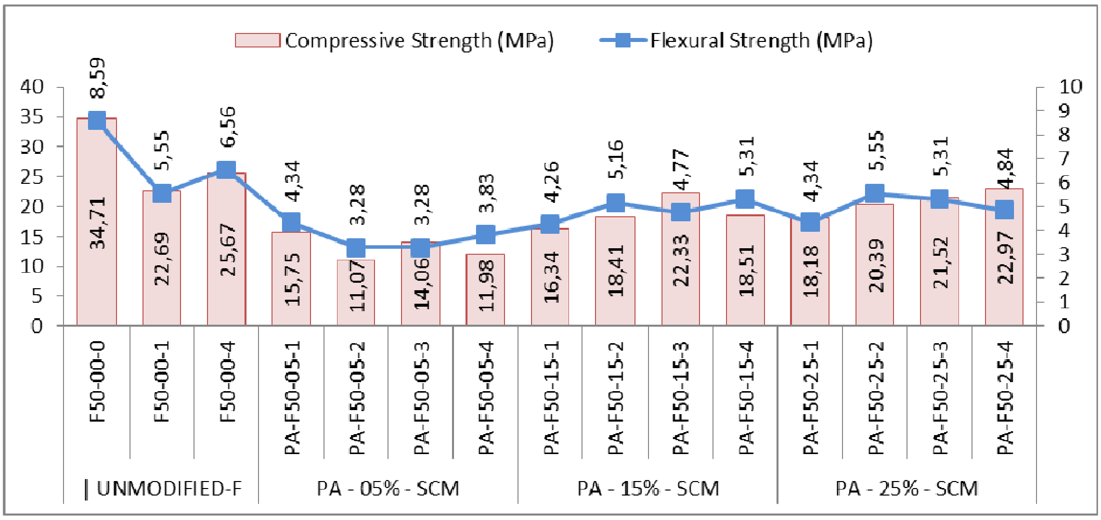


Figure 4.11 : Pre. – Hardened properties of Cement + Fly Ash (50%) + Polymer A (5%-25%) specimens.

4.3.1.4 Polymer modified specimens: cement + slag

It was observed that compressive strength of specimens prepared using polymer admixture decreased regardless of curing regimens as fly ash added mixtures. It was obtained that results of specimens prepared with 15% polymer admixture were better than the other specimens (Figure 4.12, Figure 4.13, Figure 4.14).

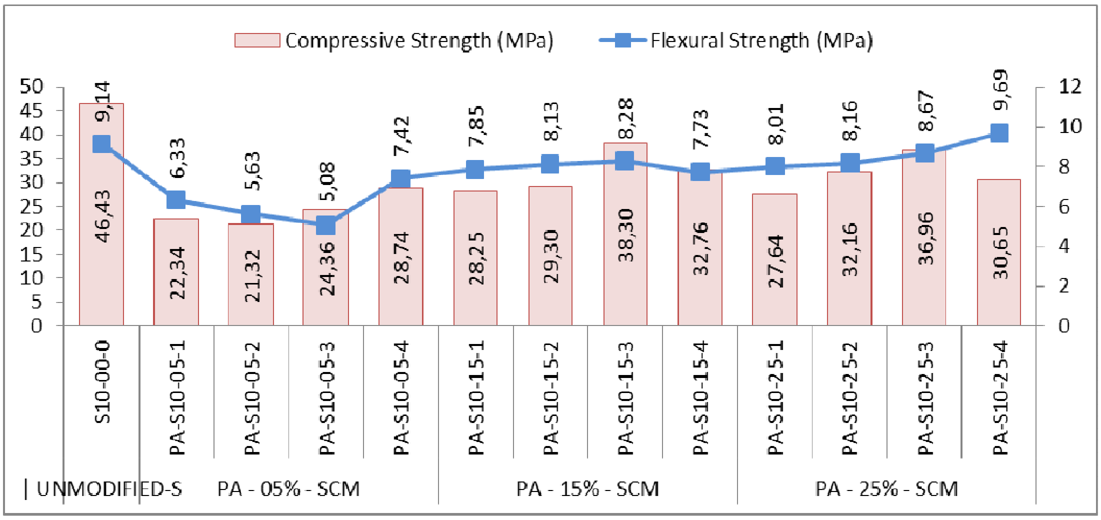


Figure 4.12 : Pre. – Hardened properties of Cement + Slag (10%) + Polymer A (5%-25%) specimens.

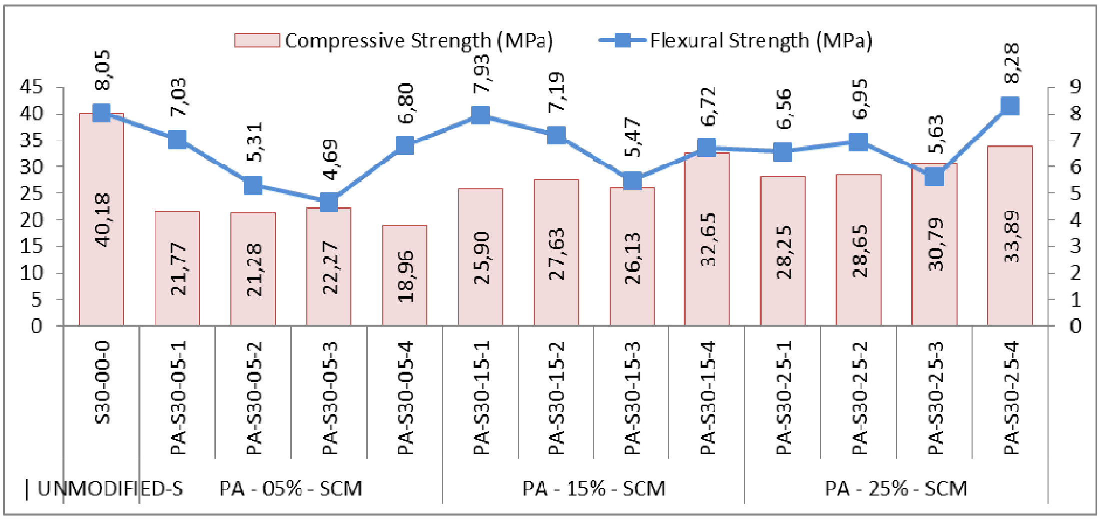


Figure 4.13 : Pre. – Hardened properties of Cement + Slag (30%) + Polymer A (5%-25%) specimens.

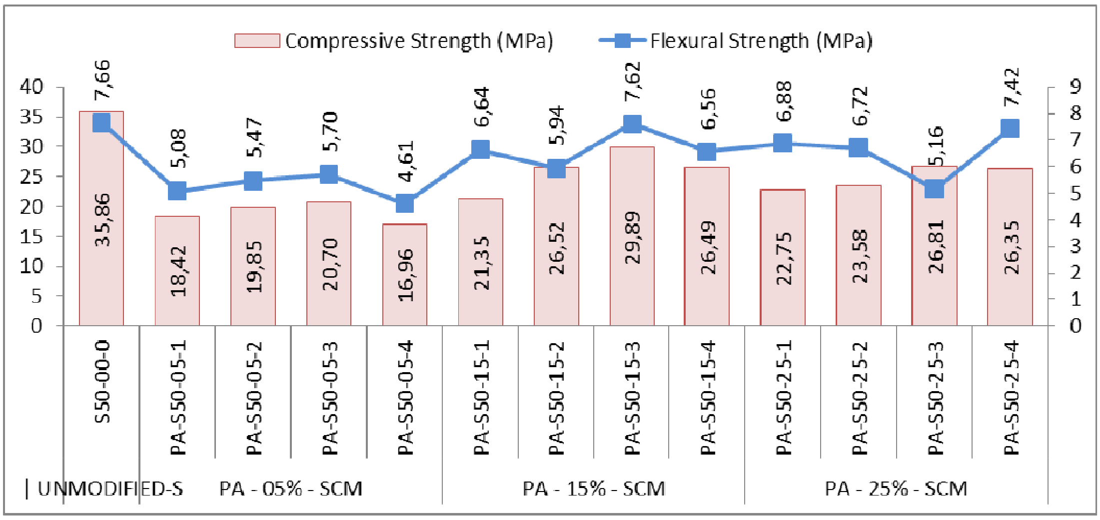


Figure 4.14 : Pre. – Hardened properties of Cement + Slag (50%) + Polymer A (5%-25%) specimens.

4.3.1.5 Polymer modified specimens: cement + fly ash + slag

Specimens incorporating both fly ash and slag were prepared with different polymer admixture amounts.

It was observed that compressive and flexural strenth of specimens decrased with respect to increasing SCM amount. In addition, it was observed that 15% polymer admixture provided better result than other polymer admixture ratios (Figure 4.15, Figure 4.16, Figure 4.17), similar to previous results.

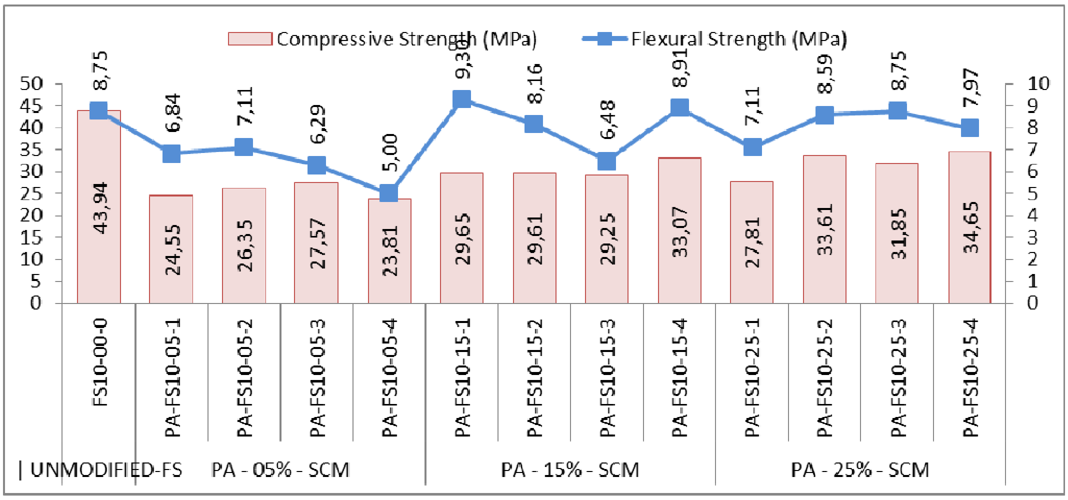


Figure 4.15 : Pre. – Hardened properties of Cement + Fly Ash (5%) + Slag (5%) + Polymer A (5%-25%) specimens.

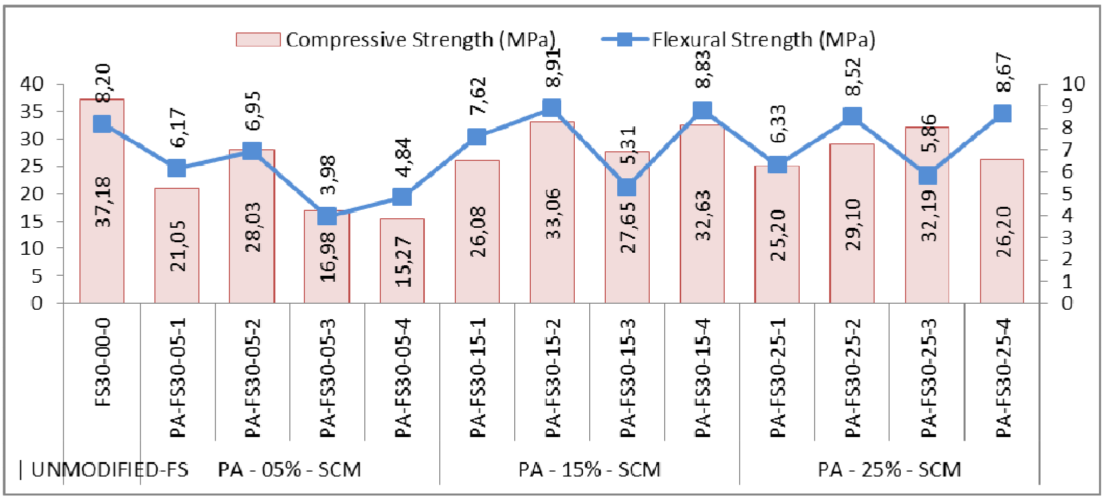


Figure 4.16 : Pre. – Hardened properties of Cement + Fly Ash (15%) + Slag (15%) + Polymer A (5%-25%) specimens.

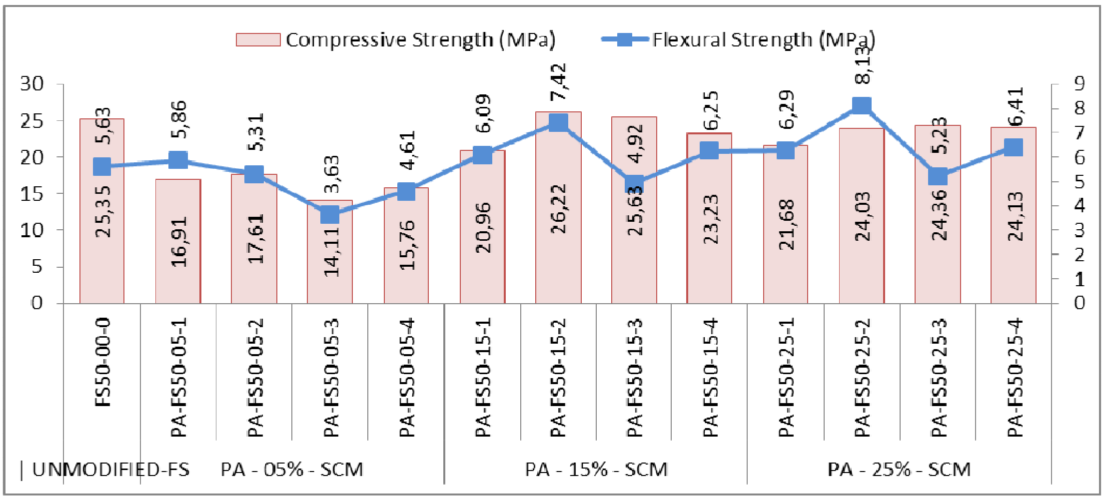


Figure 4.17 : Pre. – Hardened properties of Cement + Fly Ash (25%) + Slag (25%) + Polymer A (5%-25%) specimens.

4.3.2 Comparative test results

4.3.2.1 Polymer modified specimens (polymer B): cement

Polymer B, which is one of two polymer admixtures used for comparative tests, was incorporated into specimens. For comparative tests, only two curing conditions were applied. In order to reflect worst case scenario, curing regime #1 (28 days curing at room environment) was selected. In order to reflect best case scenario, curing regimen #4 (3 days immersend in water + 25 days curing at room environment) was selected (Figure 4.18).

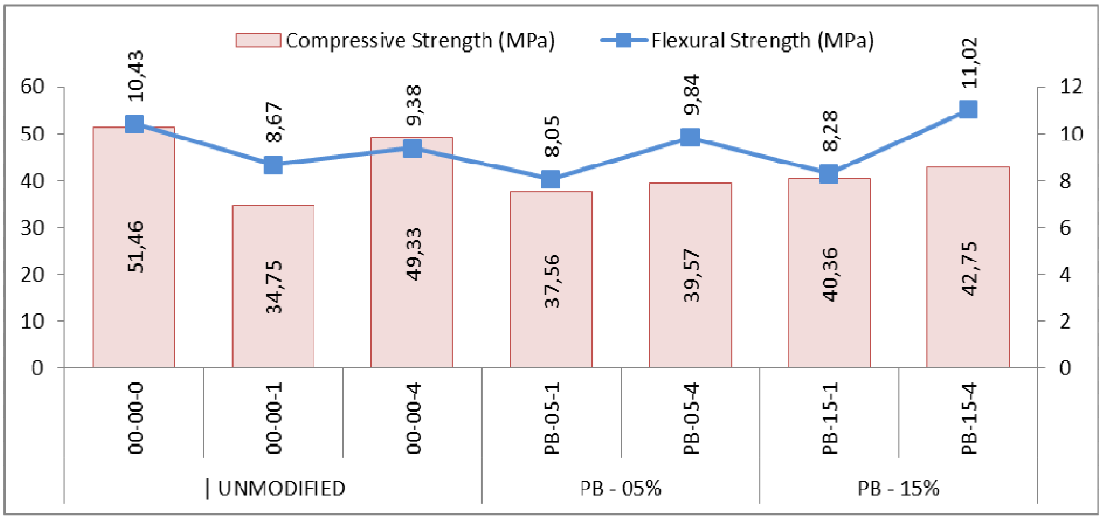


Figure 4.18 : Comp. – Hardened properties of Cement + Polymer B (5-15%) specimens.

4.3.2.2 Polymer modified specimens (polymer B): cement + fly ash

It was observed that 5% Polymer B addition for comparative tests resulted in lowered strength values than unmodified specimens incorporation SCM. On the other hand, 15% Polymer B addition provided significant increase when compared to 5% Polymer B addition. It was noted that flexural strength values increased when curing regime #4 was applied (Figure 4.19, Figure 4.20, Figure 4.21).

4.3.2.3 Polymer modified specimens (polymer C): cement

Polymer C, which is other polymer admixture used for comparative tests, was incorporated into the mixtures.

It was observed that 5% of Polymer C provided similar results when compared to specimens incorporated 15% of Polymer C (Figure 4.22).

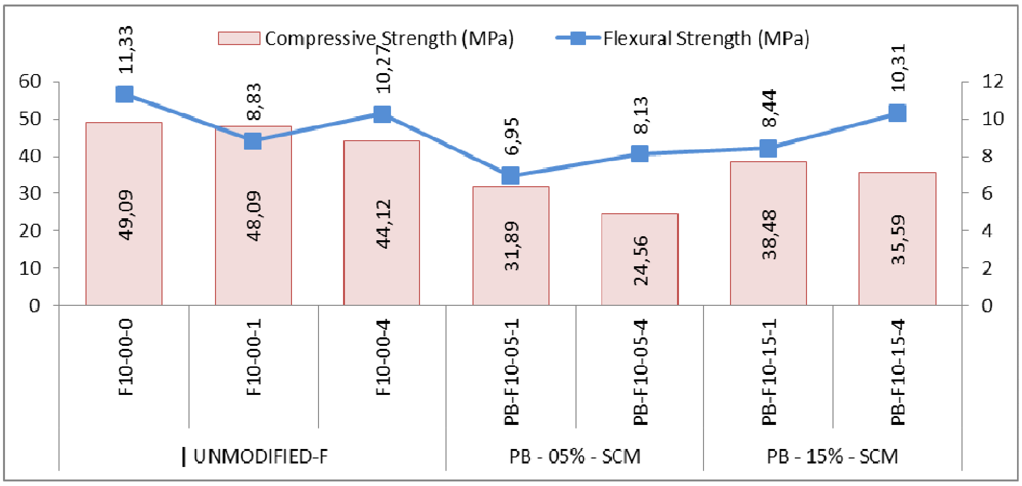


Figure 4.19 : Comp. – Hardened properties of Cement + Fly Ash (10%) + Polymer B (5-15%) specimens.

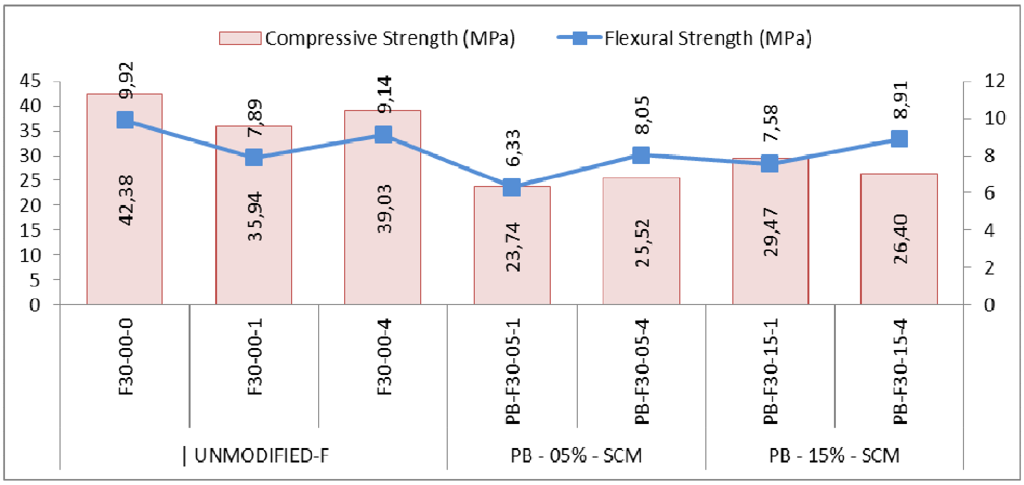


Figure 4.20 : Comp. – Hardened properties of Cement + Fly Ash (30%) + Polymer B (5-15%) specimens.

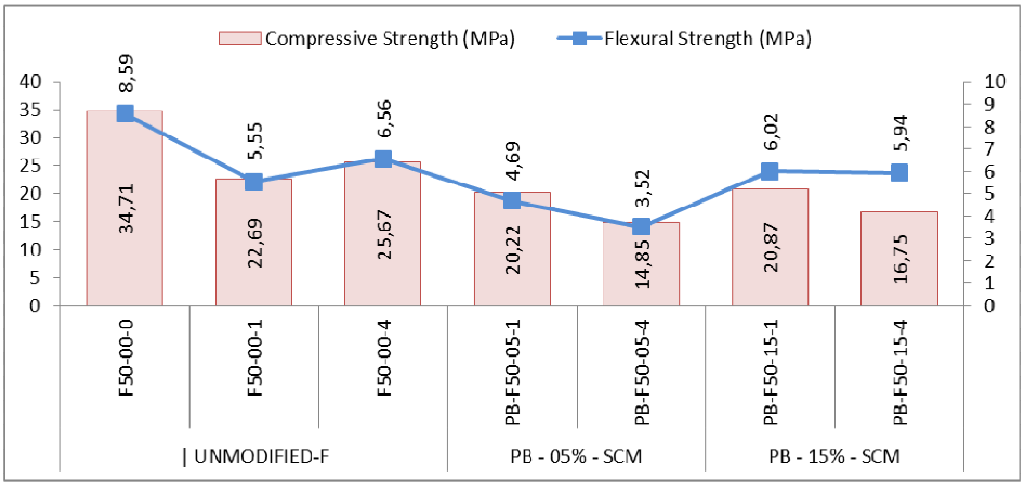


Figure 4.21 : Comp. – Hardened properties of Cement + Fly Ash (50%) + Polymer B (5-15%) specimens.

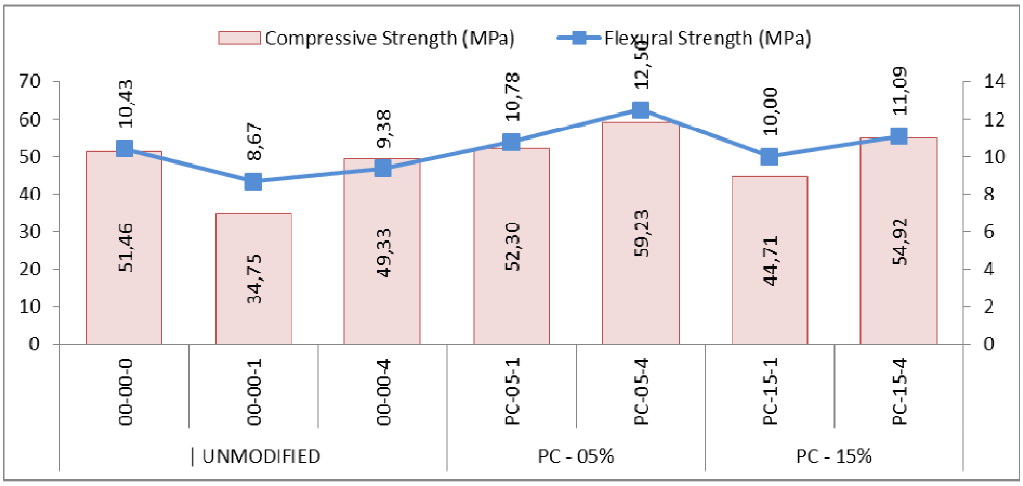


Figure 4.22 : Comp. – Hardened properties of Cement + Polymer C (5-15%) specimens.

4.3.2.4 Polymer modified specimens (polymer C): cement + fly ash

It was observed that 5% Polymer C incorporation results similar results 15% Polymer C incorporation. Under same curing conditions, Polymer C addition mostly provided better results when compared to unmodified specimens (Figure 4.23, Figure 4.24, Figure 4.25).

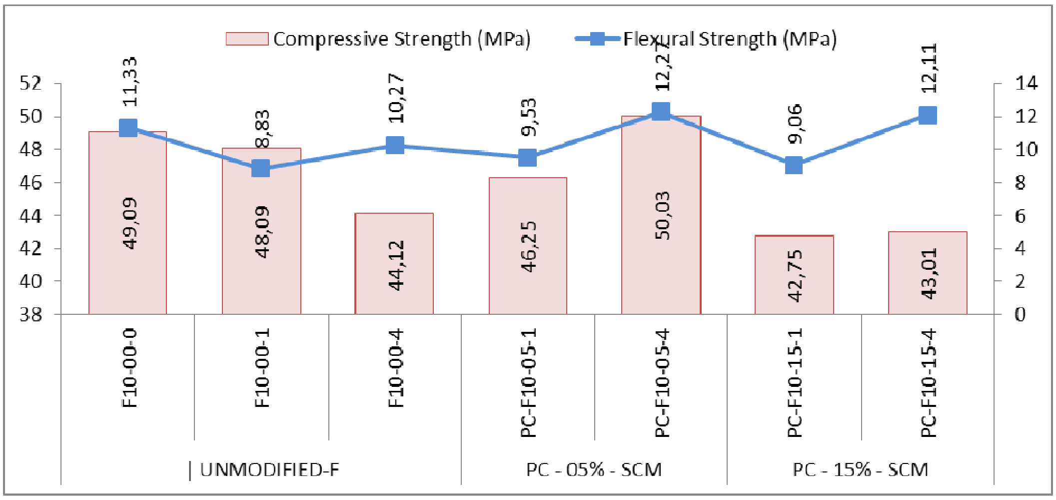


Figure 4.23 : Comp. – Hardened properties of Cement + Fly Ash (10%) + Polymer C (5-15%) specimens.

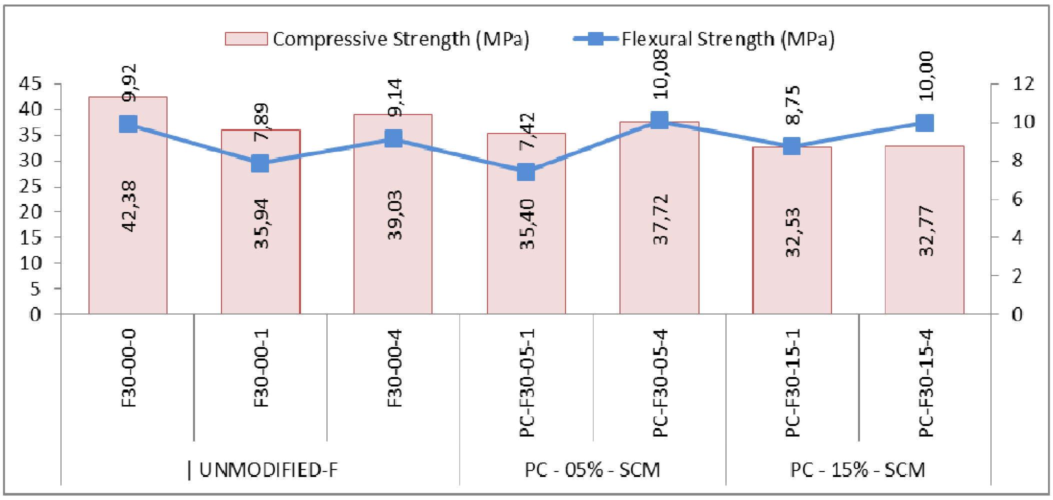


Figure 4.24 : Comp. – Hardened properties of Cement + Fly Ash (30%) + Polymer C (5-15%) specimens.

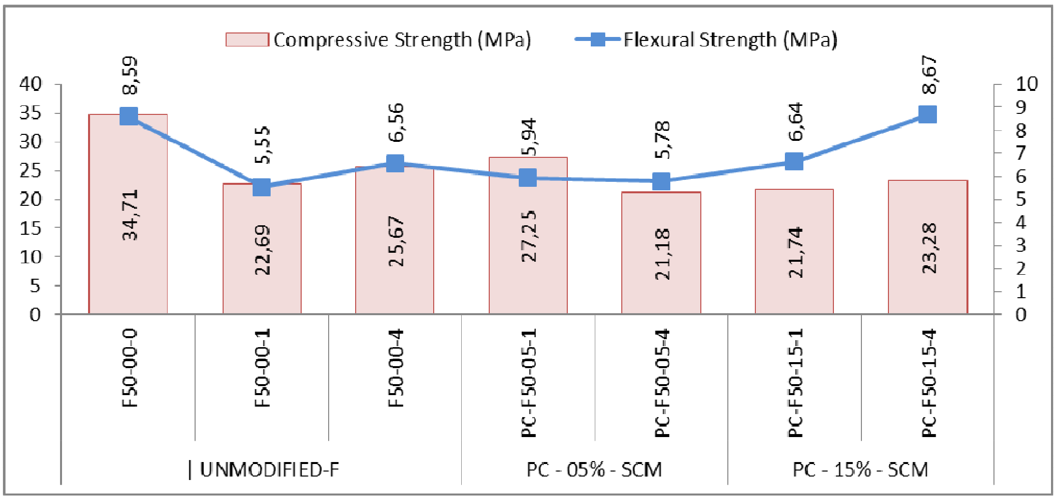


Figure 4.25 : Comp. – Hardened properties of Cement + Fly Ash (50%) + Polymer C (5-15%) specimens.

4.3.3 Specimens with similar workability

4.3.3.1 Unmodified specimens with similar workability: cement based

In these mixtures, water / binder ratio was modified in order to achieve same workability as polymer added mixtures and hardened strength properties were determined.

Most of the polymer aded specimens showed better test results when curing regimen 4 was applied. For this reason, curing regime #4 was compared.

For all specimens, it was observed that although similar workabiliy was achieved by increasing water content of specimens, hardened test results descreased with respect to increasing water / binder ratio (Figure 4.26).

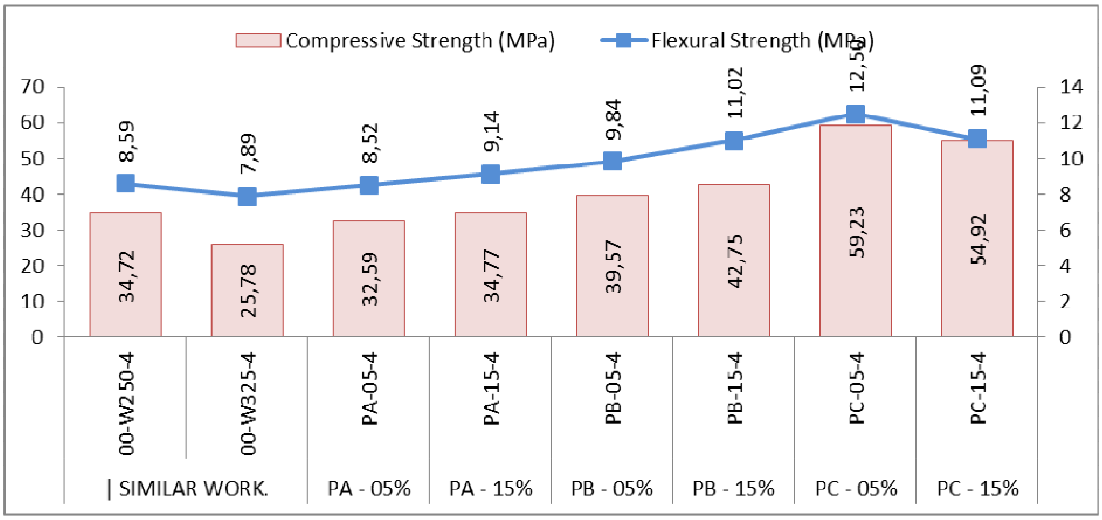


Figure 4.26 : Comp. – Hardened properties of specimens with similar workability – Cement.

4.3.3.2 Unmodified specimens with similar workability: cement + fly ash

In these mixtures, water / binder ratio was modified and hardened strength properties of specimens incorporating SCM was determined.

For all specimens, it was observed that although similar workabiliy was achieved by increasing water content of specimens, hardened test results descreased with respect to increasing water / binder ratio (Figure 4.27, Figure 4.28, Figure 4.29).

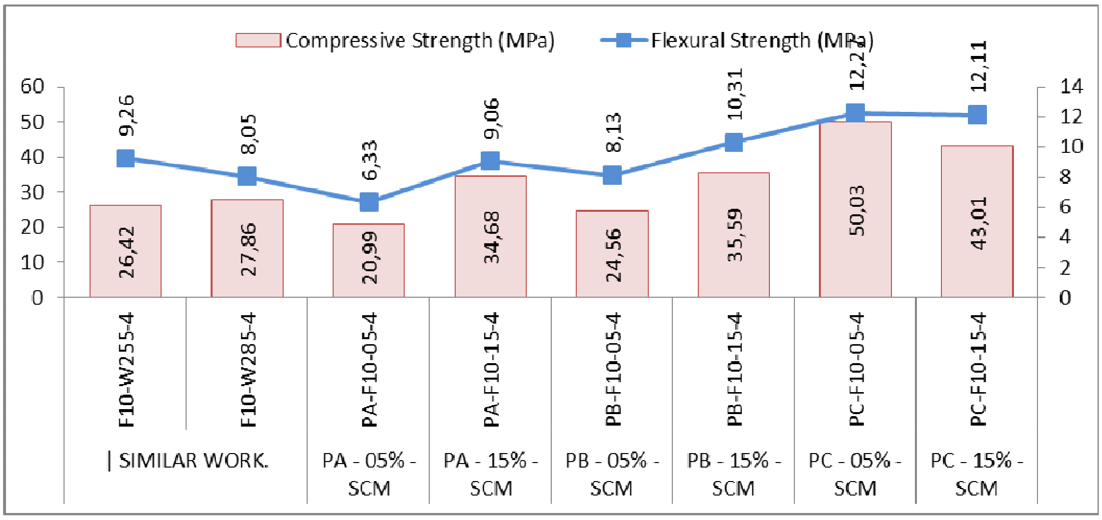


Figure 4.27 : Comp. – Hardened properties of specimens with similar workability – Cement + Fly Ash (10%).

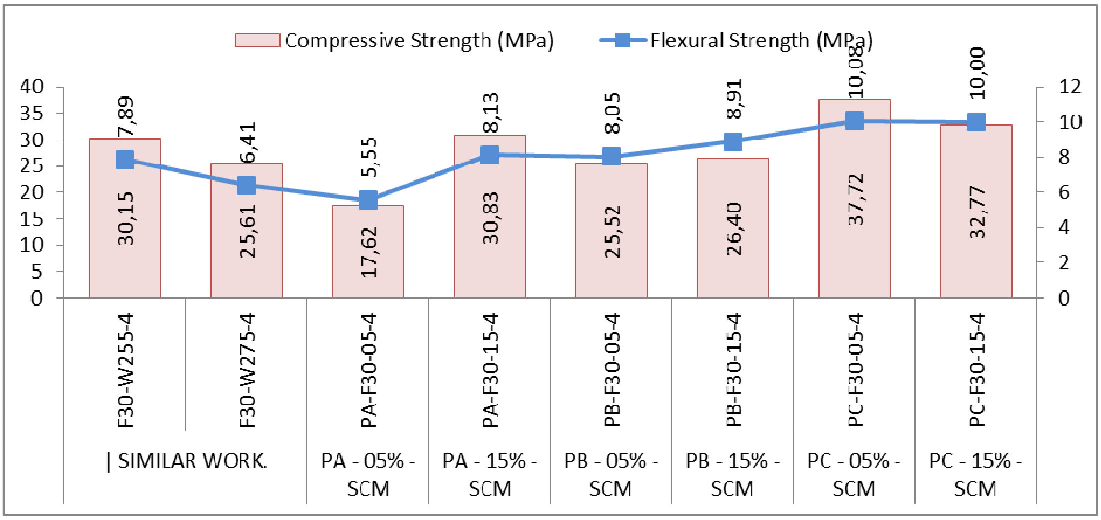


Figure 4.28 : Comp. – Hardened properties of specimens with similar workability – Cement + Fly Ash (30%).

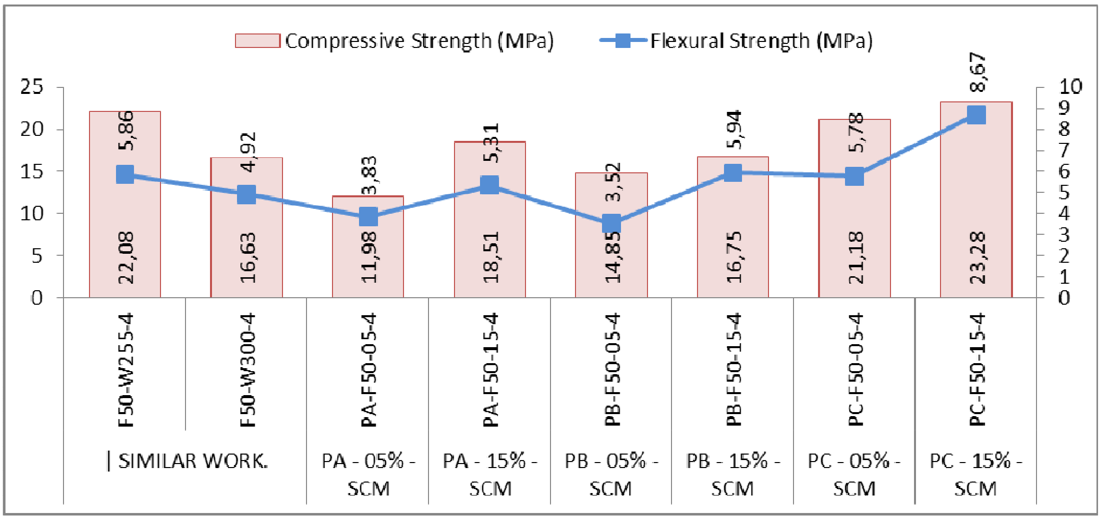


Figure 4.29 : Comp. – Hardened properties of specimens with similar workability – Cement + Fly Ash (50%).

4.3.4 Durability charactericties: capillary rise test

4.3.4.1 Unmodified specimens: cement + SCM incorporation

Capillary rise tests were performed on unmodified specimens and unmodified specimens incorporating SCM.

As SCM, fly ash and slag were used. Specimens were cured under three different curing regimens: immersed in water for 28 days (curing regime #0), 28 days at room environment (curing regime #1), 3 days immersed in water + 25 days at room environment (curing regime #4).

It was observed that sorptivity of specimens increased with respect to duration they are kept at room environment during curing time and that incorporation of SCM decreased permeability (Figure 4.30). Sorptivity of unmodified specimens kept at room environment for 28 days was ~2,5 times higher than that cured in water for 28 days. In addition, 10% fly ash incorporation descreased sorptivity.

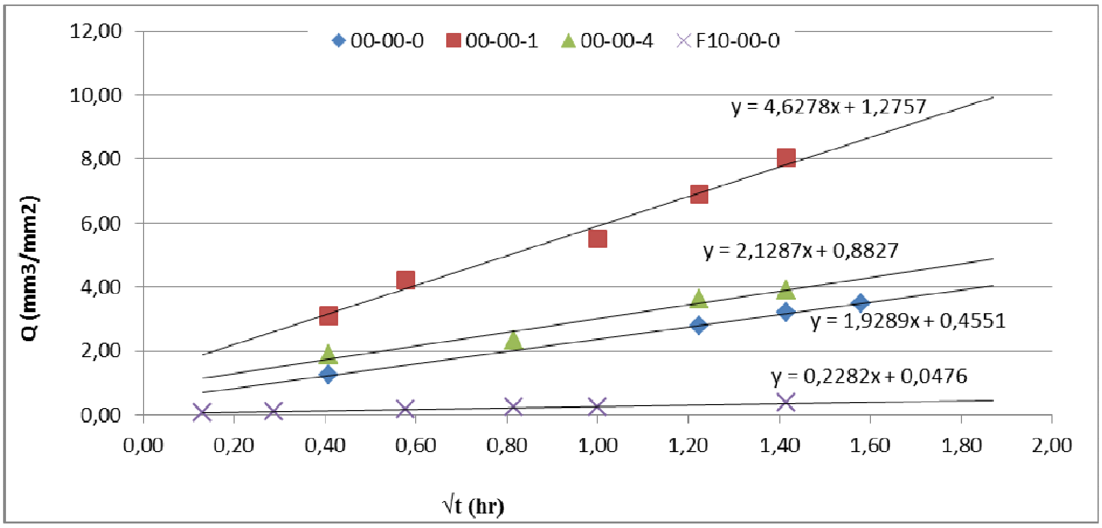


Figure 4.30 : Sorptivity coefficient of unmodified samples (1).

However, permeability of specimens changed with respect to amount and type of SCM incorporated into specimens. Fly ash incorporation provided lowest sorptivity coefficient values. Althouth slag incoporporation decreased sorptivity coefficient when compared to unmodified specimens, sorptivity coefficient was still higher than those incorporporationg fly ash and slag at the same time (Figure 4.31, Figure 4.32, Figure 4.33).

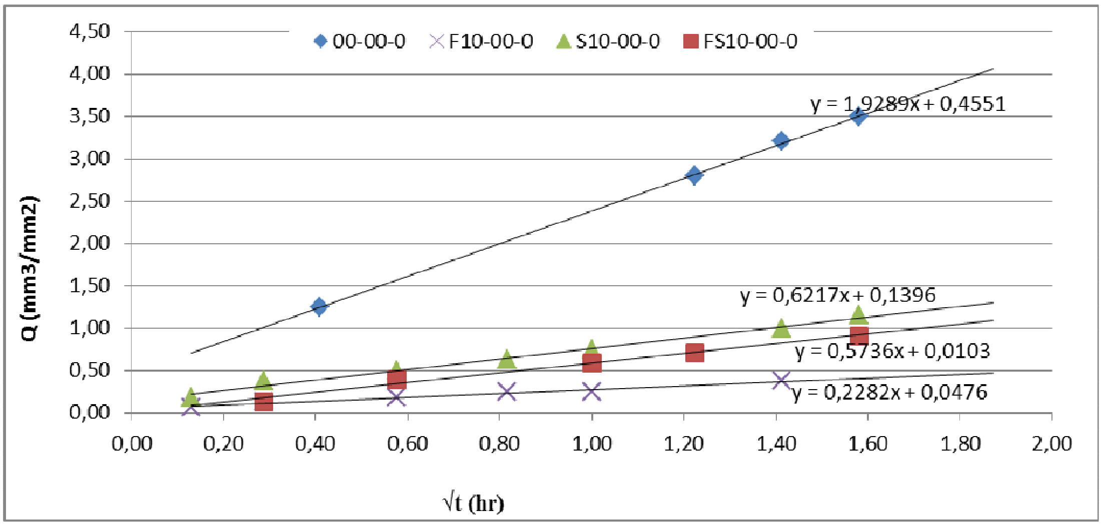


Figure 4.31 : Sorptivity coefficient of unmodified samples (2).

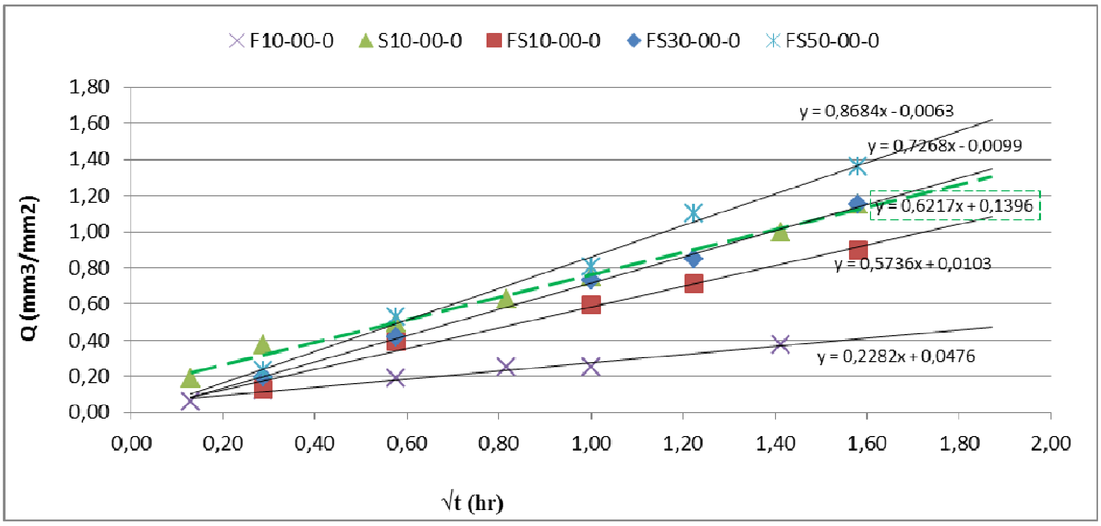


Figure 4.32 : Sorptivity coefficient of unmodified samples (3).

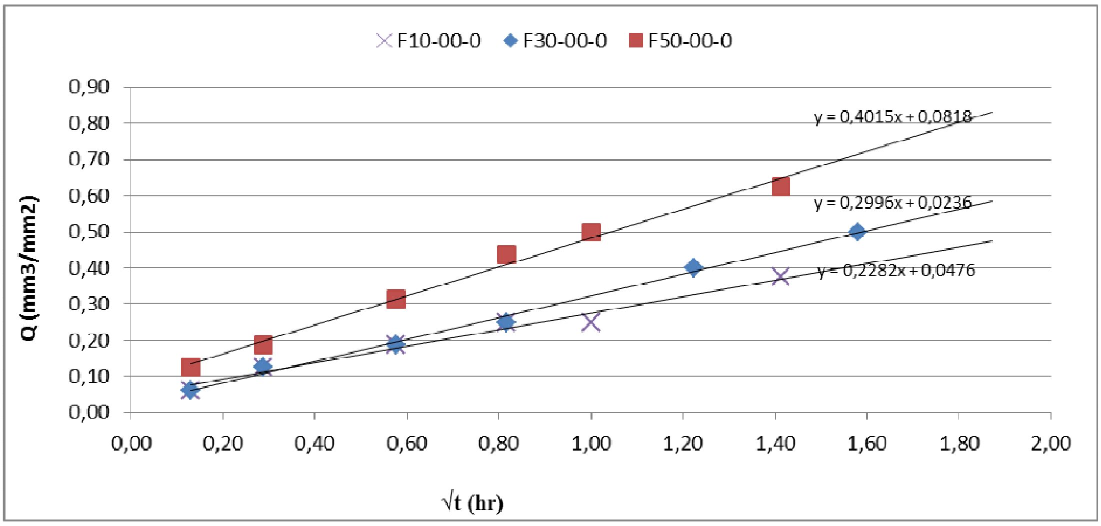


Figure 4.33 : Sorptivity coefficient of unmodified samples (4).

Sorptivity coefficients for unmodified specimens are tabulated below in Table 4.1:

Table 4.1 : Sorptivity coefficients unmodified specimens.

Specimen Label (unmodified)	00-00-0	00-00-1	00-00-4	F10-00-0	F10-00-1	F10-00-4	F30-00-0	F30-00-1	F30-00-4	F50-00-0	F50-00-1	F50-00-4	S10-00-0	S30-00-0	S50-00-0	FS10-00-0	FS30-00-0	FS50-00-0
Sorptivity Coefficient	1,93	4,63	2,13	0,23	1,95	1,49	0,30	2,69	1,85	0,40	3,22	2,78	0,62	0,85	0,90	0,57	0,73	0,87
REMARKS				LOWEST														

4.3.4.2 Preliminary - polymer modified specimens: cement + polymer

Preliminary capillary rise tests were performed on polymer modified specimens in order to determine best curing conditions for polymer modified specimens.

For preliminary test, specimens were prepared using Polymer A admixture with polymer / cement ratio of 5%, 15% and 25% Different curing regimens were applied and capillay rise tests were performed on specimens.

It was observed that permability of specimens, which curing regime #4 was applied, was the lowest. In addition, curing regime #1 resulted in highest sorptivity coefficient values; curing regime #2 and curing regime #3 resulted in slightly lower sorptivity coefficient values (Figure 4.34). Lowest sorptivity coefficient for preliminary tests was obtained for specimen incorporating 15% polymer / cement ratio, which is cured under curing regime #4 (Figure 4.35).

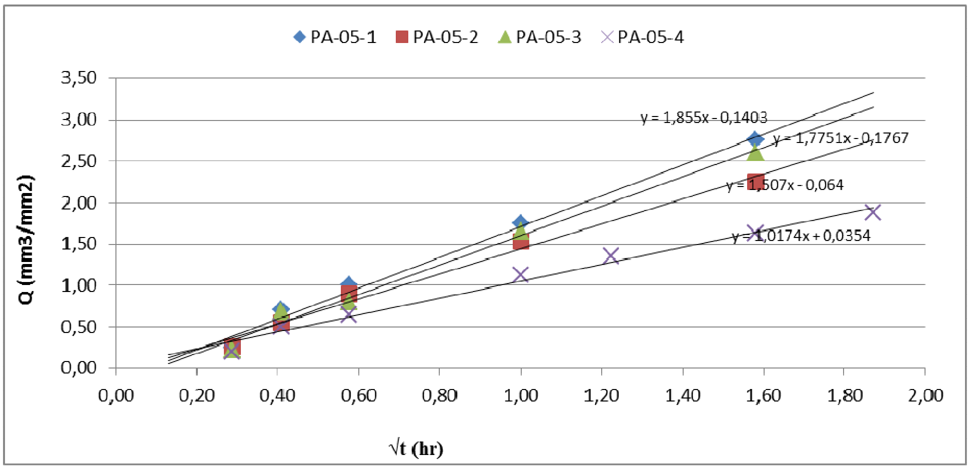


Figure 4.34 : Sorptivity coefficient of preliminary polymer modified samples - Polymer A (1).

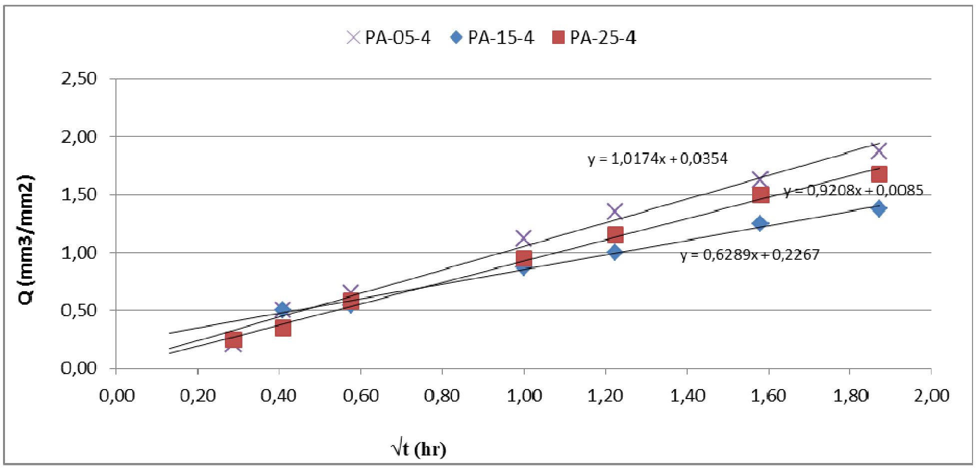


Figure 4.35 : Sorptivity coefficient of preliminary polymer modified samples – Polymer A (2).

4.3.4.3 Preliminary - polymer modified specimens: cement + fly ash + polymer

Preliminary capillary rise tests were performed on polymer modified specimens incorporating SCM in order to determine best curing conditions for comparative tests. Fly ash was used as SCM and it was incorporated into specimens with proportions of 10%, 30% and 50% of total binder ratio.

Polymer modified specimens were prepared using Polymer A admixture and five different curing regimens were applied. Capillary rise tests were performed on polymer modified specimens, which polymer / total binder ratios are 5%, 15% and 25%.

It was observed that polymer modified SCM incorporated specimes, which were cured 3 days immersed in water + 25 days at room environment (curing regime #4) provided lowest permeability (Figure 4.36). It was noted that sorptivity of specimens with 25% polymer admixture incorporation was higher than that of specimens with 15% polymer admixture incorporation (Figure 4.37). In addition, it was recorded that sorptivity of polymer modified SCM incorporated specimens increased with respect to increasing amount of SCM incorporated (Figure 4.38).

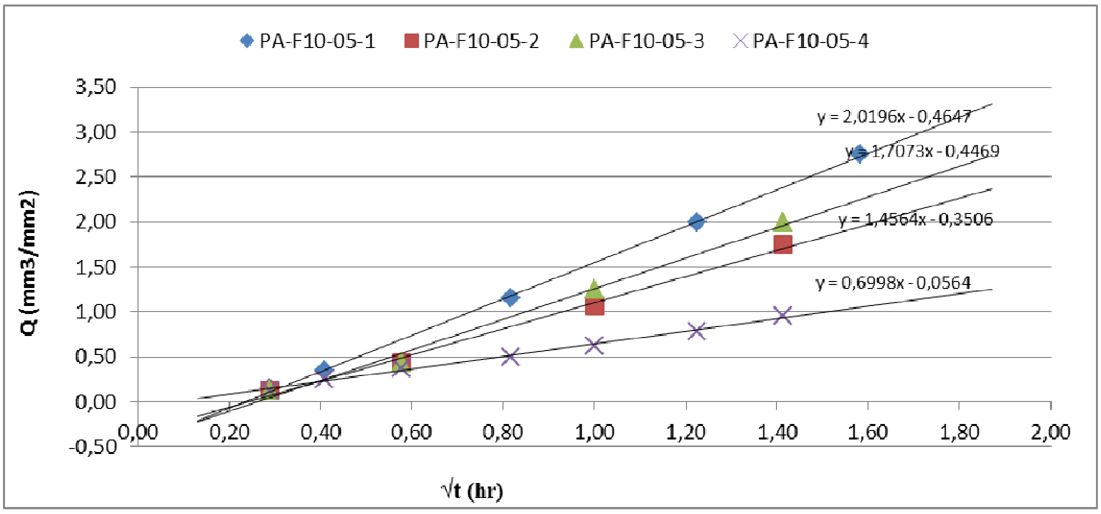


Figure 4.36 : Sorptivity coefficient of preliminary polymer modified samples incorporating SCM – Polymer A (1).

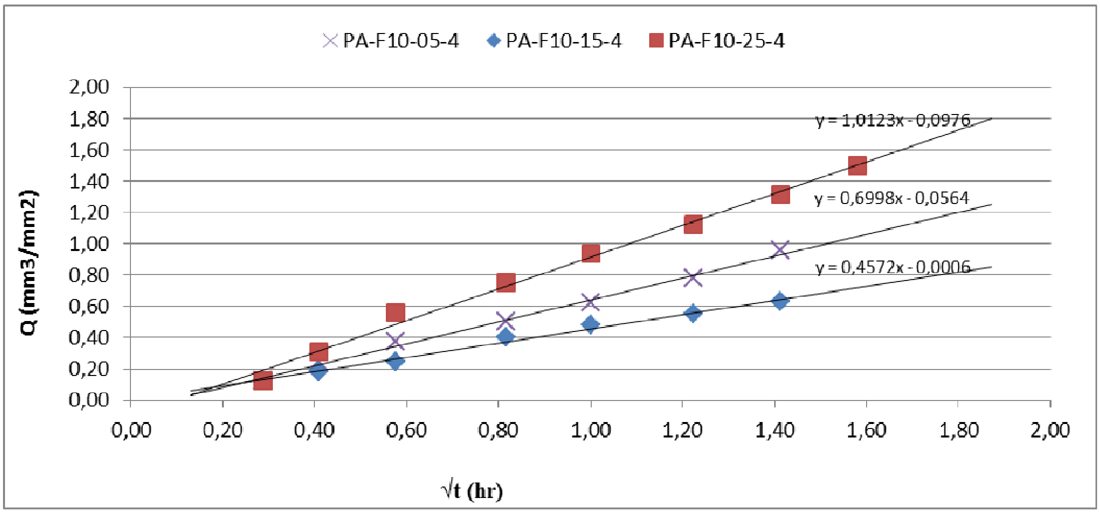


Figure 4.37 : Sorptivity coefficient of preliminary polymer modified samples incorporating SCM – Polymer A (2).

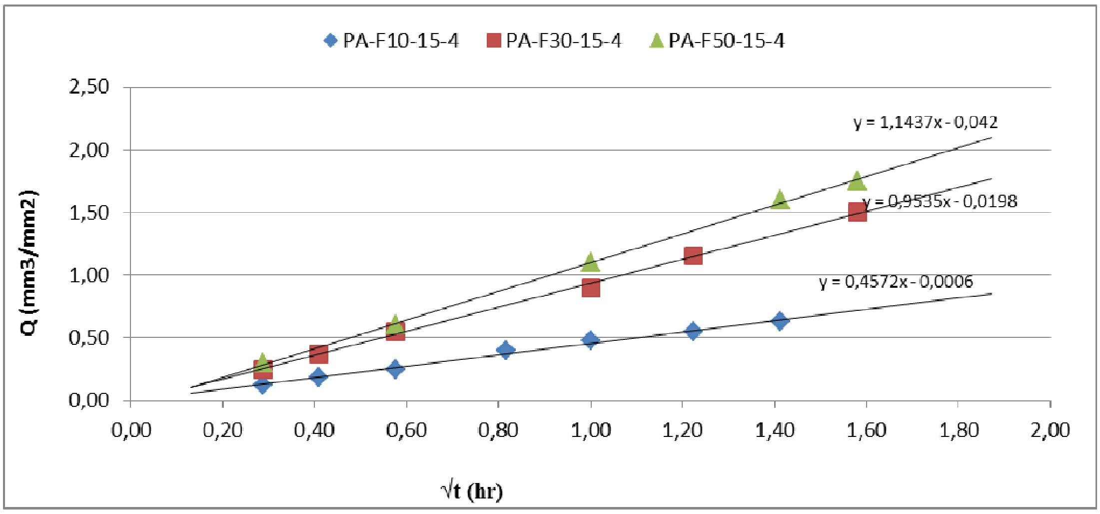


Figure 4.38 : Sorptivity coefficient of preliminary polymer modified samples incorporating SCM – Polymer A (3).

4.3.4.4 Comparative - polymer modified specimens: cement + polymer

Comparative capillary rise tests were performed on polymer modified specimens prepared by two different polymer admixtures.

Polymer B and Polymer C admixtures with 5% and 15% of total binder amount were used for preparation of specimens. Selected curing regimens, which are curing regime #1 and curing regime #4, were applied and capillary rise tests were performed on specimens.

Polymer modified specimens with 15% polymer admixture were less permeable than polymer modified specimens with 5% polymer admixture. It was also observed that specimes which were cured 3 days immersed in water + 25 days at room environment (curing regime #4) showed lower permeability than specimens cured at room environment (curing regime #1) (Figure 4.39, Figure 4.40).

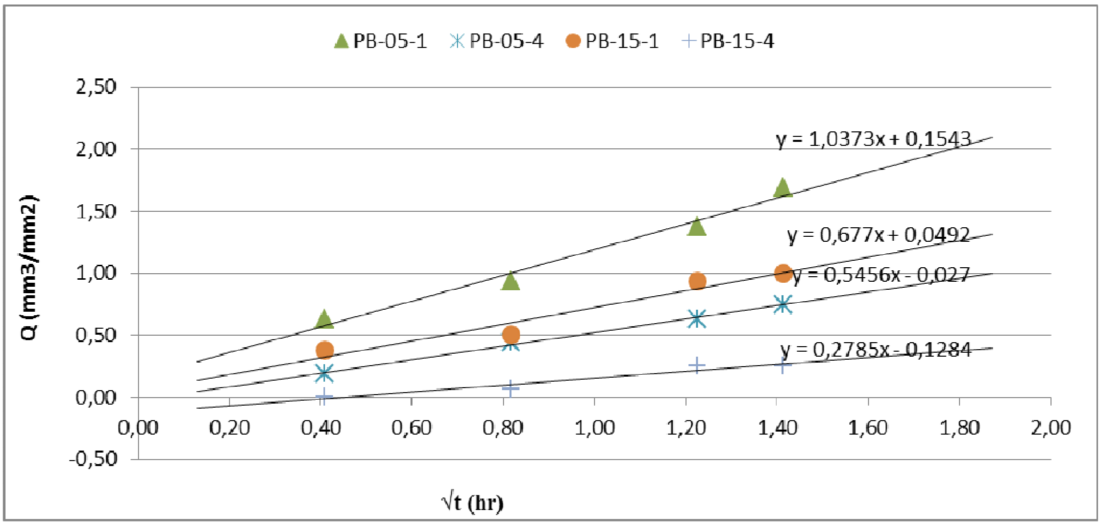


Figure 4.39 : Sorptivity coefficient of comparative polymer modified samples (Polymer B).

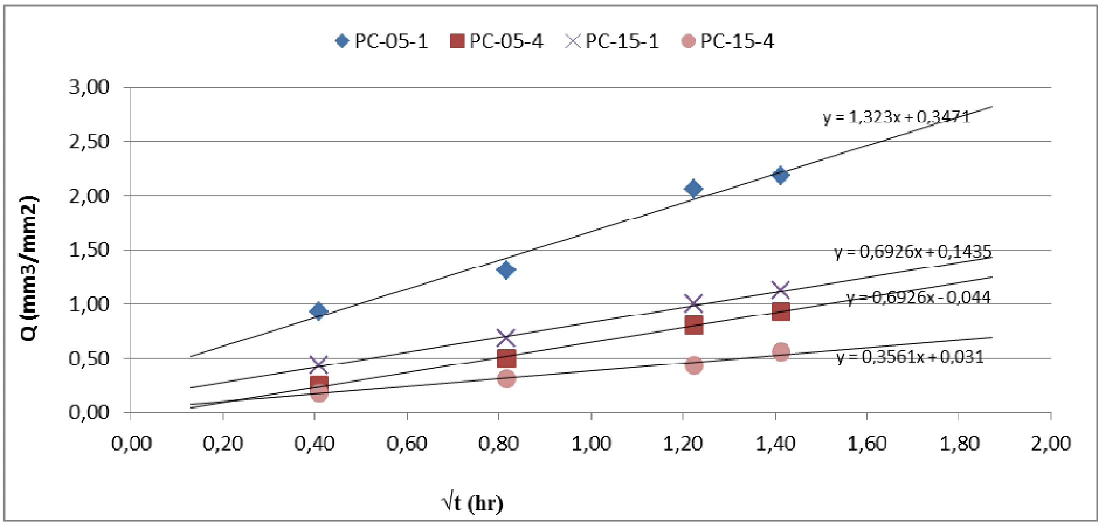


Figure 4.40 : Sorptivity coefficient of comparative polymer modified samples (Polymer C).

In addition, it was recorded that under same curing conditions and same polymer content, permeability of polymer modified specimens showed difference with respect to brand of polymer admixture (Figure 4.41).

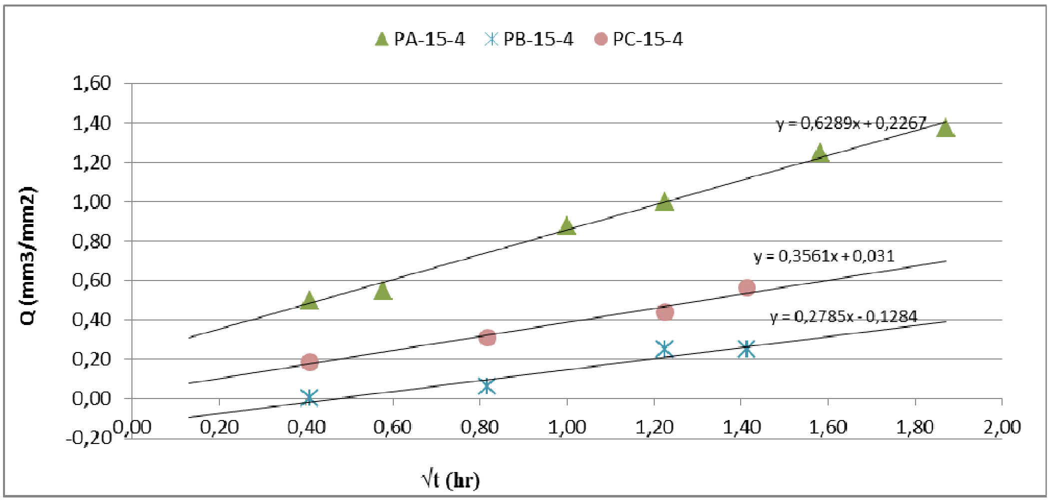


Figure 4.41 : Comparison of sorptivity coefficient of polymer modified samples (Polymer A, B, C).

4.3.4.5 Comparative - polymer modified specimens: cement + fly ash + polymer

Capillary rise test were performed on modifed specimens incorporation SCM.

Fly ash was used as SCM with ratio of 10%, 30% and 50% of total binder amount. For polymer modified specimens, two different polymer admixtures (Polymer B and Polymer C) were used with ratios of 5% and 15% of total binder amount.

Lowest sorptivity coefficient for polymer modified specimens was obtained for curing regime #4. However, fly ash incorporation increased sorptivity of polymer modified specimens (Figure 4.42, Figure 4.43, Figure 4.44, Figure 4.45).

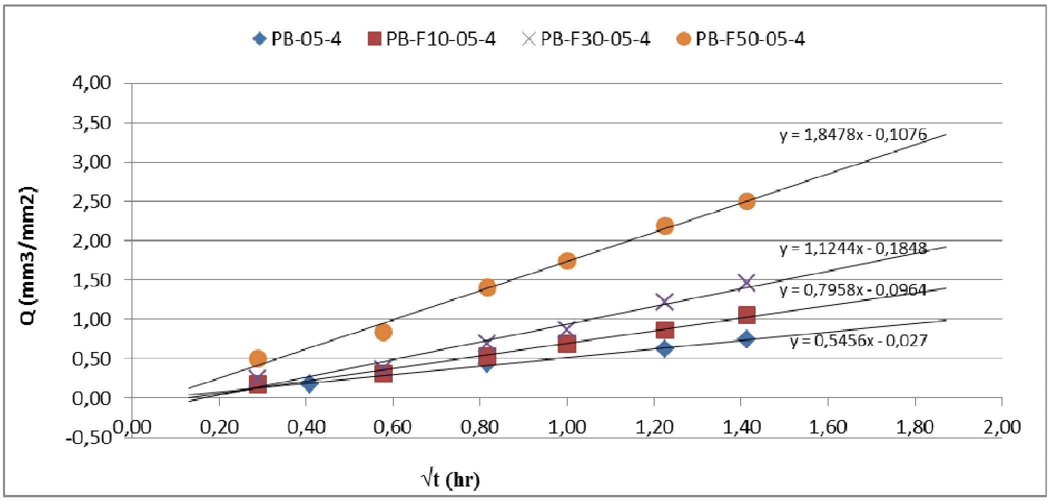


Figure 4.42 : Comparison of sorptivity coefficient of polymer modified samples with SCM (Polymer B – 5%).

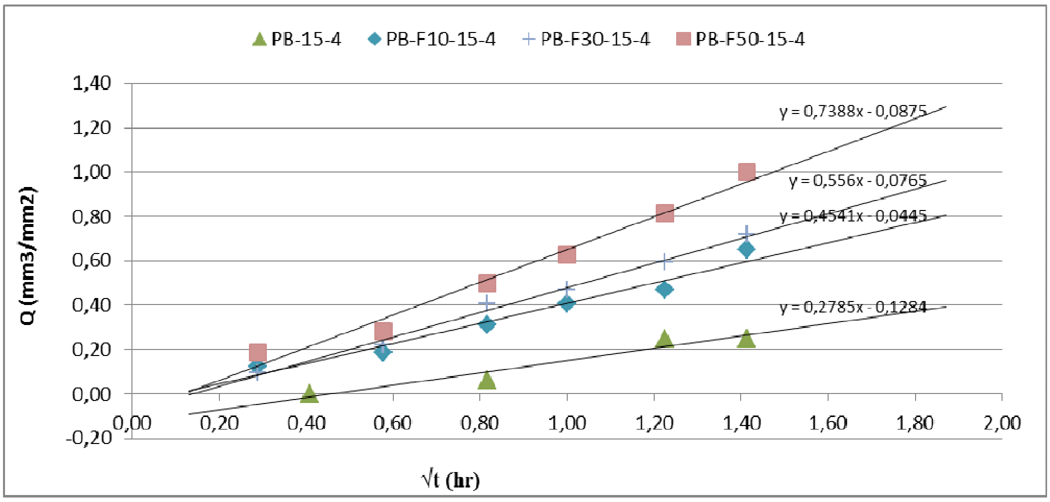


Figure 4.43 : Comparison of sorptivity coefficient of polymer modified samples with SCM (Polymer B – 15%).

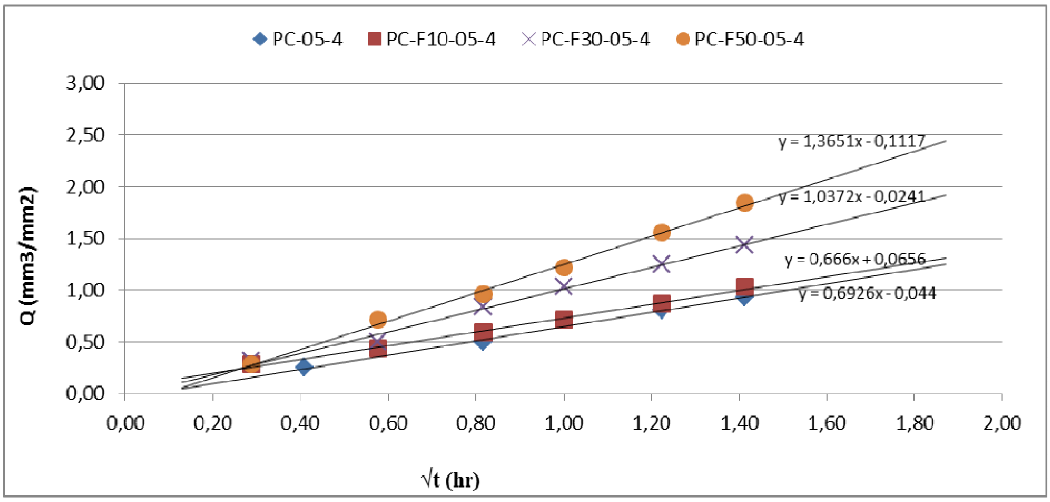


Figure 4.44 : Comparison of sorptivity coefficient of polymer modified samples with SCM (Polymer C – 5%).

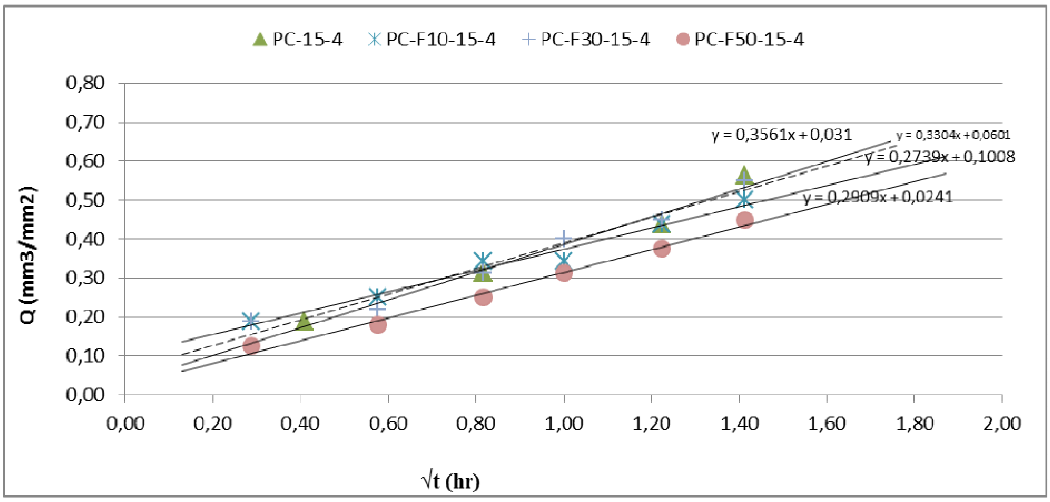


Figure 4.45 : Comparison of sorptivity coefficient of polymer modified samples with SCM (Polymer C – 15%).

In addition, it was recorded that under same curing conditions, permeability of polymer modified specimens showed difference with respect to brand of polymer admixture (Figure 4.46).

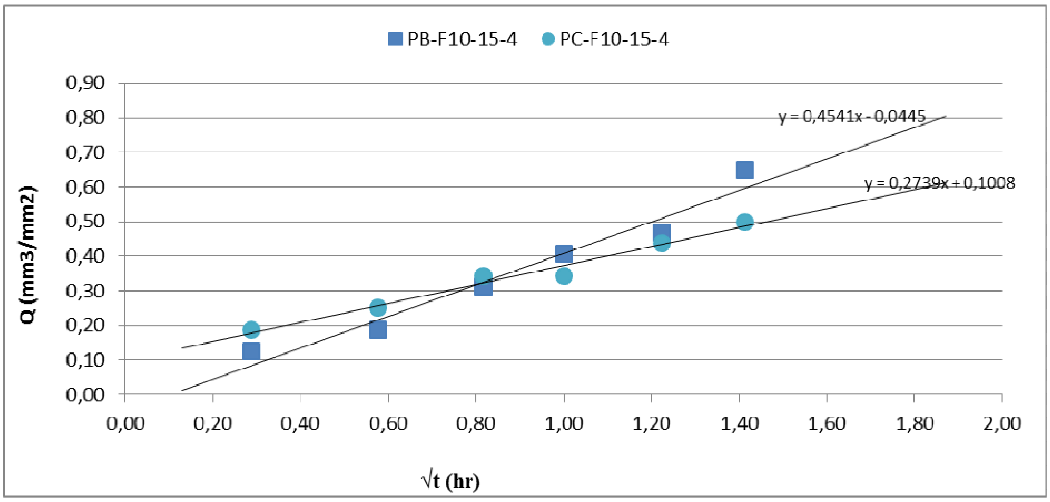


Figure 4.46 : Comparison of sorptivity coefficient of polymer modified samples with SCM (Polymer B, C – 15%).

4.3.4.6 Comparative: mixtures with similar workability

Capillary rise tests were performed on specimens, for which water / binder ratio had been modified in order to achieve similar workability as polymer admixture.

Water content of unmodified specimens and specimens incorporating SCM was increased in accordance with results of flow test. Fly ash was used as SCM with 10%, 30% and 50% of total binder amount. After application of selected curing regimens, capillary rise tests were performed and compared to polymer modified specimens.

For all specimens, it was observed that although similar workabiliy could be achieved by increasing water content of specimens, permeability has also increased with respect to increasing water / binder ratio. Lowest sorptivity coefficient for polymer modified specimens was nearly 5 times smaller than those of specimens with vary water / binder ratio cured under same conditions. ($S_{PC\text{-}F10\text{-}15\text{-}4}$=0,274 mm/√hr; $S_{F10\text{-}W255\text{-}4}$=1,49 mm/√hr) (Figure 4.47, Figure 4.48, Figure 4.49).

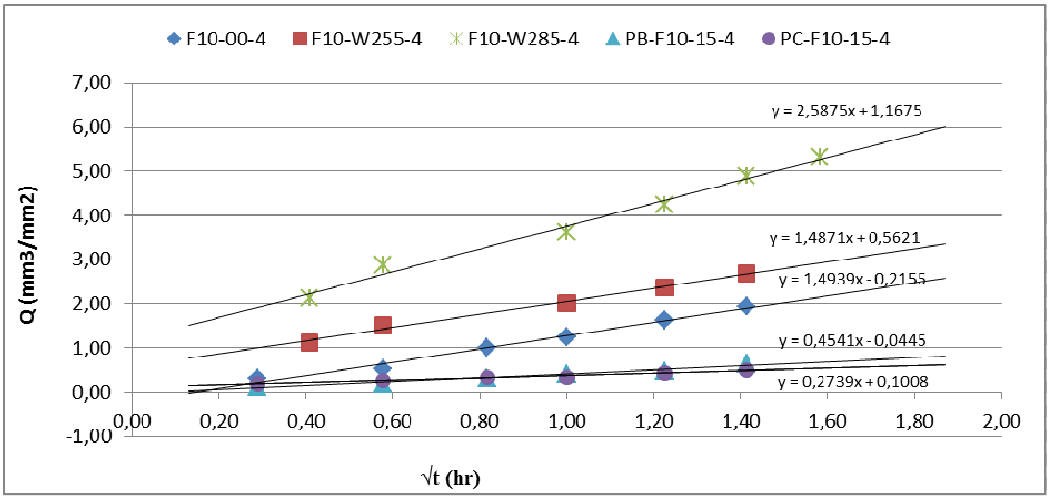


Figure 4.47 : Comparison of sorptivity coefficient of specimens with similar workability.

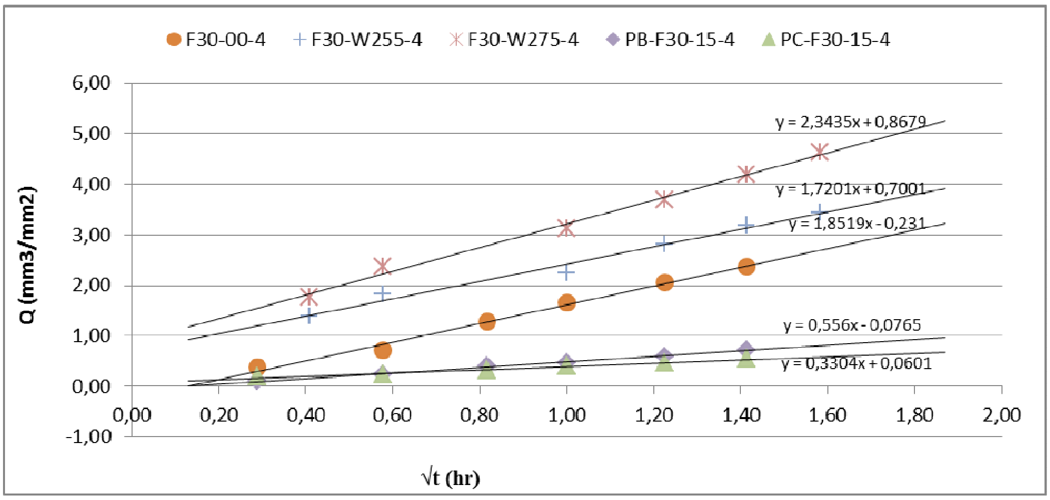


Figure 4.48 : Comparison of sorptivity coefficient of specimens with similar workability.

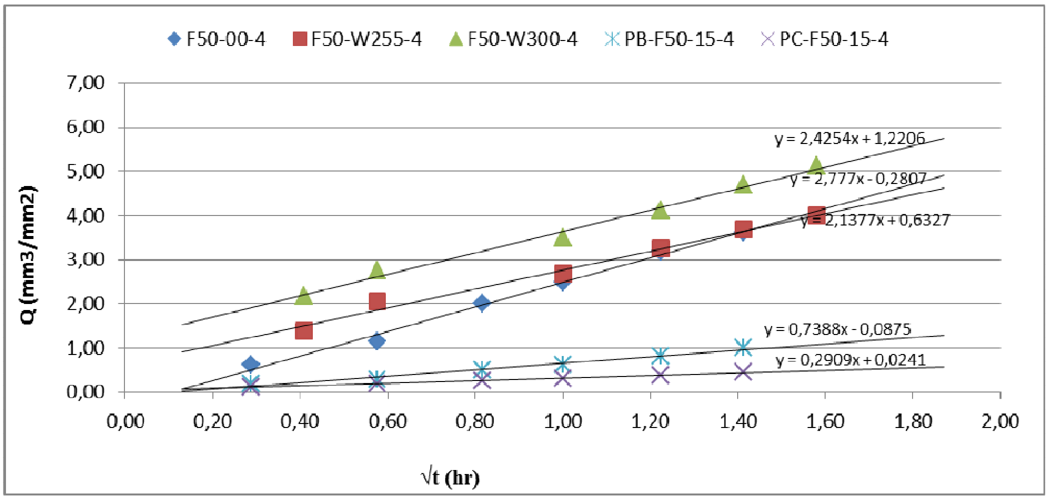


Figure 4.49 : Comparison of sorptivity coefficient of specimens with similar workability.

5. DISCUSSION

Properties of polymer modified mortars with 5% - 25% polymer / binder ratio, effect of different curing conditions on polymer modified mortars and effects of fly ash and slag incorporation to properties of polymer modified mortars were studied. Results obtained from study are detailed as follows.

5.1 Workability Results

- It was observed that incorporation of SCM up to a limit value (usually 30%) increases workability as reported [26]. When ratio of SCM incorporation exceeds a limit value, workability decreases.
- Polymer modification influenced fresh properties of specimens and increased workability. Increase in workability has been attributed to “ball bearing” action of polymer particles, the entrained air and dispersing effect of surfactants [27]. However, although same polymer / binder ratios were used from different brands of polymer admixture, workability of specimens were different. In addition, at some cases, it was noted that use of specific polymer admixture with SCM incorporated specimens did not increase workability (Figure 4.5).

5.2 Compressive and Tensile Strength Results

- For unmodified specimens, SCM incorporation up to 10% of total binder amount does not significantly change strength properties. However, SCM incorporation higher than 10% considerably decreases strength properties. In addition, lowest strength properties were observed for specimens incorporating both fly ash and slag (Figure 5.1).
- Preliminary tests, using Polymer A, were performed in order to determine favorable curing conditions for polymer modified specimens. It was observed that curing regime #4, which is 3 days curing immersed in water and 25 days

curing at room environment, provided favorable results in terms of flexural strength and durability characteristic. This curing regime allowed both reasonable extent of cement hydration under wet conditions and polymer film formation under dry conditions.

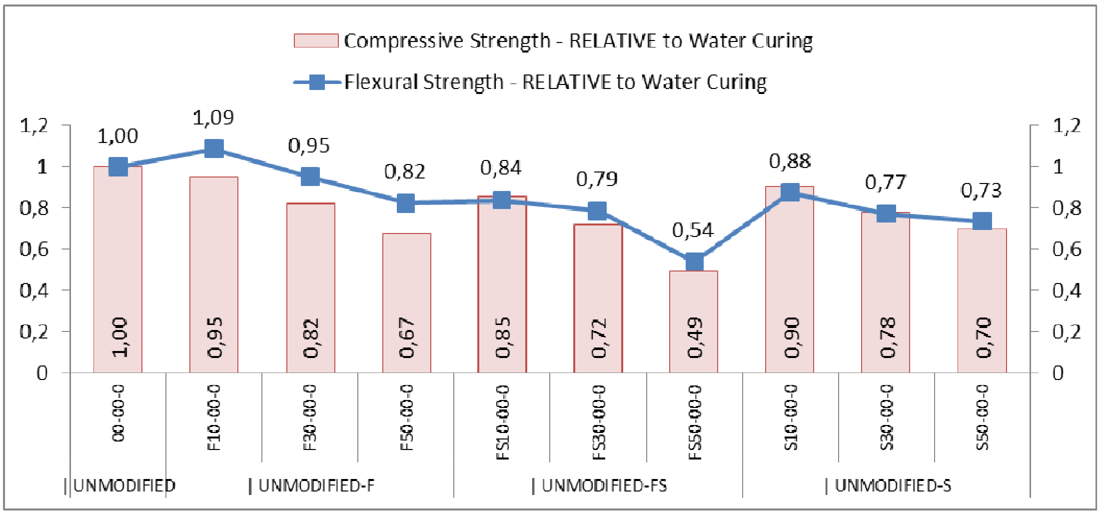


Figure 5.1 : Relative strength values of SCM incorporated unmodified specimens with respect to plain unmodified specimen.

- In most of the cases, comparative tests for compressive strength of polymer modified specimens cured under curing regime #1 were lower than that of unmodified specimens which were water cured for 28 days. Compressive strength under curing regime #1 resulted in 27% decrease for comparative testing (Figure 5.2). However, compressive strength under curing regime #4 mostly resulted in up to 15% higher strength values when compared to water cured specimens (Figure 5.3). There are different views regarding decrease of compressive strength of polymer modified specimens: On one hand it is suggested that polymer film formation acts like void inside cement paste and on the other hand, it is suggested that compressive strength is decreased due to retardation effect caused by polymer modification [14].
- Comparative tests for flexural strength of polymer modified specimens were decreased by up to 23% under curing regime #1 when compared to unmodified specimen which were water cured for 28 days (Figure 5.2). However, flexural strength under curing regime #4 increased up to 20% when compared to unmodified specimens which were water cured for 28 days (Figure 5.3). The improvement of the flexural strength may be due to the reinforcement of the Interfacial Transition Zone between the cement matrix

and the aggregates; and to the bridging of the cement matrix micro-cracks by the polymer [22], [15].

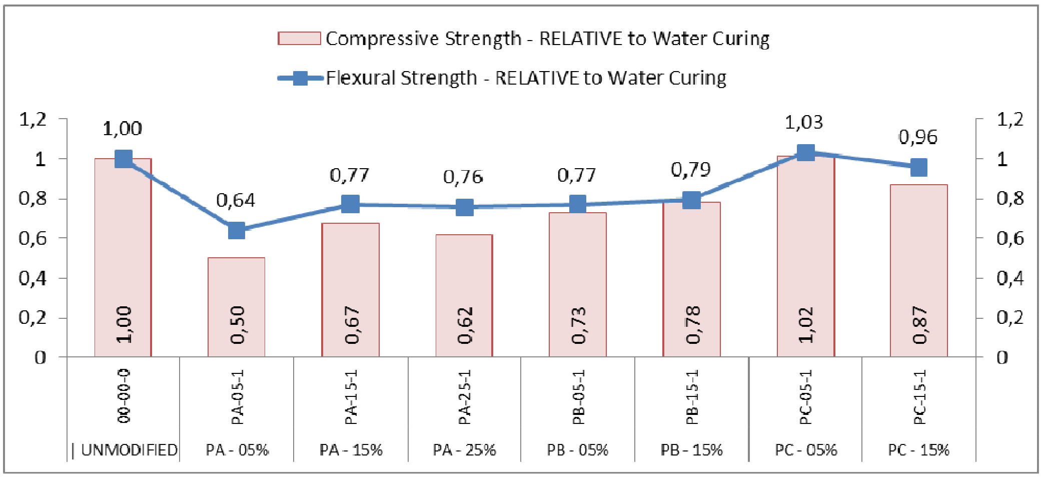


Figure 5.2 : Relative strength of polymer modified specimens under curing regime #1 with respect to curing regime #0.

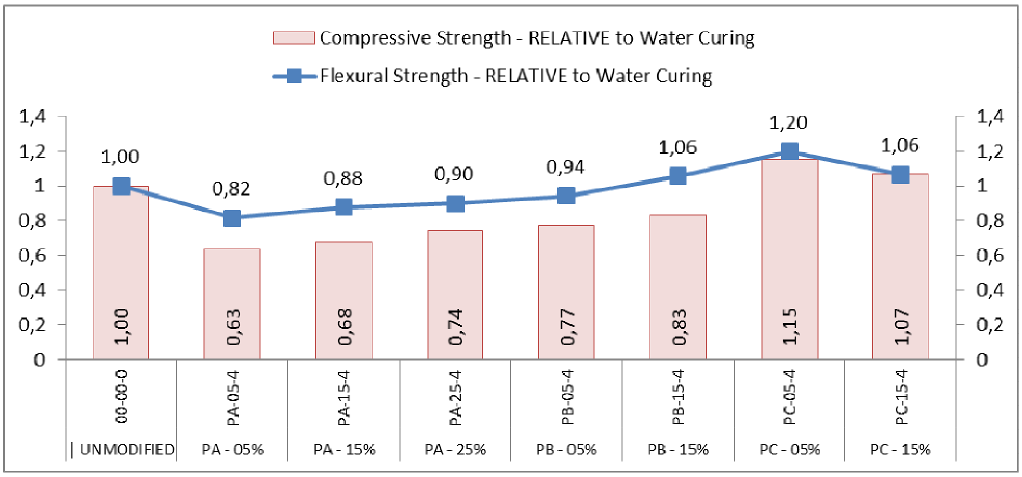


Figure 5.3 : Relative strength of polymer modified specimens under curing regime #4 with respect to curing regime #0.

- When same curing regimen was applied to unmodified and polymer modified specimens after 28 days of curing, compressive and flexural strength of polymer modified specimens were generally higher than of unmodified specimens (Figure 5.4, Figure 5.5). Under curing regime #1, compressive strength and flexural strength was increased up to 50% and 24% respectively. Under curing regime #4, compressive strength and flexural strength was increased up to 20% and 33% respectively.

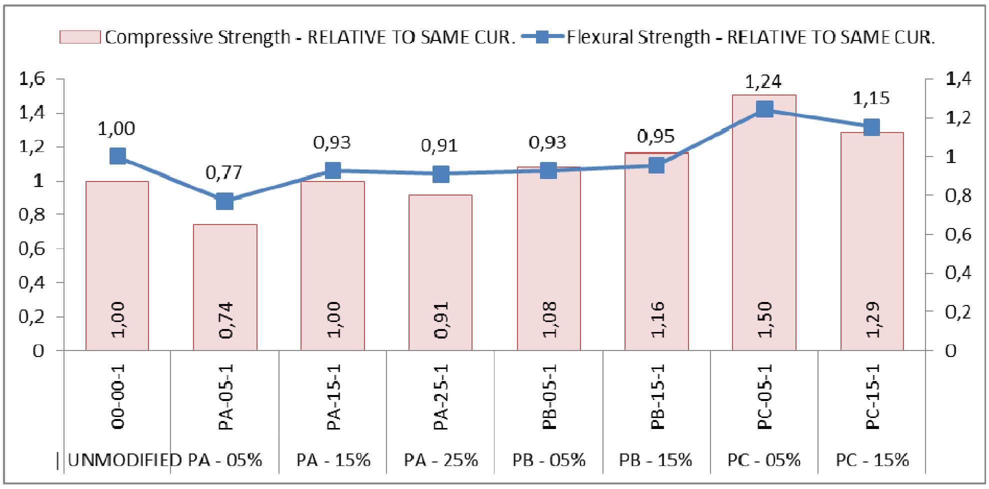


Figure 5.4 : Relative strength of polymer modified specimens with respect to same curing conditions – Curing regime #1.

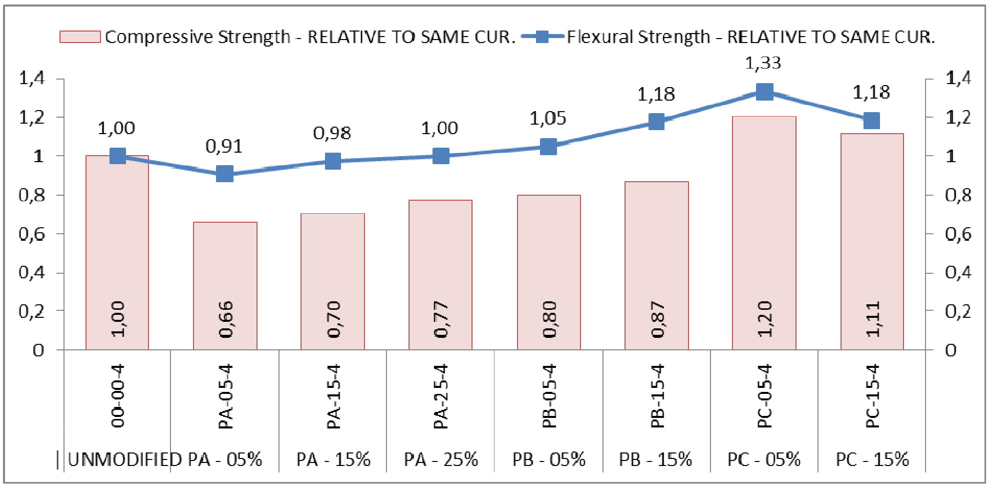


Figure 5.5 : Relative strength of polymer modified specimens with respect to same curing conditions – Curing regime #4.

- Strength values of polymer modified specimens incorporating SCM varied with respect to type of polymer admixture, curing condition and ratio of SCM. In general, it was observed that curing regime #4 provided better test results for polymer modified specimens. When polymer modified specimens incorporating SCM were compared with unmodified specimens which were water cured for 28 days, specimens prepared with Polymer C admixture showed similar compressive strength values when polymer / binder ratio was 5%. Compressive strength decreased when polymer / binder ratio was 15%. For 5% polymer / binder ratio, similar flexural strength values were observed up to 30% SCM incorporation. For 15% polymer / binder ratio, flexural strength values were similar for all values of SCM incorporation (Figure 5.6, Figure 5.7, Figure 5.8).

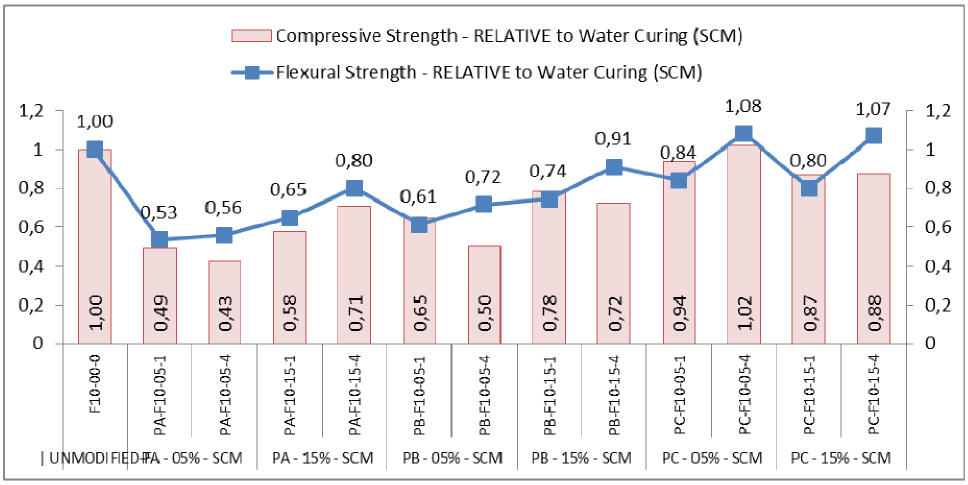


Figure 5.6 : Relative strength of SCM incorporated polymer modified specimens w.r.t. unmodified specimen – Fly ash 10%.

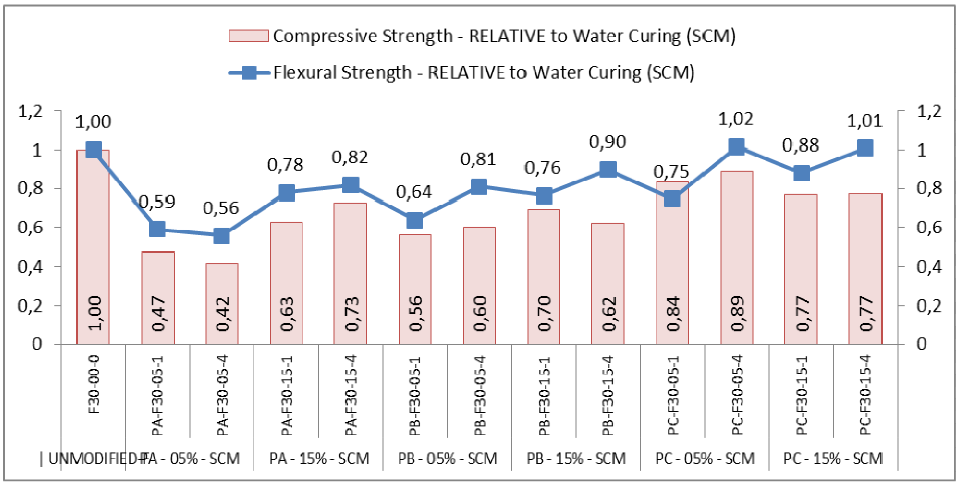


Figure 5.7 : Relative strength of SCM incorporated polymer modified specimens w.r.t. unmodified specimen – Fly ash 30%.

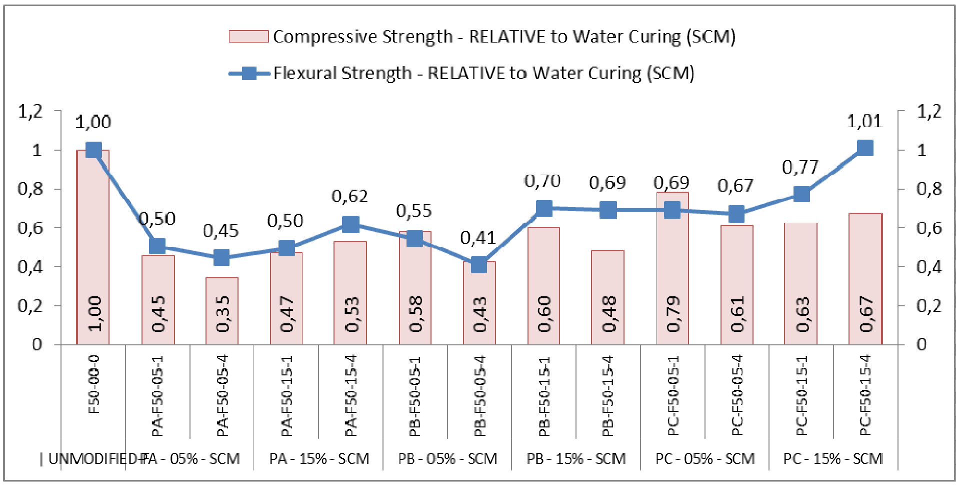


Figure 5.8 : Relative strength of SCM incorporated polymer modified specimens w.r.t. unmodified specimen – Fly ash 50%.

- Strength values of polymer modified specimens incorporating SCM were also compared to those of unmodified specimens incorporating SCM under same curing conditions. In general, Polymer C admixture improved strength properties for all incorporation ratio and curing condition (Figure 5.9, Figure 5.10, Figure 5.11, Figure 5.12, Figure 5.13, Figure 5.14).

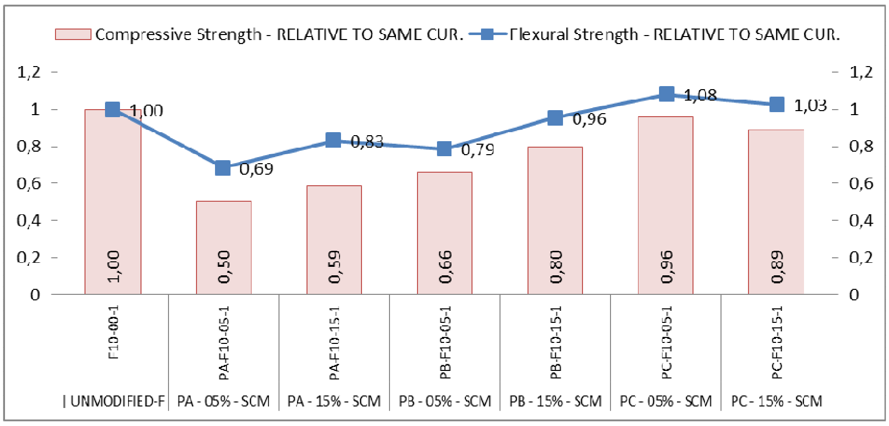


Figure 5.9 : Relative strength of SCM incorporated polymer modified specimens w.r.t. same curing conditions – Curing regime #1 – Fly Ash 10%.

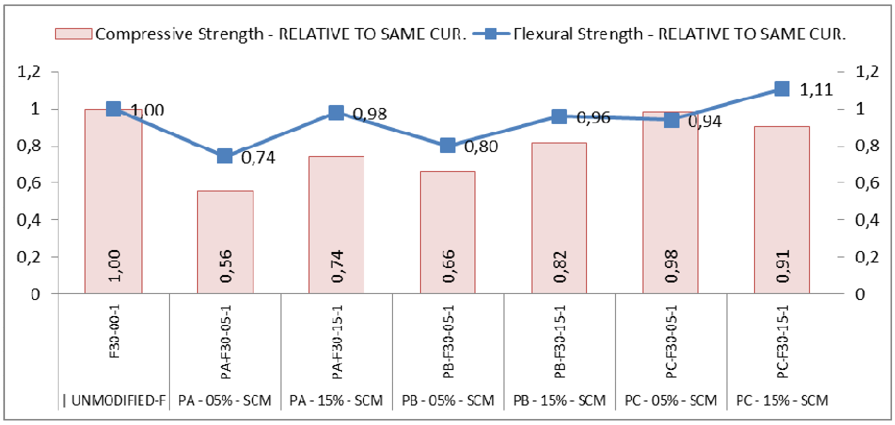


Figure 5.10 : Relative strength of SCM incorporated polymer modified specimens w.r.t. same curing conditions – Curing regime #1 – Fly Ash 30%.

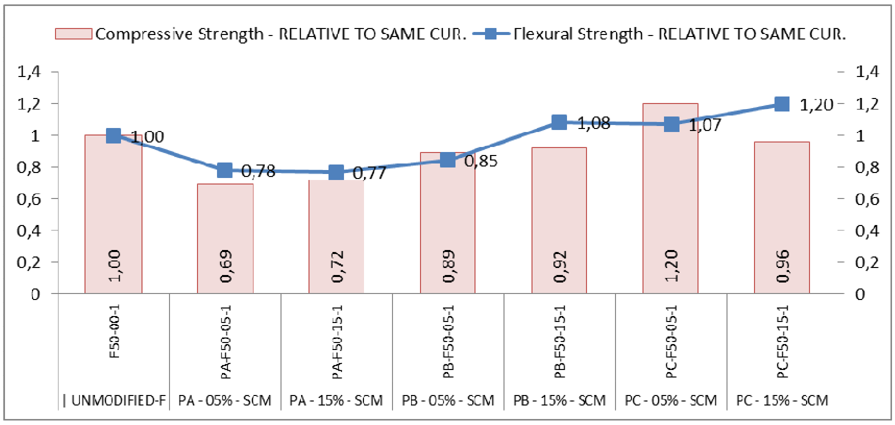


Figure 5.11 : Relative strength of SCM incorporated polymer modified specimens w.r.t. same curing conditions – Curing regime #1 – Fly Ash 50%.

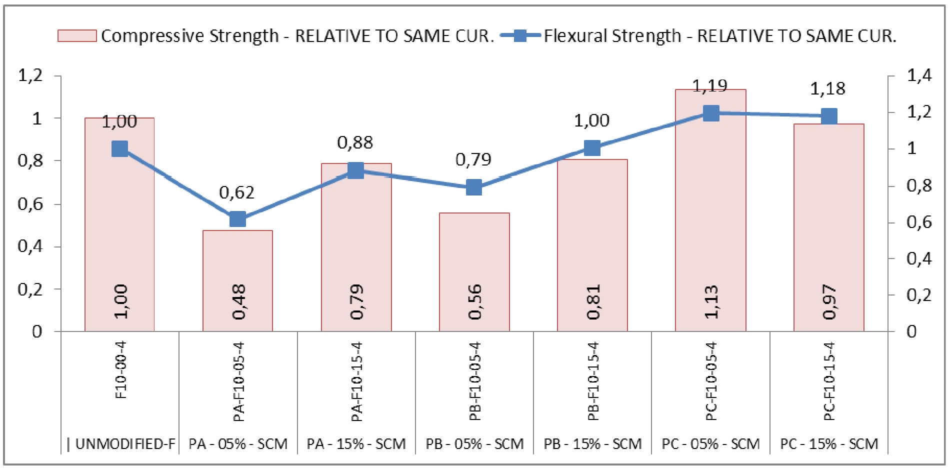


Figure 5.12 : Relative strength of SCM incorporated polymer modified specimens w.r.t. same curing conditions – Curing regime #4 – Fly Ash 10%.

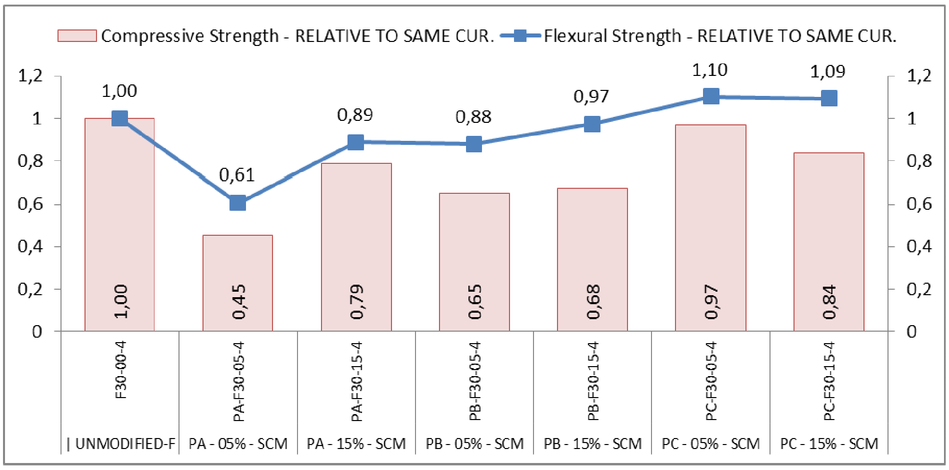


Figure 5.13 : Relative strength of SCM incorporated polymer modified specimens w.r.t. same curing conditions – Curing regime #4 – Fly Ash 30%.

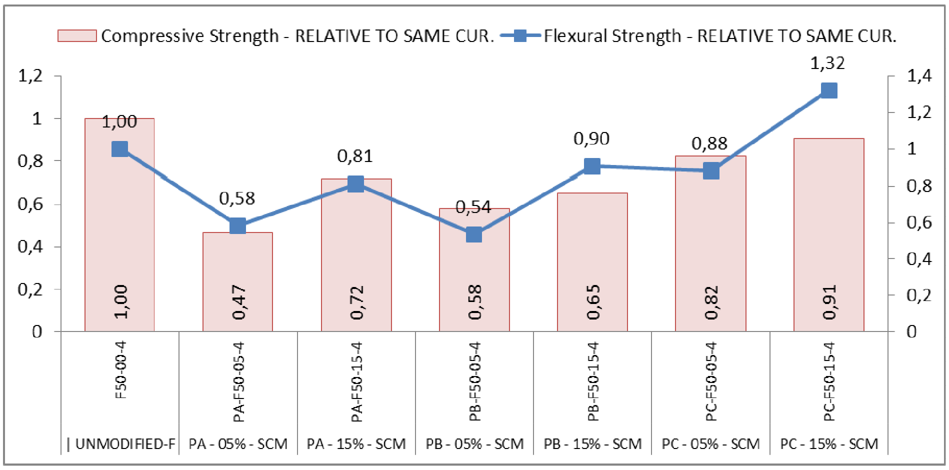


Figure 5.14 : Relative strength of SCM incorporated polymer modified specimens w.r.t. same curing conditions – Curing regime #4 – Fly Ash 50%.

5.3 Sorptivity Results

- Durability characteristics were observed by performing capillary rise test. Incorporation of SCM lowered permeability of specimens. According to evaluation of test results for curing regime #0 (28 days water curing), permeability of only fly ash incorporated specimens were lower than slag incorporated specimens or both fly ash and slag incorporated specimens, whereas permeability of slag incorporated specimens were higher than those.
- Lowest permeability values were obtained for 10% of SCM incorporation among specimens. Permeability of SCM incorporated specimens increased with respect to increasing SCM incorporating ratio and duration of air curing (Figure 5.15).

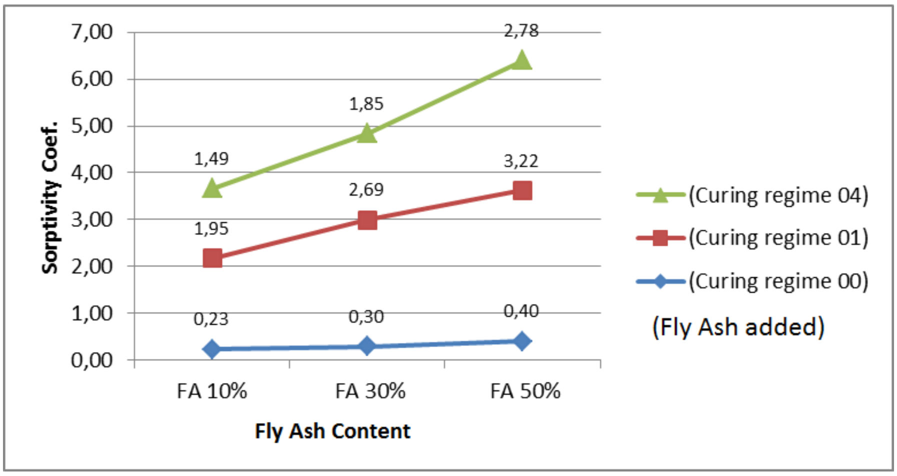


Figure 5.15 : Comparison of sorptivity coefficients w.r.t. SCM incorporation ratio and different curing conditions.

- Curing regime #4 provided better sorptivity values for polymer modified specimens with respect to other curing regimens. Under same curing conditions and same polymer content, permeability of polymer modified specimens showed difference with respect to type and brand of polymer admixture. Permeability of polymer modified specimens prepared with 15% polymer admixture addition was lower than 5% polymer admixture addition. It was recorded that Polymer B admixture provided better results than Polymer C admixture (Figure 5.16, Figure 5.17, Figure 5.18, Figure 5.19). Change of sorptivity with respect to type of polymer admixture has also been reported [28].

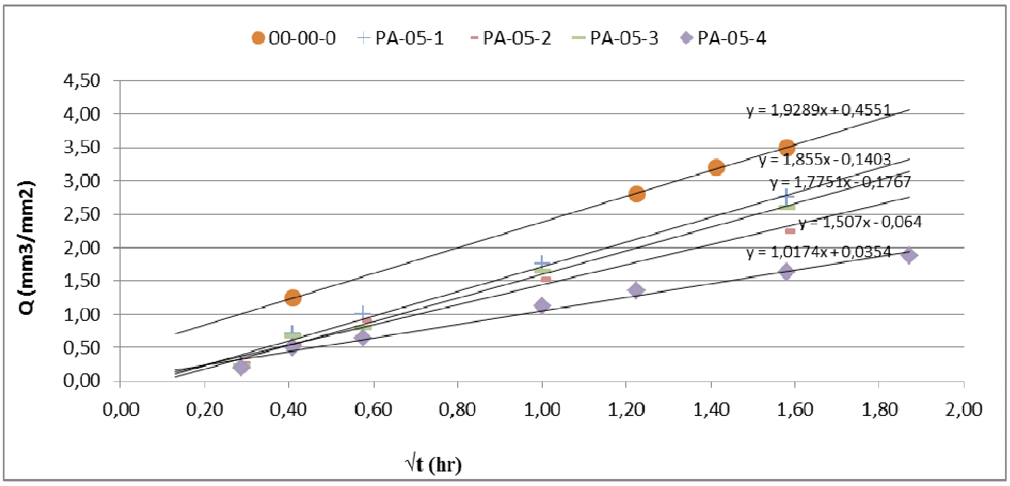


Figure 5.16 : Sorptivity graph for polymer modified specimens – preliminary test 5% polymer A incorporation.

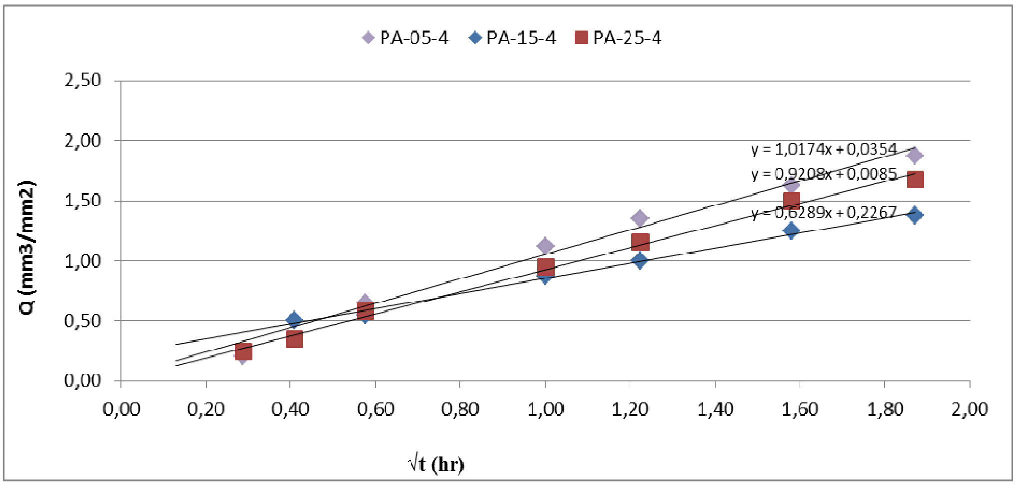


Figure 5.17 : Sorptivity graph for comparison of polymer modified specimens – preliminary test.

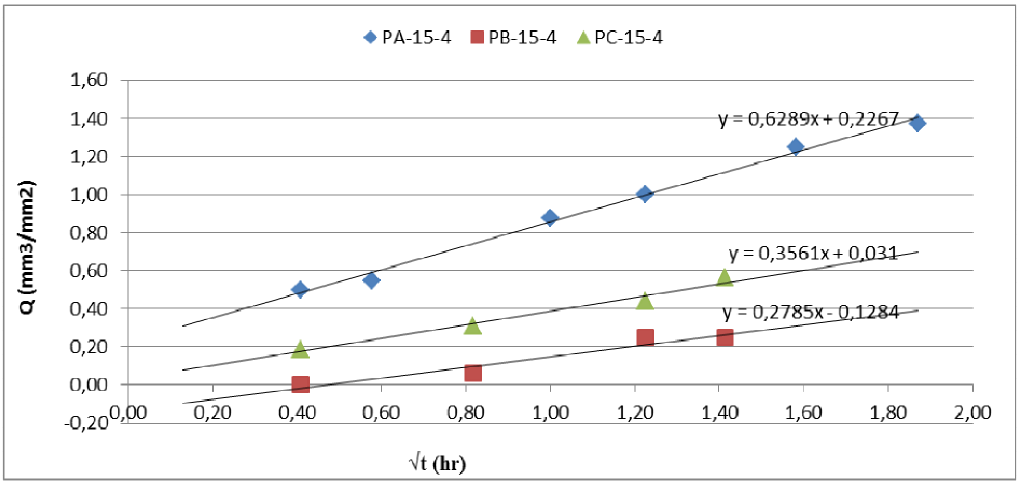


Figure 5.18 : Sorptivity graph for comparison of polymer modified specimens – comparative test.

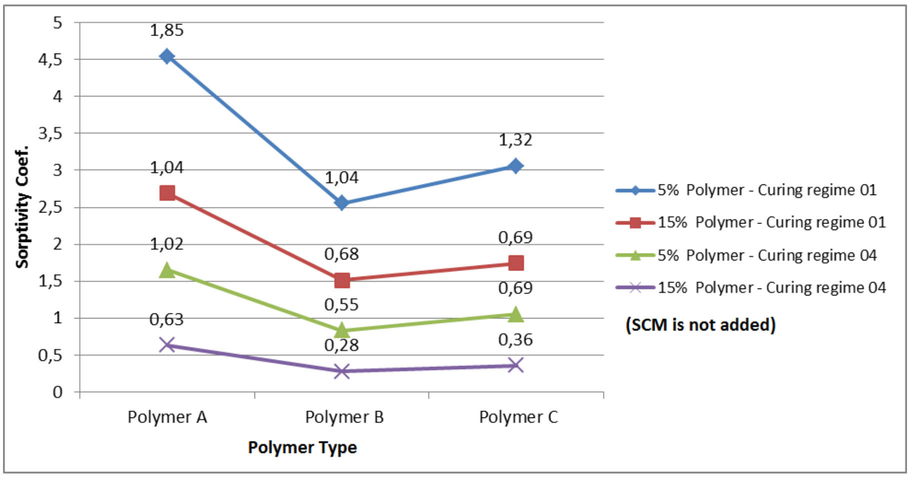
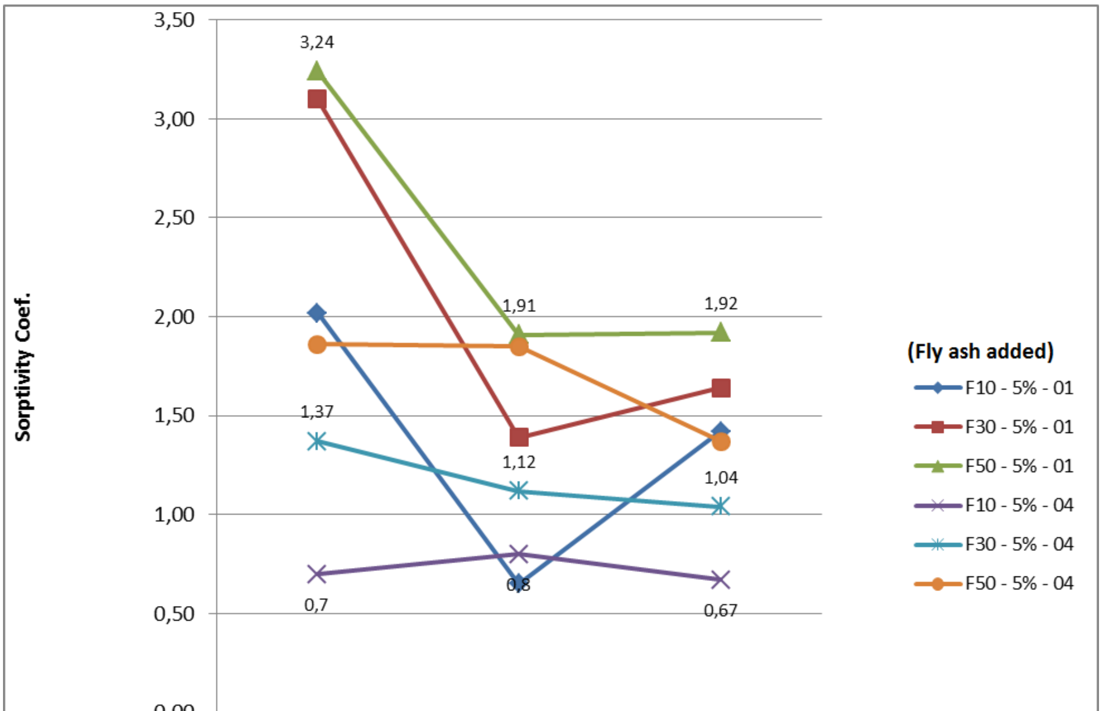


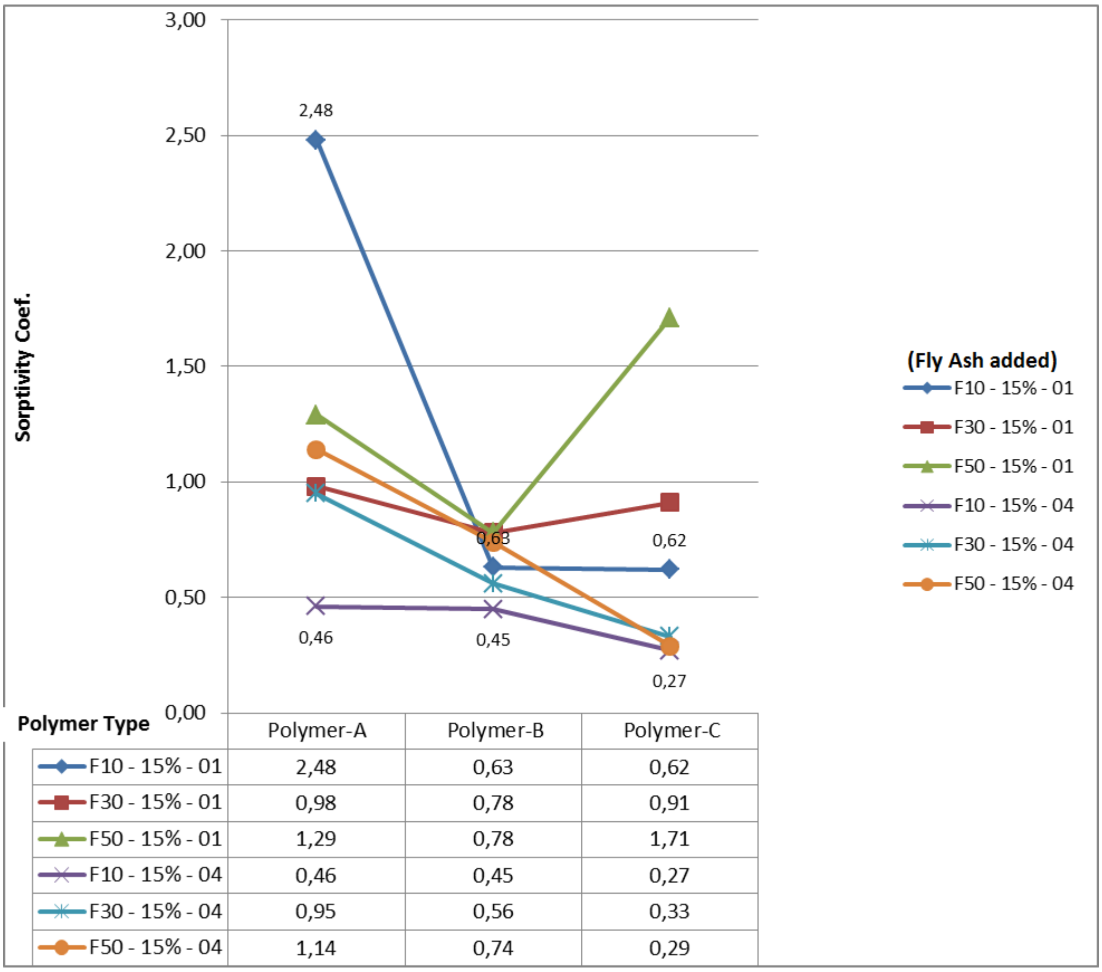
Figure 5.19 : Comparison of sorptivity values for polymer modified specimens w.r.t. polymer type, polymer ratio and curing regime.

- Durability properties of fly ash incorporated polymer modified mortars with respect to different fly ash content, different polymer types and different curing regimes have been presented in Figure 5.20, Figure 5.21.



Polymer Type	Polymer-A	Polymer-B	Polymer-C
F10 - 5% - 01	2,02	0,65	1,42
F30 - 5% - 01	3,1	1,39	1,64
F50 - 5% - 01	3,24	1,91	1,92
F10 - 5% - 04	0,7	0,8	0,67
F30 - 5% - 04	1,37	1,12	1,04
F50 - 5% - 04	1,86	1,85	1,37

Figure 5.20 : Comparison of sorptivity values for SCM incorporated polymer modified specimens w.r.t. polymer properties and curing regime (1).



Polymer Type	Polymer-A	Polymer-B	Polymer-C
F10 - 15% - 01	2,48	0,63	0,62
F30 - 15% - 01	0,98	0,78	0,91
F50 - 15% - 01	1,29	0,78	1,71
F10 - 15% - 04	0,46	0,45	0,27
F30 - 15% - 04	0,95	0,56	0,33
F50 - 15% - 04	1,14	0,74	0,29

Figure 5.21 : Comparison of sorptivity values for SCM incorporated polymer modified specimens w.r.t. polymer properties and curing regime (2).

- o Durability characteristics for polymer modified specimens were also observed and compared to unmodified specimens cured at the same conditions. Permeability of polymer modified specimens were lower than SCM incorporated unmodified specimens under same curing conditions (Figure 5.22).

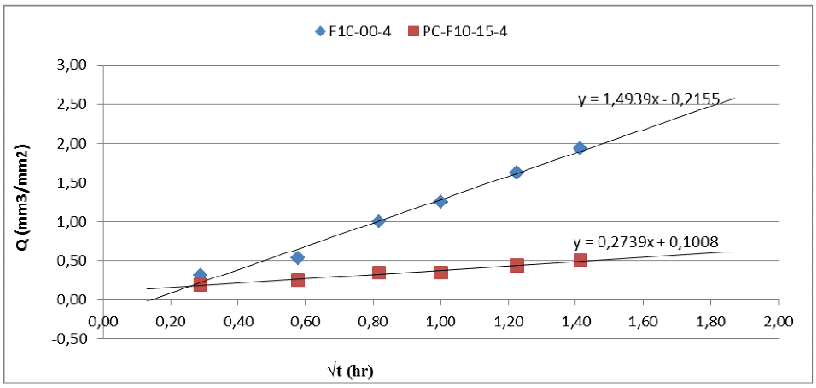


Figure 5.22 : Comparison of sorptivity for SCM incorporated specimen with polymer modified specimen under same curing condition.

- In general, it was observed that under same curing conditions SCM incorporation increased sorptivity of polymer modified specimens (Figure 5.23). In addition, it was also noted that different sorptivity values were obtained with respect to type of polymer admixture.

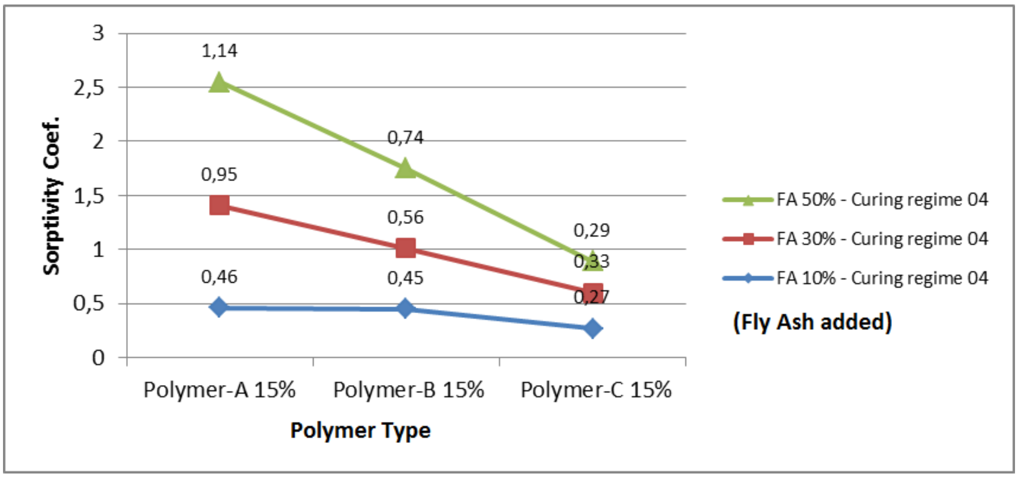


Figure 5.23 : Comparison of sorptivity for polymer modified and SCM incorporated specimens w.r.t. SCM incorporation ratio and polymer type.

- Sorptivity coefficients of specimens cured for 28 days under different curing regimes are listed in Table 5.1 and Table 5.2.

Table 5.1 : Sorptivity coefficients unmodified specimens.

UNMODIFIED SPECIMENS					
SPECIMEN	DESCRIPTION	POLYMER TYPE & CONTENT	CURING CONDITION	SCM TYPE & CONTENT	S. Coefficient
00-00-0	Unmodified	-	(0) - 28 days water	-	1,93
00-00-1	Unmodified	-	(1) - 28 days air	-	4,63
00-00-4	Unmodified	-	(4) - 3 W + 25 Air	-	2,13
F10-00-0	Unmodified	-	(0) - 28 days water	Fly ash 10%	0,23
F10-00-1	Unmodified	-	(1) - 28 days air	Fly ash 10%	1,95
F10-00-4	Unmodified	-	(4) - 3 W + 25 Air	Fly ash 10%	1,49
F30-00-0	Unmodified	-	(0) - 28 days water	Fly ash 30%	0,30
F30-00-1	Unmodified	-	(1) - 28 days air	Fly ash 30%	2,69
F30-00-4	Unmodified	-	(4) - 3 W + 25 Air	Fly ash 30%	1,85
F50-00-0	Unmodified	-	(0) - 28 days water	Fly ash 50%	0,40
F50-00-1	Unmodified	-	(1) - 28 days air	Fly ash 50%	3,22
F50-00-4	Unmodified	-	(4) - 3 W + 25 Air	Fly ash 50%	2,78
FS10-00-0	Unmodified	-	(0) - 28 days water	Fly Ash 5% + Slag 5%	0,57
FS30-00-0	Unmodified	-	(0) - 28 days water	Fly Ash 15% + Slag 15%	0,73
FS50-00-0	Unmodified	-	(0) - 28 days water	Fly Ash 25% + Slag 25%	0,87
S10-00-0	Unmodified	-	(0) - 28 days water	Slag 10%	0,62
S30-00-0	Unmodified	-	(0) - 28 days water	Slag 30%	0,85
S50-00-0	Unmodified	-	(0) - 28 days water	Slag 50%	0,90

Table 5.2 : Sorptivity coefficients polymer modified specimens.

POLYMER MODIFIED SPECIMENS					
SPECIMEN	DESCRIPTION	POLYMER TYPE & CONTENT	CURING CONDITION	SCM TYPE & CONTENT	S. Coefficient
PB-05-1	Modified	Polymer B - 5%	(1) - 28 days air	-	1,04
PB-05-4	Modified	Polymer B - 5%	(4) - 3 W + 25 Air	-	0,55
PB-15-1	Modified	Polymer B - 15%	(1) - 28 days air	-	0,68
PB-15-4	Modified	Polymer B - 15%	(4) - 3 W + 25 Air	-	0,28
PB-F10-05-1	Modified	Polymer B - 5%	(1) - 28 days air	Fly ash 10%	0,65
PB-F10-05-4	Modified	Polymer B - 5%	(4) - 3 W + 25 Air	Fly ash 10%	0,80
PB-F10-15-1	Modified	Polymer B - 15%	(1) - 28 days air	Fly ash 10%	0,63
PB-F10-15-4	Modified	Polymer B - 15%	(4) - 3 W + 25 Air	Fly ash 10%	0,45
PB-F30-05-1	Modified	Polymer B - 5%	(1) - 28 days air	Fly ash 30%	1,39
PB-F30-05-4	Modified	Polymer B - 5%	(4) - 3 W + 25 Air	Fly ash 30%	1,12
PB-F30-15-1	Modified	Polymer B - 15%	(1) - 28 days air	Fly ash 30%	0,78
PB-F30-15-4	Modified	Polymer B - 15%	(4) - 3 W + 25 Air	Fly ash 30%	0,56
PB-F50-05-1	Modified	Polymer B - 5%	(1) - 28 days air	Fly ash 50%	1,91
PB-F50-05-4	Modified	Polymer B - 5%	(4) - 3 W + 25 Air	Fly ash 50%	1,85
PB-F50-15-1	Modified	Polymer B - 15%	(1) - 28 days air	Fly ash 50%	0,78
PB-F50-15-4	Modified	Polymer B - 15%	(4) - 3 W + 25 Air	Fly ash 50%	0,74
PC-05-1	Modified	Polymer C - 5%	(1) - 28 days air	-	1,32
PC-05-4	Modified	Polymer C - 5%	(4) - 3 W + 25 Air	-	0,69
PC-15-1	Modified	Polymer C - 15%	(1) - 28 days air	-	0,69
PC-15-4	Modified	Polymer C - 15%	(4) - 3 W + 25 Air	-	0,36
PC-F10-05-1	Modified	Polymer C - 5%	(1) - 28 days air	Fly ash 10%	1,42
PC-F10-05-4	Modified	Polymer C - 5%	(4) - 3 W + 25 Air	Fly ash 10%	0,67
PC-F10-15-1	Modified	Polymer C - 15%	(1) - 28 days air	Fly ash 10%	0,62
PC-F10-15-4	Modified	Polymer C - 15%	(4) - 3 W + 25 Air	Fly ash 10%	0,27
PC-F30-05-1	Modified	Polymer C - 5%	(1) - 28 days air	Fly ash 30%	1,64
PC-F30-05-4	Modified	Polymer C - 5%	(4) - 3 W + 25 Air	Fly ash 30%	1,04
PC-F30-15-1	Modified	Polymer C - 15%	(1) - 28 days air	Fly ash 30%	0,91
PC-F30-15-4	Modified	Polymer C - 15%	(4) - 3 W + 25 Air	Fly ash 30%	0,33
PC-F50-05-1	Modified	Polymer C - 5%	(1) - 28 days air	Fly ash 50%	1,92
PC-F50-05-4	Modified	Polymer C - 5%	(4) - 3 W + 25 Air	Fly ash 50%	1,37
PC-F50-15-1	Modified	Polymer C - 15%	(1) - 28 days air	Fly ash 50%	1,71
PC-F50-15-4	Modified	Polymer C - 15%	(4) - 3 W + 25 Air	Fly ash 50%	0,29

5.4 Test Results for Specimens With Similar Workability

- Water / binder ratio of specimens were modified in order to obtain similar workability as polymer admixture. Curing regime #4, which provided favorable results to modified specimens, was applied. The increase in water /

binder ratio and limited duration of water curing caused lower strength values than unmodified specimens (Figure 5.24).

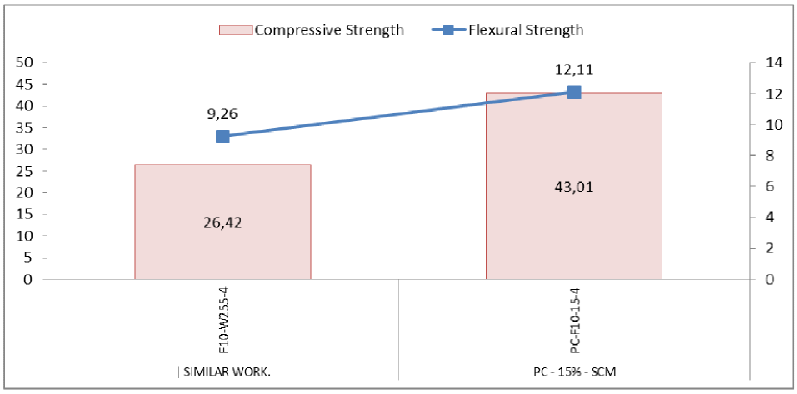


Figure 5.24 : Comparison of specimens with similar workability under same curing condition.

- o Due to increased water / binder ratio for similar workability, porosity of specimens were also increased and thus, higher permeability was observed. Sorptivity of SCM incorporated specimen was nearly 5 times higher than polymer modified specimen which has similar workability when same curing regime was applied (Figure 5.25). This may be attributed to enhanced pore structure due to presence of polymer admixture [29].

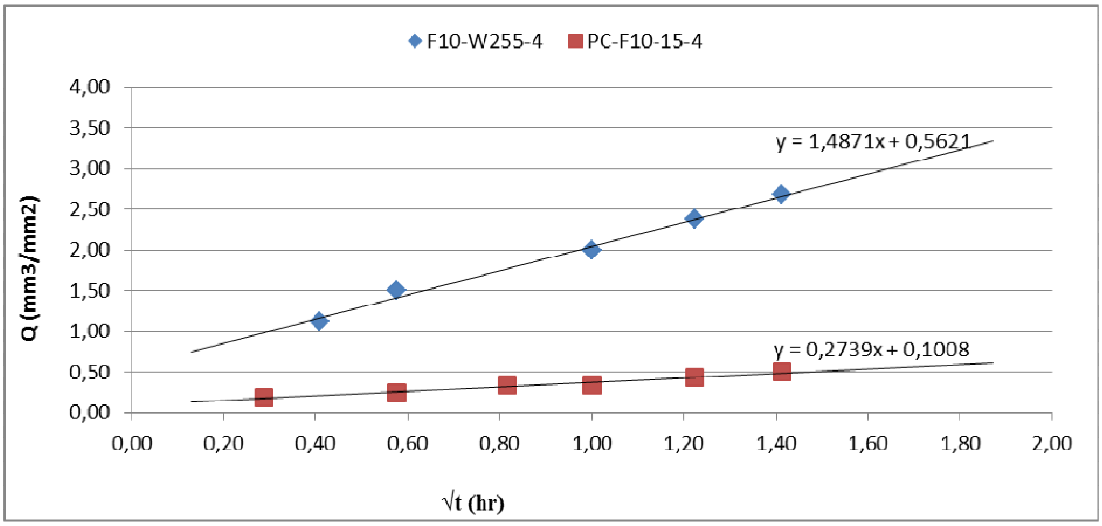


Figure 5.25 : Comparison of sorptivity for SCM incorporated specimen with polymer modified specimen which has similar workability.

- o Sorptivity coefficients for specimens, which water / binder ratio was modified for similar workability purposes, are listed in Table 5.3.

- o Sorptivity coefficients for all specimens after 24 hr of sorptivity test are presented in Appendix E.

Table 5.3 : Sorptivity coefficients water / binder modified specimens.

WATER / BINDER MODIFIED SPECIMENS					
SPECIMEN	DESCRIPTION	POLYMER TYPE & CONTENT	CURING CONDITION	SCM TYPE & CONTENT	S. Coeff.
00-W250-4	W / binder modified	-	(4) - 3 W + 25 Air	-	1,65
00-W325-4	W / binder modified	-	(4) - 3 W + 25 Air	-	2,10
F10-W255-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 10%	1,49
F10-W285-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 10%	2,59
F30-W255-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 30%	1,72
F30-W275-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 30%	2,34
F50-W255-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 50%	2,14
F50-W300-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 50%	2,43
FS10-W245-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 5% + Slag 5%	1,33
FS10-W285-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 5% + Slag 5%	1,65
FS30-W250-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 15% + Slag 15%	1,79
FS30-W305-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 15% + Slag 15%	2,57
FS50-W255-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 25% + Slag 25%	2,53
FS50-W325-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 25% + Slag 25%	4,35
S10-W245-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 10%	1,76
S10-W290-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 10%	1,97
S30-W250-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 30%	1,56
S30-W290-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 30%	2,59
S50-W245-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 50%	2,22
S50-W290-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 50%	4,53

6. CONCLUSION

- Supplementary cementing material (SCM) incorporation up to a limit ratio (usually 30%) increased workability.
- Workability is increased with respect to polymer addition, which as a result, water content can be decreased in order to achieve similar workability.
- Depending on type of polymer admixture incorporated, different workability, strength and sorptivity properties are achieved. In other words, although same ratio of polymer is incorporated, different workability results are obtained with respect to type of polymer admixture.
- Depending on type of polymer admixture and applied curing regimen, different strength values were obtained. For example, incorporation of EVA polymer (Polymer C) with 5% and 15% polymer / binder ratio and curing in 4^{th} curing condition (3 days immersed in water + 25 days at room environment) exposed higher compressive and flexural strength than the control one, whereas SBR polymer incorporation (Polymer B) resulted in lower values at the same curing condition. Also, 5% EVA polymer (Polymer C) incorporated mixture, which is cured in 1^{st} curing condition (28 days at room environment) showed slightly higher strength than the control mixture, whereas SBR polymer incorporation (Polymer B) resulted in lower values at the same curing condition.
- It was observed that EVA polymer (Polymer C) showed better strength values when compared to SBR polymer (Polymer A and Polymer B). In addition, best curing condition for polymer modified mortar was curing regime #4 (3 days immersed in water + 25 days at room environment), which allowed both cement hydration and polymer film formation.
- In accordance with 28 days test results, lower strength properties are obtained with respect to increasing SCM ratio.

- SCM incorporation decreases sorptivity values. For 28 days old specimens, 10% fly ash incorporated specimens which were cured in curing regime #0 (28 days water curing) showed lowest sorptivity coefficient.
- Polymer admixture incorporation decreases sorptivity. However, sorptivity coefficient is dependent on polymer type, polymer ratio and curing condition. Under curing regime #4, EVA type polymer (Polymer C) provided lower sorptivity values than SBR type polymer (Polymer B). However, under curing regime #1, better sorptivity values could be obtained from SBR type polymer (Polymer B). In general, 15% polymer incorporation and curing regime #4 resulted in better sorptivity characteristics.
- SCM incorporation to polymer modified specimens did not improve their sorptivity characteristics.
- Under curing regime #4 (3 days water + 25 days air), lowest sorptivity coefficient was obtained for 10% fly ash incorporated unmodified specimens ($S_{F10\text{-}00\text{-}4}$ = 1,49 mm / √(hr)). Under same curing conditions, not the lowest but lower sorptivity coefficient could be obtained from 15% EVA polymer modified specimens incorporating 50% fly ash ($S_{PC\text{-}F50\text{-}15\text{-}4}$ = 0,29 mm / √(hr)). Sorptivity coefficient for 50% fly ash incorporated unmodified specimen under same curing condition is $S_{F50\text{-}00\text{-}4}$ = 2,78 mm / √(hr)).
- Under curing regime #1 (28 days air), lowest sorptivity coefficient was obtained for F10-00-1 ($S_{F10\text{-}00\text{-}1}$ = 1,95 mm / √(hr)). Under same curing conditions, not the lowest but lower sorptivity coefficient could be obtained from 15% SBR polymer modified specimens incorporating 50% fly ash ($S_{PB\text{-}F50\text{-}15\text{-}1}$ = 0,78 mm / √(hr)). Sorptivity coefficient for 50% fly ash incorporated unmodified specimen under same curing condition is $S_{F50\text{-}00\text{-}1}$ = 3,22 mm / √(hr)).
- Graphical display of sorptivity coefficients are presented in Appendix D. In addition, 24 hr sorptivity coefficient are presented in Appendix E.

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APPENDICES

APPENDIX A : Mix design table for mortars
APPENDIX B : Flow diameter values for unmodified and modified mix designs
APPENDIX C : Capillary rise test results for specimens
APPENDIX D : Graphical display of sorptivity coefficients
APPENDIX E : 24 hr sorptivity coefficients

APPENDIX A

Table A.1 : Unmodified mix design – Cement, cement + fly ash; cement+ slag; cement + fly ash + slag.

#	NAME	BINDER (gr)			AGGREGATE (gr)		WATER (gr)	POLYMER (gr)					TOTAL (gr)			
		CM	FA	SL	CS	SN		SLD %	SLD	LQD	TOT	P/C	BIN.	SLD	LQD	LQD/BIN.
1	00-00-0	450,0	0,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
2	00-00-1	450,0	0,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
3	00-00-4	450,0	0,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
4	F10-00-0	405,0	45,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
5	F10-00-1	405,0	45,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
6	F10-00-4	405,0	45,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
7	F30-00-0	315,0	135,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
8	F30-00-1	315,0	135,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
9	F30-00-4	315,0	135,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
10	F50-00-0	225,0	225,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
11	F50-00-1	225,0	225,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
12	F50-00-4	225,0	225,0	0,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
13	S10-00-0	405,0	0,0	45,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
14	S30-00-0	315,0	0,0	135,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
15	S50-00-0	225,0	0,0	225,0	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
16	FS10-00-0	405,0	22,5	22,5	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
17	FS30-00-0	315,0	67,5	67,5	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%
18	FS50-00-0	225,0	112,5	112,5	877,5	472,5	225,0					0%	450,0	1350,0	225,0	50%

Table A.2 : Unmodified mix design – Various water / binder ratio in order to achieve same workability as modified specimens.

#	NAME	BINDER (gr)			AGGREGATE (gr)		WATER (gr)	POLYMER (gr)					TOTAL (gr)			
		CM	FA	SL	CS	SN		SLD %	SLD	LQD	TOT	P/C	BIN.	SLD	LQD	LQD/BIN.
19	00-W-250	450,0	0,0	0,0	877,5	472,5	250,0					0%	450,0	1350,0	250,0	56%
20	00-W-325	450,0	0,0	0,0	877,5	472,5	325,0					0%	450,0	1350,0	325,0	72%
21	F10-W-255	405,0	45,0	0,0	877,5	472,5	255,0					0%	450,0	1350,0	255,0	57%
22	F10-W-285	405,0	45,0	0,0	877,5	472,5	285,0					0%	450,0	1350,0	285,0	63%
23	F30-W-255	315,0	135,0	0,0	877,5	472,5	255,0					0%	450,0	1350,0	255,0	57%
24	F30-W-275	315,0	135,0	0,0	877,5	472,5	275,0					0%	450,0	1350,0	275,0	61%
25	F50-W-255	225,0	225,0	0,0	877,5	472,5	255,0					0%	450,0	1350,0	255,0	57%
26	F50-W-300	225,0	225,0	0,0	877,5	472,5	300,0					0%	450,0	1350,0	300,0	67%
27	S10-W-245	405,0	0,0	45,0	877,5	472,5	245,0					0%	450,0	1350,0	245,0	54%
28	S10-W-290	405,0	0,0	45,0	877,5	472,5	290,0					0%	450,0	1350,0	290,0	64%
29	S30-W-250	315,0	0,0	135,0	877,5	472,5	250,0					0%	450,0	1350,0	250,0	56%
30	S30-W-290	315,0	0,0	135,0	877,5	472,5	290,0					0%	450,0	1350,0	290,0	64%
31	S50-W-245	225,0	0,0	225,0	877,5	472,5	245,0					0%	450,0	1350,0	245,0	54%
32	S50-W-290	225,0	0,0	225,0	877,5	472,5	290,0					0%	450,0	1350,0	290,0	64%
33	FS10-W-245	405,0	22,5	22,5	877,5	472,5	245,0					0%	450,0	1350,0	245,0	54%
34	FS10-W-285	405,0	22,5	22,5	877,5	472,5	285,0					0%	450,0	1350,0	285,0	63%
35	FS30-W-250	315,0	67,5	67,5	877,5	472,5	250,0					0%	450,0	1350,0	250,0	56%
36	FS30-W-305	315,0	67,5	67,5	877,5	472,5	305,0					0%	450,0	1350,0	305,0	68%
37	FS50-W-255	225,0	112,5	112,5	877,5	472,5	255,0					0%	450,0	1350,0	255,0	57%
38	FS50-W-325	225,0	112,5	112,5	877,5	472,5	325,0					0%	450,0	1350,0	325,0	72%

Table A.3 : Details Modified mixture specimens for preliminary tests − Polymer A.

#	NAME	BINDER (gr)			AGGREGATE (gr)		WATER (gr)	POLYMER (gr)					TOTAL (gr)			
		CM	FA	SL	CS	SN		SLD %	SLD	LQD	TOT	P/C	BIN.	SLD	LQD	LQD/BIN.
39	PA-05-1	450,0	0,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
40	PA-05-2	450,0	0,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
41	PA-05-3	450,0	0,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
42	PA-05-4	450,0	0,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
43	PA-15-1	450,0	0,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
44	PA-15-2	450,0	0,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
45	PA-15-3	450,0	0,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
46	PA-15-4	450,0	0,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
47	PA-25-1	450,0	0,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
48	PA-25-2	450,0	0,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
49	PA-25-3	450,0	0,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
50	PA-25-4	450,0	0,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
51	PA-F10-05-1	405,0	45,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
52	PA-F10-05-2	405,0	45,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
53	PA-F10-05-3	405,0	45,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
54	PA-F10-05-4	405,0	45,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
55	PA-F10-15-1	405,0	45,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
56	PA-F10-15-2	405,0	45,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
57	PA-F10-15-3	405,0	45,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
58	PA-F10-15-4	405,0	45,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
59	PA-F10-25-1	405,0	45,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
60	PA-F10-25-2	405,0	45,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
61	PA-F10-25-3	405,0	45,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
62	PA-F10-25-4	405,0	45,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
63	PA-F30-05-1	315,0	135,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%

Table A.3 (continued) : Details Modified mixture specimens for preliminary tests − Polymer A.

#	NAME	BINDER (gr)			AGGREGATE (gr)		WATER (gr)	POLYMER (gr)					TOTAL (gr)			
		CM	FA	SL	CS	SN		SLD %	SLD	LQD	TOT	P/C	BIN.	SLD	LQD	LQD/BIN.
64	PA-F30-05-2	315,0	135,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
65	PA-F30-05-3	315,0	135,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
66	PA-F30-05-4	315,0	135,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
67	PA-F30-15-1	315,0	135,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
68	PA-F30-15-2	315,0	135,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
69	PA-F30-15-3	315,0	135,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
70	PA-F30-15-4	315,0	135,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
71	PA-F30-25-1	315,0	135,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
72	PA-F30-25-2	315,0	135,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
73	PA-F30-25-3	315,0	135,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
74	PA-F30-25-4	315,0	135,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
75	PA-F50-05-1	225,0	225,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
76	PA-F50-05-2	225,0	225,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
77	PA-F50-05-3	225,0	225,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
78	PA-F50-05-4	225,0	225,0	0,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
79	PA-F50-15-1	225,0	225,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
80	PA-F50-15-2	225,0	225,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
81	PA-F50-15-3	225,0	225,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
82	PA-F50-15-4	225,0	225,0	0,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
83	PA-F50-25-1	225,0	225,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
84	PA-F50-25-2	225,0	225,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
85	PA-F50-25-3	225,0	225,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
86	PA-F50-25-4	225,0	225,0	0,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
87	PA-S10-05-1	405,0	0,0	45,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
88	PA-S10-05-2	405,0	0,0	45,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
89	PA-S10-05-3	405,0	0,0	45,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%

Table A.3 (continued) : Details Modified mixture specimens for preliminary tests − Polymer A.

#	NAME	BINDER (gr)			AGGREGATE (gr)		WATER (gr)	POLYMER (gr)					TOTAL (gr)			
		CM	FA	SL	CS	SN		SLD %	SLD	LQD	TOT	P/C	BIN.	SLD	LQD	LQD/BIN.
90	PA-S10-05-4	405,0	0,0	45,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
91	PA-S10-15-1	405,0	0,0	45,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
92	PA-S10-15-2	405,0	0,0	45,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
93	PA-S10-15-3	405,0	0,0	45,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
94	PA-S10-15-4	405,0	0,0	45,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
95	PA-S10-25-1	405,0	0,0	45,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
96	PA-S10-25-2	405,0	0,0	45,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
97	PA-S10-25-3	405,0	0,0	45,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
98	PA-S10-25-4	405,0	0,0	45,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
99	PA-S30-05-1	315,0	0,0	135,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
100	PA-S30-05-2	315,0	0,0	135,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
101	PA-S30-05-3	315,0	0,0	135,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
102	PA-S30-05-4	315,0	0,0	135,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
103	PA-S30-15-1	315,0	0,0	135,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
104	PA-S30-15-2	315,0	0,0	135,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
105	PA-S30-15-3	315,0	0,0	135,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
106	PA-S30-15-4	315,0	0,0	135,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
107	PA-S30-25-1	315,0	0,0	135,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
108	PA-S30-25-2	315,0	0,0	135,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
109	PA-S30-25-3	315,0	0,0	135,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
110	PA-S30-25-4	315,0	0,0	135,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
111	PA-S50-05-1	225,0	0,0	225,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
112	PA-S50-05-2	225,0	0,0	225,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
113	PA-S50-05-3	225,0	0,0	225,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
114	PA-S50-05-4	225,0	0,0	225,0	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
115	PA-S50-15-1	225,0	0,0	225,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%

Table A.3 (continued) : Details Modified mixture specimens for preliminary tests − Polymer A.

#	NAME	BINDER (gr)			AGGREGATE (gr)		WATER (gr)	POLYMER (gr)					TOTAL (gr)			
		CM	FA	SL	CS	SN		SLD %	SLD	LQD	TOT	P/C	BIN.	SLD	LQD	LQD/BIN.
116	PA-S50-15-2	225,0	0,0	225,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
117	PA-S50-15-3	225,0	0,0	225,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
118	PA-S50-15-4	225,0	0,0	225,0	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
119	PA-S50-25-1	225,0	0,0	225,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
120	PA-S50-25-2	225,0	0,0	225,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
121	PA-S50-25-3	225,0	0,0	225,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
122	PA-S50-25-4	225,0	0,0	225,0	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
123	PA-FS10-05-1	405,0	22,5	22,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
124	PA-FS10-05-2	405,0	22,5	22,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
125	PA-FS10-05-3	405,0	22,5	22,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
126	PA-FS10-05-4	405,0	22,5	22,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
127	PA-FS10-15-1	405,0	22,5	22,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
128	PA-FS10-15-2	405,0	22,5	22,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
129	PA-FS10-15-3	405,0	22,5	22,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
130	PA-FS10-15-4	405,0	22,5	22,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
131	PA-FS10-25-1	405,0	22,5	22,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
132	PA-FS10-25-2	405,0	22,5	22,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
133	PA-FS10-25-3	405,0	22,5	22,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
134	PA-FS10-25-4	405,0	22,5	22,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
135	PA-FS30-05-1	315,0	67,5	67,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
136	PA-FS30-05-2	315,0	67,5	67,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
137	PA-FS30-05-3	315,0	67,5	67,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
138	PA-FS30-05-4	315,0	67,5	67,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
139	PA-FS30-15-1	315,0	67,5	67,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
140	PA-FS30-15-2	315,0	67,5	67,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
141	PA-FS30-15-3	315,0	67,5	67,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%

Table A.3 (continued) : Details Modified mixture specimens for preliminary tests − Polymer A.

#	NAME	BINDER (gr)			AGGREGATE (gr)		WATER (gr)	POLYMER (gr)					TOTAL (gr)			
		CM	FA	SL	CS	SN		SLD %	SLD	LQD	TOT	P/C	BIN.	SLD	LQD	LQD/BIN.
142	PA-FS30-15-4	315,0	67,5	67,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
143	PA-FS30-25-1	315,0	67,5	67,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
144	PA-FS30-25-2	315,0	67,5	67,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
145	PA-FS30-25-3	315,0	67,5	67,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
146	PA-FS30-25-4	315,0	67,5	67,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
147	PA-FS50-05-1	225,0	112,5	112,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
148	PA-FS50-05-2	225,0	112,5	112,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
149	PA-FS50-05-3	225,0	112,5	112,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
150	PA-FS50-05-4	225,0	112,5	112,5	877,5	464,2	210,8	37%	8,3	14,2	22,5	5%	450,0	1350,0	225,0	50%
151	PA-FS50-15-1	225,0	112,5	112,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
152	PA-FS50-15-2	225,0	112,5	112,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
153	PA-FS50-15-3	225,0	112,5	112,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
154	PA-FS50-15-4	225,0	112,5	112,5	877,5	447,5	182,5	37%	25,0	42,5	67,5	15%	450,0	1350,0	225,0	50%
155	PA-FS50-25-1	225,0	112,5	112,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
156	PA-FS50-25-2	225,0	112,5	112,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
157	PA-FS50-25-3	225,0	112,5	112,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%
158	PA-FS50-25-4	225,0	112,5	112,5	877,5	430,9	154,1	37%	41,6	70,9	112,5	25%	450,0	1350,0	225,0	50%

Table A.4 : Cement + Polymer B (+Polymer C) admixture mix design.

#	NAME	BINDER (gr)			AGGREGATE (gr)		WATER (gr)	POLYMER (gr)					TOTAL (gr)			
		CM	FA	SL	CS	SN		SLD %	SLD	LQD	TOT	P/C	BIN.	SLD	LQD	LQD/BIN.
159	PB-05-1	450,0	0,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
160	PB-05-4	450,0	0,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
161	PB-15-1	450,0	0,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
162	PB-15-4	450,0	0,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
163	PC-05-1	450,0	0,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
164	PC-05-4	450,0	0,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
165	PC-15-1	450,0	0,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
166	PC-15-4	450,0	0,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%

Table A.5 : Cement + Fly ash + Polymer B admixture mix design.

#	NAME	BINDER (gr)			AGGREGATE (gr)		WATER (gr)	POLYMER (gr)					TOTAL (gr)			
		CM	FA	SL	CS	SN		SLD %	SLD	LQD	TOT	P/C	BIN.	SLD	LQD	LQD/BIN.
167	PB-F10-05-1	405,0	45,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
168	PB-F10-15-1	405,0	45,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
169	PB-F10-05-4	405,0	45,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
170	PB-F10-15-4	405,0	45,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
171	PB-F30-05-1	315,0	135,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
172	PB-F30-15-1	315,0	135,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
173	PB-F30-05-4	315,0	135,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
174	PB-F30-15-4	315,0	135,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
175	PB-F50-05-1	225,0	225,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
176	PB-F50-15-1	225,0	225,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
177	PB-F50-05-4	225,0	225,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
178	PB-F50-15-4	225,0	225,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%

Table A.6 : Cement + Fly ash + Polymer C admixture mix design.

#	NAME	BINDER (gr)			AGGREGATE (gr)		WATER (gr)	POLYMER (gr)					TOTAL (gr)			
		CM	FA	SL	CS	SN		SLD %	SLD	LQD	TOT	P/C	BIN.	SLD	LQD	LQD/BIN.
179	PC-F10-05-1	405,0	45,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
180	PC-F10-15-1	405,0	45,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
181	PC-F10-05-4	405,0	45,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
182	PC-F10-15-4	405,0	45,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
183	PC-F30-05-1	315,0	135,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
184	PC-F30-15-1	315,0	135,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
185	PC-F30-05-4	315,0	135,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
186	PC-F30-15-4	315,0	135,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
187	PC-F50-05-1	225,0	225,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
188	PC-F50-15-1	225,0	225,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%
189	PC-F50-05-4	225,0	225,0	0,0	877,5	465,1	209,9	33%	7,4	15,1	22,5	5%	450,0	1350,0	225,0	50%
190	PC-F50-15-4	225,0	225,0	0,0	877,5	450,2	179,8	33%	22,3	45,2	67,5	15%	450,0	1350,0	225,0	50%

APPENDIX B

Table B.1: Flow diameter values for unmodified and modified mix designs.

CEMENT MORTAR		CEMENT + FLY ASH		CEMENT + FLY ASH + SLAG		CEMENT + SLAG		COMPARATIVE STUDY	
Label	Flow diameter (cm)	Label	Flow diameter (cm)	Label	Flow diameter (cm)	Label	Flow diameter (cm)	Label	Flow diameter (cm)
00-00-00	14	F10-00-0	15	FS10-00-0	16,8	S10-00-0	17	PC-05	15
00-W-250	20,2	PA-F10-05	19,5	PA-FS10-05	18,75	PA-S10-05	19,5	PC-15	16,5
00-W-325	24,5	PA-F10-15	20,75	PA-FS10-15	22	PA-S10-15	20,75	PC-F10-05	17,5
PA-05	20,4	PA-F10-25	24	PA-FS10-25	24	PA-S10-25	23,2	PC-F10-15	19
PA-15	23,3	F10-W-255	20	FS10-W-245	19	S10-W-245	19,5	PC-F30-05	18
PA-25	25	F10-W-285	23,8	FS10-W-285	23,6	S10-W-290	23	PC-F30-15	14
		F30-00-0	15,5	FS30-00-0	16,6	S30-00-0	15,8	PC-F50-05	14
		PA-F30-05	19,8	PA-FS30-05	18,3	PA-S30-05	19,3	PC-F50-15	17
		PA-F30-15	22,5	PA-FS30-15	22,5	PA-S30-15	21,5	PB-05	19,5
		PA-F30-25	23,2	PA-FS30-25	23,6	PA-S30-25	23,5	PB-15	18,5
		F30-W-255	20	FS30-W-250	18,4	S30-W-250	19,1	PB-F10-05	15
		F30-W-275	23,5	FS30-W-305	23,6	S30-W-290	23,1	PB-F10-15	15
		F50-00-0	13	FS50-00-0	14	S50-00-0	16	PB-F30-05	19
		PA-F50-05	18,5	PA-FS50-05	18,4	PA-S50-05	18,3	PB-F30-15	15,5
		PA-F50-15	21,5	PA-FS50-15	23	PA-S50-15	22,5	PB-F50-05	14,5
		PA-F50-25	22,8	PA-FS50-25	24,2	PA-S50-25	23,8	PB-F50-15	17
		F50-W-255	18,5	FS50-W-255	19,2	S50-W-245	18,5		
		F50-W-300	22,5	FS50-W-325	24,5	S50-W-290	23,8		

APPENDIX C

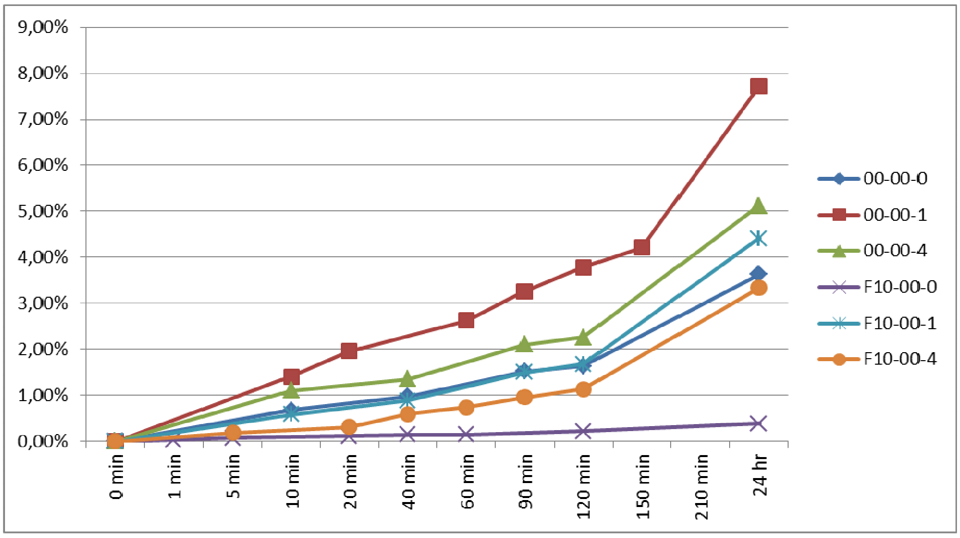

Figure C.1 : Dur. – Capillary rise test – Cement + Fly Ash (10%).

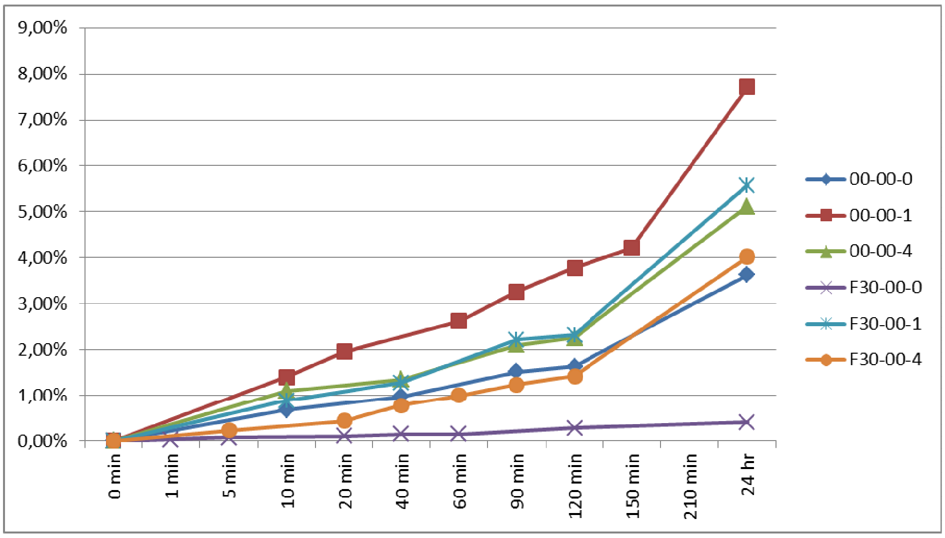

Figure C.2 : Dur. – Capillary rise test – Cement + Fly Ash (30%).

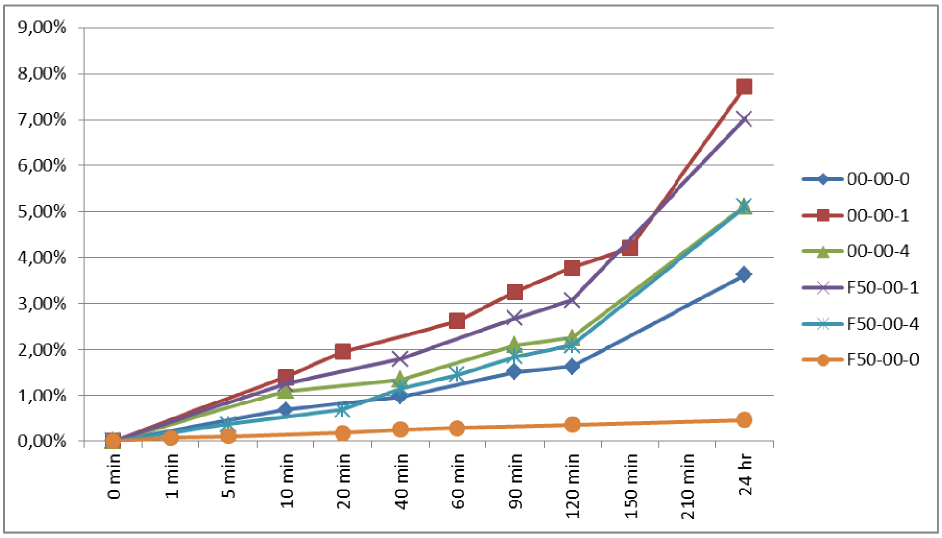

Figure C.3 : Dur. – Capillary rise test – Cement + Fly Ash (50%).

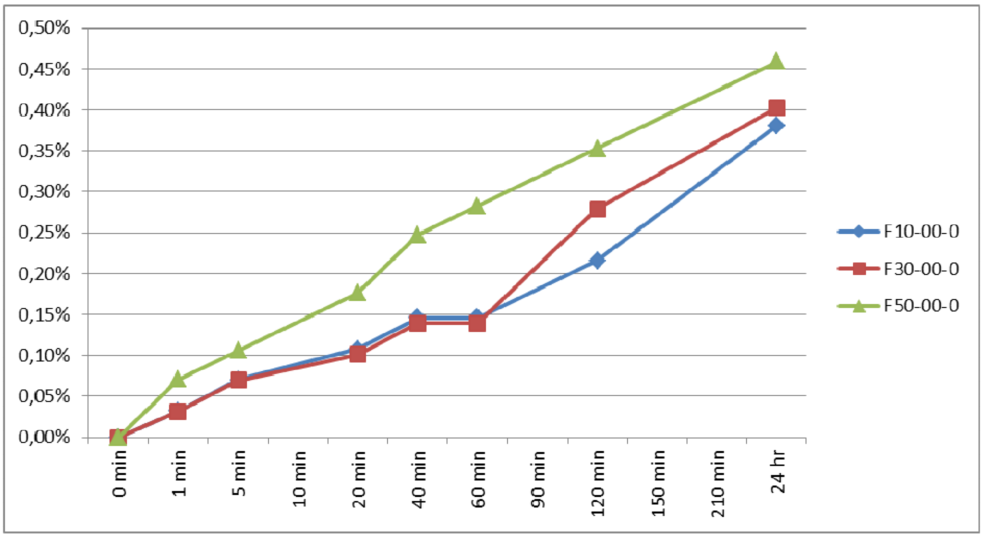

Figure C.4 : Dur. – Capillary rise test – Comparison of fly ash incorporated specimens.

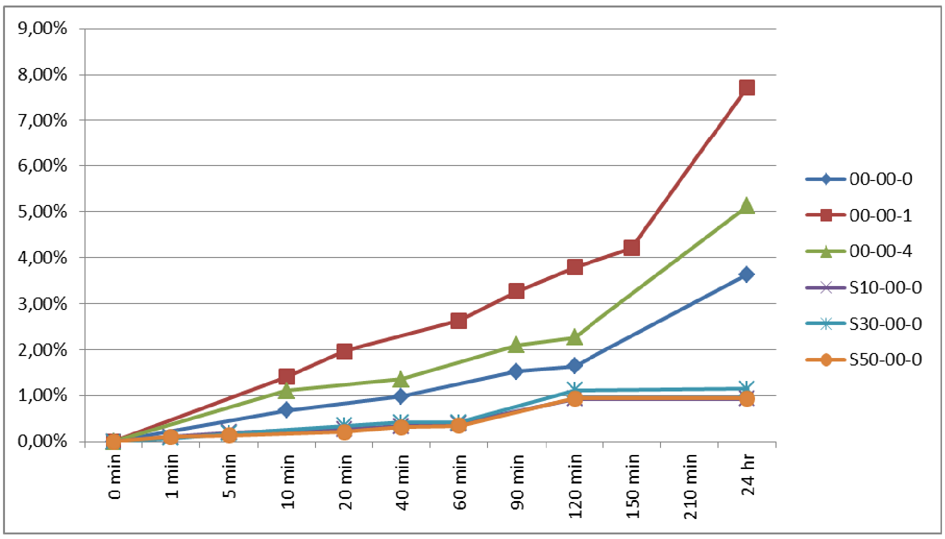

Figure C.5 : Dur. – Capillary rise test – Cement + Slag (10% - 30% - 50%).

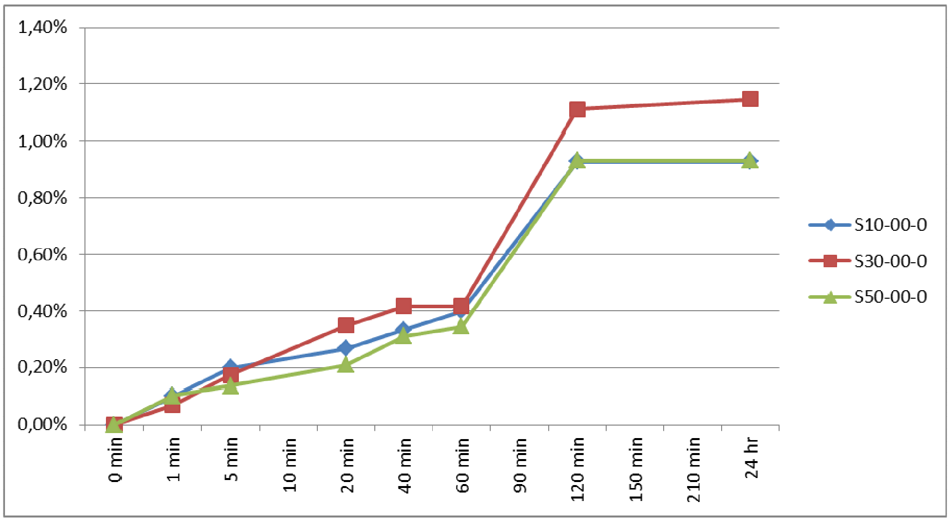

Figure C.6 : Dur. – Capillary rise test – Comparison of slag incorporated specimens.

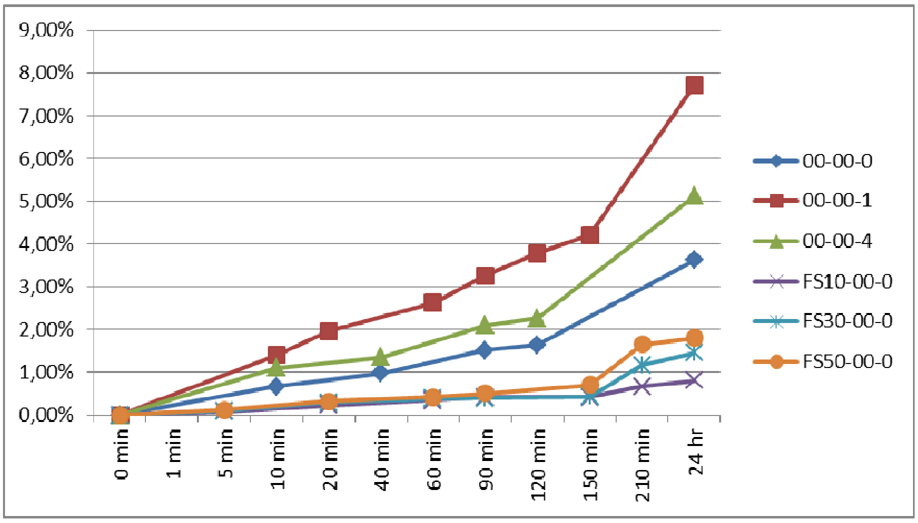

Figure C.7 : Dur. – Capillary rise test – Cement + Fly Ash (5% - 15% - 25%) + Slag (5% - 15% - 25%).

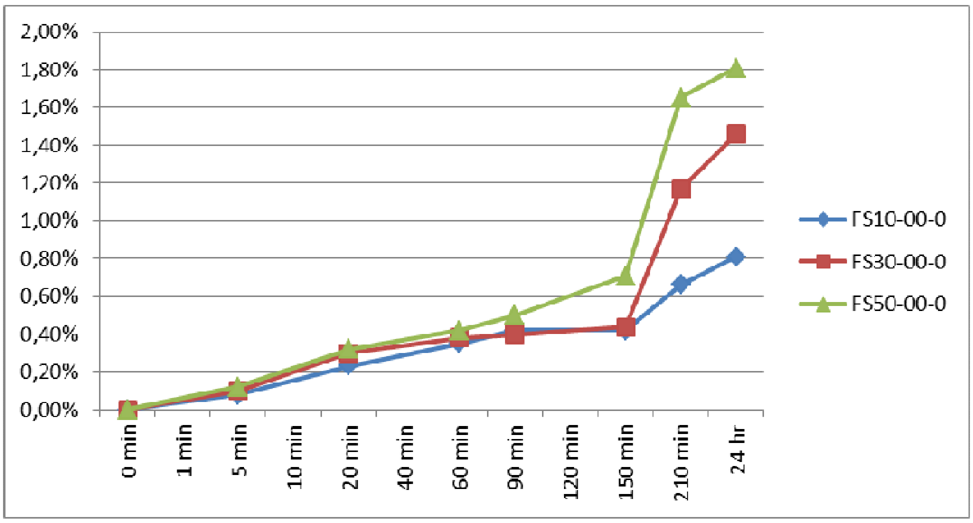

Figure C.8 : Dur. – Capillary rise test – Comparison of fly ash and slag incorporated specimens (1).

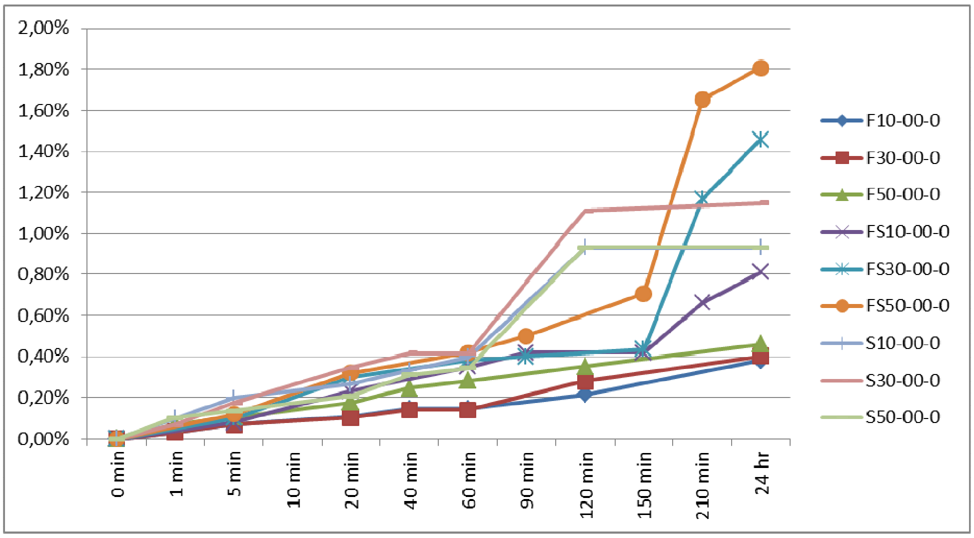

Figure C.9 : Dur. – Capillary rise test – Comparison of fly ash and slag incorporated specimens (2).

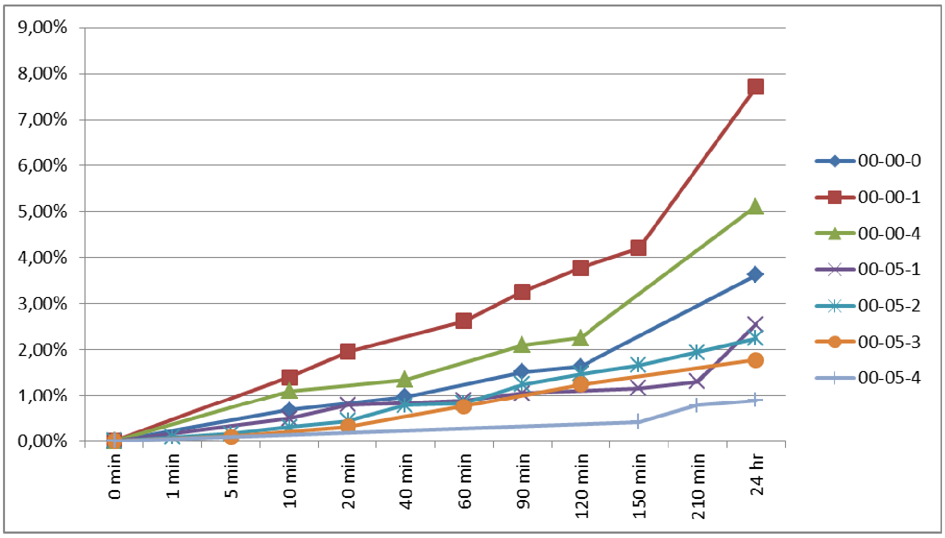

Figure C.10 : Dur. – Capillary rise test – Pre. – Cement + Polymer (5%).

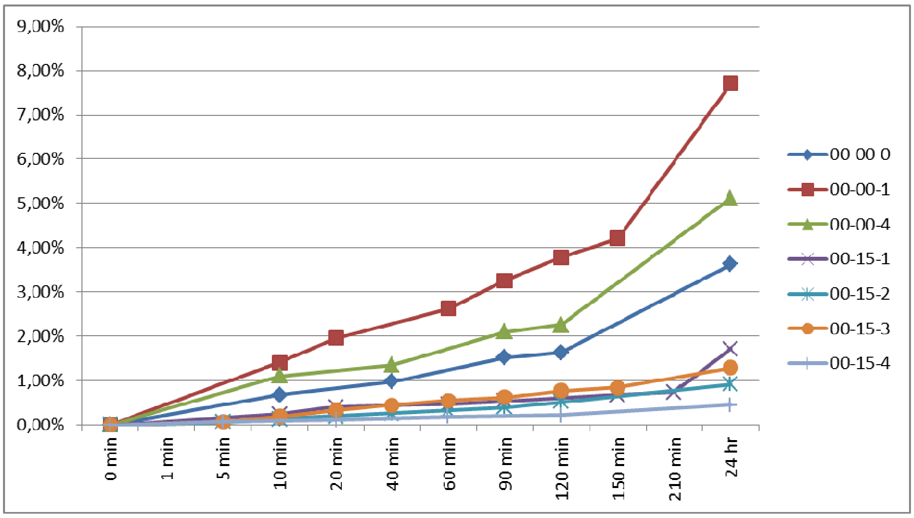

Figure C.11 : Dur. – Capillary rise test – Pre. – Cement + Polymer (15%).

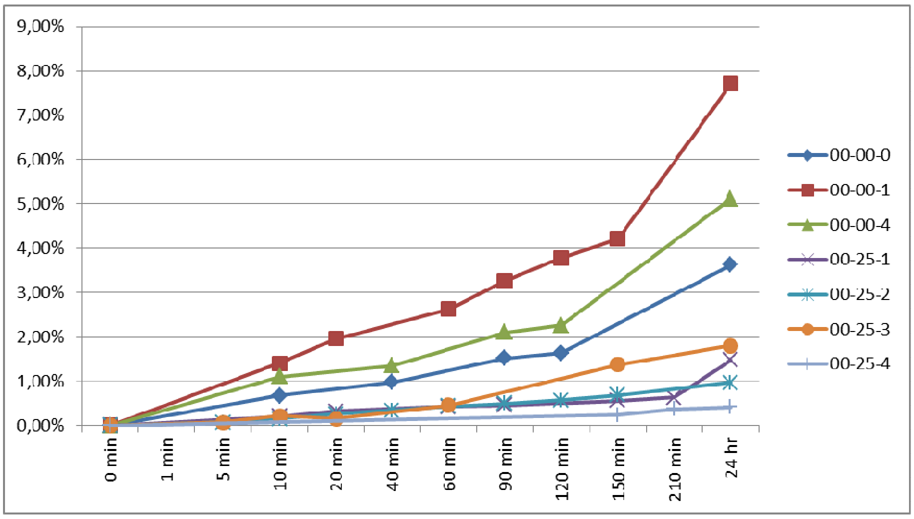

Figure C.12 : Dur. – Capillary rise test – Pre. – Cement + Polymer (25%).

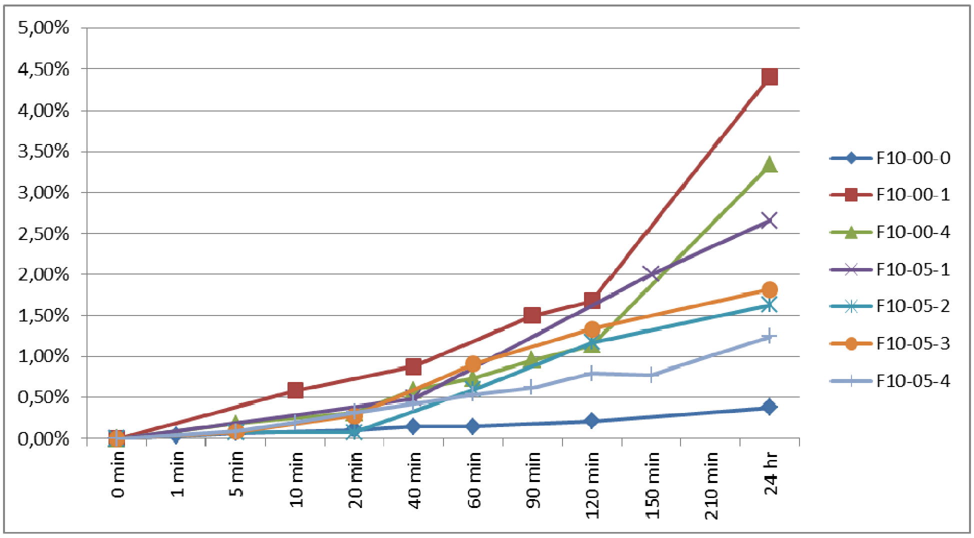

Figure C.13 : Dur. – Capillary rise test – Pre. – Cement + Fly Ash (10%) + Polymer (5%).

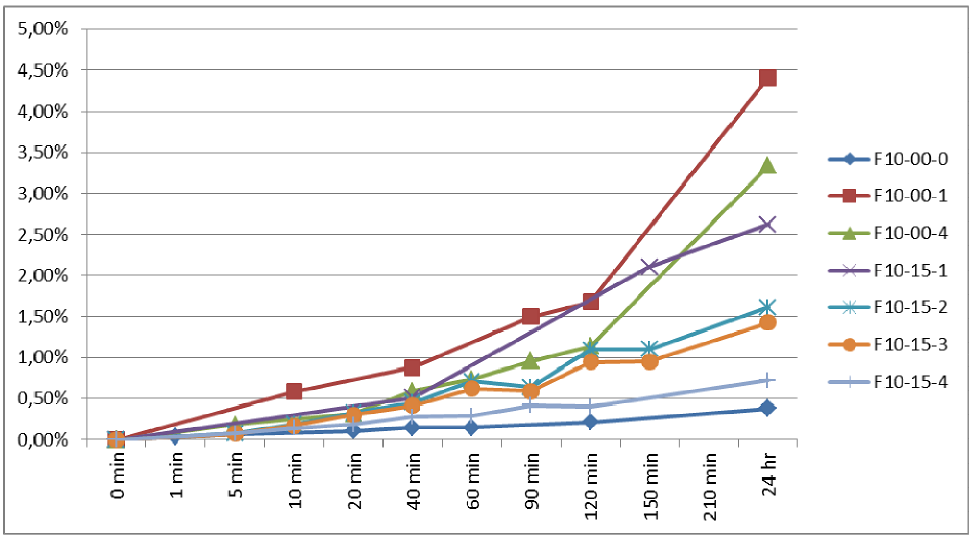

Figure C.14 : Dur. – Capillary rise test – Pre. – Cement + Fly Ash (10%) + Polymer (15%).

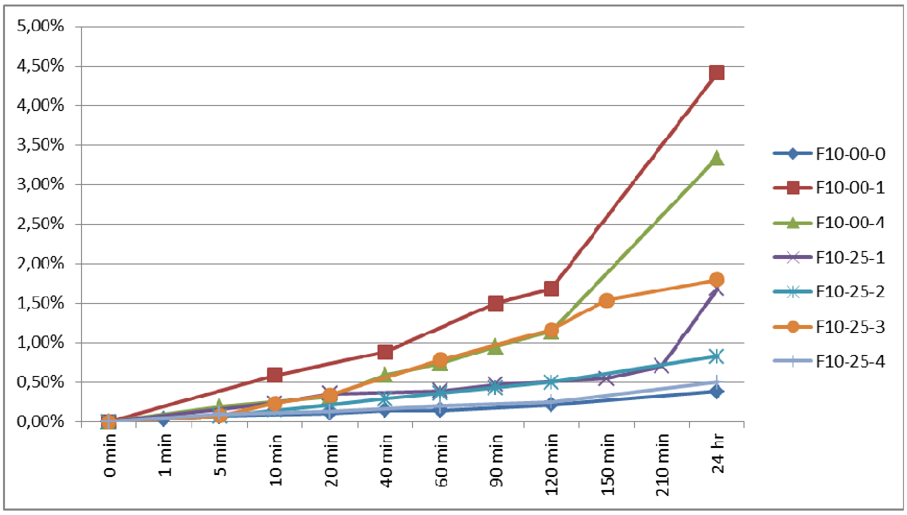

Figure C.15 : Dur. – Capillary rise test – Pre. – Cement + Fly Ash (10%) + Polymer (25%).

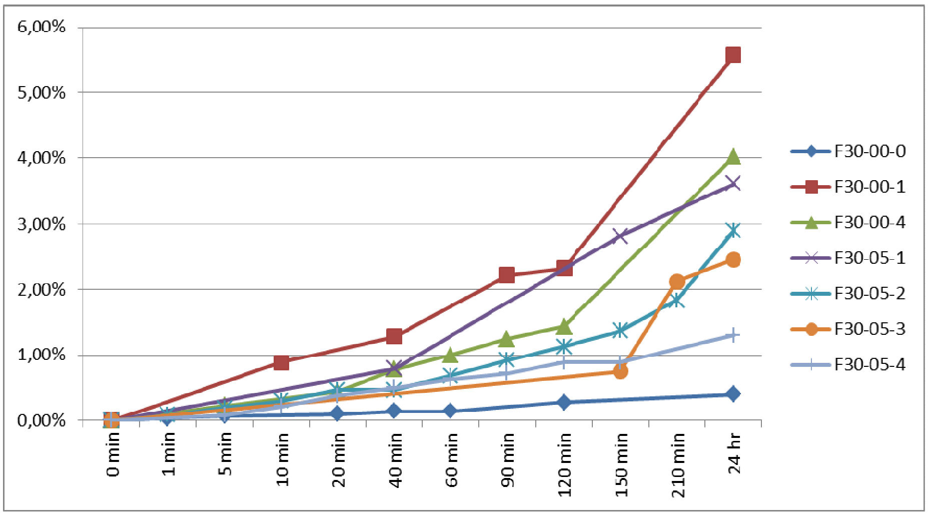

Figure C.16 : Dur. – Capillary rise test – Pre. – **Cement** + Fly Ash (30%) + Polymer (5%).

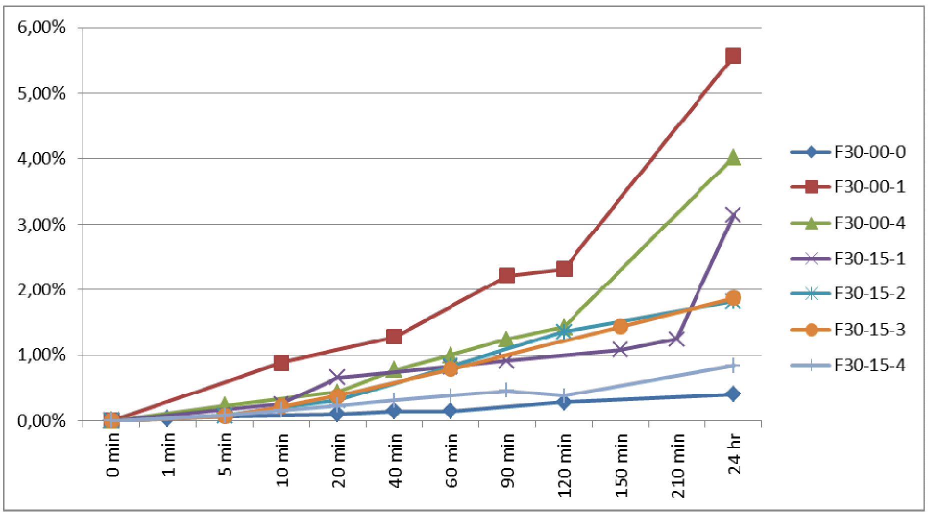

Figure C.17 : Dur. – Capillary rise test – Pre. – Cement + Fly Ash (30%) + Polymer (15%).

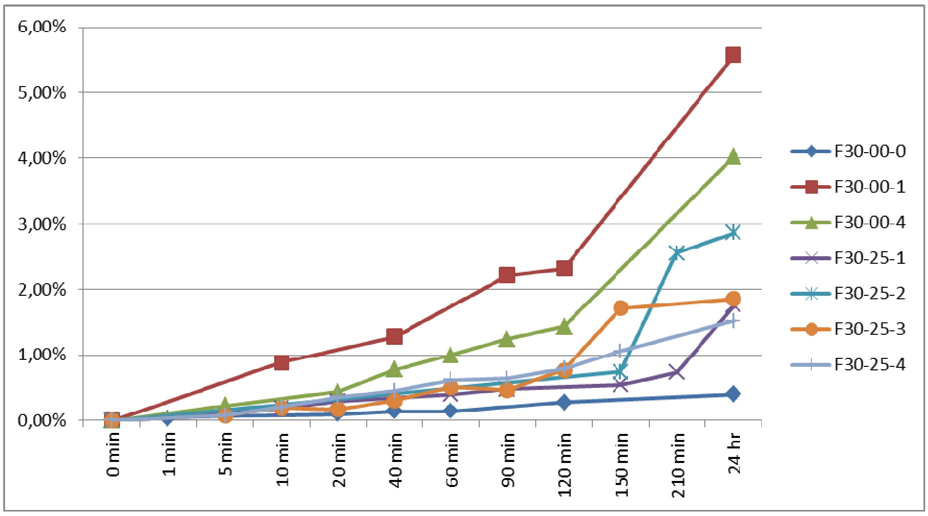

Figure C.18 : Dur. – Capillary rise test – Pre. – Cement + Fly Ash (30%) + Polymer (25%).

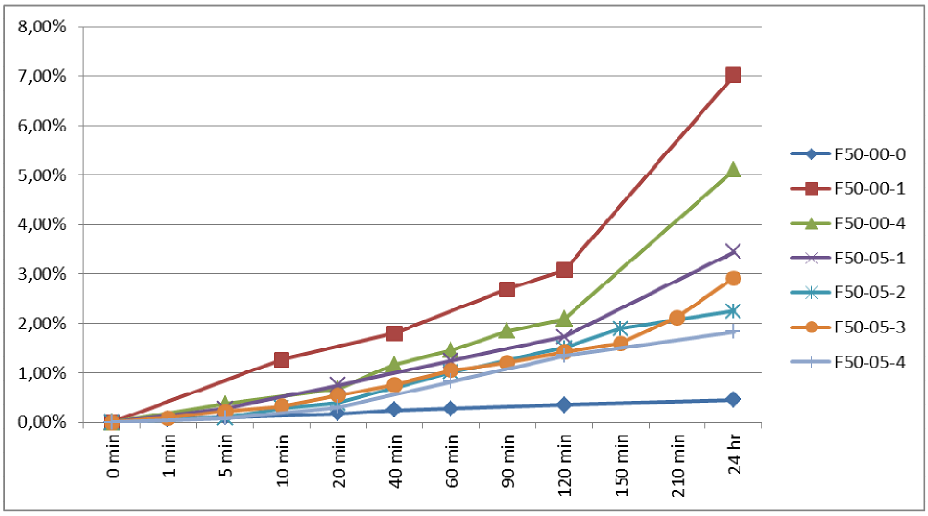

Figure C.19 : Dur. – Capillary rise test – Pre. – Cement + Fly Ash (50%) + Polymer (5%).

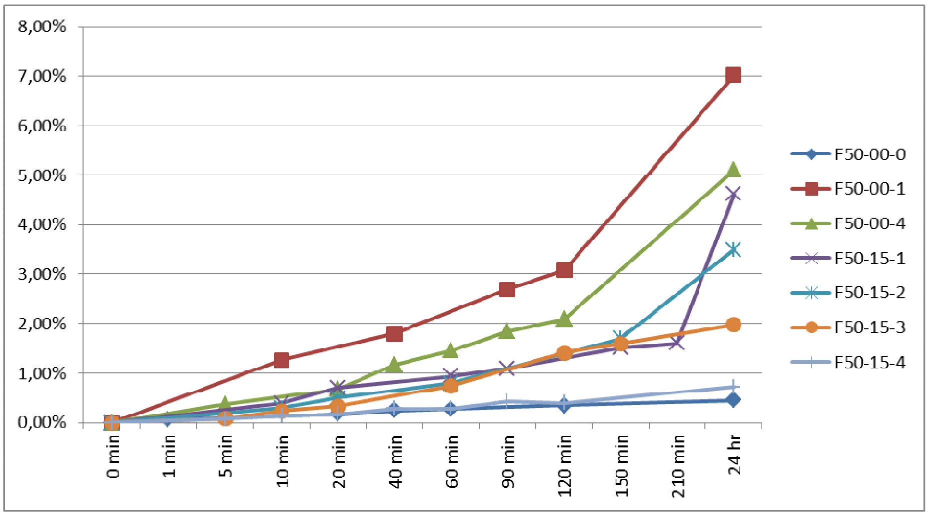

Figure C.20 : Dur. – Capillary rise test – Pre. – Cement + Fly Ash (50%) + Polymer (15%).

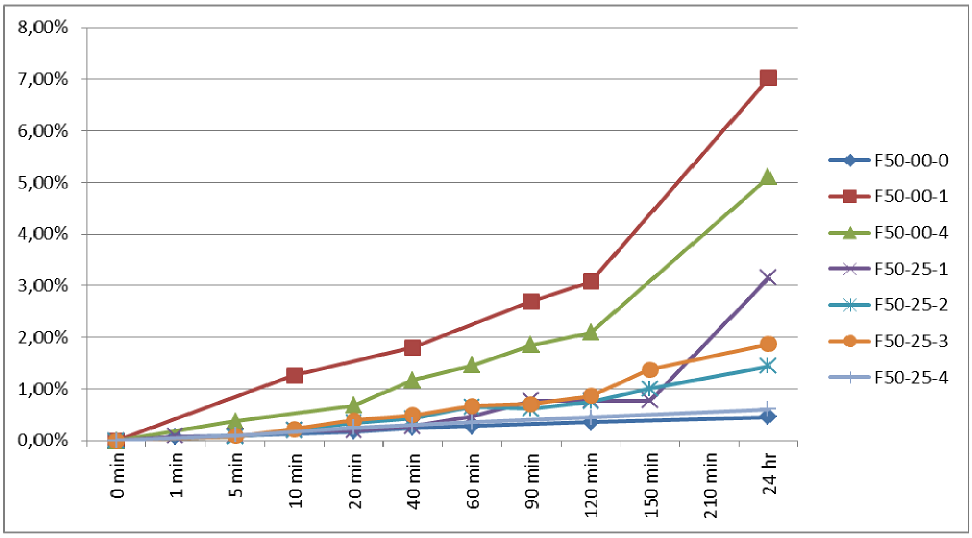

Figure C.21 : Dur. – Capillary rise test – Pre. – Cement + Fly Ash (50%) + Polymer (25%).

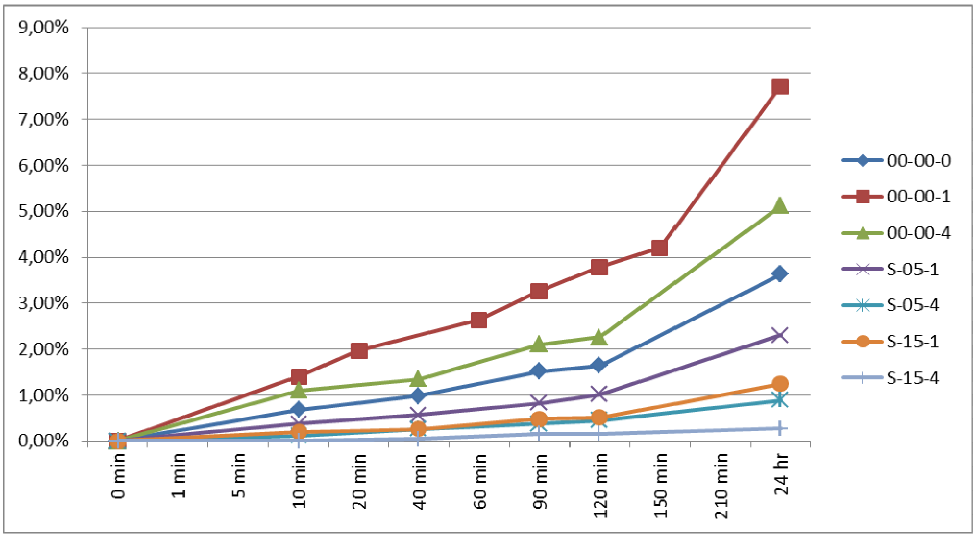

Figure C.22 : Dur. – Capillary rise test – Comp. – Cement + Polymer B (5% - 15%).

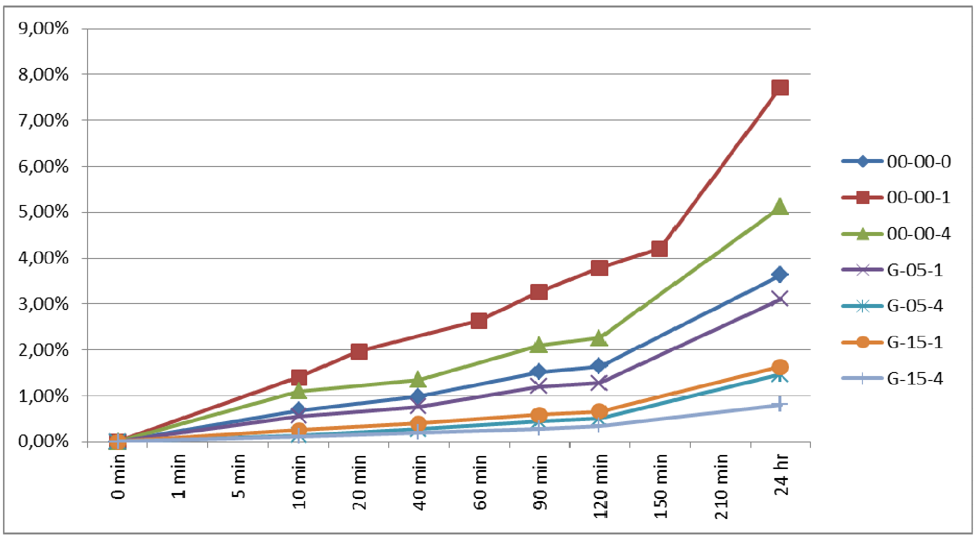

Figure C.23 : Dur. – Capillary rise test – Comp. – Cement + Polymer C (5% - 15%).

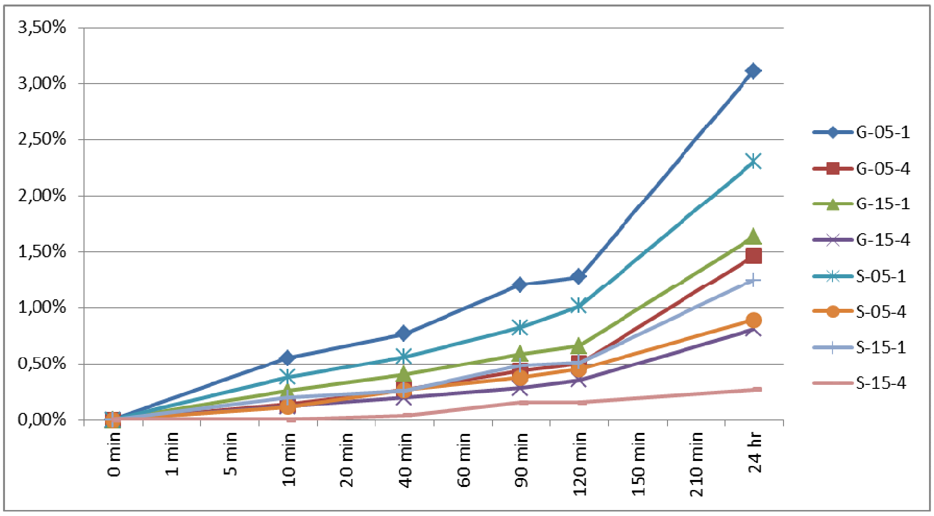

Figure C.24 : Dur. – Capillary rise test – Comp. – Comparison of modified specimens.

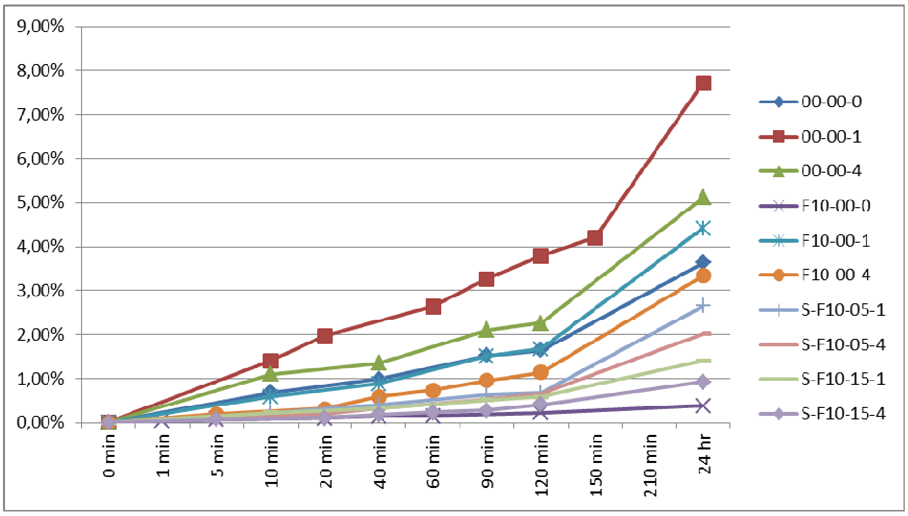

Figure C.25 : Dur. - Capillary rise test – Comp. – Cement + Fly Ash (10%) + Polymer B (5% - 15%).

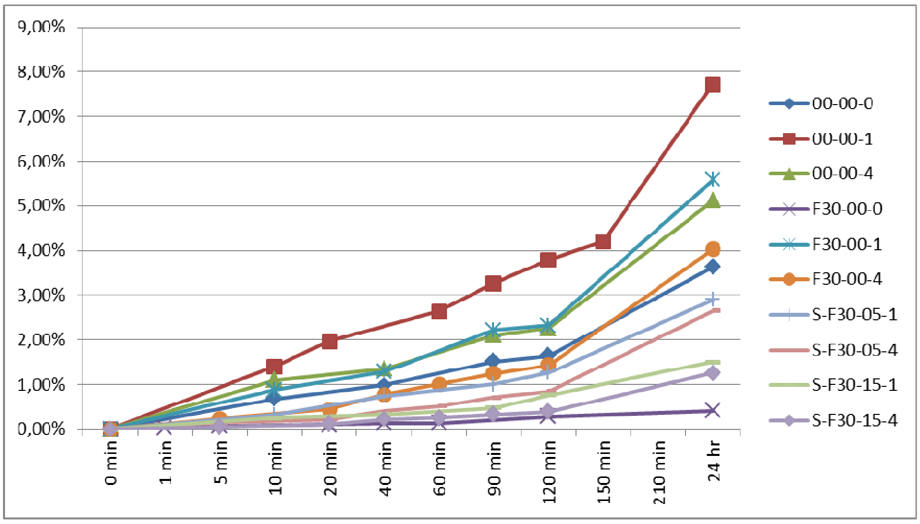

Figure C.26 : Dur. - Capillary rise test – Comp. – Cement + Fly Ash (30%) + Polymer B (5% - 15%).

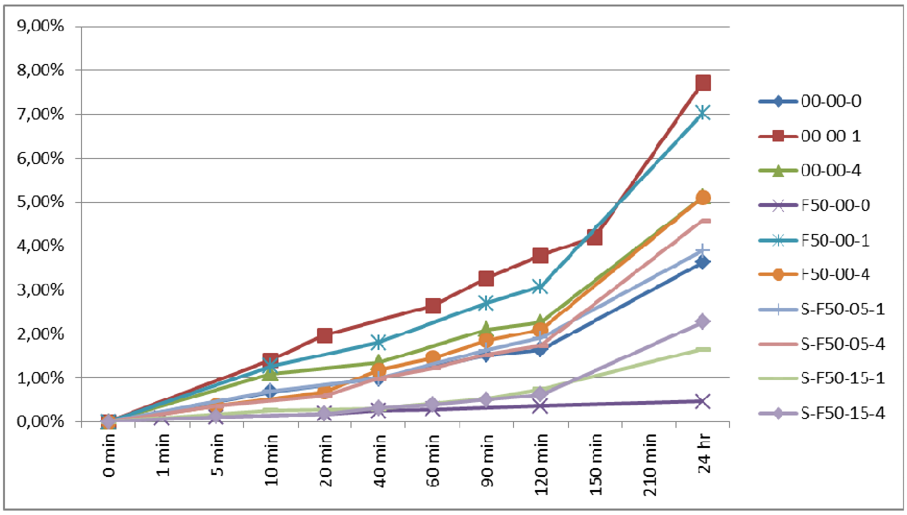

Figure C.27 : Dur. - Capillary rise test – Comp. – Cement + Fly Ash (50%) + Polymer B (5% - 15%).

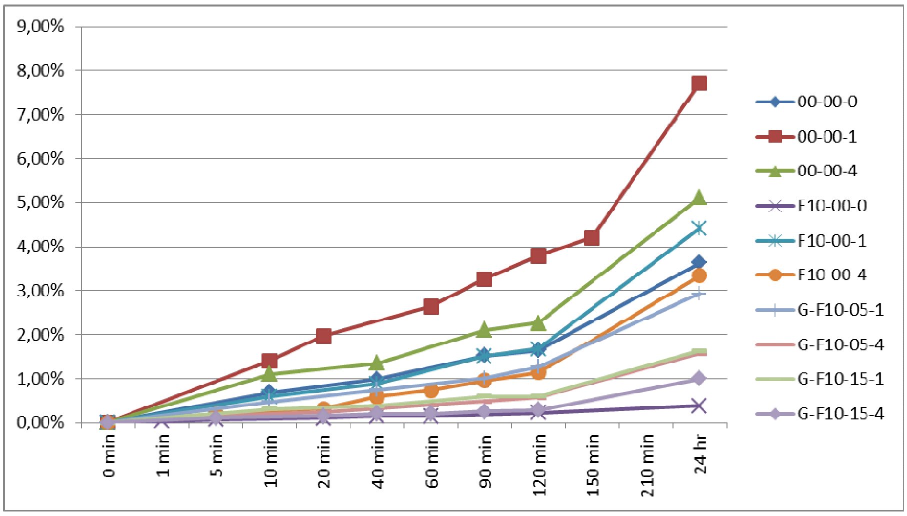

Figure C.28 : Dur. - Capillary rise test – Comp. – Cement + Fly Ash (10%) + Polymer C (5% - 15%).

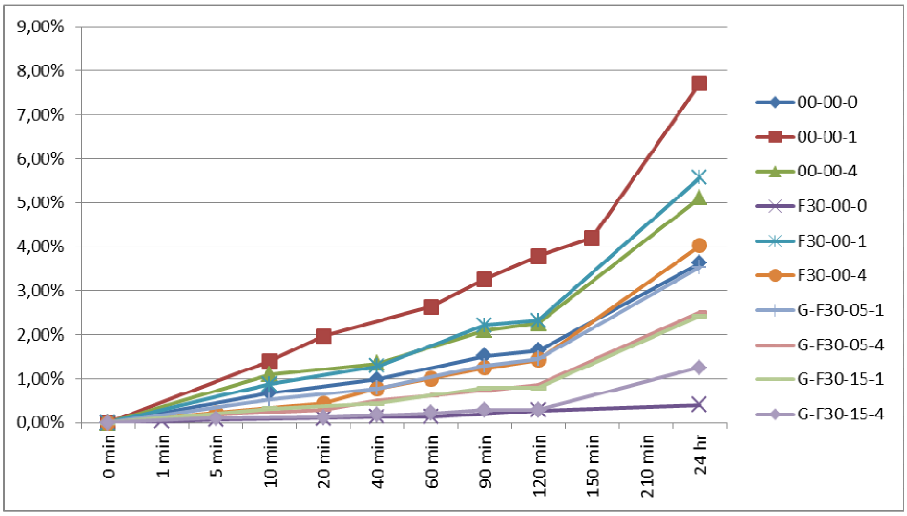

Figure C.29 : Dur. - Capillary rise test – Comp. – Cement + Fly Ash (30%) + Polymer C (5% - 15%).

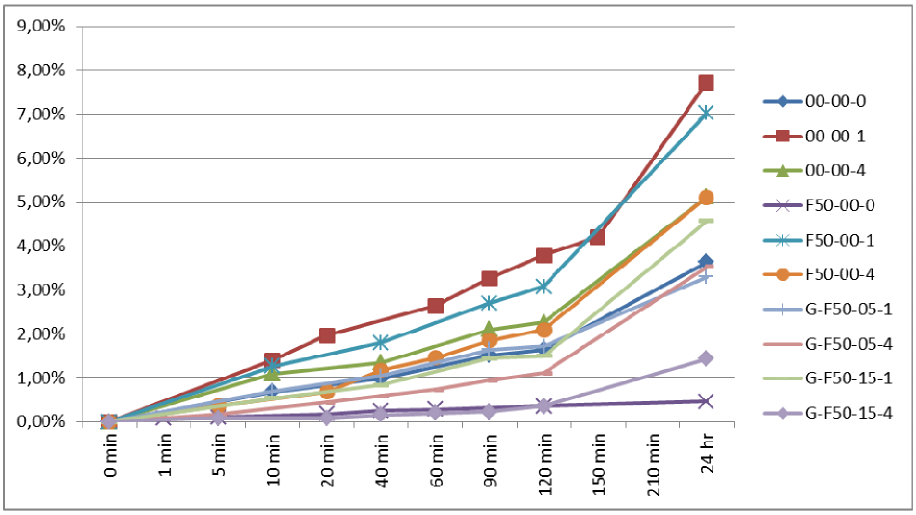

Figure C.30 : Dur. - Capillary rise test – Comp. – Cement + Fly Ash (50%) + Polymer C (5% - 15%).

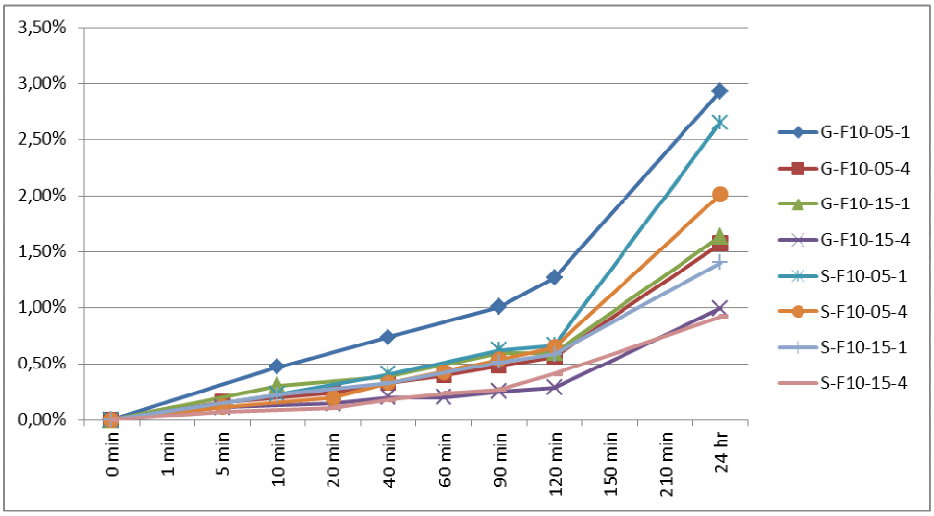

Figure C.31 : Dur. - Capillary rise test – Comp. – Comparion of polymer admixtures for specimens with fly ash 10%.

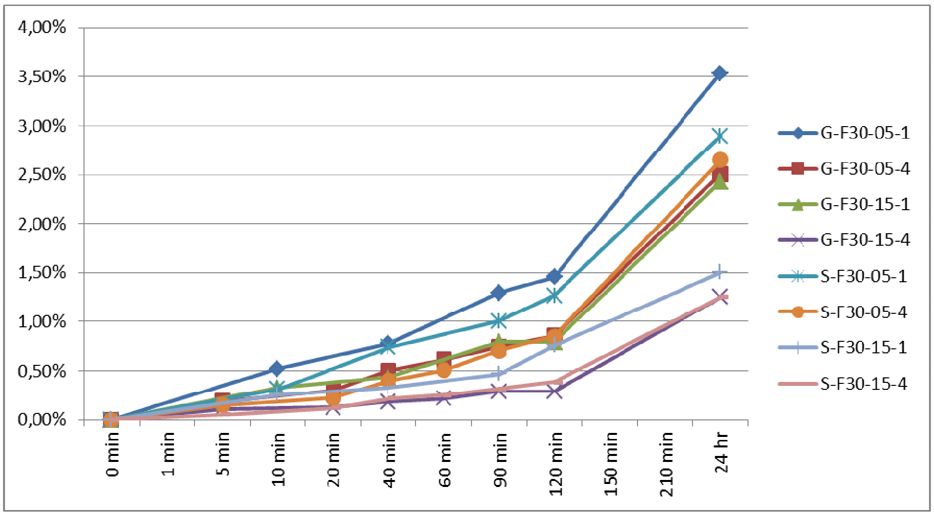

Figure C.32 : Dur. - Capillary rise test – Comp. – Comparion of polymer admixtures for specimens with fly ash 30%.

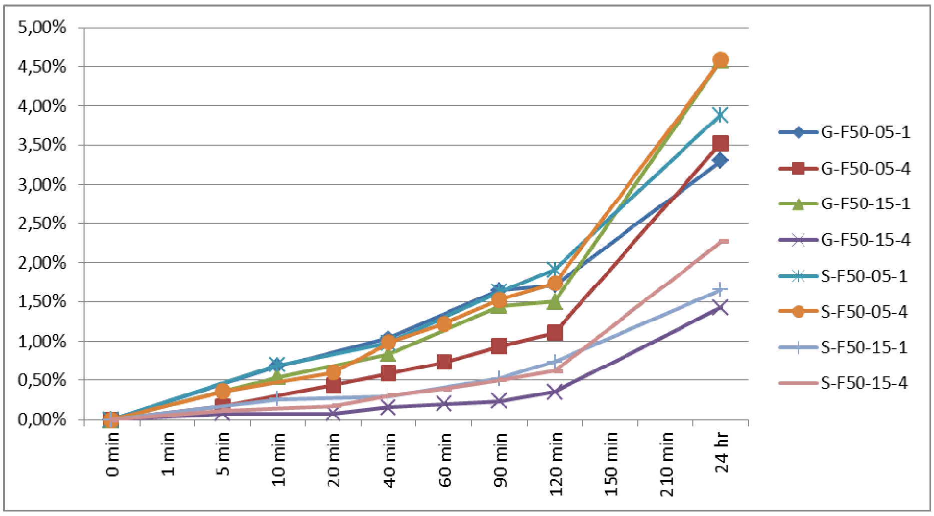

Figure C.33 : Dur. - Capillary rise test – Comp. – Comparion of polymer admixtures for specimens with fly ash 50%.

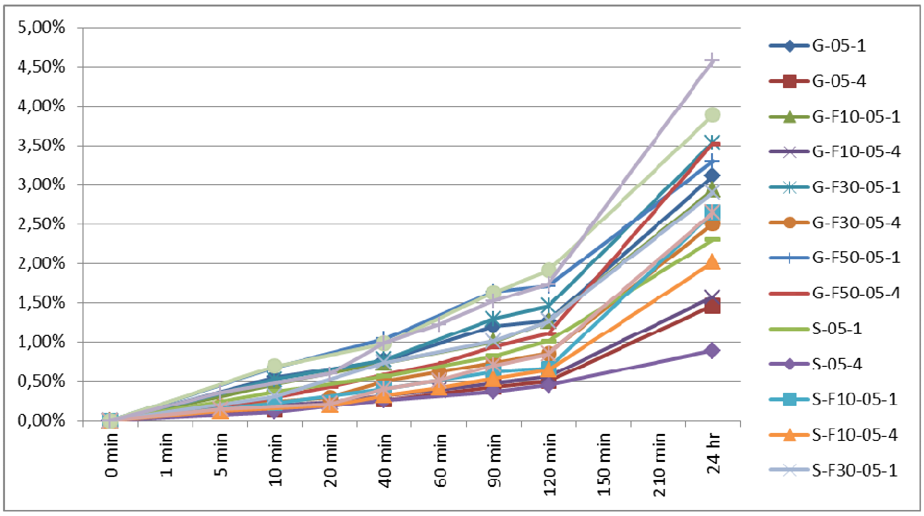

Figure C.34 : Dur. - Capillary rise test – Comp. – Comparion of polymer admixtures (5%) for specimens with fly ash.

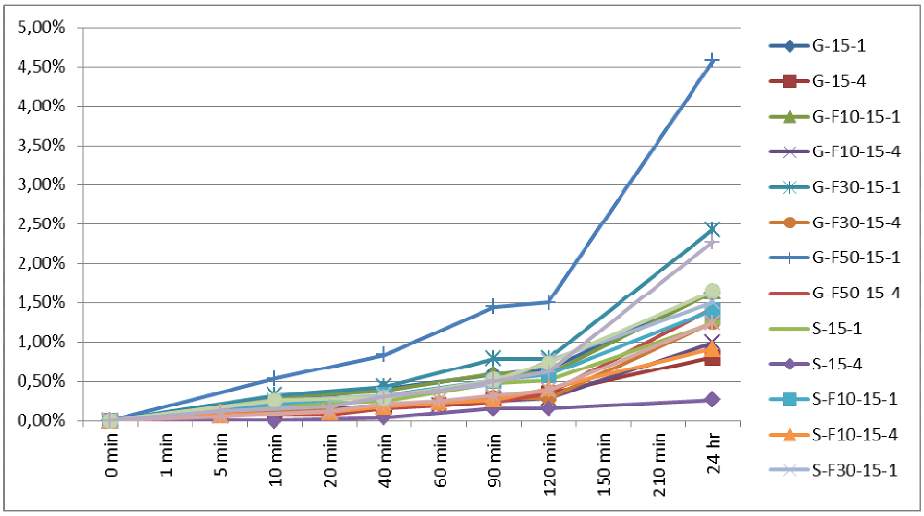

Figure C.35 : Dur. - Capillary rise test – Comp. – Comparion of polymer admixtures (15%) for specimens with fly ash.

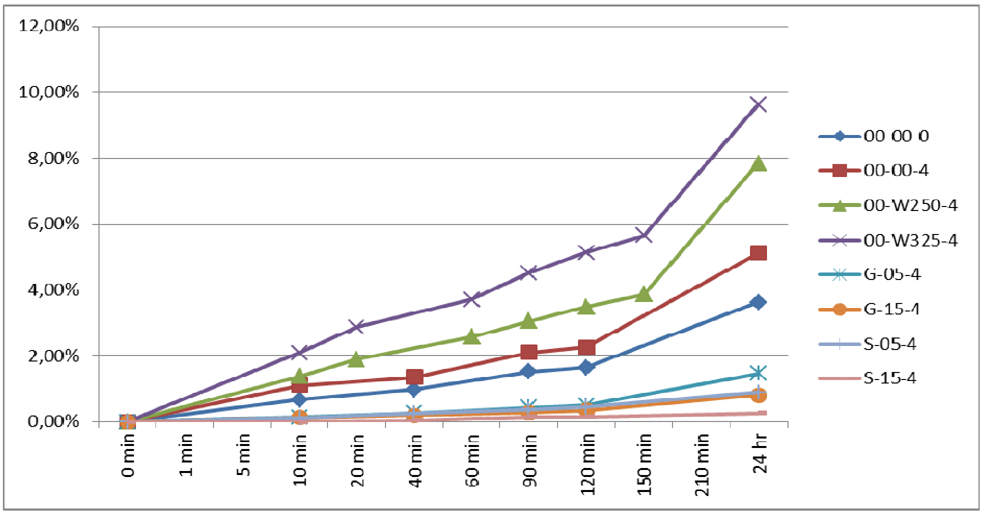

Figure C.36 : Dur. - Capillary rise test – Comp. – Similar workability – Cement.

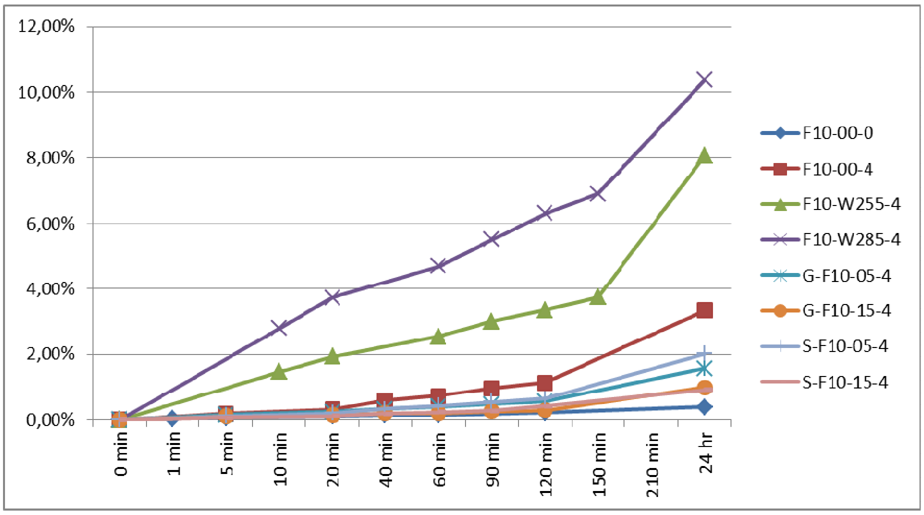

Figure C.37 : Dur. - Capillary rise test – Comp. – Similar workability – Cement + Fly Ash (10%).

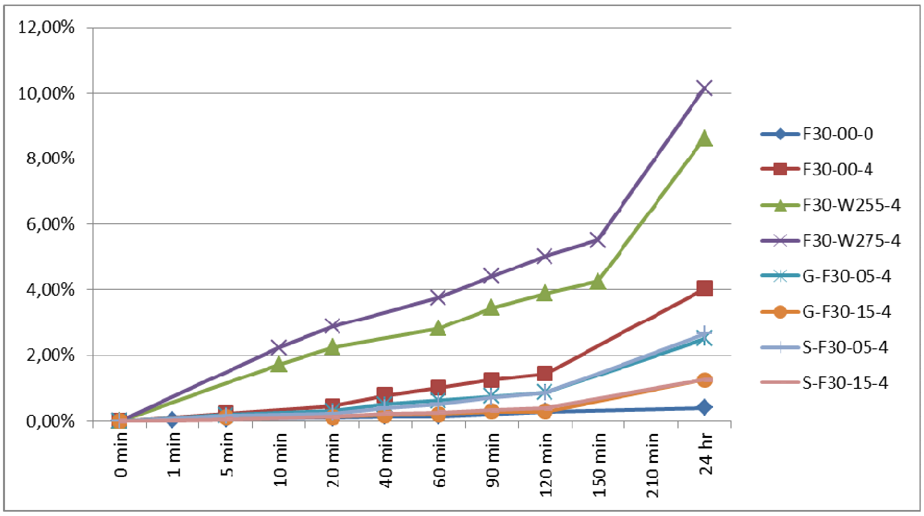

Figure C.38 : Dur. - Capillary rise test – Comp. – Similar workability – Cement + Fly Ash (30%).

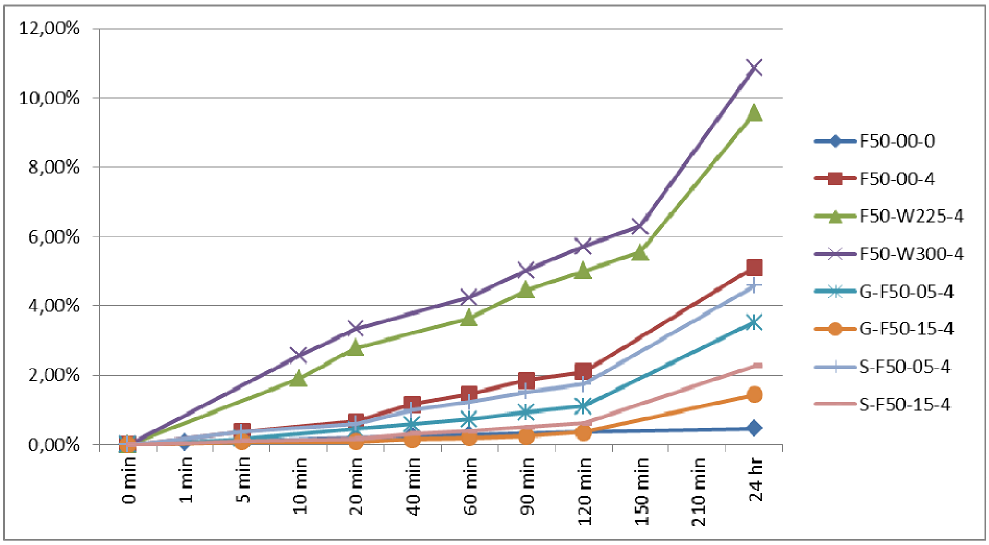

Figure C.39 : Dur. - Capillary rise test – Comp. – Similar workability – Cement + Fly Ash (50%).

APPENDIX D

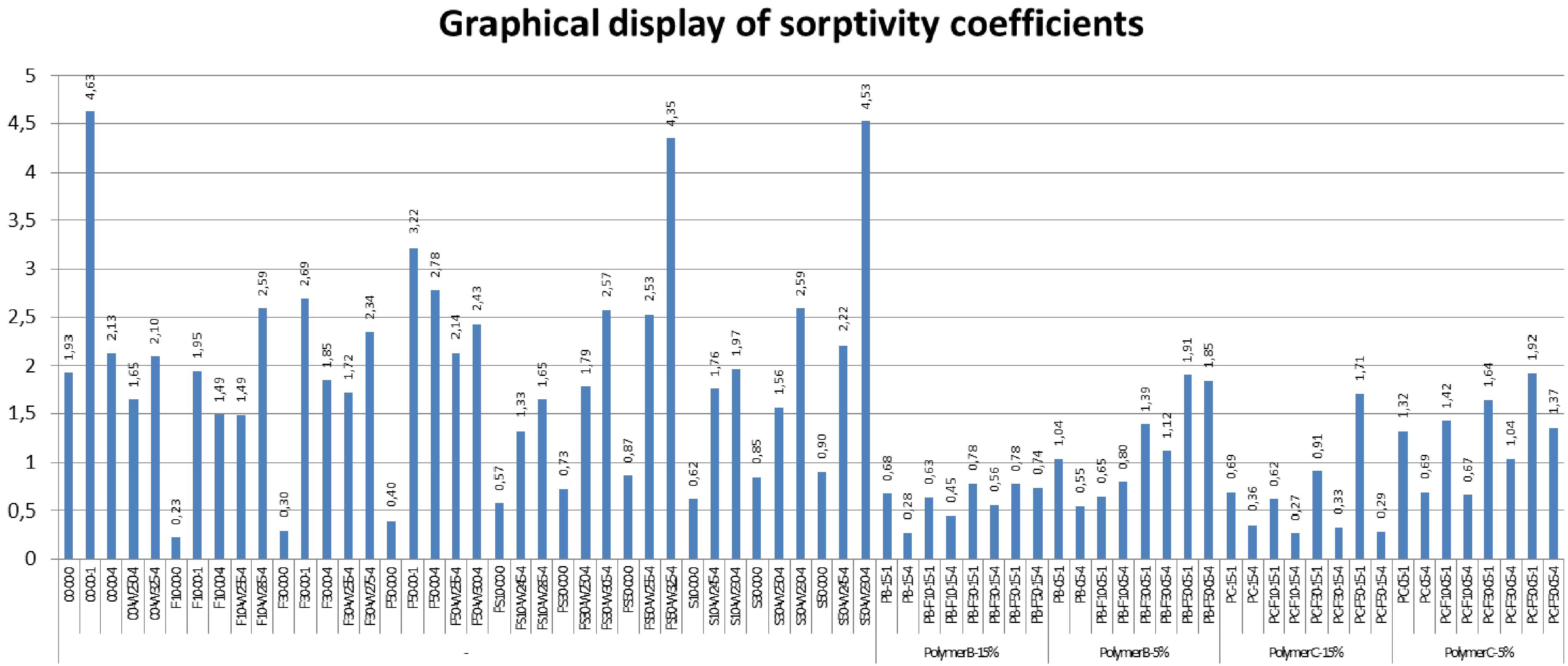

Figure D.1 : Graphical display of sorptivity coefficients.

APPENDIX E

Table E.1: 24 hr sorptivity coefficients.

SPECIMEN	DESCRIPTION	POLYMER TYPE & CONTENT	CURING CONDITION	SCM TYPE & CONTENT	S. Coefficient - 24hr
00-00-0	Unmodified	-	(0) - 28 days water	-	6,70
00-00-1	Unmodified	-	(1) - 28 days air	-	15,79
00-00-4	Unmodified	-	(4) - 3 W + 25 Air	-	8,84
F10-00-0	Unmodified	-	(0) - 28 days water	Fly ash 10%	0,66
F10-00-1	Unmodified	-	(1) - 28 days air	Fly ash 10%	7,78
F10-00-4	Unmodified	-	(4) - 3 W + 25 Air	Fly ash 10%	5,81
F30-00-0	Unmodified	-	(0) - 28 days water	Fly ash 30%	0,72
F30-00-1	Unmodified	-	(1) - 28 days air	Fly ash 30%	9,94
F30-00-4	Unmodified	-	(4) - 3 W + 25 Air	Fly ash 30%	6,88
F50-00-0	Unmodified	-	(0) - 28 days water	Fly ash 50%	0,81
F50-00-1	Unmodified	-	(1) - 28 days air	Fly ash 50%	12,63
F50-00-4	Unmodified	-	(4) - 3 W + 25 Air	Fly ash 50%	9,13
FS10-00-0	Unmodified	-	(0) - 28 days water	Fly Ash 5% + Slag 5%	1,37
FS30-00-0	Unmodified	-	(0) - 28 days water	Fly Ash 15% + Slag 15%	2,81
FS50-00-0	Unmodified	-	(0) - 28 days water	Fly Ash 25% + Slag 25%	3,47
S10-00-0	Unmodified	-	(0) - 28 days water	Slag 10%	1,75
S30-00-0	Unmodified	-	(0) - 28 days water	Slag 30%	2,06
S50-00-0	Unmodified	-	(0) - 28 days water	Slag 50%	2,00
PA-05-1	Polymer Modified	Polymer A - 5%	(1) - 28 days air	-	4,50
PA-05-4	Polymer Modified	Polymer A - 5%	(4) - 3 W + 25 Air	-	3,50
PA-15-1	Polymer Modified	Polymer A - 15%	(1) - 28 days air	-	3,37
PA-15-4	Polymer Modified	Polymer A - 15%	(4) - 3 W + 25 Air	-	2,00
PA-25-1	Polymer Modified	Polymer A - 25%	(1) - 28 days air	-	2,88
PA-25-4	Polymer Modified	Polymer A - 25%	(4) - 3 W + 25 Air	-	1,50
PB-05-1	Polymer Modified	Polymer B - 5%	(1) - 28 days air	-	3,91
PB-05-4	Polymer Modified	Polymer B - 5%	(4) - 3 W + 25 Air	-	1,50
PB-15-1	Polymer Modified	Polymer B - 15%	(1) - 28 days air	-	2,44
PB-15-4	Polymer Modified	Polymer B - 15%	(4) - 3 W + 25 Air	-	0,44
PB-F10-05-1	Polymer Modified	Polymer B - 5%	(1) - 28 days air	Fly ash 10%	3,81
PB-F10-05-4	Polymer Modified	Polymer B - 5%	(4) - 3 W + 25 Air	Fly ash 10%	3,34
PB-F10-15-1	Polymer Modified	Polymer B - 15%	(1) - 28 days air	Fly ash 10%	2,44
PB-F10-15-4	Polymer Modified	Polymer B - 15%	(4) - 3 W + 25 Air	Fly ash 10%	1,63
PB-F30-05-1	Polymer Modified	Polymer B - 5%	(1) - 28 days air	Fly ash 30%	4,50
PB-F30-05-4	Polymer Modified	Polymer B - 5%	(4) - 3 W + 25 Air	Fly ash 30%	4,66

Table E.1 (continued) : 24 hr sorptivity coefficients.

SPECIMEN	DESCRIPTION	POLYMER TYPE & CONTENT	CURING CONDITION	SCM TYPE & CONTENT	S. Coefficient - 24hr
PB-F30-15-1	Polymer Modified	Polymer B - 15%	(1) - 28 days air	Fly ash 30%	2,62
PB-F30-15-4	Polymer Modified	Polymer B - 15%	(4) - 3 W + 25 Air	Fly ash 30%	2,34
PB-F50-05-1	Polymer Modified	Polymer B - 5%	(1) - 28 days air	Fly ash 50%	6,13
PB-F50-05-4	Polymer Modified	Polymer B - 5%	(4) - 3 W + 25 Air	Fly ash 50%	6,78
PB-F50-15-1	Polymer Modified	Polymer B - 15%	(1) - 28 days air	Fly ash 50%	2,81
PB-F50-15-4	Polymer Modified	Polymer B - 15%	(4) - 3 W + 25 Air	Fly ash 50%	3,75
PC-05-1	Polymer Modified	Polymer C - 5%	(1) - 28 days air	-	5,44
PC-05-4	Polymer Modified	Polymer C - 5%	(4) - 3 W + 25 Air	-	2,75
PC-15-1	Polymer Modified	Polymer C - 15%	(1) - 28 days air	-	2,81
PC-15-4	Polymer Modified	Polymer C - 15%	(4) - 3 W + 25 Air	-	1,31
PC-F10-05-1	Polymer Modified	Polymer C - 5%	(1) - 28 days air	Fly ash 10%	5,59
PC-F10-05-4	Polymer Modified	Polymer C - 5%	(4) - 3 W + 25 Air	Fly ash 10%	2,91
PC-F10-15-1	Polymer Modified	Polymer C - 15%	(1) - 28 days air	Fly ash 10%	3,12
PC-F10-15-4	Polymer Modified	Polymer C - 15%	(4) - 3 W + 25 Air	Fly ash 10%	1,75
PC-F30-05-1	Polymer Modified	Polymer C - 5%	(1) - 28 days air	Fly ash 30%	6,13
PC-F30-05-4	Polymer Modified	Polymer C - 5%	(4) - 3 W + 25 Air	Fly ash 30%	4,28
PC-F30-15-1	Polymer Modified	Polymer C - 15%	(1) - 28 days air	Fly ash 30%	4,28
PC-F30-15-4	Polymer Modified	Polymer C - 15%	(4) - 3 W + 25 Air	Fly ash 30%	2,19
PC-F50-05-1	Polymer Modified	Polymer C - 5%	(1) - 28 days air	Fly ash 50%	6,06
PC-F50-05-4	Polymer Modified	Polymer C - 5%	(4) - 3 W + 25 Air	Fly ash 50%	6,03
PC-F50-15-1	Polymer Modified	Polymer C - 15%	(1) - 28 days air	Fly ash 50%	7,78
PC-F50-15-4	Polymer Modified	Polymer C - 15%	(4) - 3 W + 25 Air	Fly ash 50%	2,31
00-W250-4	W / binder modified	-	(4) - 3 W + 25 Air	-	5,69
00-W325-4	W / binder modified	-	(4) - 3 W + 25 Air	-	5,87
F10-W255-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 10%	6,50
F10-W285-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 10%	7,62
F30-W255-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 30%	6,81
F30-W275-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 30%	8,19
F50-W255-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 50%	6,81
F50-W300-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly ash 50%	9,19
FS10-W245-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 5% + Slag 5%	5,88
FS10-W285-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 5% + Slag 5%	7,31
FS30-W250-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 15% + Slag 15%	7,06
FS30-W305-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 15% + Slag 15%	6,44
FS50-W255-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 25% + Slag 25%	7,38
FS50-W325-4	W / binder modified	-	(4) - 3 W + 25 Air	Fly Ash 25% + Slag 25%	10,38
S10-W245-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 10%	7,12
S10-W290-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 10%	5,75
S30-W250-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 30%	6,37
S30-W290-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 30%	8,31
S50-W245-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 50%	7,00
S50-W290-4	W / binder modified	-	(4) - 3 W + 25 Air	Slag 50%	10,13

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