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DURABILITY PROPERTIES OF POLYMER-MODIFIED LIGHTWEIGHT FLY ASH AGGREGATE CONCRETES

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Durability properties of polymer-modified lightweight fly ash aggregate concretes

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Shimal Jameel YOUNUS

ABSTRACT

DURABILITY PROPERTIES OF POLYMER-MODIFIED LIGHTWEIGHT FLY ASH AGGREGATE CONCRETES

YOUNUS, Shimal Jameel
M.Sc. Thesis in Civil Engineering
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The aim of this thesis is to examine the durability properties of natural rubber latex (NRL) modified lightweight concretes (LWCs). The LWC was produced from lightweight fine and coarse aggregates (LWAs) which ware manufactured by cold bonding of class F fly ash. The NRL which is an elastic hydrocarbon polymer was used as an addition in the concrete production as 2% and 5% of the weight of total binder content (400 kg/m^3), considering the solid polymer content. The observed properties of polymer modified concretes ware evaluated by rapid chloride permeability test (RCPT), soaking, test, and water sorptivity and corrosion current density by linear polarization resistance (LPR) test. Moreover, the LWCs were tested for compressive strength to determine mechanical performance. The tests were carried out at the end of 28 and 90 days of curing. However, the specimens used for soaking test were immersed in NaCl solution after 28 days of curing and tested for chloride ion penetration at different intervals. Moreover, the reinforced LWCs used for LPR test were immersed in NaCl solution and tested at specified periods of chloride exposures. The results indicated that the modification of the lightweight concretes with NRL resulted in improvement of the durability related properties of LWCs.

Keywords: Durability, Lightweight concrete, Natural rubber latex, Polymer modified concrete.

ÖZET

POLİMERLE MODİFİYE EDİLMİŞ UÇUCU KÜL HAFİF AGREGALI BETONLARIN DURABİLİTE ÖZELLİKLERİ

YOUNUS, Shimal jameel
Yüksek lisanas tezi, Inşaat Mühendisliği
Danışman: Doç. Dr. Erhan GÜNEYİSİ
Eylül 2013, 54 sayfa

Bu çalışmanın amacı, doğal kauçuk lateks (DKL) kullanılarak üretilen hafif betonların (HB) durabilite özelliklerinin araştırılmasıdır. Hafif betonlar, F sınıfı uçucu külden soğuk bağlama yöntemiyle üretilen hafif iri ve ince agregalar kullanılarak üretilmiştir. Doğal kauçuk lateks elastik bir hidrokarbon polimer olup, DKL modifiyeli betonlarda katı polimer içeriği toplam baglayici miktarının (400 kg/m^3) %2 ve % 5i oranlarında olacak şekilde betona ilave edilmiştir. Polimer modifiye betonlar klorür iyonu işleme derinliği, hızlı klorür geçirgenlik testi, kılcal su emme deneyi ve doğrusal polarizasyon yöntemiyle korozyon akım yoğunluğu deneylerine tabii tutulmuşlardır. Deneyler 28 ve 90 günlük kür süreleri sonunda gerçekleştirilmiştir. Ayrıca, klorür işleme deneyine tabi tutulan prizmatik numuneler 28 günluk kür süresi sonunda NaCl çözeltisine maruz bırakılmış ve değişik aralıklarla klorür iyon işleme derinlikleri ölçülmüştür. Donatılı hafif betonların korozyon olçümleri için numuneler klorür etkisine maruz bırakılmış ve değişik aralıklarda çözeltiden çıkartılarak test edilmişlerdir. Deneylerden elde edilen bulgulara göre hafif betonların DKL ile modifiye edilmesiyle bu betonların durabilite özelliklerinde önemli iyileşmeler sağlanmıştır. İFI

Anahtar Kelimeler: Durability, Hafif ağırlıklı beton, Doğal kauçuk lateks, Polimer.
modifiye beton

To my dear parents, wife's, kids, brothers, sisters, and all friends to give me their full support encouragement over the time.

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LIST OF SYMBOLS/ ABREVIATIONS

ACI	American Concrete Institute
ACIFC	American Concrete Institute for Fiber Reinforced Concrete
ASTM	American System for Testing Materials
C-S-H	Calcium Silica Hydrated (Gel)
DRC	Dry Rubber Content
FA	Fly Ash
HPC	High Performance Concrete
LWA	Lightweight Aggregate
LWA	Lightweight Aggregate Concrete
LWC	Lightweight Concrete
LWCA	Lightweight Coarse Aggregate
MST	Mechanical Stability Time
NRC	Non Rubber Contents
NWAC	Normal Weight Aggregate Concrete
NRL	Natural Rubber Latex
NWC	Normal Weight Concrete
OPC	Ordinary Portland cement

PIC	Polymer Impregnated Concrete
SF	Silica Fume
SP	Superplasticizer
TSC	Total Solid Content
VFA	Volatile Fatty Acid Number
W/B	Water/Binder ratio
W/C	Water/Cement ratio

CHAPTER 1

1. INTRODUCTION

1.1. General

Polymers are used in producing polymer modified concretes (PMC) in order to improve its workability, strength, drying shrinkage, and durability (Ohama, 1987; Ray, 1994). Because of the rapid setting, ability to withstand environmental conditions and high strength properties, PMC is increasingly being used as an alternative to Portland cement concrete in many applications, such as, highway pavements, construction and repair of structures, waste water pipes, bridge decks, and even structural and decorative construction panels.

The different uses of polymer indicate that no commercially available product could be compounded to perform all these tasks Therefore, the expression of polymer concrete can never suggest only one product but a family of all products. The further knowledge coming from advances in material science and coupling agents by collecting the information will be used to develop the database for PMC and their applications and properties (Rossignolo, 2002). On the other hand, economical and technical impacts to encourage the structural use of polymer to produce lightweight aggregate concrete (LWAC) has increasingly been raised (Alduaij et al., 1999; Haque et al., 1999).

Latex is the stable dispersion of polymer microparticles in an aqueous medium. Water is present as a medium of dispersion and this forms the major component (Bradley et al., 2006). Latexes may be natural or synthetic. Rubber latex system can be classified into two classes. The synthetic latex is normally obtained from emulsion addition polymerization and condensation polymerization. Natural latex is obtained from plants. Natural rubber latex (NRL) may be tapped off from part of plants, such as bark, roots, leaves, stems, tubers, and fruits (Sridee, 2006).

The use of network polymers, such as latexes or resins, to modify the properties of hardened mortars or concretes is not new (ACI548, 1991; Blaga et al., 1986). Examples include resin-impregnated concretes made by polymerization of a monomer absorbed into the hardened concrete or latex-modified mortars in which a part of the cement paste is replaced by latex which coalesces during hardening (Morin et al., 2011). In the literature, there have been some studies regarding performance properties of polymer latex modified mortars or concretes such as improving workability, drying shrinkage, strength characteristics, and transport features (Bala et al. 2010; Barluenga and Hemandez, 2004; Ohama, 1995; Özturan, 1995).

Structural lightweight concrete is defined as concrete having a minimum 28-day compressive strength of 17 MPa, and an equilibrium density between 1120 and 1850 kg/m^3 (ACI 231R-03, 2003). Reinforced concrete structures with reduced self-weight can be achieved through utilization of lightweight aggregates (LWA) in concrete production. LWAs can be either natural or artificial. The natural lightweight aggregates are generally obtained from volcanic sources such as crushed volcanic slag, volcanic tuff, and pumice. However, with increasing concern over the excessive exploitation of natural aggregates, synthetic lightweight aggregate produced from environmental waste is a viable new source of structural aggregate material. The uses of structural grade lightweight concrete (LWC) reduce considerably the self-load of a structure and permit larger precast units to be handled (Lo and Cui, 2004; Gesoğlu et al., 2012).

1.2. Objectives

The purpose of this thesis is to investigate the durability properties of natural rubber latex (NRL)-modified fly ash lightweight aggregate concrete, the investigated properties are water sorptivity, rapid chloride permeability, chloride penetration by soaking, and monitoring corrosion behavior via linear polorization resistance (LPR) test. Moreover, compressive strength test is applied at specified ages. The study consists of two stages. In the first stage of the study, the manufacturing of artificial lightweight aggregate by cold-bonding pelletization of fly ash and cement was achieved while the second stage includes the production of the NRL-modified lightweight concretes, and testing of the aforementioned properties. The tests are carried out at 28 and 90 days of water curing for compressive strength, water sorptivity, and RCPT. However, soaking and LPR tests require different procedure.

1.3. Thesis Organization

This thesis contains five chapters.
Chapter 1 presents the general information about the thesis. Moreover, objective and thesis organization, are presented.

Chapter 2 includes literature review and background about polymers and their use in concrete, lightweight concrete, properties of lightweight concrete, NRL, effect of NRL on properties of concrete.

Chapter 3 provides the experimental procedure adopted. Furthermore, the properties of materials (cement, fly ash, superplasticizer, production of lightweight aggregate) are given.

Chapter 4 presents the test results and discussion.

Chapter 5 presents contains the summary of findings and recommendations for future studies.

CHAPTER 2

2. LITERATURE REVIEW AND BACKGROUND

2.1. Lightweight Concrete (LWC)

Lightweight aggregate and lightweight aggregate concrete are not new materials. During the Roman Empire, both the Colosseum and the Pantheon were partially constructed with materials that can be characterized as lightweight aggregate concrete (aggregates of crushed lava, crushed brick and pumice) and it can be said that lightweight aggregate concrete has been known since the Roman Empire. (European Union, 1988)

Natural vesicular aggregates such as pumice and scoria have been used to produce lightweight concrete for over 2000 years. The Port of Cosa, the Pantheon Dome and the Coliseum, which were built during the Roman Empire, are three of the most famous structures. These structures stand today as the evidences of durabile structures lasting for centuries. For example, Pantheon is still in use for the aim for which it was designed. One of the most important basic rules in the construction of the structures is the minimizing the maintenance costs and getting a long service life (Bremner and Stepanoua, 1994).

It is revealed by the examination of Roman constructions; they preferred to use natural lightweight aggregates for making concrete. Utilization of large deposits of pumice and scoria is perhaps the reason for this. The deposits of these aggregates are found highly fissured beds that can be easily used to obtain suitable gradation for concrete aggregate. Using LWC increases the productivity of labor in construction. The LWC industry therefore, may be enhanced by this reason (Theodore and John, 1997). The photograph of typical lightweight concrete can be seen in Figure 2.1.

Figure 2.1 Lightweight concrete (Acheson and Glover, 2003)

2.1.1. Definition of Lightweight Concrete (LWC)

Presently, various definitions are used in systems and standards to define LWC, chiefly established on its density. The higher limitation of LWAC varies from air-dry density of 1840 kg/m^3 to 2100 kg/m^3 according to EuroLightCon Document of LWC Definitions and International Consensus Report (European Union, 1988). As for constructional LWAC, its compressive strength with density is needed together. In ACI 213-87, structural LWC is explained as concrete that has 17.2 MPa at 28 days as a lowest cylinder compressive strength with equivalent air-dry density not exceeding 1850 kg/m^3(ACI 213R-87, 1999).

Lightweight concrete, which has relative lower density than the conventional concrete, is a type of concrete in which special aggregate are used. While the volume of the mixture is occupied by lightweight aggregate, some additional qualities such as mobility and lower dead load can be obtained accordingly. In some countries such as the USA, the United Kingdom and Sweden, lightweight concrete is progressively used. The low density and thermal conductivity of lightweight concretes are the main advantages of using this type of concrete, as well as reduction of dead load. Moreover, faster building rate in construction and lower haulage and handling costs are the other advantages of using lightweight concrete. The cross-section of lightweight concrete specimen taken from the study of Ismail et al. (2003) can be seen in Figure 2.2.

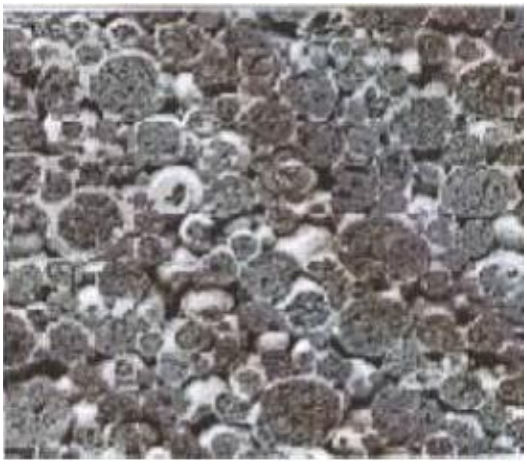
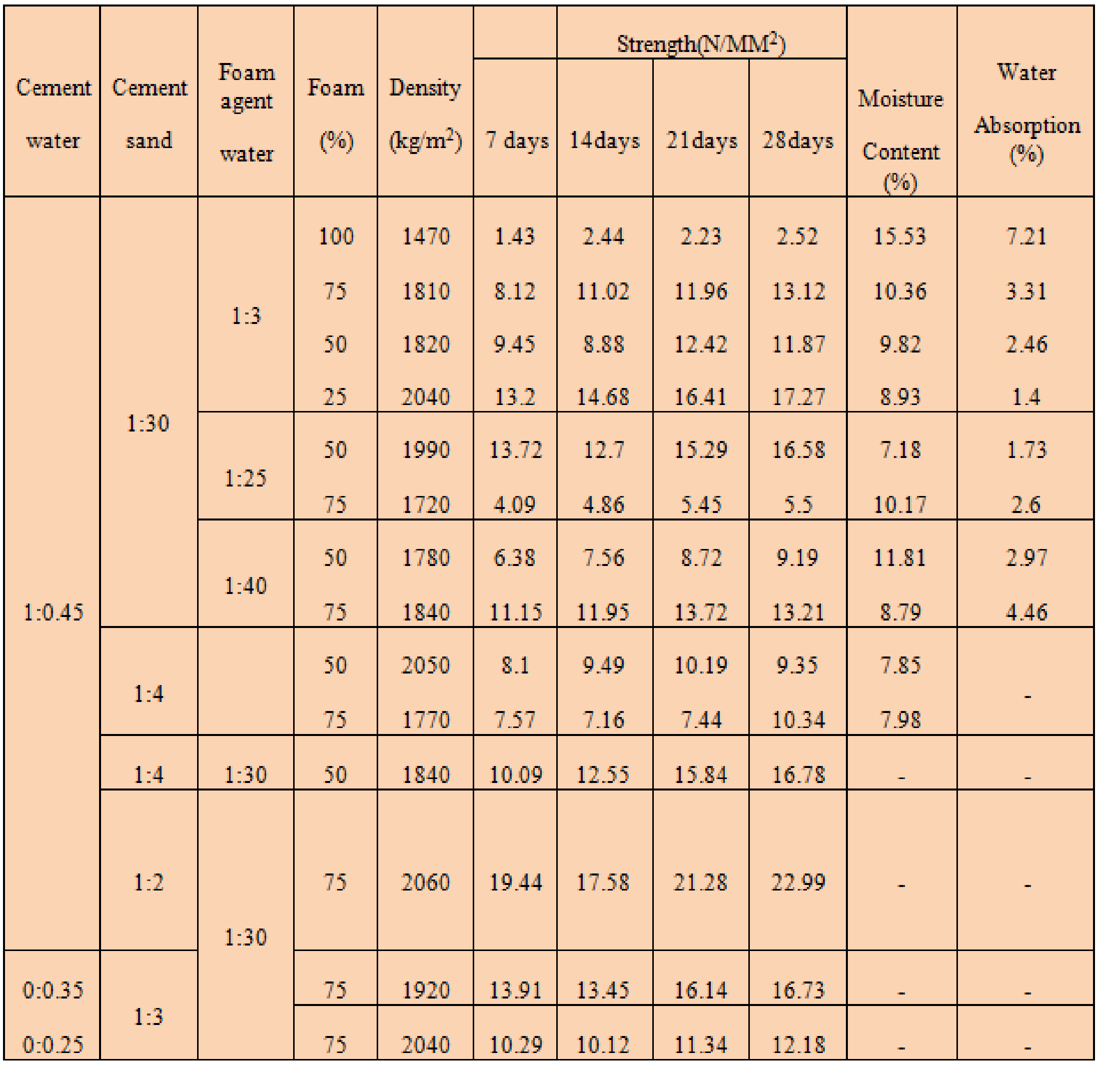


Figure 2.2 Lightweight concrete parts (Ismail et al., 2003)

Ismail et al. (2003) studied the performance of aerated lightweight concrete. They concluded that to obtain an adequate cohesion between cement and water, sufficient water-to-cement ratio was very important. Because inadequate water might result in lack of cohesion between cement and water while too much water may result in formation of laitance layers by run off aggregate due to cement. It would cause the weaker strength (Ismail et al., 2003). The properties of lightweight concrete in the study of Ismail et al. (2003) are presented in Table 2.1.

Table 2.1 The properties of lightweight concrete (Ismail et al., 2003)



Cement water	Cement sand	Foam agent water	Foam (%)	Density (kg/m^2)		Strength(N/MM^2)			Moisture Content (%)	Water Absorption (%)
					7 days	14days	21days	28days		
1:0.45	1:30	1:3	100	1470	1.43	2.44	2.23	2.52	15.53	7.21
			75	1810	8.12	11.02	11.96	13.12	10.36	3.31
			50	1820	9.45	8.88	12.42	11.87	9.82	2.46
			25	2040	13.2	14.68	16.41	17.27	8.93	1.4
		1:25	50	1990	13.72	12.7	15.29	16.58	7.18	1.73
			75	1720	4.09	4.86	5.45	5.5	10.17	2.6
		1:40	50	1780	6.38	7.56	8.72	9.19	11.81	2.97
			75	1840	11.15	11.95	13.72	13.21	8.79	4.46
	1:4		50	2050	8.1	9.49	10.19	9.35	7.85	-
			75	1770	7.57	7.16	7.44	10.34	7.98	
	1:4	1:30	50	1840	10.09	12.55	15.84	16.78	-	-
	1:2	1:30	75	2060	19.44	17.58	21.28	22.99	-	-
0:0.35	1:3		75	1920	13.91	13.45	16.14	16.73	-	-
0:0.25			75	2040	10.29	10.12	11.34	12.18	-	-

Although lightweight concrete was successfully used during the ancient Roman times, it does not lose its popularity due to the fact that it has lower density and has superior thermal insulation properties (Chandra and Berntsson, 2000).

The reduction in the dead load of structural elements by LWC makes it particularly attractive for multi-story buildings when it's compared with normal weight concrete (NWC). Semi lightweight concretes, which are produced by lightweight coarse aggregate and natural sand, are concerned with most studies. However, the total lightweight concretes for the investigations can be easily produced by using the commercially available lightweight fine aggregate (Berra and Ferrar, 1990). The waste materials can also be used as fine lightweight aggregate. They provide more environmental and economic benefits (Kayali and Hague, 1997). The using of lightweight concretes is expanded by enhancement in technology. For example, perlite, having outstanding insulation properties and being also used for vessels, roof decks and other application, is commonly utilized in masonry construction due to enhancing the fire ratings, reducing noise transmission, being incorruptible, and thermal resistance (Ismail et al., 2003).

2.1.2. Mechanical Properties of Lightweight Concrete (LWC)

In the United States, lightweight aggregate concrete used to build over 100 World War II ships. Their capacity ranged from 3000 to 140000 tons and using of lightweight aggregate concrete in buildings and bridges after their successful performance has been noticed (Ahmad, 2005). This may be considered as an evidence for possibility of production of LWC with proper mechanical performance.

In the study of Gesoğlu et al. (2013), LWCs incorporating steel fiber and silica fume (SF) were produced. They carried out a series of mechanical testing; such as compressive strength, splitting tensile strength, and the bond between rebar and LWC. They concluded that with incorporation of SF and steel fiber high performance LWC production can be achieved (Gesoğlu et al., 2013).

Mechanical performance of LWC is surely depending on the type of LWA. For example, Güneyisi et al. (2013) carried out an experimental study on durability aspects and mechanical properties of LWC produced with different types of LWAs. LWC produced with sintered LWA revealed relatively higher compressive strength than that of LWCs with cold-bonded LWA (Güneyisi et al., 2013).

2.2. Description of Polymers

The polymer is a large class of materials composing of many small molecules known as monomers; formations of long chains which are called as macromolecules which are made by the linkage of monomers. Polymers are classified as macromolecules which and micro molecules. A typical polymer may contain tens of thousands of monomers. Because of their large size, polymers are classified as micro molecules and macromolecules. The tars, oils, gums, and resins are the form of the polymer the humans have taken advantage of it during the centuries (Stevens, 1948).

Nevertheless, it was not until the industrial revolution to the modern polymer manufacturing began to develop. After 1830s, Charles Goodyear managed the production of natural rubber through a process called "vulcanization". 40 years subsequently some, and successfully marketed celluloid a hard plastic formed from nitrocellulose. In spite of this advancement, progress was slow in polymer science in the 1930s, when it was created substances such as vinyl, neoprene, polystyrene, nylon. The introduction of this revolutionary substances explosion in polymer research is continuing on the day (Stevens, 1948).

Unmatched in the diversity of their characteristics, using polymers such as cotton, rubber, and plastics all wool at almost every manufacturing. It can be produced the natural and synthetic polymers with a broad range of hardness, heat resistance, and density. With the continued search at the field of science and applications of polymers, they are playing an increasingly play in society ever before (Stevens, 1948).

Polymer monomer can be defined as; molecule that combines with others (different or identical) to form a polymer such as Ethylene (PE–polyethylene), also Oligomer: low molecular weight polymer, constituted of at least two monomers and Polymer: it has a long molecule made up by polymer the repetition of small modules synonym: macromolecule High molecular weight (M) such as, Polystyrene (Spratt, 1974).

Polymers are classified depending on their technical properties and scientific uses of the following items (Harris et al., 1996):

1 - Plastics heat plasticity (Thermoplastics): This product contains polymers that change characteristics influence of heat, which can turn to fuses.

2 - Rigid polymers thermally (heat plasticity or Thermoset Polymers): Experiencing these polymers, chemical changes happen when heated Vti_apk (cross-linked) where

thermally treated polymeric chains become insoluble and non-fusion and poor conductors of heat and electricity.

3 - Rubber elastic polymers (Elastomers): This type of polymers is characterized by its flexible and elongation qualities and its ability to stretch and contraction.

4 - Fiber (Fibers): This product is characterized with special polymers like the power durability and its ability to shape and must be polymeric chains capable of arrangement towards the axis of the fiber in order to gain strength and durability. Using a large proportion of these polymers in adhesive materials epithelium.

2.2.1. Polymer in Concrete

A polymer is a Latin word consisting of two syllables (poly) means multi and (Meir) which means part. The polymer molecule is made up of small chemical molecules associated with each chemical bond. The concept of (development) polymer concrete and mortar cement is not new. In 1923, the concept appeared for the first time by Crosson, where the use of clothing routes consisting of components natural rubber (natural rubber latexes) which used cement filler (filler). Where polymers are not added to the concrete in large quantities and 5% of the weight of cement is the percentage appropriate to add the polymer to concrete (Harris et al., 1996).

Many patents, applications and products about polymer were developed. In North America, latex modified concrete (LMC) was used in the overlay bridge in the state of Michigan in 1958, and also used in the corridors of Highway 401 in North York. Concrete mixtures of either type of a monomer or polymer in a scattered, liquid, Powder with fresh concrete mixtures and cement mortar can be made, and it can be processed afterwards that if that's needed (Ohama, 1995).

2.2.3. Polymer Impregnated Concrete

The application of polymer-impregnated concrete (PIC) for improving the durability of concrete slabs, especially highway bridge decks, has been widely investigated (Yimprasert et al., 1976).

Moreover partially impregnated concrete is usually accomplished by impregnating conventional portland cement concrete to a less-thanfull depth using a simple soaking technique, in contrast to fully impregnated concrete, which has been impregnated to the full depth of the section using the vacuum pressure technique. The partial impregnation is intended to provide the concrete with a relatively impermeable, in-depth protective zone to increase its durability (Bhutta and ohama, 1997).

While there would be some increase in strength in the impregnated zone, the primary purpose of partial impregnation is to increase durability by reducing the permeability. The chief function of the partial impregnation is to reduce the permeability of the concrete to moisture and aggressive solutions. The concrete pores in the impregnated zone contain fewer polymers than could be achieved with the full impregnation techniques (Fowler et al., 1995).

2.2.3. Polymer Modified Concrete

The polymer can modify the characteristics of concrete in three different ways. They are polymer impregnated concrete, polymer concrete, and polymer-modified concrete. The most commonly used is polymer-modified concrete (PMC). The polymer is introduced into the mix in the formation water-based emulsion and the polymers that are widely used are styrene-butadiene rubber (SBR) latex, ethylene-viny1 acetate (EVA) and polyacrylic ester (PAE) (Ohama, 1997).

Claims has been laid that polymer improves the workability and strength of concrete (Brandt, 1995). Polymer-modified concrete have two phases of strength development, in which the polymer and the cement hydration products commingle and create two interpenetrating matrices (Kardon, 1997).

Among the applications of polymer-modified concrete is in rehabilitation work of buildings and highways, and construction in a high chemical contains area. A lot of future use is foreseen as polymer modified concrete has a potential to be commercialized, as the market and raw materials is easily available (Makhtar, 2005).

A lot of claims have been laid that polymer-modified concrete improves workability but there is very little evidence available to substantiate it or make direct comparisons between fresh ordinary concrete and polymer-modified concrete (Bartos, 1992).

The latex has an important role to improve the interparticle bonds. Beside the strength of the mixture that agglomerate structure of the hardened cement paste usually consists of hydroxide, calcium silicate and aluminate bound together by relatively weak Van der Waal's forces. Therefore the first micro crack that happen in cement paste because of evaporation of excess mixing water. Polymers have a good role to reduce the micro crack in the matrix. By the polymer film bridge the macro crack propagation is restricts. Figure 2.3 shows latex modified concrete and Portland cement concrete (Ohama, 1987).

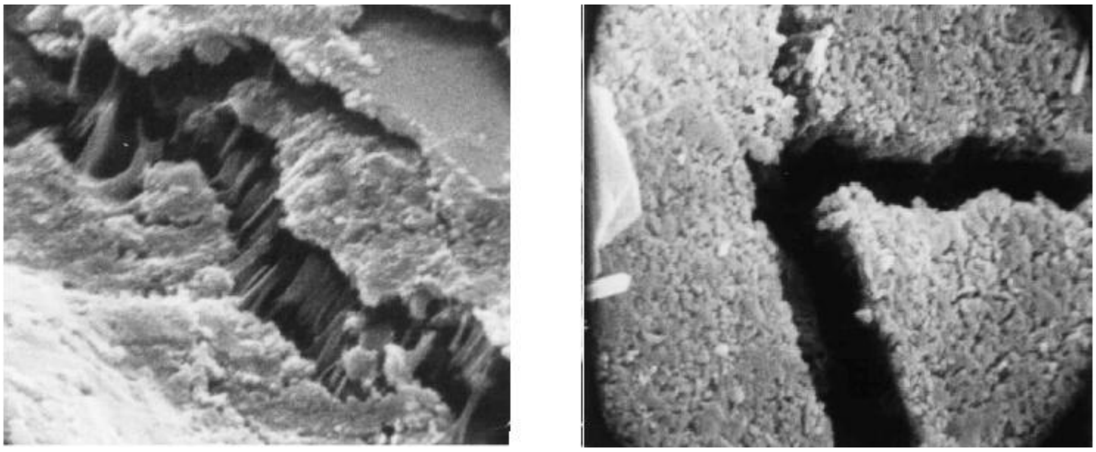


Figure 2.3 Latex modified concrete and Portland cement concrete (James, et al., 1995)

2.2.4. Effect of Polymers on Mechanical Properties of Concrete

Use of polymers with different types of fillers provides a good adhesion and good binding properties. Some of the studies are given below.

Mandel and Said (1990) conducted an experimental study on the effect of acrylic polymer on the mechanical properties of mortar they foundm that the mechanical properties of mortar and the adhesion between steel fiber and mortar improved by mixing acrylic polymer in the system (Mandel and Said, 1990).

Kim et al. (1995) studied the characteristic of polymer (polyvinyl alcohol-PVA) concrete and mortar, with use 2% of the polymer by weight based on cement by comparing the characteristic polymer (PMC) with those without polyvinyl alcohol.

Muthukumar and Mohan (2005) studied the chemistry and mechanical resistance properties of furan-based polymer concretes. They concluded that they were cost-effective materials for construction in civil engineering applications (Kim et al. (1995).

Aggarwal et al. (2007) reported the properties of (P M C) using acrylic emulsion and epoxy and found that these materials had superior strength properties and better resistance to the penetration of chloride ions and carbon dioxide than PMCs based on vinyl acetate, copolymers of vinyl acetate–ethylene, styrene–butadiene, styrene–acrylic, and acrylic-styrene-butadiene rubber emulsions (Aggarwal et al., 2007).

Ohama et al. (1994) investigated the effect of the monomer ratio on the typical properties of polymer-modified mortars with styrene-butyl acrylate latexes. They found that the properties (pore-size distribution, flexural and compressive strengths, water absorption, and drying shrinkage) were affected largely by both monomer ratio and polymer-cement ratio (Ohama et al., 1994).

2.2.5. Effect of Polymers on Durability of Concrete

The polymer has a long history in the construction industry where it begins with the use of natural polymer asphalt in the mortar of the clay brick walls of Babylonia back in the fourth millennium B.C. (Kardon, 1997). In 1909, official right was granted to Backland of the USA to use polymer in Portland cement concrete. This was followed by a few more countries namely France and Britain (Kardon, 1997).

The use of network polymers, such as latexes or resins, to modify the properties of hardened mortars or concretes is not new (ACI548, 1991, Blaga et al., 1986). Examples include resin-impregnated concretes made by polymerization of a monomer absorbed into the hardened concrete or latex-modified mortars in which a part of the cement paste is replaced by latex which coalesces during hardening (Morin et al., 2011). In the literature, there have been some studies regarding performance properties of polymer latex modified mortars or concretes such as improving workability, drying shrinkage, strength characteristics, and transport features (Bala et al., 2010; Barluenga and Hemandez, 2004; Ohama, 1995; Özturan, 1995).

2.3. Natural Rubber Latex (NRL)

Latex is a stable dispersion of organic polymer particles in an aqueous surfactant solution giving a milky fluid that is generally white to off-white in color. Latex’s are classified as two types based on ASM C1042-85. Type I, reemulsifiable latex, can be only in applications that are not subjected to immersion in water or humidity. Type II, non-remulsifiable latexes, can be used where water immersion or high humidity is expected (National Cooperative Highway Research Program, 1988).

Latexes disperse is used extensively for modified cement-based mortar and concrete because it allows to improve some unwanted characteristics of stiffness cement such as fragility and low motion strength. In addition, the cohesion and adhesion of new and markedly strengthened and mortar harden the concrete. These return the effects of plastic film-forming and that result from the fusion of the latex molecules when water is consumed by cement, water and evaporation (Gretz et al., 2010). Table 2.2 shows the chemical analysis of latex concentrate.

Table 2.2 Chemical analysis of latex concentrates (Bala et al., 2009)

Property	TSC%	DRC%	NRC%	PH	VFA%	NH3%	MST(s)	Type
Value	61.54	60.09	1.45	10.07	0.018	0.25	1227	Multiple

The first reference to latex was in the 16th century when Spanish explorers reported that some South American Indians were using rubber latex obtained from the tree. However, the first patent for latex used in mortars and concretes was obtained in Britain by Cresson on January 12, 1923 (Diamond, 1989). In recognition of the global development in the areas of elastomeric latexes, these substances were classified in ASTM C 1042-85 (2009) as emulsifiable latexes (Bala et al., 2009).

This historically important patent was issued for using cement as filler to paving materials with natural rubber latexes (NRL). Drying these particles coalesce to form a continuous film. An organic polymer is a substance composed of giant molecules formed by the union of a number of simple molecules known as monomers. Polymers can be divided into two groups: homopolymers and copolymers. When a polymer is made by the polymerization of one type of monomer, it is called a homopolymer; if it is made by the polymerization of different monomers, it is called a copolymer. Natural rubber latex (NRL) is a dispersion of polyisoprene (a homopolymer) that is polymerized by the tree (National Cooperative Highway Research Program, 1988).

Another patent was issued to Lefebvre in 1924 (Bosui J., 1990). He was the first person who intended to produce latex-modified mortars and concrete using the present concept of a mixture proportioning method. Using a similar idea, Kirkpatrick obtained a patent in 1925 (ACI Committee, 1991).

The patent for suggesting the use of synthetic rubber in latex-modified systems were first issued to Bond in 1932 (Emberson et al., 1990) and in 1933 a patent was issued to Rod well in Germany to apply synthetic resin latexes, including polyving1 acetate latexes. In the 1940, some patent on latex–modified systems with synthetic latexes such as polychoroprene rubber (neoprene) latexes and polyacrylicester latexes were issued. Polyvinyl acetates were also used for modifying mortars and concretes that found some practical applications. Griffiths conducted feasibility studies on the application of natural rubber-modified systems in the United Kingdom. The uses of synthetic latexes in latex-modified systems were also studied. Geist et al. (1953) conducted a basic study on polyvinyl acetate modified mortar and laid the foundation for valuable research on latex-modified mortar and concrete. Until the early 20th century, the only available latex was natural rubber latex. Since World War II, there has been a tremendous increase in the availability of other types of polymers on the market and there has been extensive research and development in latex-modified concrete systems. The initial investigation of styrene-butadiene latex-modified Portland cement was conducted in 1956 by the Dow Chemical Company in Michigan. A cooperative effort between Dow Chemical and the Michigan Highway Department resulted in field trial in 1958 (Bethany, 2007).

Since the 1960s, styrene-butadiene rubber, polyacrylicester, and polyvinylidene chloride-viny1 chloride modified mortars and concretes have been used increasingly in practical application. Research and development activities in polymer-modified mortar and concrete have been conducted in various countries, including the U.S., the former Soviet Union, Germany, Japan, and the U.K. In Japan, several standards for quality and testing methods of latex-type cement modifiers and latex-modified mortars have been issued as Japanese Industrial Standards (JIS). A bibliography, latex-modified concretes and mortars. A partially Annotated Bibliography of Their Performance Characteristics and Applications, is available as a separate document from the publications office, Transportation Research Board, 2101 Constitution Avenue, Washington, D.C (Bethany, 2007).

Due to improved performance in tensile , flexural, and bond strength, shock resistance, abrasion resistance, waterproofing and chemical resistance, latex-modified mortars and concretes have been used in many applications, such as deck coverings for ships, overlays for new bridge decks, repair of old bridge decks, highway and airport pavement , parking garages, new floors, floor topping steel coatings, adhesives tile adhesives, grout, stucco work, patch applications, and anticorrosive applications. Many researchers have reported satisfactory results when latex-modified system were used in surface coatings, pavement toppings and patching of damaged concrete. Styrene-butadiene rubber latex has been primarily used for bridge-deck overlays, floors, and parking garages, whereas, whereas acrylic polymers were mainly used as tile adhesive , grout, floor toppings, stucco, spray coats, terrazzo floor, and patching of damaged concrete. It has been reported by Shafer that a half-inch section of latex-modified system placed on a badly scaled and spelled Michigan bridge in 1957 performed well until 1970. Steel and Judy have reported that 18 bridge decks (where chloride ion penetration from the application of deicing salts was the major problem) that received a thin overlay of 1 to 2 in. Of latex-modified concrete or mortar in West Virginia has given encouraging results, particularly against chloride penetration (Bethany, 2007).

It was estimated that each year in the U.S., 1.5 million yd^2 ($1.25*106\ m^2$) of bridge receive overlays of PMC, mostly of styrene-butadiene latex-modified concrete. Marusin described repair techniques using acrylic modified cast-in-place Portland cement concrete in repairs of concrete columns, spandrels, and balconies on a high-rise housing complex in Chicago (Bethany, 2007).

2.3.1. Effect of NRL on Properties of Concrete

Latexes used for cement coating application and admixtures for LMC mortars for repair and rehabilitation. Acrylic latexes are used extensively in such construction and have excellent durability properties. Acrylics resist discoloration when exposed to elevated temperatures and are not attacking easily by acids and bases. Acrylics are chemically inert and are transparent in the spectral region between 350 and 300 nanometers (NM), which is the most photo chemically active region of the solar spectrum. Since acry1-ics are largely transparent to natural sunlight and do not absorb UV radiation, they are durable outdoors. However, modification of acrylics with other polymers that absorb UV radiation will reduce the durability of acrylic system for exterior applications (National Cooperative Highway Research Program, 1988).

Latexes are becoming more important because of their health and safety advantage over solvent – based products. Some of these advantages include (Ramakrishnan, 1992):

- No flammability,
- Nontoxicity ,
- Reasonable viscosity at 60 percent solids compared to a 10 percent limit for solvent-based systems, and
- Emulsion polymerization permits customization of properties.

CHAPTER 3

3. EXPERIMENTAL STUDY

3.1. Materials

3.1.1. Cement

Ordinary Portland cement was used in this study (CEM I 42.5R) conforming to the TS EN 197-1 (which mainly based on the European EN 197-1). It had a specific gravity of 3.15 g/cm^3 and Blaine fineness of 326 m^2/ kg. It was utilized in the production of both artificial aggregates and concretes. Physical and chemical properties of the cement are given in Table 3.1.

Table 3.1 Chemical and physical properties of cement and fly Ash.

Chemical composition	Cement	Fly ash
CaO	62.58	4.24
SiO_2	20.25	56.20
Al_2O_3	5.31	20.17
Fe_2O_3	4.04	6.69
MgO	2.82	1.92
SO_2	2.73	0.49
K_2O	0.92	1.89
Na_2O	0.22	0.58
Loss of ignition	3.02	1.78
Specific gravity	3.15	2.25
Blaine fineness(m^2/kg)	326	287

3.1.2. Fly Ash

A class F fly ash (FA) conforming to ASTM C 618 was utilized for manufacturing cold-bonded artificial fly ash aggregates. It was provided from Ceyhan Sugözü thermal power plant located in Mediterranean region in Turkey. FA has a specific gravity of 2.25 and specific surface of 287 m^2/kg. Table 3.1 presents the chemical and some physical characteristics of the fly ash used.

3.1.3. Superplasticizer (SP)

The superplasticizer was adjusted at the time of mixing to realize the specified slump. Table 3.2 indicates the properties of SP.

Table 3.2 Properties of superplasticizer

Property	Superplasticizer
Name	Daracem 200
Color	Dark Brown
State	Liquid
Specific Gravity (kg/lt)	1,19-1.2
Chemical	Sulfonated Naphthalene Formaldehyde
Freezing Point	-4 ^{0}C

3.1.4. Lightweight Aggregate

In the first stage of the experimental program, lightweight fly ash aggregates were produced through the cold bonding agglomeration process of fly ash and Portland cement (PC) in a tilted pan at an ambient temperature. For this, 10% PC and 90% FA were mixed in powder form in the pelletizer as shown in Figure 3.1. After the dry powder mixture of about 10-13 kg was fed into the pan, the disc was rotated at a constant speed to assure the homogeneity of the mixture (Figure 3.2). The amount of sprayed water used during pelletization process has been determined as the coagulant to form spherical pellets with the motion of rolling disc (Gesoglu, 2004; Arslan and Baykal, 2004). Then, the water was sprayed on the mixture with a quantity of 22 % by weight. The formation of pellets occurred between 10-12 minutes in trial productions (Figure 3.3). The total pelletization time was determined as 20 minutes for the compaction of fresh pellets. Finally, they were kept in sealed plastic bags for 28 days in a curing room in which the temperature and relative humidity were 21^{o}C and 70%, respectively (Figure 3.4). At the end of the curing period, hardened aggregates were sieved into fractions of 0-4 mm and 4-16 mm sizes to be used as fine and coarse aggregate in concrete production, respectively, as shown in Figure 3.5.

Figure 3.1 General shape of the pillarization disc

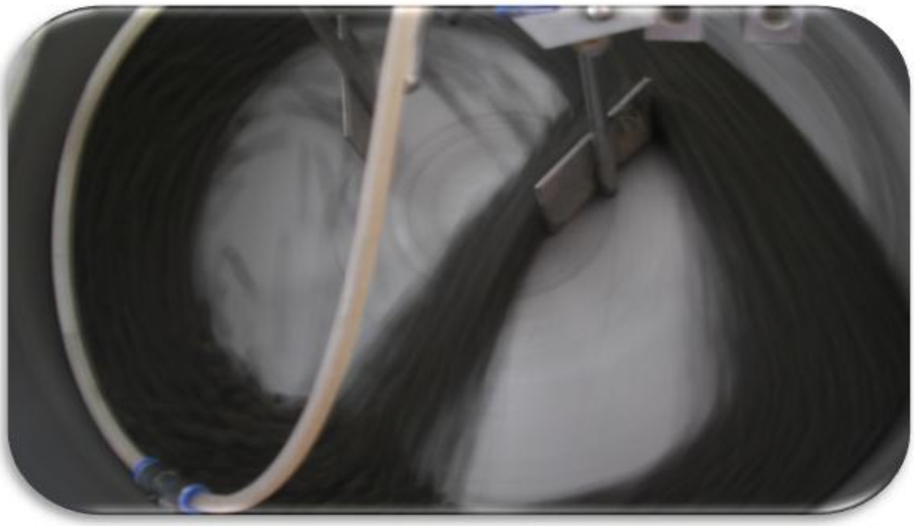


Figure 3.2 After poured material in pelletization disk

Figure 3.3 Spherical pellets formation after approximately 20 minutes

Figure 3.4 Moisture curing of fresh aggregates by keeping in sealed plastic bags

Figure 3.5 Lightweight aggregate stock after 28 days curing

3.1.5. Natural Rubber Latex (NRL)

In this study, the properties of natural rubber latex (NRL) modified lightweight concretes (LWCs) were investigated. For this purpose, NRL from Indonesia was utilized as polymer modifier.

Use natural rubber latex primarily found in Indonesia. Natural rubber latex is produced from the heave Brasiliensis rubber tree. These trees are grown on large plantations. As shown in Figure 3.6 natural rubbers latex is a bleary, white liquid that is collected by cutting thin strips of bark from the tree, and allowing the latex to drop into collecting pots private. The natural rubber latex is then gathered, poured into containers, and its processing this material to station where it is sprained or concentrated (http://www.chemionics.com/natlatex.html, 14.01.2012).

Figure 3.6 Brasiliensis rubber tree (http://www.chemionics.com/natlatex.html, 14.01.2012)

3.1.6. Mix Proportion

The natural rubber latex was used as addition in concrete production, naphthalene sulphonated formaldehyde based superplasticizer was also used to provide the slump of 14±2 cm. The concrete mixture without NRL was designated as control while the others were denoted as 2% NRL and 5% NRL. The solid NRL/total binder content was used as 0.0, 0.02, and 0.05 for the mixtures. LWC mixtures with water-to-binder ratio (w/b) of 0.40 and binder content of 400 kg/m^3 were designed. Volume fractions of coarse and fine aggregates were equal for each mixture. Fly ash (FA) was also used as 20% of the total binder content. To ensure a constant w/b ratio, the amount of water was decreased by 52% of the weight of NRL Table 3.3 shows the details of the concrete mixtures.

Table 3.3 Details of the mix proportions of the concretes

Mix ID	Water	Cement	Fly ash	Latex	LWCA*	LWFA*	SP*	Unit weight
Control	**160**	**340**	**60**	**0.0**	**666.6**	**645.8**	**6**	**1878**
2% NRL	**148.7**	**340**	**60**	**21.3**	**660.2**	**639.8**	**3**	**1873**
5% NRL	**137.5**	**340**	**60**	**42.6**	**647.5**	**627.4**	**6**	**1860**

*LWCA: Lightweight coarse aggregate,

*LWFA: Lightweight fine aggregate,

*SP: Superplasticiser

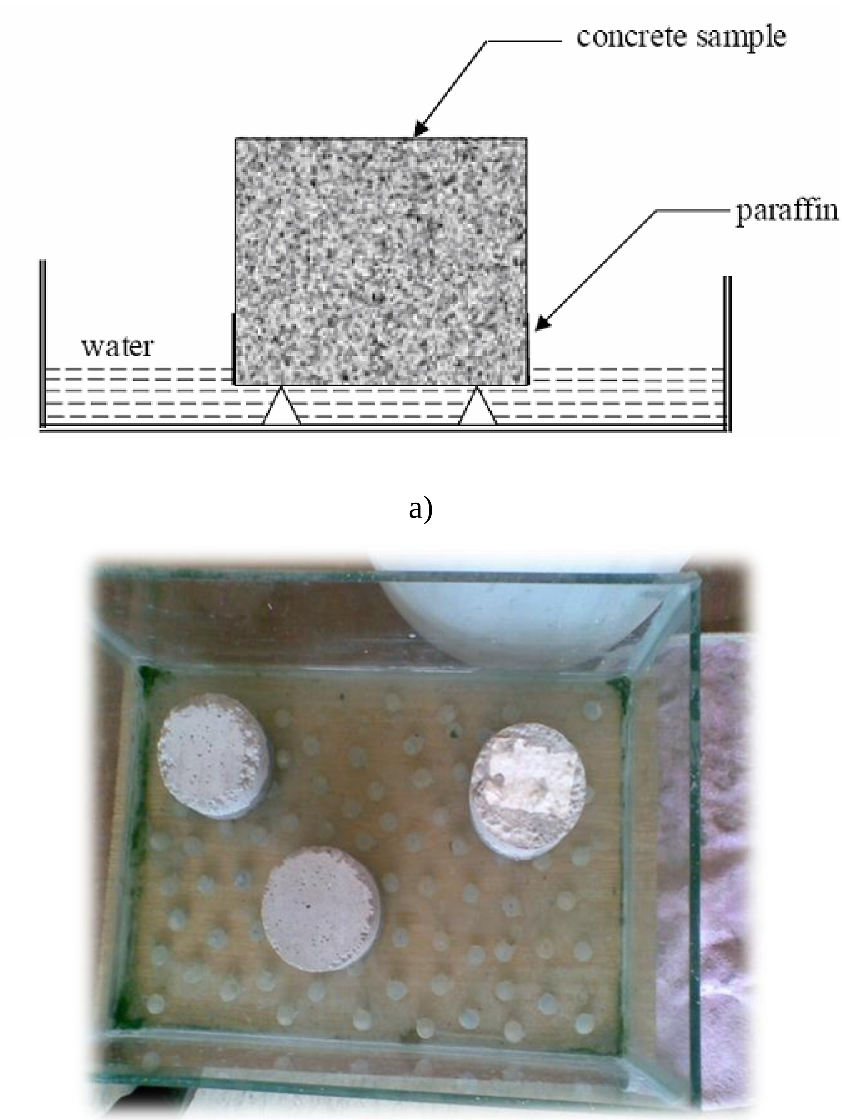
3.2. Tests for Mechanical Properties

3.2.1. Compressive Strength

The concrete cubes (100x100x100 mm) were used for the compressive strength test at the end of 28 and 90 days of water curing. The compression test was carried out on the specimens by a 2000 KN capacity testing machine. The test procedure followed during the test was in conformity with ASTM C39 (2012). Three specimens from each mixture were tested at each testing age, to monitor the compressive strength development. The compressive strength was computed from the average of three specimens at each testing age.

3.2.2. Sorpitivtiy

The sorptivity test measures the rate at which water is drawn into the pores of concrete. For this, three test specimens having a dimension of Ø100x50 mm are employed. The specimens are dried in an oven at about 50 ^{o}C until constant mass and then allowed to cool to the ambient temperature in a sealed container. Afterwards, the sides of the specimens are coated with paraffin and as shown in Fig. 3.8a-b, the sorptivity test is carried out by placing the specimens on glass rods in a tray such that their bottom surface up to a height of 5 mm is in contact with water. This procedure is considered to allow free water movement through the bottom surface. The total surface area of water within the tray should not be less than 10 times that of the specimen cross-sectional area. The specimens are removed from the tray and weighed at different time intervals up to 1 hour to evaluate mass gain. The volume of water absorbed is calculated by dividing the mass gained by the nominal surface area of the specimen and by the density of water. These values are plotted against the square root of time. The slope of the line of the best fit is defined as the sorptivity coefficient of concrete. For each test, the measurements are obtained from three specimens and the average values are reported. The test was conducted at the ages of 28 and 90 days.



a)

d)

Figure 3.7 View of sorptivity test

3.2.3. Chloride ion penetration

The prismatic test specimens (100x100x500-mm) after being subjected to 28 days of initial water curing were soaked continuously in 3% NaCl solution for 90 days. At the end of 90-day chloride exposure period, the test specimens were withdrawn from the soaking to determine the depth of chloride penetration into the control and NRL modified concretes. For this, the prisms were first split at mid-point and the freshly split surfaces were soon sprayed with 0.1N silver nitrate ($AgNO_3$) solution. The $AgNO_3$ solution preferentially reacts with the free chloride present in the harden matrix to form a white precipitate of silver chloride (AgCl); whereas at greater depths, where free chlorides are absent, $AgNO_3$ reacts with the hydroxides to form a brown precipitate of silver oxide (AgO). Thus, the depth of chloride penetration is clearly indicated as the boundary of color change (Güneyisi and Mermerdaş, 2007; Otsuki et al., 1992). Measuring the depth of color change was performed from the four sides of the split section at intervals of 20 mm. Measurements made close to the corners of the section were ignored (Figure 3.8).

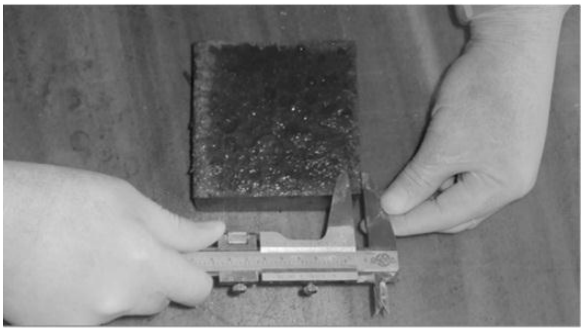


Figure 3.8 Measuring the chloride penetration depth

3.2.4. Linear polarization resistance (LPR)

The term linear polarization refers to the linear regions of the polarization curve, in which slight changes in current applied to corroding metal in an ionic solution cause corresponding changes in the potential of the metal (Liu, 1996). This technique uses a single voltage scan or ramp programmed from an initial potential to a final potential (range generally limited to +/- 20mV vs. open circuit at Ecorr) that progresses at a defined step height per step time. Technique also referred to as LPR, provides capability to calculate corrosion rate. The linear polarization resistance method has been considered to be a relatively simple and reliable technique to assess the rate of corrosion reinforcement in concrete (Maslehuddin and Al-Amoudi, 1992; Andrade et al., 1986).

Corrosion current density (Icorr) value of less than 0.1 $\mu A/cm^2$ indicates negligible corrosion, while a value greater than 0.3 μA/cm2 indicates active corrosion (Rodrigez et al., 1994). Therefore, in this investigation, an Icorr value of 0.3 $\mu A/cm^2$ was considered as the threshold criterion for corrosion initiation. The corrosion current density was measured using the DC linear polarization resistance method with lower potentials. The resistance to polarization (Rp) was determined by conducting a linear polarization scan in the range of ±25 mV of the open circuit potential at a scan rate of 0.1 mV per second. The corrosion current density (Icorr) will be then calculated using the Stern–Geary Formula (Equation 3.1) (Stern and Geary, 1957). B is calculated by the formula given in Equation (3.2).

$$I_{corr}=B/R_p \tag{3.1}$$

$$B= (\beta_a.\beta_c)/(2.303(\beta_a+\beta_c)) \tag{3.2}$$

Where B is a constant based on the anodic and cathodicTafel constants (βa and βc) and R_p is polarization resistance (Stern and Geary, 1957). The value of B was taken as 26 mV considering steel in active condition (Maslehuddin and Al-Amoudi, 1992).

In this study, VersaSTAT 3 a potentiostat/galvanostat with an optional frequency response analyzer (FRA) contained in a single unit was used to polarize the steel at a rate of 0.1 mV/s. Tafel constants were utilized in the calculation of the corrosion current density. The test set up is schematically illustrated in Figure. 3.9.

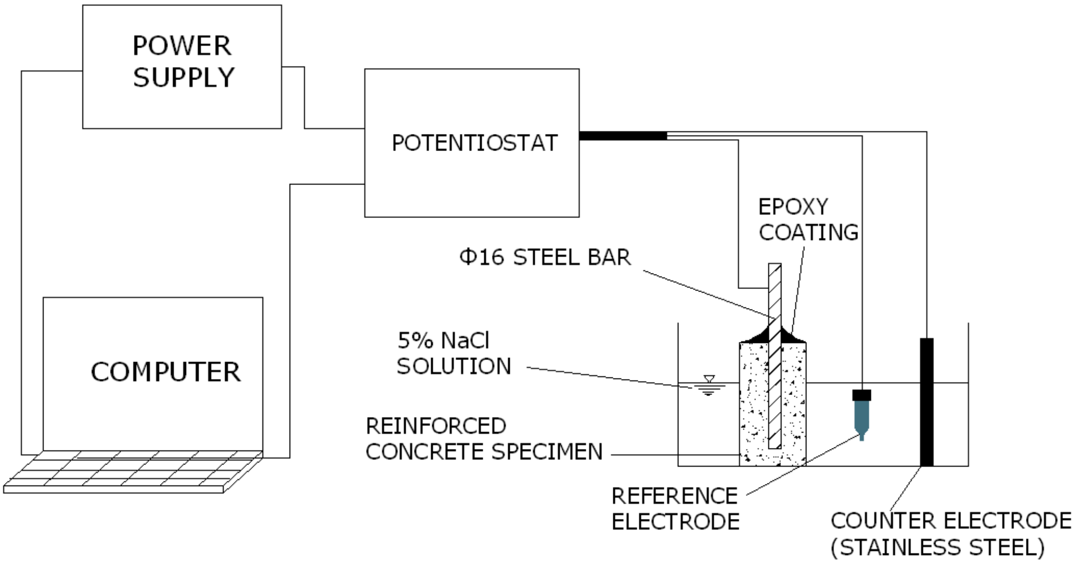


Figure 3.9 Schematic presentation of the linear polarization resistance test set up

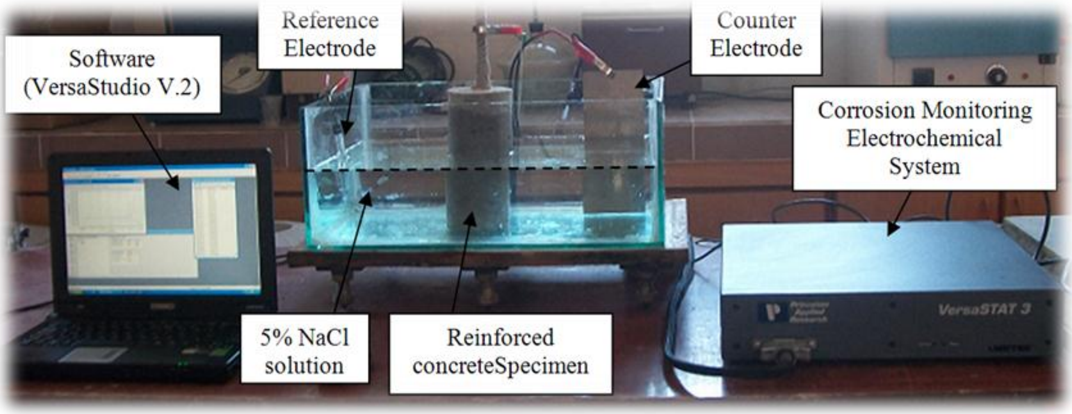
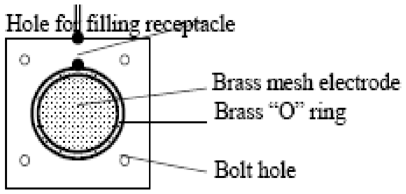


Figure 3.10 View of the potentiostat/galvanostat test set up

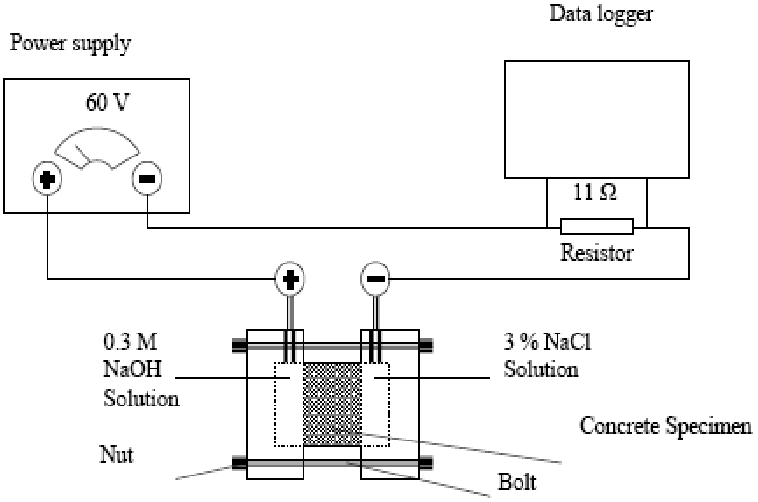
In Figure 3.10, the view of the potentiodynamic test set up was also presented. This test was applied to the LWCs incorporating 0%, 2%, and 5% NRL respectively. Moreover, a chloride exposure regime with immersion of the specimens into 3% NaCl solution was adopted. After 7 days of initial water curing, the concrete specimens were transferred to 3% NaCl solution. Corrosion rate monitoring through linear polarization resistance method was carried out over 40 weeks of exposure at various exposure periods.

3.2.5. Rapid chloride penetration test (RCPT)

The rapid chloride permeability test (RCPT) was conducted in order to determine the resistance of the concretes to the penetration of chloride ions according to ASTM C 1202 (2012). Three specimens for each mortar mixture will be tested simultaneously at each testing age (28 and 90 days). After curing, a 50 mm thick disc sample is cut from the middle of each Ø100x200 mm cylinder and moisture conditioned as mentioned in ASTM C1202 (2012). Then, the disc specimens are transferred to the test cell in which one face of the specimen is in contact with 0.30 N NaOH solution and the other face is with 3% NaCl solution (Figures 3.11 and 3.12). A direct voltage of 60.0 ± 0.1 V is applied across the faces. A data logger registered the current passing through the concrete specimen over a period of 6 hours. Terminating the test after 6 hours, current (in amperes) versus time (in seconds) are plotted for each concrete and the area underneath the curve is integrated to obtain the charge passed (in coulombs). ASTM C1202 (2012) classifies the chloride permeability into five classes from ‘High’ to ‘Negligible’ on the basis of the coulombs calculated (Table 3.3).



A. Acrylic receptacle



B. Test Setup

Figure 3.11 Schematic presentation of the test set up for RCPT

Figure 3.12 Photographic view of the RCPT test set up

Table 3.4 Interpretation of the test results obtained using RCPT test (ASTM C1202, 2012)

Charge passed (Couloumbs)	**Chloride permeability**
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligable

CHAPTER 4

4. TEST RESULTS AND DISCUSSIONS

Some durability and mechanical properties of natural rubber latex (NRL) modified lightweight concretes (LWC) produced with cold-bonded fly ash aggregates were investigated in this study. The test result regarding the compressive strength, chloride permeability by soaking and rapid testing, water sorptivity test and monitoring the corrosion behaviour of reinforcement embedded in concrete by linear polarization resistance (LPR) test has been given and discussed in the following sections.

4.1. Compressive Strength

Compressive strength test results obtained from cube specimens are shown in Table 4.1. Moreover, the compressive strength development was graphically depicted in Figure 4.1. Addition of NRL caused considerable reduction in compressive strength of the concrete. Control concrete at both ages showed higher compressive strength. Increasing amount of NRL resulted in systematic decrease in compressive strength values. For example, 2% and 5% NRL addition caused 38% and 58% decrease in 28 day compressive strength, respectively. It is reported that the latex coalesces into continuous films or membranes and these bind the cement hydrates together to form a monolithic network (Ohama, 1987and Sakdapipanich, 2007). Ismail et al. (2011) stated that the excess latex tends to prevent the aggregate particles from becoming closer, thereby creating weaker regions for earlier crack developments during mechanical- property tests. Therefore, the mechanical properties of NRL modified concretes deteriorate for increased amounts. Similarly, in the study of Ismail et al. (2011), increasing the rates of NRL incorporation resulted in continuous fall in compressive strength of the concrete.

Table 4.1 Compressive strength test results

Mixture	**Compressive strength (MPa)**	
	28 days	90 days
Control	26.1	32.2
2% NRL	16.0	23.2
5% NRL	10.6	13.9

ACI-213R (1999) defines structural lightweight concrete as the concrete made with lightweight aggregate with the air-dried unit weight at 28 days is usually in the range of 1440 to 1850 kg/m^3 and the compressive strength is more than 17.2 MPa. As seen from Figure 4.1, incorporation NRL into LWC resulted in lower compressive strength than the limiting value specified in ACI code. However, based on the tendency observed from the figure, it may be suggested that utilization of NRL lower than 2% appears to be suitable for mix designs satisfying the limiting 28 day compressive strength value required for the structural concrete. Therefore the LWCs produced in this study can be suggested as thin overlay repair or insulation material.

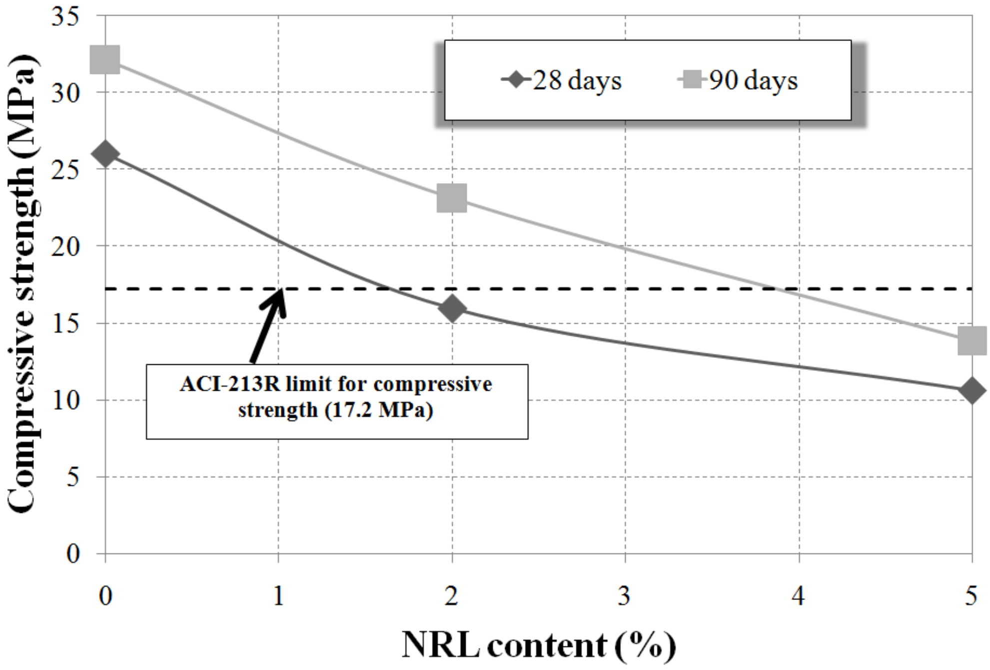


Figure 4.1 Compressive strength development of plain and NRL modified LWCs

4.2. Water sorptivity

The variation in sorptivity values with curing age and the amount of NRL is given in Table 4.2 and Figure 4.2. The sorptivity values ranged between 0.22 and 0.37

mm/min$^{1/2}$, mainly depending on amount of NRL and testing age. The influence of NRL on the sorptivity of the concretes is appeared to be significantly positive. For example, 5% NRL incorporation provided 38% and 40% reduction in sorptivity values for testing ages of 28 and 90 days, respectively.

Table 4.2 Water sorptivity test results

Mixture	Sorptivity (mm/min$^{1/2}$)	
	28 days	90 days
Control	0.372	0.359
2% NRL	0.311	0.306
5% NRL	0.233	0.217

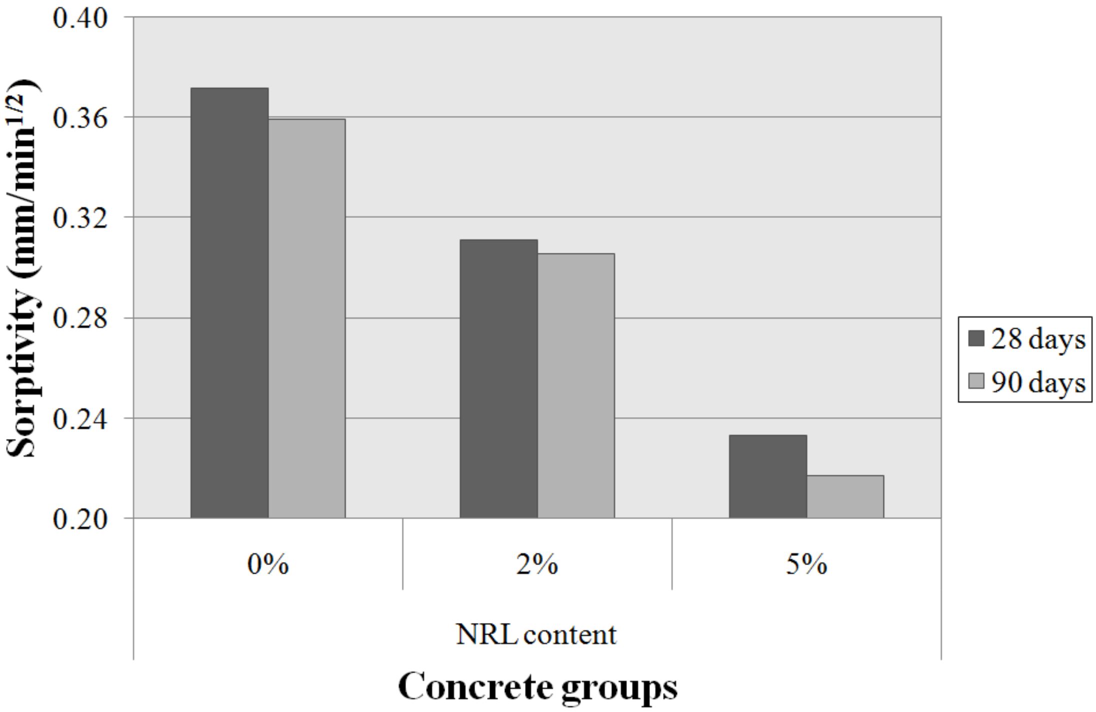


Figure 4.2 Sorptivity test results of plain and NRL modified LWCs

As the time passes, the concretes with fly ash (FA) reveals important enhancement in sorptivity values when compared to the ones without FA. However, due to the fact that the amount of FA was kept constant in the concrete mixtures the level of improvement in sorptivity values were not so much as the age increased. The main governing factor, therefore, is the inclusion of NRL. The result reported by İsmail et al. (2011) revealed that as a result of using waste latex paint (WLP) in concrete the water absorption of concrete is decreasing when the WLP content was increasing. They explain this as a result of the pore-blocking effect of the polymer particles (Mohammad et al., 2008). Moreover, it was notified that polymer is a water-impermeable material, so the polymer particles which distribute in the concrete pores will block the water to infiltrate through the concrete particles.

4.3. Resistance to chloride ion penetration (RCPT)

In order to evaluate the resistance of LWCs with and without NRL against chloride ions, two different chloride resistances testing were utilized. The test results of electrical indication of chloride permeability in terms of total charge passed are shown in Table 4.3 and Figure 4.3. Moreover, the results of soaking test are graphically demonstrated in Figures 4.4 and 4.5, indicating chloride penetration depth profile and the corresponding chloride penetration coefficients respectively.

The measured total charges passed values for LWCs with and without NRL were in the range of 3696-9681 C and 4780-10171 C, respectively. ASTM C1202 classifies the chloride penetrability of concretes as “high” for total charge values above 4000 C and “moderate” for the values between 2000 C and 4000 C. From the results presented herein, it was observed that LWC having high chloride ion penetrability could be improved through utilizing NRL with 5%, resulting in moderate rating. Based on this result the LWCs produced in this study are in "high" chloride permeability class as per ASTM C1202. Depths of chloride penetration for LWC without NRL were in the range of about 9 to 19 mm, while those with NRL had penetration depths between 6 and 17 mm, respectively, depending mainly upon the amount of NRL and period of immersion. The analytical expression of chloride penetration by a coefficient can be considered as an effective way to characterize the chloride permeability of the concretes. The coefficients calculated are 3.85, 3.27, and 2.71 mm\week$^{1/2}$, respectively.

Table 4.3 illustrates that unlike sorptivity test results reduction in chloride permeability of LWCs due to NRL incorporation was not as effective as the age. However, the results given presented in soaking test results proved that inclusion of

NRL provided high rate of decrease in chloride penetration depth and the calculated penetration coefficients. This can be explained by the fact that the rapid chloride permeability test is not a direct indication of chloride permeability. The most critical parameter affecting the obtained results is chemistry of the matrix of the concrete solution as well as pore structure. Complicated nature of the chemical mechanism together with the inclusion of NRL may reflect a misleading indication of chloride penetration resistance by RCPT.

Table 4.3 Rapid chloride permeability test result

Mixture	**Rapid chloride permeability(Coulumbs)**	
	28 days	90 days
Control	10172	4781
2% NRL	9681	4149
5% NRL	7738	3696

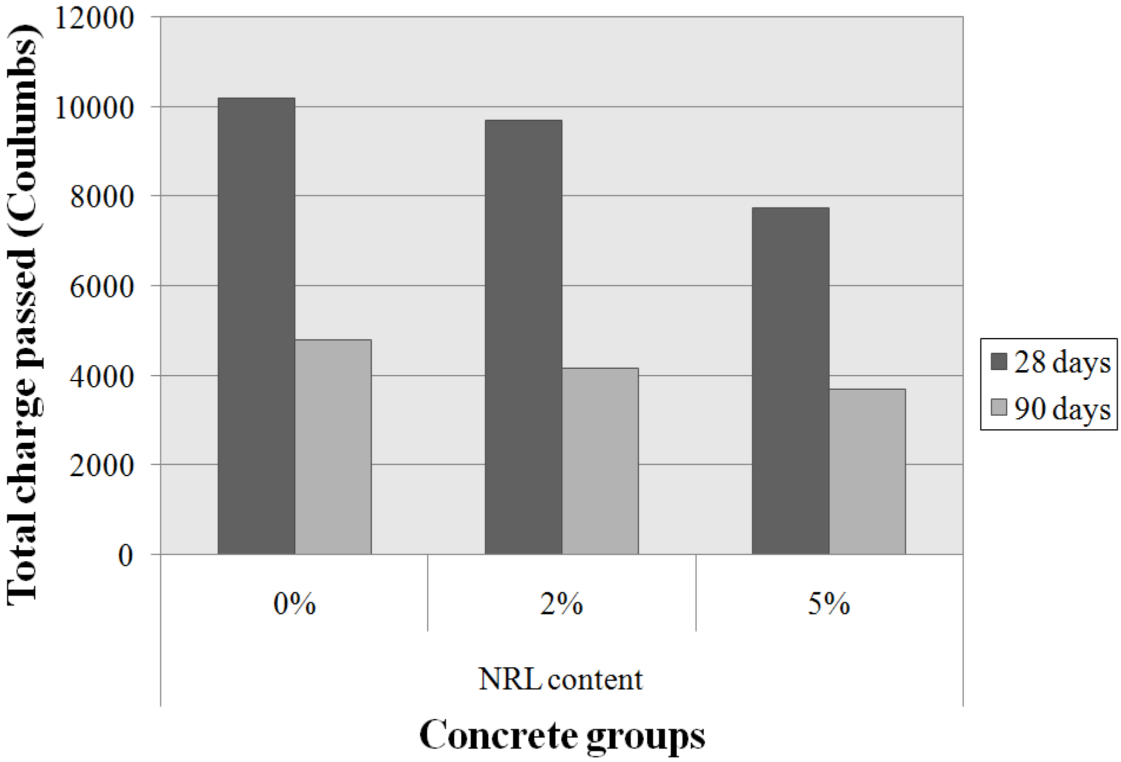


Figure 4.3 Rapid chlorite penetration showing the total charge passed

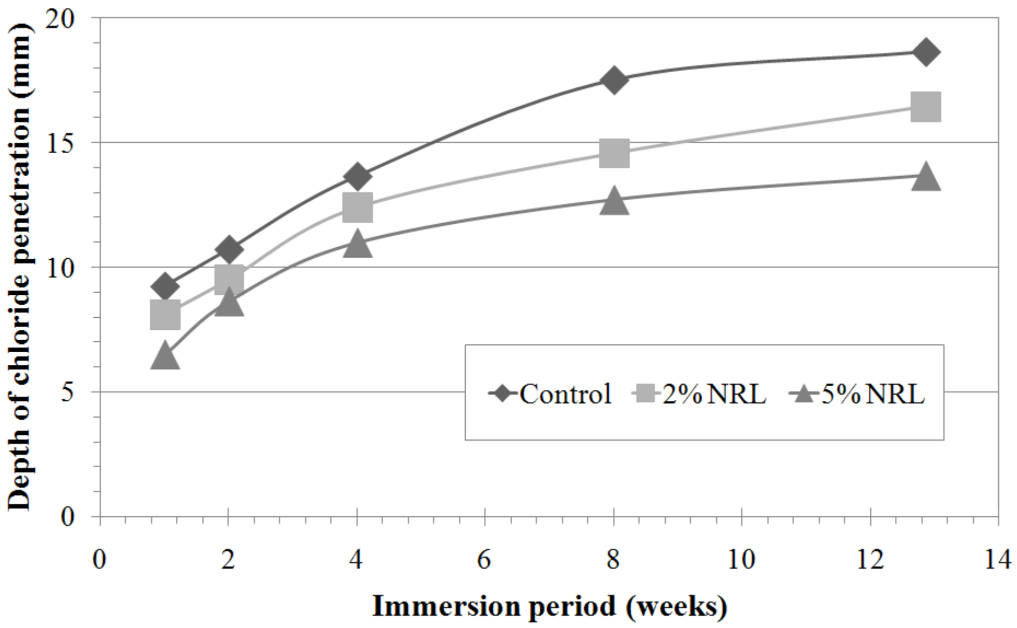


Figure 4.4 Chloride ion penetration depth (mm)

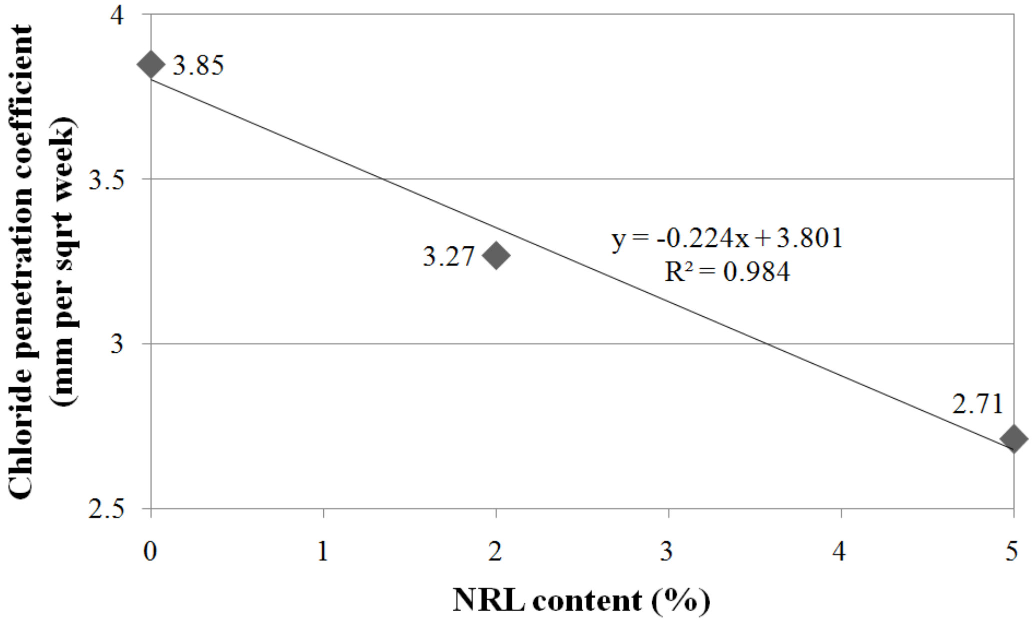


Figure 4.5 Chloride ion penetration coefficients

Ismail and Bala (2012) performed a study on the durability performance of the concretes incorporated with NRL. They reported experimental findings on performance of natural rubber latex (NRL) modified concrete in acidic as well as sulfated environments. They revealed that inclusion of appropriate quantity of latex into concrete plays a significant role in curbing attack of H_2SO_4 and Na_2SO_4. In the study of Neelamegam et al. (2000), it was reported that significant reduction in water absorption of NRL-modified mortar when compared with the normal mix was observed. The main impact of the latex made on the total water absorbed by the modified mortar was mainly due to reduced porosity in the modified phase.

4.5. Linear polarization resistances (LPR)

Linear polarization resistance (LPR) is used to rapidly identify corrosion upsets and initiate remedial action, thereby prolonging service life and minimizing unscheduled downtime. LPR can be utilized as a high accuracy corrosion monitoring system in almost all types of water-based, corrosive environments.

The effect of NRL incorporation and exposure periods on the variation of corrosion current density (Icorr) by LPR is shown in Figure 4.6. As it can be observed from the figure, although the tendency of the variation was not so clear up to first five weeks of exposure, the effectiveness of NRL become distinguishable after this time. As a result of pore blocking effect and the continuation of the hydration resulted in the decrease of I_{corr} values up to 30 weeks. However, from this point ahead the chloride attack due to permanent exposure dominated the enhancement of the concrete due to hydration. Besides, the I_{corr} values measured for the LWC without NRL progressively increased between the time intervals of 5-40 weeks of exposure period.

In the literature, there have been different discussions on the corrosion behavior of steel bar embedded in concrete based on the value of the corrosion current density result. Several researchers have determined that current density values which are greater than 0.3 $\mu A/cm^2$ may be indicative of active corrosion (Andrade et al., 1990; Al-Amoudi et al., 2003). Andrade and Alonso (2001) have reported a set of data for the levels of corrosion rates. They stated that corrosion current density between 0.1 $\mu A/cm^2$ and 0.5 $\mu A/cm^2$ can be considered as low and the values between 0.5–1 $\mu A/cm^2$ are moderate. However, the current density values greater than 1 $\mu A/cm^2$ are considered high while the values below 0.1 $\mu A/cm^2$ are assumed to be negligible

(Gonzales et al., 1996; Andrade and Alonso, 2001). Gonzalez et al. (1996) claimed that corrosion current density less than 0.2 µA/cm^2 would be acceptable with no durability risks. Other researchers have nominated the value of 0.3 µA/cm^2 as the threshold for active reinforcement corrosion (Al-Amoudi et al., 2003). However, rates that are above the value of 1 µA/cm^2 are considered as hazardous (Rodriguez et al., 1994). In the light of this information, it can be inferred that utilizing NRL can effectively decrease the I_{corr} values below the critical levels depending on the replacement level and chloride exposure period.

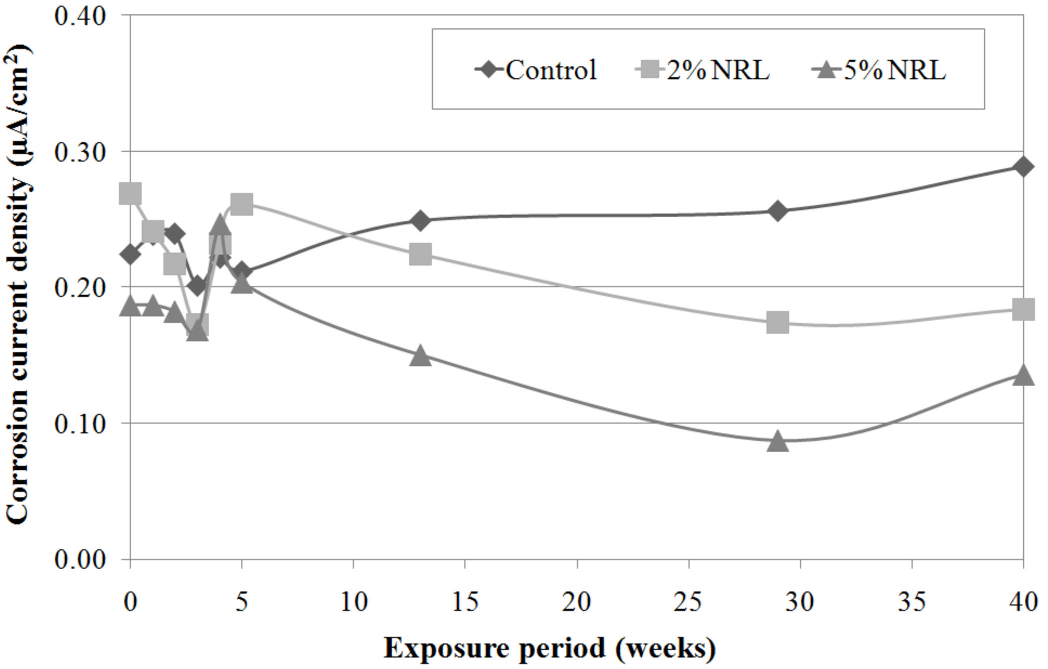


Figure 4.6 Variation of the I_{corr} values of LWCs produced with and without NRL

CHAPTER 5

5- Conclusion

The primary purpose of this research was to assess the effects of natural rubber latex (NRL) on engineering properties of concrete. For this, basically three different concrete mixtures with different mix proportions were taken into account during the experimental study. The following conclusions can be drawn from the experimental results presented.

- LWC with a unit weight of approximately 1880 kg/m^3 was produced through using LWA manufactured from cold bonding pelletization of FA. The unit weight of LWC can also be decreased up to 1860 kg/m^3 due to NRL incorporation. However, it was noticed that NRL did not help in enhancing the workability of fresh concrete as was determined from the slump test where the more polymer added, the lower the workability was measured.

- NRL did not contribute in improving the compressive strength of the concrete for the amounts used in this study. However, with the use of 2% NRT, compressive strength of 2%, 15.0 MPa in 28 days and 23.2 MPa in 90days was achieved for the concrete. There was 25% increase in compressive strength of control concrete at 90 days when compared to the results of 28 days. However, the concretes with 2% NRL and 5% NRL gained 45% and 3% compressive strength at 90 days, respectively. For the same period of time, it was also observed that existence of higher amounts of NRL membranes or films within concrete resulted in less compressive strength with respect to control mixture.

- As a result of incorporating NRL into concrete, noticeable reductions in chloride penetration depth were observed. 10% and 15% reduction in chloride ingress depth were observed for the LWCs, modified with 2% and 5% NRL, respectively. Moreover, the chloride penetration coefficients of NRL incorporating LWCs were much lower than the control concrete. Improvement in rapid chloride permeability test results was observed as a result of utilization of NRL. Such that, using 5% NRL provided the LWC to be in "moderate" chloride permeability class according to ASTM C1202.

- The LWCs with NRL demonstrated better corrosion behaviour than the control. Increasing the amount of NRL from 2% to 5% resulted in higher enhancement in protection of LWC against corrosion. At the end of 30 weeks of exposure it was noticed that LWC with 5% NRL had I_{corr} value of less than 0.1 µA/cm^2, indicating negligible corrosion. However, due to the continuous exposure deterioration in corrosion behavior of NRL modified reinforced LWC started just after 30 days of exposure.

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APPENDIX-A

Figure A.1 Photographic view of pelletization system

Figure A.2 Form of artificial lightweight fly ash aggregate

Figure A.3 Fresh lightweight aggregate kept in sealed bags for air curing

Figure A.4 Hardened lightweight aggregate sieved and ready for mixes

Figure A.5 Lightweight aggregate immersed in water before mix to get saturated surface dry aggregate aggregate

Figure A.6 Test specimens after mixing, vibrating, and finishing

Figure A.7 Measurement of compressive strength

Figure A.8 RCPT set-up

Figure A. 9 Measurement of salt penetration

Figure A. 10 Measurement of sorptivity