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Recycling waste latex paint in overlays, rigid pavements, and pervious concrete

Oscar Inez Quiroz
University of Nevada, Las Vegas

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RECYCLING WASTE LATEX PAINT IN
OVERLAYS, RIGID PAVEMENTS,
AND PERVIOUS CONCRETE

by

Oscar Inez Quiroz

Bachelor of Science in Engineering
University of Nevada, Las Vegas
2009

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science in Engineering
Department of Civil and Environmental Engineering
Howard R. Hughes College of Engineering

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Oscar Inez Quiroz

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Department of Civil and Environmental Engineering

Aly Said, Committee Chair

Samaan Ladkany, Committee Member

Ying Tian, Committee Member

David Hatchett, Graduate College Representative

Ronald Smith, Ph. D., Vice President for Research and Graduate Studies
and Dean of the Graduate College

August 2011

ABSTRACT

Recycling Waste Latex Paint in Overlays, Rigid Pavements, and Pervious Concrete

by

Oscar Inez Quiroz

Dr. Aly M. Said, Examination Committee Chair
Assistant Professor, Civil and Environmental Engineering
University of Nevada, Las Vegas

With over 16 million gallons of latex paint (WLP) being disposed every year it is the largest by volume, liquid hazardous waste in the United States. WLP is difficult to recycle and hazardous to the environment due to the volatile organic compounds it contains. Several methods exist for disposing WLP including paint swaps, combustion, drying and discarding in a landfill, and by placing pigments in cement. Many communities are moving to dispose WLP by drying and placing in a landfill due to the reduced cost. However, this is the least preferred technique for the environment because it creates a need for new resources.

Concrete is one of the most widely used construction materials in the world. Nonetheless, normal concrete has several disadvantages including low tensile strength, low weight to strength ratio, and low chemical resistance. Latex-modified concrete (LMC) was created to overcome several disadvantages found in normal concrete. The latex in LMC increases the cost of concrete which makes LMC economically practical only in special applications, such as bridge overlays, anti-corrosive linings, waterproofing, parking decks, and patching deteriorating concrete.

This thesis studies the ability of WLP to be used as a replacement for pure latex and as a method to improve normal concrete for special applications. These applications

include bridge overlays, rigid pavements, and pervious concrete. Bridge overlays were studied due to latex being commonly used in bridge overlay concrete mixtures. Rigid pavements were studied because pavements are commonly used and WLP has the ability to improve normal concrete properties. Finally, WLP was studied in pervious concrete due to the importance of having a strong cementitious paste in pervious concrete.

Fresh concrete properties were tested along with hardened and durability properties. Testing was performed on the latex paint, pure latex, and the cementitious paste. The tested fresh properties include slump, air entrainment, and unit weight. The tested hardened properties will consist of compressive strength, tensile strength, modulus of elasticity, and modulus of rupture. Tests for durability and chemical resistance include chloride penetration resistance, abrasion resistance, surface scaling, concrete porosimetry, and freeze-thaw resistance. A spectroscopy analysis tests was performed on the latex and cementitious pastes.

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CHAPTER 1

INTRODUCTION

Concrete is the construction industries most used material and the world's second most used product. Portland cement is a necessary material in concrete that binds the aggregates. However, it requires a high amount of energy to be produced. Reports state that it is responsible for up to 5% of the world's annual CO₂ emissions. Portland cement concrete has several inhibiting characteristics including a weakness in tension, susceptibility to chemical attack, and has a low strength to weight ratio. There have been several admixtures and techniques that allow concrete to overcome its vulnerabilities (Ramakrishnan, 1992; Ohama, 1995).

1.1 Overview

Latex-modified concrete (LMC) was created to overcome the vulnerabilities commonly found in concrete. However, LMC, priced between \$4 - \$5 per gallon, can increase the cost of a cubic yard of concrete from \$56 to \$156. Therefore LMC is not used for general applications (Ramakrishnan, 1992). According to several online retailers, the price of waste latex paint can range from \$1.49 to \$3.99 per gallon (AAA Closeout Liquidators, 2011). However, if the waste paint was purchased directly from a manufacturer the price of waste latex paint could decrease. Waste latex paint's (WLP) ability to replace Styrene Butadine Rubber (SBR) Latex in concrete to create an economical LMC was studied in this work.

1.1.1 Latex Paint

The United States sells an estimated 650 million gallons of paint every year. Paint is a concern for the United States due to its high volume, cost to manage, its levels of volatile organic compounds and fungicides, and hazardous metals from older paints. However, paint has high potential for reuse, recovery, and recycling (Product Stewardship Institute, 2004).

Paint is composed of binders, pigments, solvents, extenders and additives, and antimicrobials. A binder is a non-volatile film used to bind the pigments together. Acrylate is commonly used as a binder in latex paint. Binders typically make up 25% of the volume in latex paint. Pigments, which make up 15% of the volume, are fine particles that provide color to paint. Solvents are used to dissolve or break up the latex paint constitutes. They are made from organic liquids or water and make up 50% of the latex paint volume. Extenders and additives alter or enhance several properties in paint including thickness, drying, skinning, and corrosion resistance. On average, extenders and additives make up 10% of the volume in latex paint. Finally, antimicrobials are used in regions with high humidity to stop paint from spoiling or to prevent algae and fungi once the paint has been applied. (Greiner, 2004)

1.1.2 Waste Latex Paint (WLP)

In the United States 35 million gallons of latex paint remain unused every year. This creates a need to dispose the paint and use its valuable resources (Product Stewardship Institute, 2004). The most common method to dispose WLP is through solidification, which is disposed in a landfill. This method is the least preferred because it creates a need for raw resources. WLP disposed in a landfill has the potential to

contaminate the groundwater. However, with decreasing budgets, communities are allowing paint solidification (Segala, 2003). Some communities attempt to use the WLP for their own needs. For example, in Hernando County, Florida there is a requirement that a cover must be placed over any landfill to protect from odor, disease, and wind gusts. Therefore, the landfill sprays a WLP and water mixture onto the landfill as the daily cover (Greiner *et al.*, 2004). Additionally, WLP is used as fuel in incineration chambers, which is not an efficient use of the valuable materials found in latex paint. Other communities have allowed for a neighborhood paint collection, which is then stored in the neighborhood and the paint becomes available to community members. Half of all paint collected in its original container is suitable for reuse. The disadvantages include the work needed to collect the paint and the need for storage by the neighborhood. Reused paint has the ability to be high quality and comparable to new paint. This method requires filtering and the addition of additives. Segala (2003) studied a technique to recycle paint known as processed latex pigment (PLP). Sources for PLP paint include automobile manufacturing plants, entertainment production, maintenance companies, and professional painters. PLP is a patented method for recycling industrial paint sludge, water-treatment sediment, and leftover latex paint. PLP is shipped to portland cement plants to use the PLP as an additive for special cements or use the PLP as a raw material for the kiln feedstock. PLP can replace silica, aluminum, iron, and calcium carbonate. (Segala, 2003). Another method to recycle WLP is to use it in concrete as a latex addition. Several studies have investigated the ability of WLP to simulate the properties of SBR (Nehdi and Summner, 2003).

1.1.3 Polymer Modified Concrete

Polymer modified concrete (PMC) is a specialized concrete developed to improve the limitations found in standard portland cement concrete. Natural rubber was the first polymers used in concrete but due to cost limitations, the use of PMC decreased. Synthetic polymers became widely accepted in the 1960's. SBR became commonly used in bridge deck overlays after a study by the Dow Chemical Company and the Michigan Highway Department. The study found that SBR concrete had significantly lower chloride permeability than ordinary concrete (Clear and Chollar, 1978; Ramakrishnan, 1992).

It is thought that a co-matrix is formed in LMC, where the cement paste is surrounded by a polymer film. Figure 1 displays a three step formation of the polymer-cement co-matrix. (Ohama, 2005)

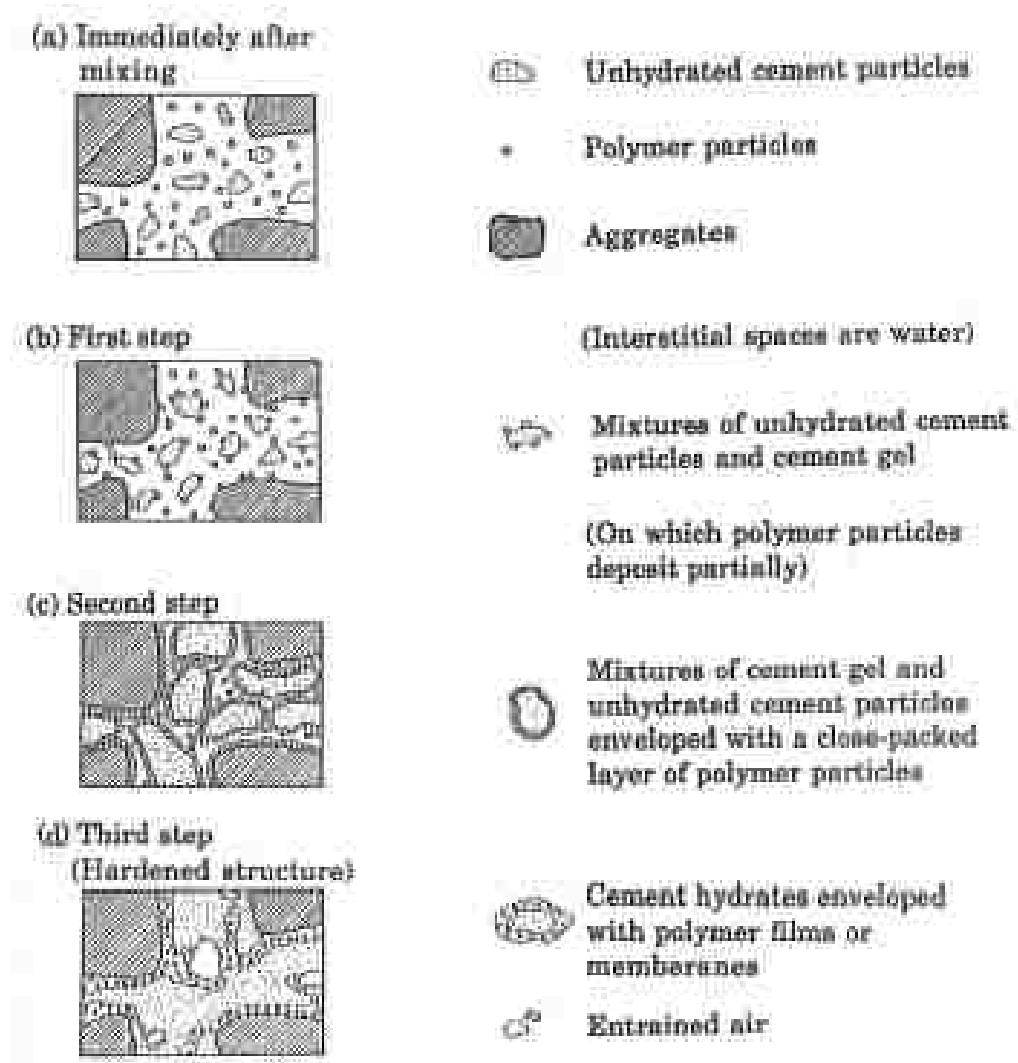


Figure 1 – Patex-modified concrete (PMC) hydration process (Ohama, 1995)

The third step exhibits water withdrawing due to cement hydration. The polymer particles bind the cement paste and create a monolithic network.

According to Ohama (1995), the reaction seen in Figure 2 improves the bond between hydrated cement and aggregates. The figure displays the reaction between a polymer and calcium from cement. Once hydrated, a calcium and polymer bond is created. The polymer and aggregates form a coordination complex around the calcium cation. The effect of the chemical bond on the LMC is governed by the polymer volume.

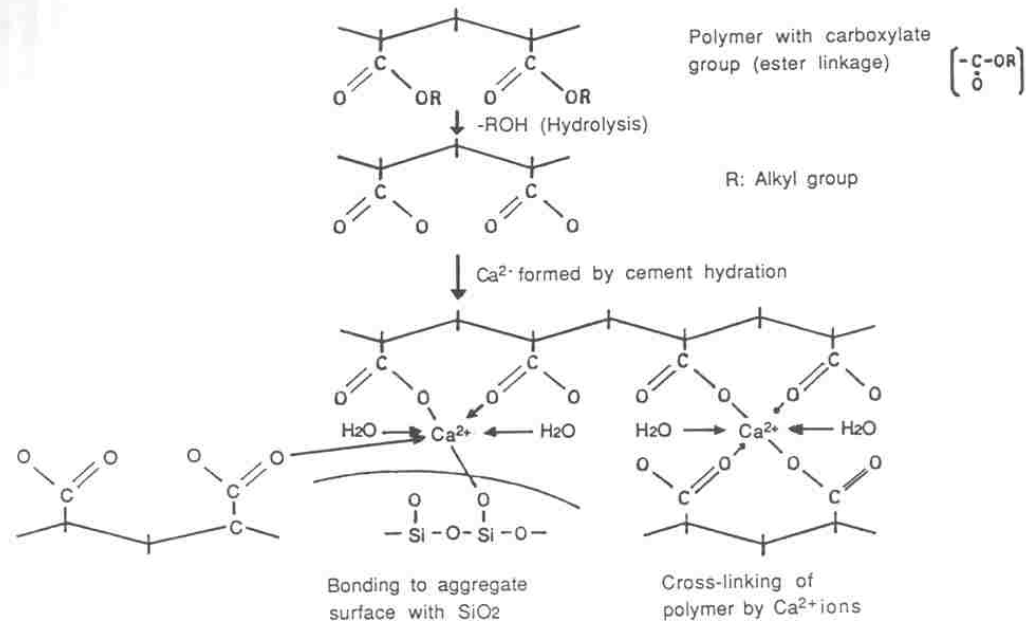


Figure 2 – Schematic illustration of reaction between polymer, ordinary portland cement, and aggregate (Ohama, 1995)

1.1.4 Latex-Modified Concrete (LMC) – Styrene Butadiene Rubber (SBR) Latex

SBR is a synthetic rubber latex which is a subcategory of polymer latex for cement modification. SBR is used to create LMC which, like polymer modified concrete, has superior qualities over normal portland cement concrete. The quality of the LMC is determined by polymer type, polymer-cement ratio, water-cement ratio, air content, and curing conditions (Ohama, 1995).

SBR is a polymer emulsion composed of styrene, butadiene, and water. SBR is able to simulate natural rubber properties in its ability to resist mild solvents and chemicals. Also, SBR has the ability to bond to many materials including cement (Huang *et al.*, 2009).

1.1.5 Recycling Latex Paint in Concrete

The effects of using WLP in concrete were studied by Nehdi and Sumner. They researched the ability to replace WLP with commercial latex and to improve normal concrete for use in sidewalks. They found that increasing the WLP replacement of SBR caused a decrease in compressive strength and flexural strength. For the sidewalk mixtures, Nehdi and Sumner found that the mixtures containing WLP displayed improved compressive strength, flexural strength, and chloride penetrability. Also, the research group conducted a field test which demonstrated improved concrete workability and finishing when WLP was added.

WLP in concrete was also investigated by Mohammed *et al.* (2008). A varying percentage of WLP was replaced in mixtures and compared to a mixture containing no latex and a mixture containing 15% latex. The study found that WLP mixtures demonstrated improved properties over normal concrete and similar properties as SBR mixtures. The study focused on concrete for sidewalks and non-structural elements.

1.1.6 Polymer Modified Pervious Concrete

Huang *et al.* (2009) investigated the ability of polymers to improve the strength in pervious concrete. Their research emphasized the balance between strength and permeability. In addition to polymers, the research group created mixtures with sand and fibers. They found improved compressive and tensile strength for concrete mixtures containing latex and for mixtures containing fibers. However, the latex mixture had a decrease of 5-10% in porosity volume. Their results demonstrated a pervious concrete mixture was capable of achieving adequate strength and permeability with the addition of polymer and sand.

1.2 Objective and Scope of Work

The purpose of this research is to investigate the ability of WLP to replace pure latex and as a method to improve normal concrete for special applications. These applications include bridge overlays, rigid pavements, and pervious concrete. Bridge overlays were studied due to the common use of SBR in bridge overlay concrete mixtures. Rigid pavements were researched because pavements are commonly used and the ability of WLP to improve normal concrete properties. Finally, WLP was studied in phase 3 due to the importance of having a strong cementitious paste in pervious concrete.

The goals for the proposed research include:

1. Mixtures containing WLP will be created to meet the requirements in specification for overlays, rigid pavements, and pervious concrete.
2. The properties of the concrete mixtures will be compared with concrete containing pure latex and to standard concrete.
3. The properties of the WLP concrete will be analyzed using infrared spectroscopy on the WLP and the WLP-cement binder.
4. Recommendations will be provided for each WLP concrete created and for the overall use of WLP in concrete.

A testing plan for overlays, rigid pavements, and pervious concrete was created to research the objectives.

1.2.1 Properties of Waste Latex Paint (WLP)

To properly mix WLP in concrete the water content of the paint was needed to be obtained. Also, an infrared spectroscopy analysis was completed on WLP and SBR to compare the differences in the latex.

1.2.2 Fresh Concrete Properties

The tests completed to find fresh properties throughout the study include:

- Slump of Hydraulic Cement Concrete: ASTM C143
- Air Content of Freshly Mixed Concrete by the Volumetric Method: ASTM C173
- Adiabatic Temperature Change: ASTM C1064
- Density of Concrete: ASTM C138

1.2.3 Mechanical Concrete Properties

Mechanical properties tested in the study include:

- Compressive Strength at various ages: ASTM C39
- Splitting Tensile Strength at 28 days: ASTM C496
- Flexural Strength of Concrete at 28 days: ASTM C78
- Static Modulus of Elasticity at 28 days: ASTM C469

1.2.4 Durability Properties

The following durability tests were completed throughout the study:

- Abrasion Resistance of Concrete by Sandblasting: ASTM C418
- Resistance to Chloride Ion Penetration at 28 days: ASTM C1202
- Resistance of Concrete to Rapid Freezing and Thawing: ASTM C666
- Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals: ASTM C672

1.3 Research Significance

This study is significant for the improvement and development of sustainable construction, reducing the cost of premium LMC, and improving the durability of normal concrete. This investigation will also help research an alternative method for disposing WLP.

1.4 Organization of Thesis

The thesis consists of six chapters. The first chapter contains an introduction and literature review of WLP in concrete. The second chapter focuses on the methodology used for all testing completed for the thesis. Chapter three contains results for recycling WLP in concrete overlays. The fourth chapter focuses on the results for rigid pavements while the fifth chapter contains results for pervious concrete. Finally, conclusions and recommendations can be found in chapter six.

CHAPTER 2

METHODOLOGY

2.1 Overview

This study is divided into three phases: Overlays, rigid pavements, and pervious concrete. The methodology section is broken into introduction to each phase, materials used in all phases, mixture proportioning for each phase, and test conducted.

2.2 Phase 1- Overlays

Overlays were researched due to the use of styrene butadiene rubber (SBR) latex in bridge deck overlays. A thin protective layer (between one and three inches) is placed on top of the bridge pavement to protect the bridge super structure from chemical attack (ACI 548.4 1998, Clear and Chollar, 1978). A waste latex paint (WLP) overlay concrete mixture would reduce the cost of the latex-modified concrete mixture (LMC).

2.3 Phase 2 – Rigid Pavements

Rigid pavements were selected for phase 2 due their need of high durability characteristics. Previous research found WLP being capable of improving chemical resistance, tensile strength, and freezing and thawing resistance. The study investigated the ability of WLP to replicate or enhance durability characteristics found in rigid pavement concrete. A successful WLP pavement mixture would be able to enhance the properties found in general rigid pavement concrete.

2.4 Phase 3 – Pervious Concrete

Pervious concrete is a unique type of concrete which contains 15% to 25% air voids. This high void ratio is achieved by reducing or removing fine aggregate as well as reducing the water to cement (w/c) ratio. Pervious concrete was first used in 1852 but has received renewed interest due to its ability to capture rainwater, recharge groundwater, reduce runoff, and meet EPA storm water regulations (Ghafoori and Dutta, 1995; Tennis *et al.*, 2007).

The ability of latex to improve pervious concrete strength was demonstrated by Huang *et al.* (2009). In their study, compressive strength improvements from 15% to 60% were found and similar improvements were established for tensile strength. The addition of latex, sand, or fiber demonstrated an improved compressive strength. However, latex was the only material capable of increasing tensile strength.

Pervious concrete was chosen as the final phase of the project for three reasons. First, latex has been proven to improve strength of pervious concrete. Therefore, the study attempts to find the strength improvement from WLP. Second, pervious concrete is increasing in use due to the move to sustainable construction. Finally, WLP has the potential to create a stronger pervious concrete with a recycled material. A successful WLP pervious concrete mixture would be able to meet or exceed pervious concrete strength characteristics.

2.5 Materials

Several materials were used for each phase of the study. The materials used in this study were from local ready mix concrete suppliers. The materials used in the study met specifications for overlays, rigid pavements, or pervious concrete.

2.5.1 Cement and Fly Ash

Type V cement was used for all phases three phases of the project. Type V cement was selected because of its local availability. This cement type is locally available due to the high sulfate content found in Southern Nevada soil. The cement used had a specific gravity of 3.15 and met ASTM 150-11 requirements.

Fly Ash type F was used as a cementitious replacement for phase 2 and 3. Fly Ash has the ability to improve sulfate resistance in concrete and is therefore commonly used by the Nevada Department of Transportation (NDOT) for its concrete pavements. Fly Ash replacement was adjusted to simulate NDOT replacement percentages for rigid pavements. The fly ash used had a specific gravity of 2.3 and met the requirements set by ASTM 618-08.

2.5.2 Fine and Coarse Aggregate

For phase 1 and 2, number 8 coarse aggregate was used to meet requirements, as defined by ASTM C33-11. Number 67 coarse aggregate was used for phase 3 of the research project. Coarse and fine aggregate properties can be seen in Table 1.

Table 1 – Aggregate physical properties

Property	Phase 1 Coarse	Phase 1 Fine	Phase 2 Coarse	Phase 2 Fine	Phase 3 Coarse
Absorption	0.60%	0.8%	1.34%	0.8%	0.6%
Specific Gravity	2.79	2.78	2.85	2.64	2.84
Dry rodded unit weight, lb/ft ³	97.11	-	98.5	-	98.6
Fineness Modulus	-	3.00	-	2.68	-

2.5.3 Waste Latex Paint

WLP1 was used for all three phases while WLP2 was only used for phase 1. Due to the superior results of WLP1 in phase 1 it was used for phase 2 and 3. The physical properties of both paints used in the project are listed in Table 2.

Table 2 – Properties of waste latex paint (WLP) used for study

Physical Properties	WLP1	WLP2
Color	White	Brown
Solid Content, Volume (Weight)	39% (54%)	33% (Not Available)
Density, lb/gal	11.11	10.4
Vehicle Type	100% Acrylic Resin	Acrylic Blended Latex
Pigment Type	Titanium Dioxide and Extender Pigments	Titanium Dioxide
Condition Obtained	Sealed	Opened
Phases Utilized	1, 2, and 3	1

2.5.4 Fibers

In phase 3, a 100% specialty cellulose fiber was incorporated into two of the mixtures. The fiber acts as a secondary reinforcement to the pervious concrete. Fibers have the ability to improve freeze-thaw resistance, durability, and bond strength between cement paste. Also, Huang *et al.* (2009) found improved compressive strength in pervious concrete containing fibers. The research group suggested using short fiber to improve dispersion in the mixtures. The fiber was chosen because it was produced from a renewable resource and because of its short length. The short length was needed to avoid

congesting the pervious concrete. The fiber has a specific gravity of 1.1, absorption of 80%, and average length of 0.08 inch.

2.5.5 Admixtures

Admixtures used throughout the study were acquired from different manufacturing suppliers. Product names have been omitted to remove endorsement of any manufacturer.

2.5.5.1 High Range Water Reducing Admixture (HRWR)

High range water reducing admixture is used to reduce the water requirements in a mixture while maintaining similar hardened properties. HRWR was used in phase 1 to reach slump requirements while maintaining compressive strength. The HRWR, used in the study, met the requirements for chemical admixtures in concrete, ASTM C494-10, Type F. The admixture has a density of 8.8 lb/gal.

2.5.5.2 Styrene Butadiene Rubber Latex (SBR)

Two different SBR manufacturers were used throughout the study. The admixtures have been designated SBR1 and SBR2. SBR1 was used for overlays and SBR2 was used for overlays and rigid pavements. The properties of the latexes used are displayed in Table 3.

Table 3 – Properties of styrene butadiene rubber (SBR) latex used for the study

Properties	SBR1	SBR2
Solid content by mass	48%	47%
pH	10 to 11	9.5
Density, lb/gal.	8.4	8.4
Phase Utilized	1	1 and 2

2.6 Mixture Proportions

2.6.1 Phase 1 – Proportions

The mixtures follow the “Standard Specification for Latex-Modified Concrete (LMC) Overlays” (ACI 548.4). The tested mixtures follow the minimum cement requirement of 658 lb/yd³. The fine aggregate was proportioned to the required amount of 50-75% of the total aggregate by weight. The minimum latex and water were proportioned to 24.5 gal/yd³ and 18.9 gal/yd³, respectively. The mixtures were covered for 24 hours and allowed to air cure in laboratory conditions. For phase 1, the solid contents published in the material data sheets for SBR1 and SBR2 were used for calculating polymer quantities. Since, the solid content of WLP2, by mass, was not published, the solid content through testing was used for calculations of WLP2. The mixture proportions are available in Table 4.

Table 4 – Phase 1 concrete proportions

MIXTURE:	NC	SBR1	SBR2	WLP 1	WLP 2
Cement, lb/yd ³	660	660	660	660	660
Water, lb/yd ³	250	90	130	180	210
Polymer, lb/yd ³	-	210	210	180	200
Total Water, lb/yd ³	250	200	240	250	310
Coarse Aggregate, lb/yd ³	1520	1210	1300	1490	1190
Fine Aggregate, lb/yd ³	1890	1890	1890	1890	1890
HRWR, oz/100 lb cement	12	0.5	0	5	4
Solid content of polymer	-	48%	47%	54%	50%
<i>w/c</i> ratio	0.38	0.3	0.36	0.38	0.47
<i>p/c</i> ratio	0	0.15	0.15	0.15	0.15

Water amount does not include water from WLP or SBR
 Total water amount does include water from WLP or SBR

2.6.2 Phase 2 – Proportions

In phase 2, three mixtures were created in the laboratory, one consisting of normal concrete (NC), one with SBR, and one containing WLP. NC was created to simulate a rigid concrete pavement mixture. These mixtures were created using the Portland Cement Association's absolute volume method for proportioning a rigid pavement mixture. All mixtures were created to have a slump between one to three inches. The water to cementitious (*w/cm*) ratio was designed to be less than 0.41 since a compressive strength of more than 6000 psi was desired at 28-days for non-air-entrained concrete (Delatte, 2009). Air entrainment was not used in the mixtures due to SBR manufacture recommendations (BASF, 2011). A summary of the mixture proportions is presented in Table 5.

The SBR mixture was created to find any improvements that LMC would have on a rigid concrete mixture. The mixture used a lower w/cm ratio due to the water-reducing effects of SBR and the requirement of a maximum slump of three inches. The WLP mixture was created to find improvements over NC and to compare WLP to a premium SBR mixture.

The SBR and WLP mixtures used a polymer to cementitious (p/cm) ratio of 0.05 due to higher p/cm ratio causing a higher slump in the SBR mixture. Polymer to cementitious ratio is defined as the weight of polymer solids divided by the weight of cementitious content.

A cementitious content of 840 lb/yd^3 was used for the mixtures. Fly ash replaced 25% of the cementitious content in all the mixtures due to similar use by NDOT.

In addition to the three mixtures, a modified WLP mixture (WLP-M) was created. This mixture was designed to have a lower w/c ratio than the original WLP mixture. This mixture used 10 oz/100# cement of HRWR to maintain similar workability with decreased water. The WLP-M mixture was tested for compressive and tensile strength.

All phase 2 samples covered for the first 24 hours and then dry cured until time of testing.

Table 5 – Phase 2 proportions

Mixture:	NC	SBR	WLP	WLP-M
Cement, lb/yd ³	630	630	630	630
Fly Ash, lb/yd ³	210	210	210	210
Total Cementitious Material	840	840	840	840
Coarse Aggregate, lb/yd ³	1200	1200	1200	1200
Fine Aggregate, lb/yd ³	1800	2020	1650	1780
*Water, lb/yd ³	290	120	260	210
Polymer, lb/yd ³	-	90	80	80
HRWR, oz/100# cement	-	-	-	10
#Total Water, lb/yd ³	290	170	290	250
Solid content of polymer	-	47%	54%	54%
w/cm ratio	.35	0.20	.35	.30
p/cm ratio	-	0.05	0.05	0.05

*Water amount does not include water from WLP or SBR

#Total water amount does include water from WLP or SBR

2.6.3 Phase 3 – Proportions

Table 6 summarizes the proportions used for the pervious concrete mixtures. Seven mixtures were created for testing. A normal concrete (NC) mixture was created to represent a regular pervious concrete. Four mixtures contain WLP with *p/cm* ratio range from 5% to 20%. The final two mixtures were created to represent the NC and the 5% WLP mixture but these mixtures contain fibers. All mixtures were created to have a *w/c* ratio of 0.35 and a void volume of 24%. The cementitious content was 625 lb/yd³ with 20% fly ash replacement. Coarse aggregate was added at 2500 lbs/yd³ and no fine

aggregate was added to the mixture. Standard pervious concrete can have up to a 1:1.1 cement to fine aggregate ratio. Zero fine aggregate was used to reduce variables that can alter strength and porosity of the concrete mixtures.

All mixtures were covered for the first 24 hours and then placed in a curing room with 100% humidity and an ambient temperature of 70°F ± 2°F until testing.

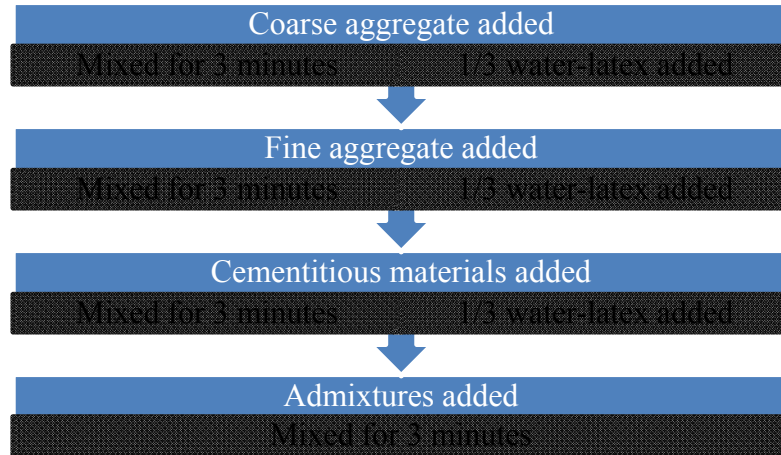
Table 6 – Phase 3 proportions

Mixture:	NC	5% WLP	10% WLP	15% WLP	20% WLP	NC+F	5% WPL+F
Cement, lb/yd ³	500	500	500	500	500	500	500
Fly Ash, lb/yd ³	125	125	125	125	125	125	125
Coarse Aggregate, lb/yd ³	2500	2380	2250	2130	2010	2500	2380
Fibers, lb/yd ³	-	-	-	-	-	1	1
Water, lb/yd ³	190	160	130	110	80	190	160
WLP, lb/yd ³	0	60	120	170	230	0	60
Total Water, lb/yd ³	190	190	190	190	190	190	190
Designed Air Content	24%	24%	24%	24%	24%	24%	24%
Solid content of polymer	-	54%	54%	54%	54%	-	54%
w/cm ratio	0.30	0.30	0.30	0.30	0.30	0.30	0.30
p/cm ratio	-	0.05	0.10	0.15	0.20	0.25	0.30

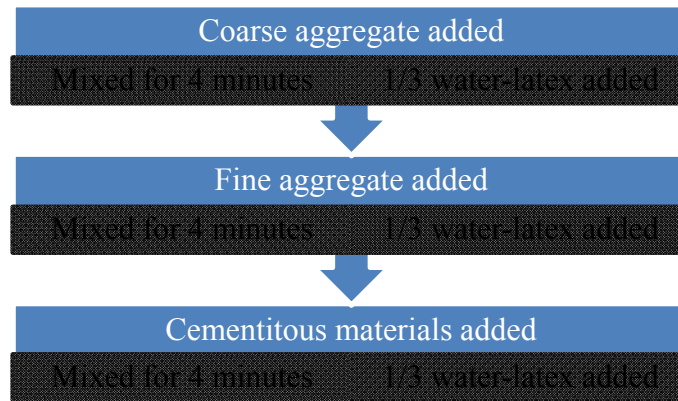
2.7 Mixing Procedures

WLP or SBR used was premixed with batching water and placed into its respective mixture as described in Figure 3. The mixtures were batched in a 3ft³ steel drum utility mixer as pictured in Figure 4. For phase 3, the two mixtures containing

fibers, NC+F and 5% WLP+F, mixed the cementitious material for six minutes and then mixed the fibers for the final three minutes.



(a) Phase 1 - Overlays



(b) Phase 2 – Rigid Pavements

Figure 3 – Mixture procedures for phase 1, 2, and 3

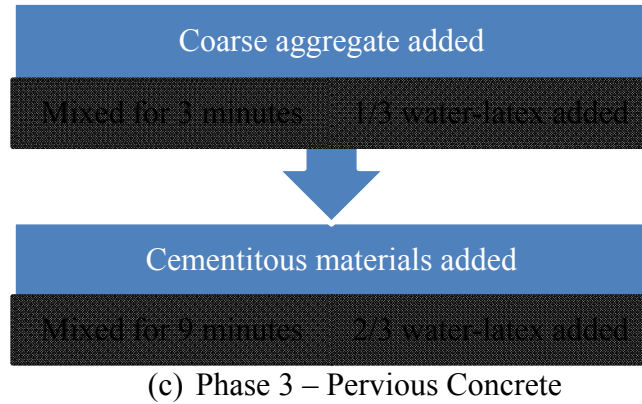


Figure 3 - (Cont.) Mixture procedures for phase 1, 2, and 3



Figure 4 – Steel drum mixer

2.8 Testing of Paint, Latex, and Cementitious Paste

To understand the differences between latex paint and commercial latex several tests were performed.

2.8.1 Paint and Latex

Tests were performed on the paints and latex to understand the chemical differences between the different samples. Following latex testing, experiments were completed on the cementitious paint concrete containing WLP and latex. Infrared spectroscopy was used for testing.

A test to estimate the solid content was used for the WLP and SBR to prepare the mixtures appropriately. Published values of solid content for the SBR and WLP were

used when available. The water content, by mass, of WLP2 was not published. Therefore, the test value was used for mixing proportioning. The water content was found by measuring an initial mass of SBR and WLP samples. The samples were then allowed to air dry in laboratory conditions. Figure 5 demonstrates the samples after drying in the laboratory. The change in mass was recorded to estimate the solid and water content.



Figure 5 – Solid content of WLP and SBR samples (from left to right SBR1, SBR2, WLP1, and WLP2)

2.8.2 Infrared Spectroscopy

Infrared radiation (IR) is part of the electromagnetic spectrum between visible light and the microwave region. Organic chemistry uses the 4,000 to 400 cm^{-1} wavenumber region since organic molecules absorb and convert this region of the spectra. The absorbance (A) of the samples for each wavenumber was recorded during testing. Absorbance was then converted to transmittance (T) which is equal to the amount of radiant power a sample transmits over the amount of radiant power given to the specimen. Equation 1 was used to convert absorbance to transmittance (Silverstein *et al.*, 2005).

$$\text{Equation 1: } A = \log_{10} \left(\frac{1}{T} \right)$$

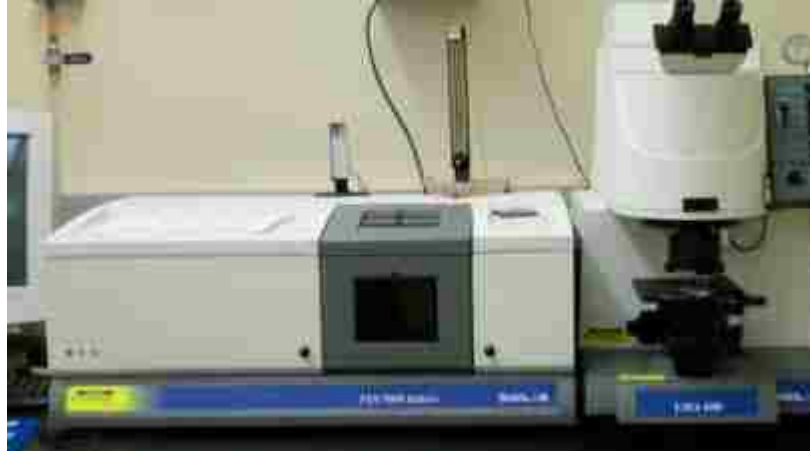
A= Absorbance

T = Transmittance

An IR spectroscopy was taken of SBR1, SBR2, WLP1, and WLP2 using a single point technique. This technique applies light waves to a thin sample, which in turn produces a vibration. A record is taken of the sound waves produced and the wavenumber is then related to a molecular structures. Wavenumbers are proportional to the energy of vibration. The samples are created by applying a thin layer of paint or latex on 1"× 2" gold covered substrate. An example of the gold substrate with WLP1 coating is exhibited in Figure 6. The samples are dried in a desiccator before testing to remove water from the results. The samples are then placed in a UMA 600 Microscope with MTEC with Single Point MCT detector accessory, as seen in Figure 6. A sample of the substrate is taken before taking readings of WLP and SBR. The single point technique allows for real time comparison of the spectra throughout the sample. The comparisons of WLP1 to WLP2 and SBR1 to SBR2 could be used to interpret the differences in the concrete properties. These differences can also be used to compare the differences in spectra from the cement samples.

IR spectroscopy was used on cement samples using a diffuse technique. The specimens are prepared by creating a cement mixture that includes cement, water, and a corresponding latex or paint. Five mixtures were created for testing, these include, NC, SBR1, SBR2, WLP1, WLP2. These mixtures were cast into 4" × 8" cylinders and then covered. At 7-days the specimens were removed from their molds and drilled as seen in Figure 6 to create grounded samples of the mixtures. The ground sample was then filtered

the through a number 200 sieve. Next, ground samples are dried in a desiccator. The samples are then tested using a Varian FTS 7000 FTIR .



(a) Phase 2 – FTIR spectrometer and microscope



(b) Phase 2 – Cementitious paste ground sample

Figure 6 – FTIR spectrometer and microscope, cementitious paste ground sample, and dried paint on gold substrate



(c) Phase 2 – Dried paint on gold substrate

Figure 6 – (Cont.) FTIR spectrometer and microscope, cementitious paste ground sample, and dried paint on gold substrate

2.9 Fresh Property Testing

2.9.1 Air Content

The air content was measured for phase 1 and 2 mixtures. The maximum air content requirement for overlays is 6.5%. The average air content for rigid pavements is 5% (Delatte, 2009). The air content testing was completed using the volumetric method according to ASTM C173 (10). The volumetric method uses a roll-a-meter air indicator as seen in Figure 7.



Figure 7 – Roll-A-Meter air indicator

2.9.2 Slump and Workability

The slump, which is a measure of the workability, was found for phase 1 and 2 mixtures. Concrete overlays have a slump requirement of three to eight inches (ACI 548.4, 1998). The designed rigid pavements have maximum slump requirements of three inches (Delatte, 2009). Slump was not tested in phase 3 because pervious concrete is known to have a negligible slump (Ghafoori and Dutta, 1995). The test was completed according to ASTM C143 using a slump cone as presented in Figure 8 (10).



Figure 8 – Slump cone used for testing

2.9.3 Adiabatic Temperature Change

The mixtures were tested for their reactivity using the adiabatic temperature test. This test measures the changing temperature in concrete through its curing process. The higher temperature during testing indicates a higher reactivity. Fresh concrete was placed in 4" × 8" cylinders and then sealed with a thermocouple placed in the center of the cylinder. The thermocouple was then connected to a data logger that recorded the change in temperature (ASTM C 1064, 08). Figure 9 demonstrates the setup of the adiabatic test.



Figure 9 – Adiabatic temperature change

2.9.4 Fresh Unit Weight

The fresh unit weight was found by placing fresh concrete in a container of known volume. The weight of the fresh concrete in the container was measured. Finally, the weight was divided by the volume to find the fresh unit weight. This was completed for phase 2 and 3, according to standard procedures (ASTM C 138). The test setup is demonstrated in Figure 10.

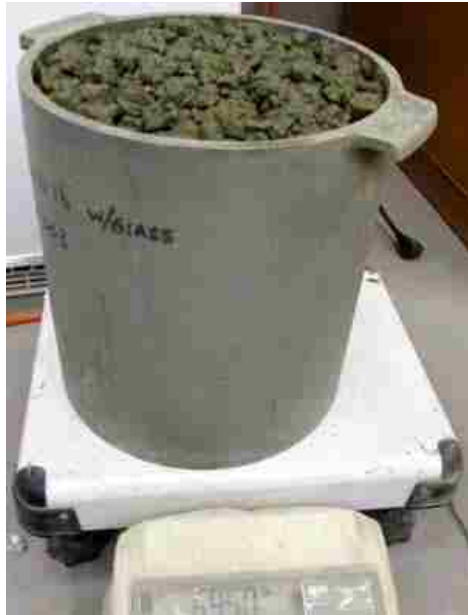


Figure 10 – Fresh unit weight of concrete

2.10 Testing of Specimens for Mechanical Properties

2.10.1 Compressive Strength

The compressive strength was tested through all three phases of the project. The compressive strength was found according to standard procedures (ASTM C39, 10). The study used 4" × 8" cylinders for testing. A cylinder being tested for its compressive strength is displayed in Figure 11.

In order for the roadway to open, the concrete must achieve compressive strength of 3,000 psi. For phase 1, the compressive strengths, of the five mixtures, were tested at 1-, 3-, 7-, and 28-days. The 1-, 3-, and 7-day measurements were used to determine when the concrete reaches the required compressive strength. The 28-day test estimates the ultimate strength of the concrete.

In phase 2, the three main mixtures were tested at 7-, 14-, 21-, and 28-days. Higher compressive strengths in rigid pavements results in pavements capable of being used with higher load bearing vehicles or being designed with reduced thickness. A 6,000 psi concrete can be used for generally all rigid pavements (Delatte, 2009).

Only 7- and 28-day cylinders were tested for phase 3. The compressive strength of pervious concrete can range from 500 psi to 4000 psi (Tennis *et al.*, 2007).



Figure 11 – Compressive strength setup

2.10.2 Splitting Tensile Strength

Mixtures were tested in tension using the splitting tensile test (ASTM C 496/C 496M-04). This test was completed for all three phases of testing. The samples were tested for tension to compare the WLP mixtures to the SBR mixtures in phases 1 and 2. The WLP mixtures were compared to the NC mixture in all three phases. NC mixtures were expected to have the lowest tensile strength since they do not contain latex. These mixtures were tested at 28 days to find the ultimate tensile strength. Figure 12 displays a concrete cylinder being loaded for the splitting tensile strength test. The splitting tensile strength was calculated as follows:

$$\text{Equation 2: } S_t = \frac{2P_{ult}}{\pi LD}$$

S_t = Split tensile strength

P_{ult} = peak load

L = length of specimen

D = diameter of specimen



Figure 12 – Splitting tensile strength

2.10.3 Flexural Strength

The flexural strength was found for phase 2 mixtures to calculate the modulus of rupture using the following equation:

$$\text{Equation 3: } R = \frac{PL}{bd^2}$$

R = Modulus of Rupture

P = Maximum Applied Load

L = Span Length

b = average width

d = average depth

A 6" × 6" × 21" concrete beam was used for testing and the test was completed according to the third point loading standard (ASTM C78, 10).

In addition to finding the maximum load held by the concrete beam, the deflection of the beam was also found through several loading intervals. This was accomplished by using a 1" × 1" × 1", steel, L-bracket attached to the center of the beam. A dial indicator

was used to find the deflection with respect to load. The loading scenario, with the dial indicator is exhibited in Figure 13.



Figure 13 – Flexural strength setup

2.10.4 Static Modulus of Elasticity

The static modulus of elasticity was found for phase 2 mixtures using standard procedures (ASTM C469, 10). A compressometer, as seen in Figure 14, was used to find the change in length of 4" × 8" cylinders at the required loading intervals. The samples were tested at 28-days.



Figure 14 – Static modulus of elasticity

2.11 Testing of Specimens for Durability Properties

Several tests were used to determine the durability of the concrete. Concrete samples were tested for their resistance to chloride, resistance to abrasion, resistance to freeze-thaw cycles, resistance to surface scaling, and to find the size of the micro pores in the cement.

Due to their intended purpose overlays must overcome damage from several possible elements. These include friction from the rubber on vehicles and chloride ion attack from salts. The abrasion by sandblasting and the rapid chloride penetration test (RCPT) were conducted on the samples to verify their ability to resist these hindrances.

Several tests were completed to determine the durability of the concrete mixtures. As a rigid pavement the concrete mixture must be able to resist abrasion from vehicle tires, chemical attack, and freeze-thaw conditions.

Phase 3 used a modified freeze-thaw test to find the ability of pervious concrete to resist freezing and thawing.

2.11.1 Abrasion by Sandblasting

Abrasion was tested on phase 1 and 2 mixtures since it represents their capacity to endure service as overlays subjected to traffic. Abrasion by sandblasting was used to test the abrasion resistance of the concrete. The test was completed according to standard (ASTM C 418-98). Three inch thick circular slabs were used for testing. Figure 15 demonstrates the test setup. The following equations from the ASTM standard were used to find the abrasion coefficient of each mixture.

$$\text{Equation 4: } V = \frac{(M_1 - M_2)}{D}$$

Equation 5: $A_c = \frac{V}{A}$

V = Volume

M₁ = Initial mass of clay

M₂ = Mass of remaining clay

D = Density

A = Area

A = Abrasion Coefficient



Figure 15 – Abrasion by sandblasting

2.11.2 Rapid Chloride Penetrability Test (RCPT)

Concrete has a vulnerability to chloride ion attack, however, LMC has been found as a solution to this vulnerability. RCPT was performed to test the vulnerability to chloride attack. The test was performed according to ASTM standard (ASTM C1202, 97) at 28-days. The test used 4" × 8" cylinders created in the laboratory. The cylinders were cut 2" thick with a diamond tip saw. The test setup can be seen in Figure 16. After the RCPT, Bassuoni's *et al.* penetration depth test was performed on the RCPT samples to

examine the actual depth of penetration. First, the RCPT samples were axially split to create half circles with 2” radius and 2” depth. Next, silver nitrate (AgNO_3) is sprayed on the cut halves to produce a film with visible discoloring. This allows the penetration of the chloride to be measured. The average of five measurements is calculated to produce the penetration depth (Bassuoni *et al.*, 2006). This was test was completed for phase 1 and 2.



Figure 16 – Rapid chloride penetrability test setup

2.11.3 Mercury Intrusion Porosimetry

The porosity of the cement paste in concrete is an important aspect in understanding the durability of concrete. Porosity in concrete allows water to expand when frozen and thereby reducing cracks. Two aspects in porosity are significant in allowing the expansion of water. First, the size of the pores will allow a greater amount of water to expand and second the connectivity of the pores will permit a larger volume to expand within the concrete. Second, the connectivity of the pores will alter the ability to resist freezing and thawing cycles. However, high porosity can result in lower compressive strength or poor durability. Since, the concrete contains micro pores the Mercury Intrusion Porosimetry (MIP) test was performed on phase 1 samples to find the

porosity and symmetry of the cement paste. Samples of the cement pastes were dried in a desiccator to remove excess water. At 28-days, the samples were tested. The pressure (p) and the capillary diameter (d) can be found using the Washburn equation. (Cook and Hover, 1998)

Equation 6: $P = -4y \cos \theta / d$

P = Pressure

Y = Surface tension of the liquid

Θ = Contact angle of the liquid

d = diameter of the capillary

The diameter of the pores allows the percentage of micro to macro pores to be found. The dividing diameter between micro and macro pores is 0.1 μm (3.9E-6 in.). The increase in micro pores to macro pores signifies an increase in durability.

2.11.4 Resistance to Rapid Freezing and Thawing

The concrete mixtures were tested for their resistance to freezing and thawing for phase 2 and 3. The test was completed using ASTM standard C666 method A and using the optional elongation process along with the transverse frequency (08). An E-Meter, as pictured in Figure 17, was used to find the transverse frequency. The following equations were used to determine the durability factor of each specimen tested:

Equation 7: $P = \frac{n_c^2}{n_0^2} \times 100$

Equation 8: $Durability\ Factor = \frac{PN}{300}$

where, P = relative dynamic modulus of elasticity

N = number of cycles at which P falls below 60%

n_c = transverse frequency

n_0 = fundamental transverse frequency at 0 cycles

A comparator, as seen in Figure 18, was used to find the change of length of the samples. Testing, on the samples, was completed at 25 cycle intervals.

A freeze-thaw cycle was set to five hours. A total of 300 cycles were run for each sample. Testing began with samples after 14-days of dry curing. Three samples were used for each concrete mixture in phase 2.



Figure 17 – Transverse elasticity test setup of freezing and thawing sample



Figure 18 – Comparator used to measure change of length in freezing and thawing sample

In phase 3, changes to the freeze-thaw test were made due to the difficulty of the e-meter and comparator to accurately record the transverse elasticity and change of length. Therefore, the mass loss was used as the indicator for freeze-thaw resistance. The samples were removed from the environmental chamber after every 5 cycles during a thawing phase. The pervious concrete samples were then tapped 25 times with a mallet and then weighed (Shu *et al.*, 2011). Two samples were used for each mixture in phase 3. The pervious concrete samples can be seen in Figure 19.



Figure 19 – Pervious concrete in freeze-thaw test

2.11.5 Resistance to Surface Scaling

The concrete was tested for its resistance to surface scaling by deicing salts. The concrete samples were tested for 50 days with 3% NaCl. Testing began with samples at 28-days. The samples were filled with NaCl, placed in freezer for 18 hours, and placed in room temperature for 6 hours. This was continued for 50 days. The tests followed ASTM C672 procedures.

2.12 Pervious Testing

The following tests were only used for phase 3 and tests specifically created for pervious concrete.

2.12.1 Porosity

The porosity of the pervious concrete samples was found by placing a 4" × 8" cylinder onto a scale. As seen in Figure 20, the cylinder was wrapped with plastic and the scale was tared. The cylinder was filled with water until water covered the surface of the

cylinder. The weight was then recorded. The test was run with three cylinders for each mixture and each cylinder was tested three times.



Figure 20 – Porosity of pervious concrete setup

2.12.2 %Void-Usable

The percent void was found by converting the weight of water recorded in the porosity testing to a volume. The water volume was then divided by the total volume of a 4” × 8” cylinder (Florida Concrete and Products Association, 1991).

2.12.3 Infiltration Rate

As seen in Figure 21, the infiltration rate was found by covering a 4” × 8” cylinder with plastic which extended at least 2” above the top of the cylinder. 21 fl. oz (600 ml) of water was placed on the concrete cylinder and the time for the water to

penetrate the top surface of the pervious cylinder was recorded. This was repeated on three cylinders and three times per cylinder.



Figure 21 – Infiltration rate test setup

CHAPTER 3
PHASE 1 RESULTS: RECYCLING WASTE LATEX PAINT IN
OVERLAY CONCRETE

3.1 Overview

Bridge overlays are used to protect a bridge superstructure from chemical attack. Latex-modified concrete (LMC) has been used in bridge overlays since the 1960's due to its ability to resist chloride ion attack (Clear and Chollar, 1978).

The present study uses five mixtures to compare the ability of waste latex paint (WLP) to simulate the properties of Styrene Butadiene Rubber (SBR) Latex in concrete. The five mixtures consisted of one normal concrete (NC) mixture, two pure latex mixtures consisting of SBR from different manufacturers, and two WLP mixtures consisting of two different paints. The paints come from two sources and are of different quality. WLP1 was acquired from a known source and WLP2 was obtained from an unknown source. Although, WLP1 and WLP2 contain acrylate latex, SBR was used in testing due to its common use in overlays (Product Stewardship Institute, 2004; Clear and Chollar, 1978).

3.2 Paint, Latex, and Cementious Paste

3.2.1 Solid Content

The water content of all mixtures began to reach the ultimate water content by day 15, as seen in Figure 22. The final solid contents found were 33%, 51%, 55%, and 50% for SBR1, SBR2, WLP1, and WLP2 respectively. WLP1 and SBR2 had a tested solid within 5% of their published values (54% and 47%). The published values of the SBR are

used for mixture proportioning. Although, WLP1 and WLP2 are from different manufactures and were obtained in opened and unopened condition they both have solid contents near 50%. A solid content of 55% and 50% were used for WLP1 and WLP2 when proportioning the mixtures in phase 1.

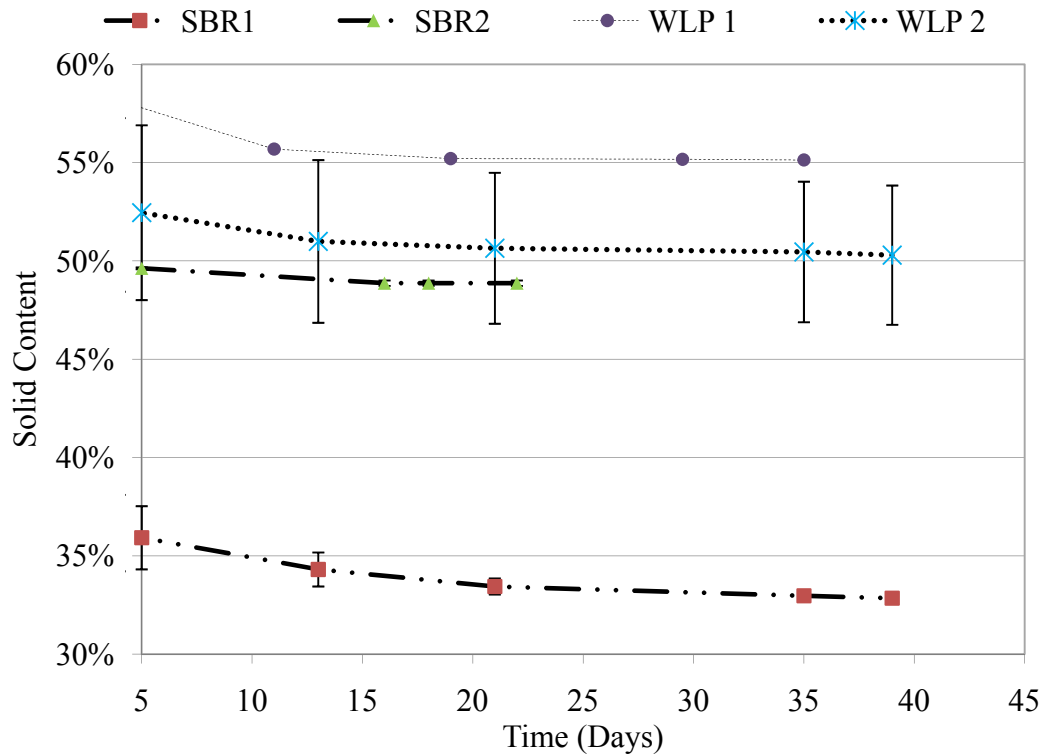
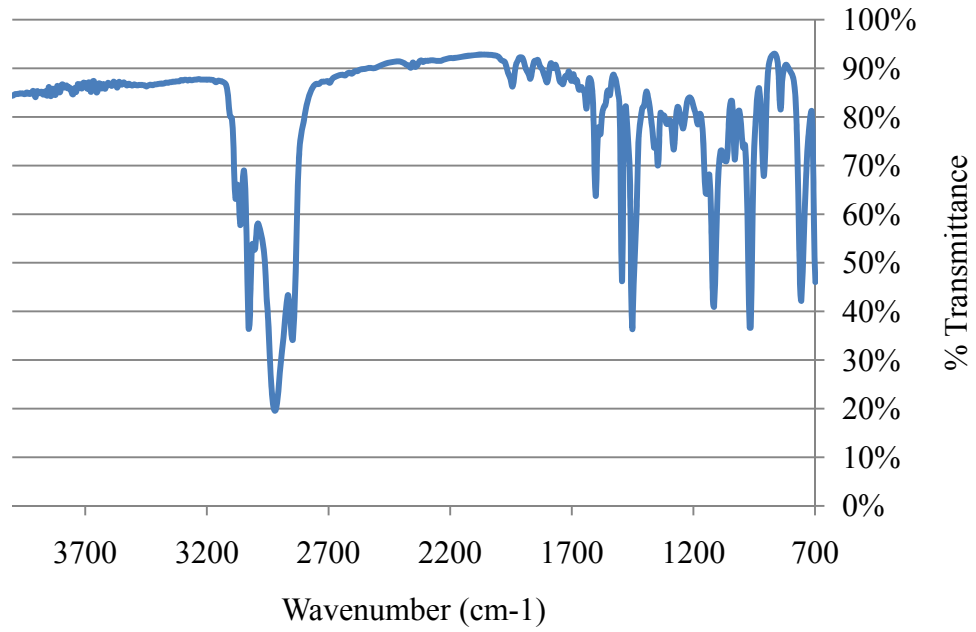


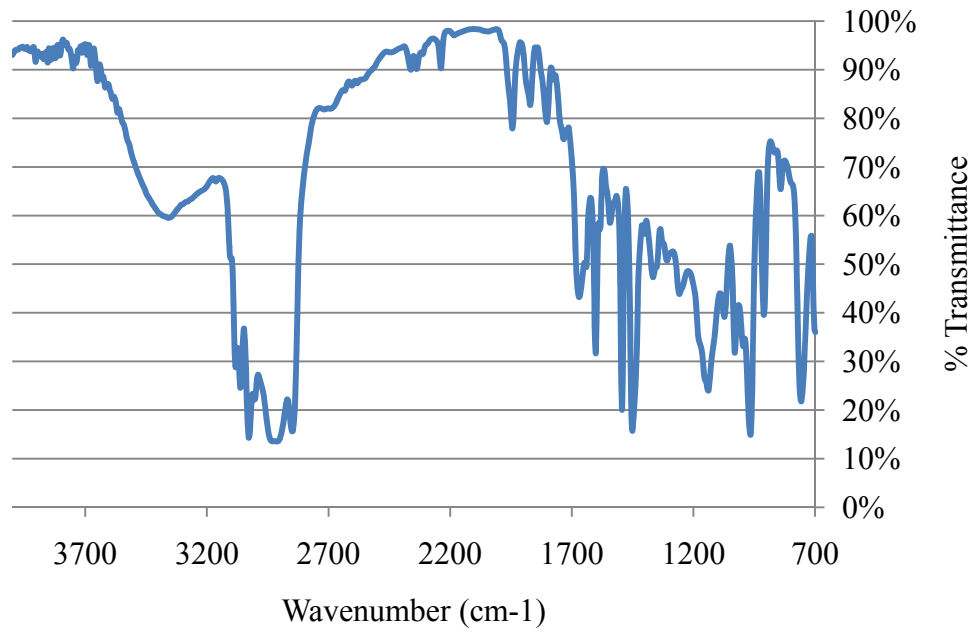
Figure 22 – Solid content of WLP and SBR

3.2.2 Infrared Spectroscopy

As can be seen from Figure 23 (C) and (D) WLP1 and WLP2 have similar wavenumber peaks, however, WLP1 has a curve with greater absorbance. The single point IR results exhibited the lowest transmittance for both SBR near 3000 cm^{-1} . Accordingly, this range of the spectra demonstrates all of the latex containing a C-H bond. Another common bond with the latex is in the 1100 cm^{-1} that is a C-O bond. Carbonyl was also found with the wavenumbers from $1600\text{-}1900\text{ cm}^{-1}$. The acrylate latex in WLP could be the reason for the carbonyl.

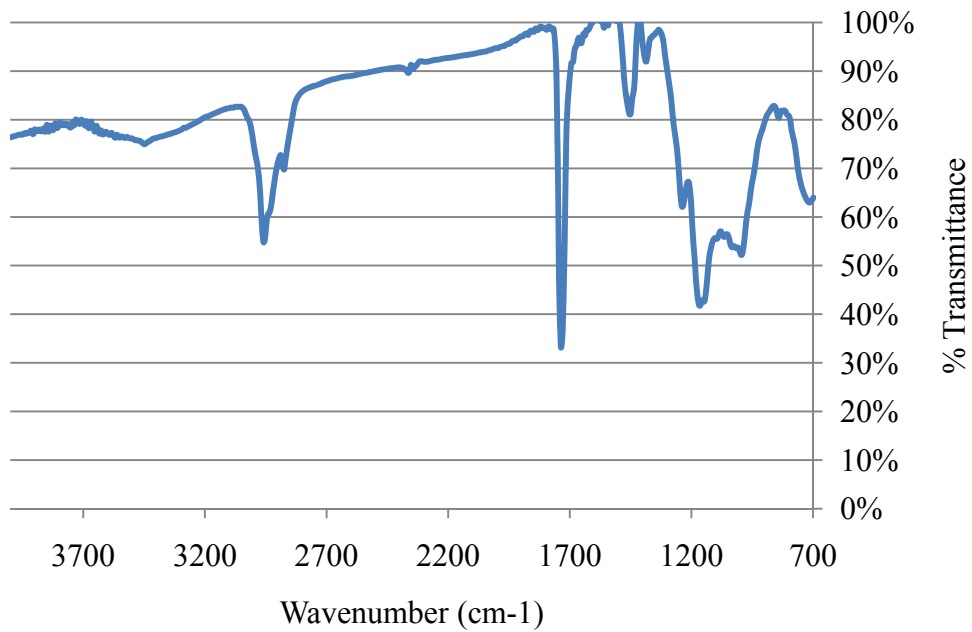


(a) SBR1

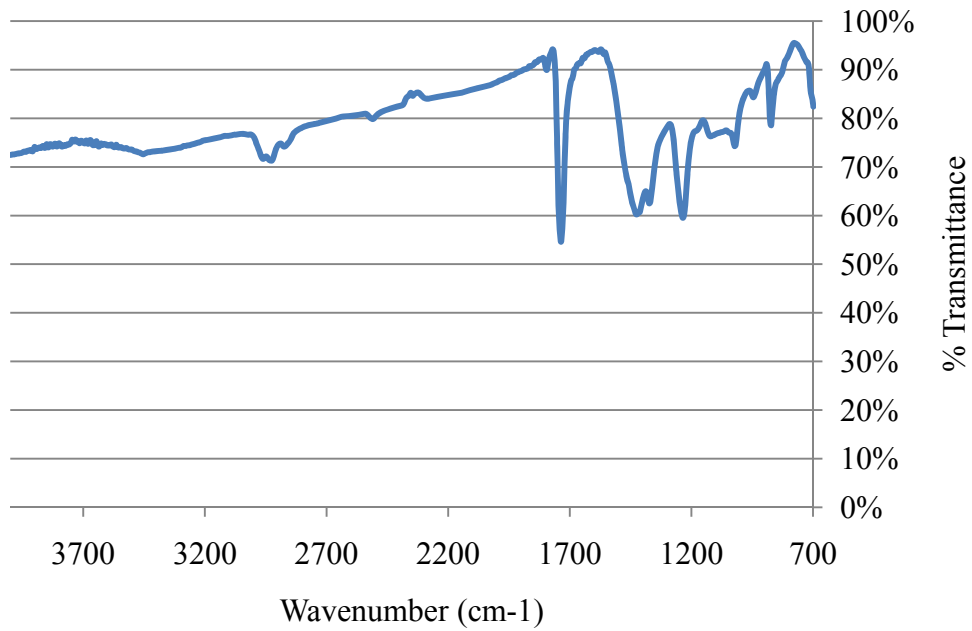


(b) SBR2

Figure 23- IR results for SBR and latex



(c) WLP1

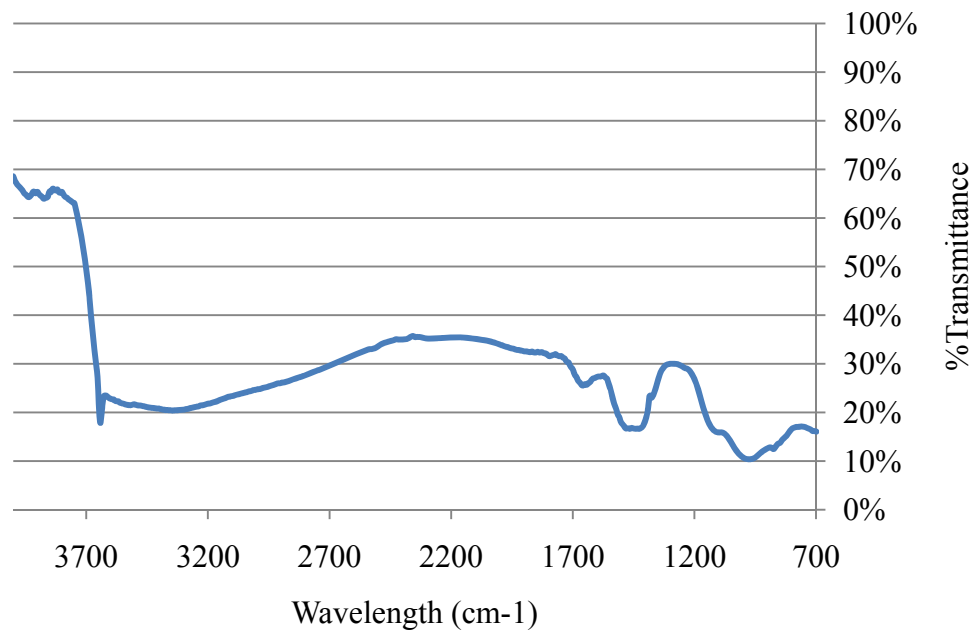


(a) WLP2

Figure 23 – (Cont.) IR Results for SBR and latex

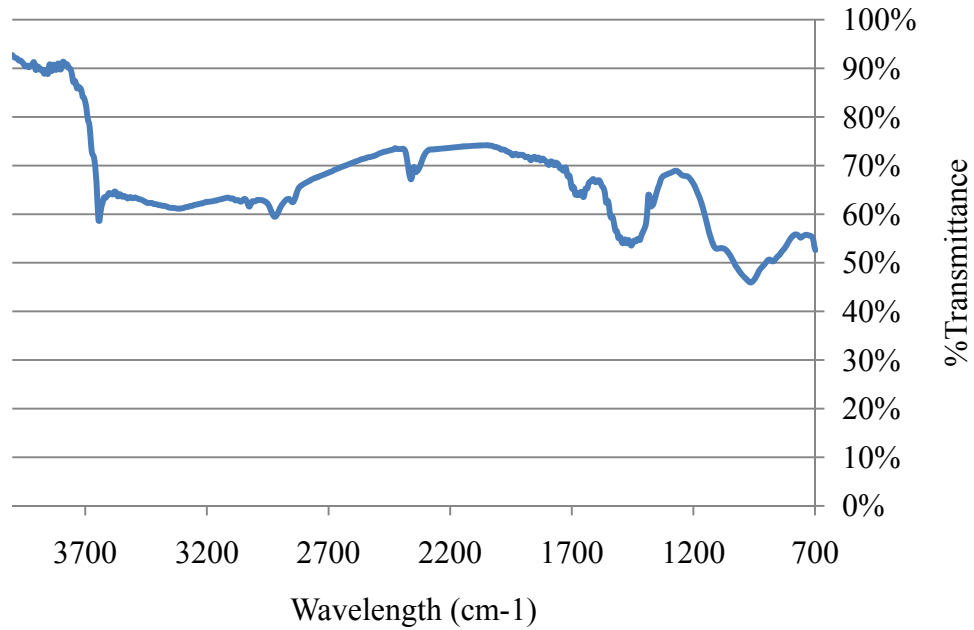
The reflectance results, tested on the cementitious paste, exhibited common bonds in the 1000 cm^{-1} and 3600 cm^{-1} spectrum. These are C-O and O-H bonds. Carbonyl was

found in the reflectance results. The peaks were lower due to the addition of cement and water. The SBR mixtures displayed a unique curve near 2400 cm^{-1} that is an O-H stretch and is in the functional function carboxylic acid. Carboxylic acid is commonly used to create polymers, which would be the reason for its spike in 2400 cm^{-1} range (Silverstein, 2005). Figure 24 demonstrates the results for the cementitious paste.

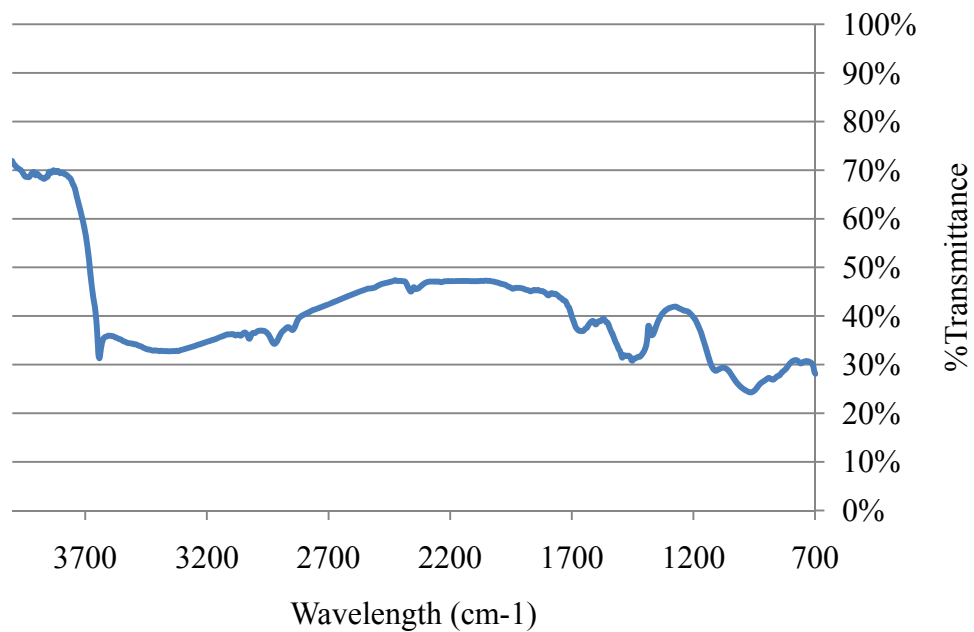


(a) NC Cementitious Paste

Figure 24 – IR results for cementitious pastes

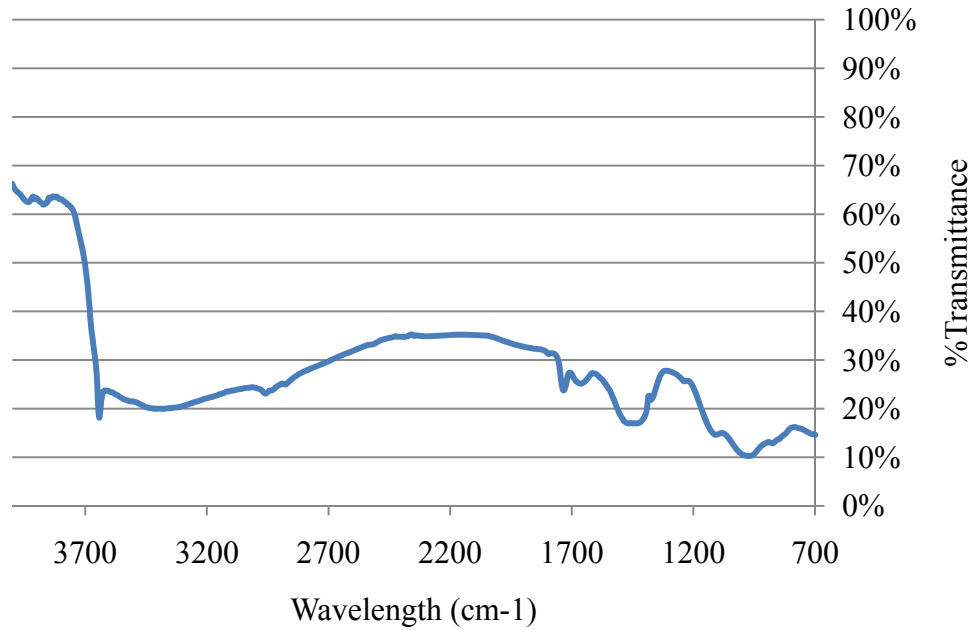


(b) SBR1 Cementitious Paste

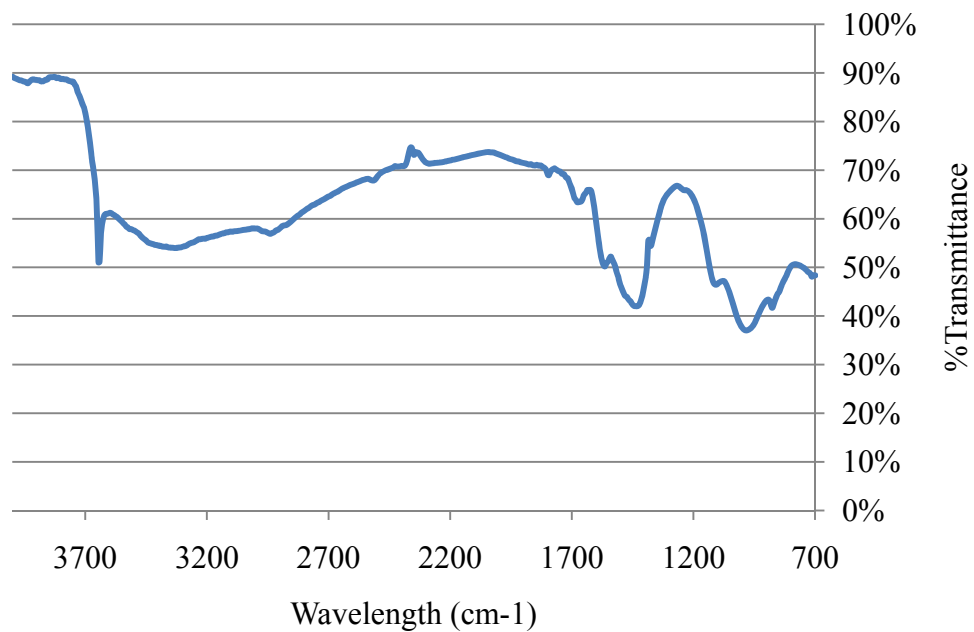


(c) SBR2 Cementitious Paste

Figure 24 – (Cont.) IR results for cementitious paste



(d) WLP1 Cementitious Paste



(e) WLP2 Cementitious Paste

Figure 24 – (Cont.) IR results for cementitious paste

3.3 Fresh Properties

3.3.1 Air Content

All of the mixtures had air contents less than the required amount of 6.5%. WLP1 and WLP2 had air contents of 1%, NC and SBR2 had an air content of 2%, and SBR1 had an air content of 4%. Through trial batches the air content was found to not have a large variance for the WLP mixtures.

3.3.2 Slump

All mixtures were created to have a slump between three to eight inches to meet the slump requirement. Table 7 displays the results for the slump and the mixture proportioning. SBR has a water reducing effect that WLP is not able to mimic. Although SBR1 does not have a high slump, it is able to achieve a slump between WLP1 and WLP2 with a lower (w/c) ratio and lower amount of High Range Water Reducing admixture (HRWR). SBR2 displayed a greater slump than WLP1 and WLP2 but does not use HRWR. The deficiency of a water reducing effect, from WLP, could be due to the viscosity of the WLP compared to SBR. WLP has a higher viscosity than SBR, which is a liquid fluid comparable to water.

Table 7 – Phase 1 fresh property results

Test	NC	SBR1	SBR2	WLP1	WLP2
Slump, in.	7 ± 0.5	$4.5 \pm .5$	$7.5 \pm .25$	$3 \pm .25$	4.75 ± 0.25
Air Content, %	2 ± 0.5	4 ± 1	2 ± 0.5	1 ± 0	1 ± 0.5

3.3.3 Adiabatic Temperature Change

The adiabatic temperature was used to find the reactivity of five mixtures. Figure 25 displays the results of the mixtures over the first 24 hours of curing. After 24 hours all of the mixtures had reached a constant temperature. The NC reached the highest temperature at 80° F. In addition, the NC had the quickest temperature gain. The NC achieved its maximum temperature 12 hours after batching. The high reactivity can be a reason as to why NC had the highest early compressive strength. The other mixtures reached their maximum temperatures between 12 and 18 hours. They also had maximum temperatures between 75° F and 78° F (24° C -26° C).

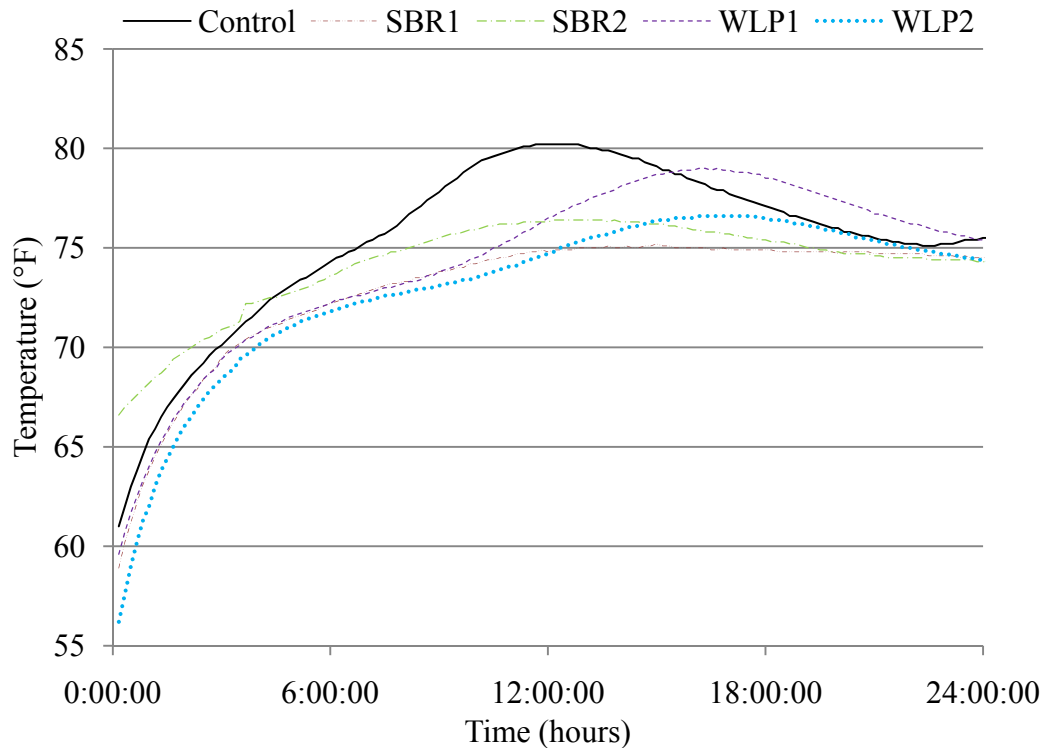


Figure 25 – Adiabatic temperature change

3.4 Hardened Properties

3.4.1 Compressive Strength

For a roadway to open to traffic the minimum required compressive strength is 3,000 psi. All of the mixtures were able to meet the requirement. Only three of the mixtures were able to reach the strength requirement within three days (NC, SBR1, and WLP1). SBR2 was able to reach the requirement within 7 days. While it only took the NC, SBR1, and WLP1 two to three days to reach the required strength, using Figure 26, it is estimated that it took SBR2 five days the reach the required strength. WLP2 reached the required opening compressive strength at an estimated 10 days. WLP1 was able to achieve the greatest ultimate strength. WLP is able to simulate and exceed SBR properties in compressive strength.

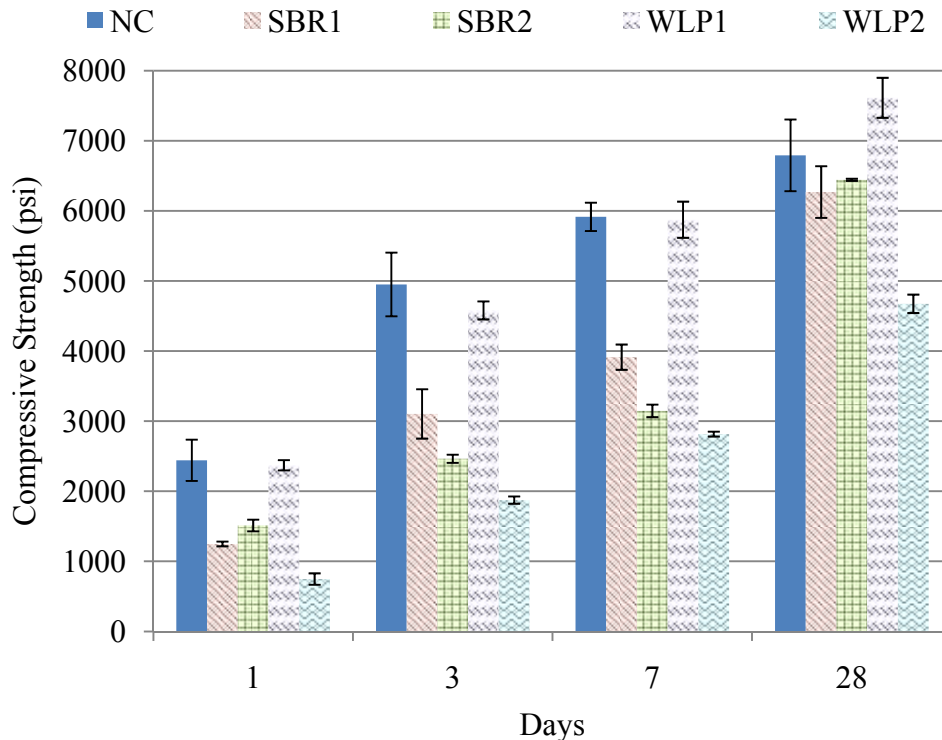


Figure 26 – Compressive strength gain of concrete samples through 28 days

3.4.2 Splitting Tensile Strength

Figure 27 demonstrates SBR2 and WLP1 as having the greatest splitting tensile strength with over 800 psi. The NC and SBR1 mixtures had a tensile strengths of 700 psi and WLP2 had a tensile strength of 660 psi. The w/c ratio of WLP2 could be the reason for its lower tensile strength.

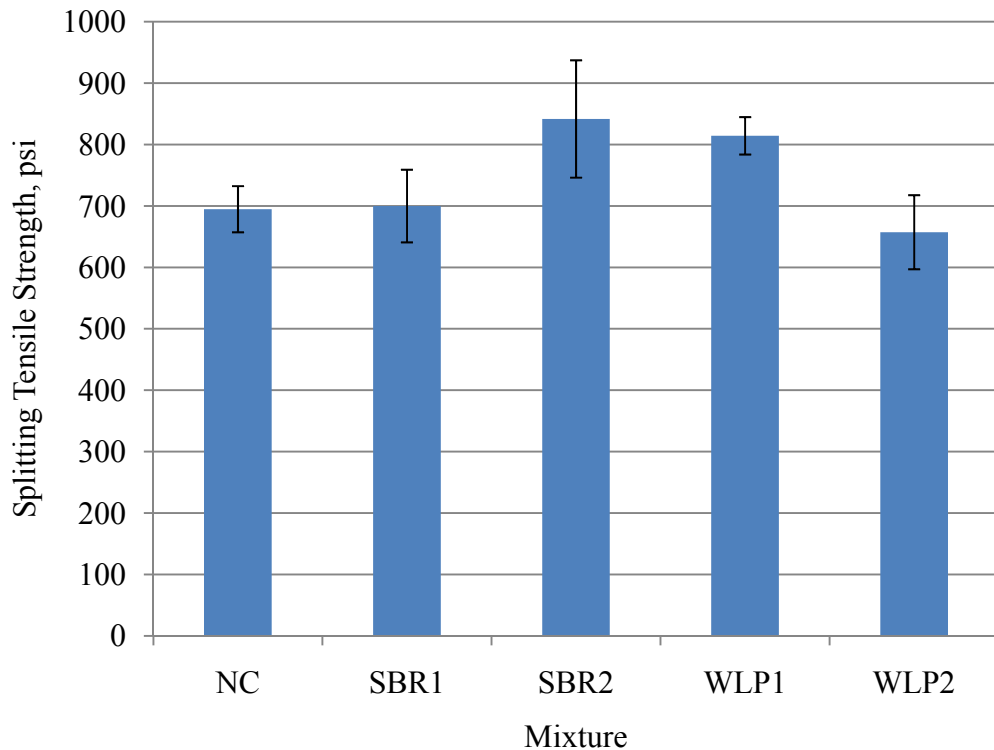


Figure 27 – Splitting tensile strength results at 28 days

3.5 Durability Properties

3.5.1 Abrasion Resistance

The abrasion resistance was found to estimate the durability of each mixture under traffic conditions. SBR1 and SBR2 were found to have the lowest, average abraded volume followed by the NC and WLP1. WLP2 had the largest abraded volume and largest abrasion coefficient. SBR1 and WLP1 had the lowest abrasion coefficient. Overall

SBR1 had the greatest abrasion resistance and WLP2 had the lowest abrasion resistance. The higher w/c ratio could be the reason for the lower abrasion resistance of WLP2. The WLP1 mixture displayed the ability to have an abrasive characteristic similar to the SBR mixtures. Figure 28 pictures the samples after testing and Table 8 summarizes the results.

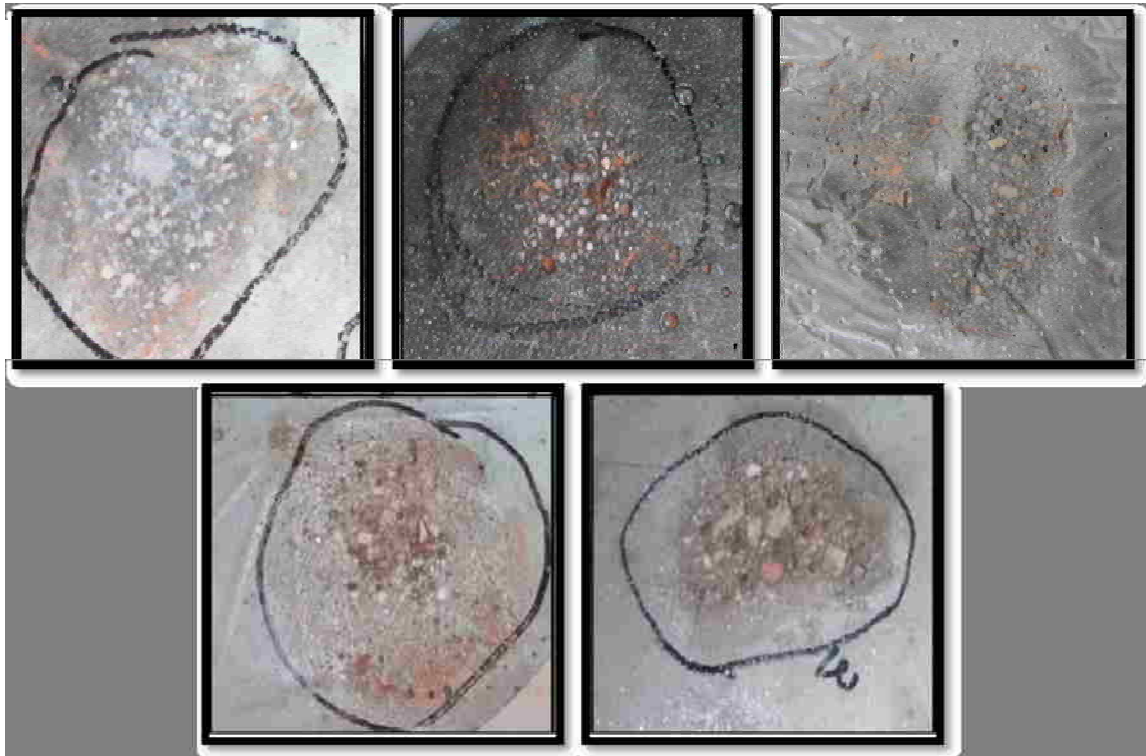


Figure 28 – Abrasion on concrete samples (Top left to bottom right: NC, SBR1, SBR2, WLP1, and WLP2)

Table 8 – Abrasion results

Mixture	Volume Abraded in ³	Surface Area in ²	Abrasion Coefficient in ³ /in ²
NC	0.15 ± 0.05	3.31 ± 1.8	0.05 ± 0.03
SBR1	0.08 ± 0.04	1.89 ± 0.65	0.04 ± 0.02
SBR2	0.09 ± 0.04	1.34 ± .78	0.07 ± 0.02
WLP1	0.15 ± 0.04	3.71 ± 0.9	0.04 ± 0.01
WLP2	0.17 ± 0.04	1.63 ± 0.74	0.11 ± 0.03

3.5.2 Rapid Chloride Penetrability Test (RCPT)

The rapid chloride penetrability test (RCPT) was performed on the mixtures to determine their penetrability to chloride ion. As can be seen in Table 9, positive results were found for mixtures with polymers. All mixtures containing SBR or WLP received the penetrability rating “very low”.

The physical penetration depth for all of the mixtures was also found. As with the RCPT results, the latex mixtures exhibited superior resistance to chloride attack with the penetration depth test. The absence of polymers in NC reduced its resistance to chloride penetration.

Table 9 – RCPT and penetration depth results

Mixture	Passed charge, coulombs	Penetrability evaluation, ASTM C1202	Penetration depth in.
Control	1751	Low	0.5 ± 0.08
SBR1	704	Very Low	0.08 ± 0.03
SBR2	944	Very Low	0.11 ± 0.04
WLP1	739	Very Low	0.19 ± 0.04
WLP2	746	Very Low	0.15 ± 0.02

3.5.3 Mercury Intrusion Porosimetry

The cumulative results for the MIP testing can be seen in Table 10. WLP2 had the greatest cumulative intrusion with both micro and macro pores. This suggests that WLP2 has the greatest porosity. This could result in overall decreases in durability of this mixture. Figure 29 illustrates SBR2, WLP1 and WLP2 as having the greatest percentage of micro pores. WLP1 had the least intrusion of all mixtures at 0.1 μm. This signifies

greater durability for the concrete. Overall, the addition of latex increases density of the cement matrix and allows less intrusion. The results indicate that a WLP mixture can have the ability to simulate SBR porosity results. This will give the concrete mixture greater durability.

Table 10 – Mercury intrusion porosimetry results

Mixture	Cumulative Intrusion at 0.1 μm , ml/g	Macro Pores, %	Micro Pores, %
NC	0.0279	57.8	42.2
SBR1	0.0265	62.2	37.8
SBR2	0.0245	48.8	51.2
WLP1	0.0199	44.6	55.4
WLP2	0.0435	55.0	45.0
Average	0.0285	53.7	46.3

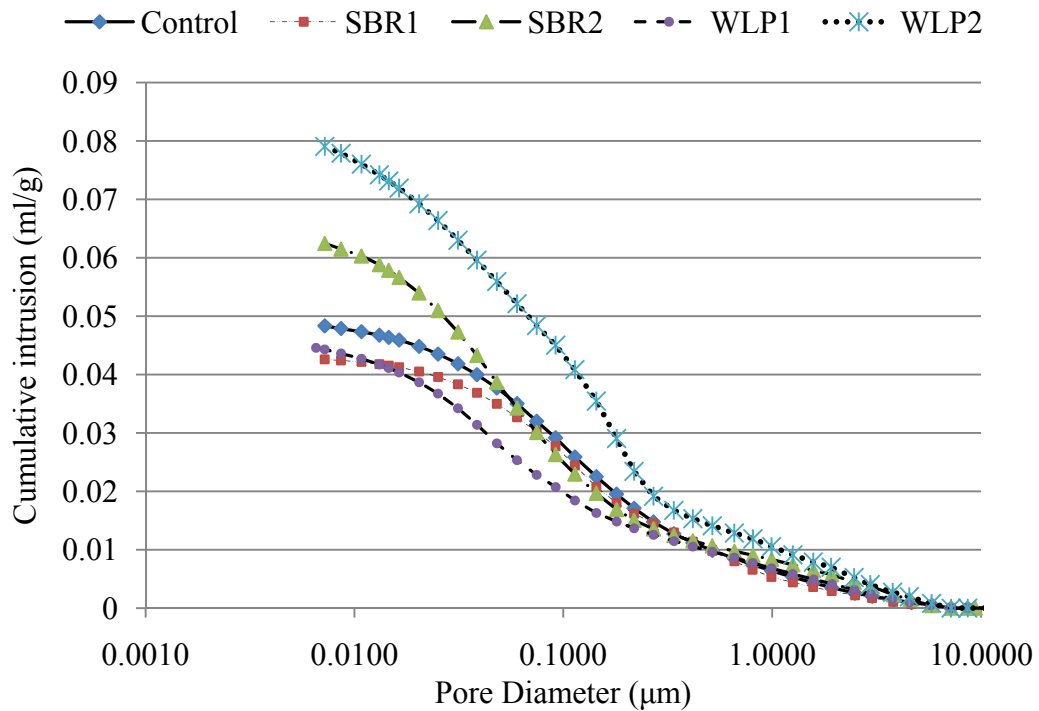


Figure 29 – Mercury intrusion results

3.6 Conclusion and Recommendations

LMC was created to overcome the common disadvantages found in concrete. WLP was added to concrete to test its ability to be used as a replacement for pure latex. Test performed include fresh concrete properties, hardened concrete properties, durability of concrete, and properties of SBR and WLP. The tests were performed within the guidelines of LMC for overlays specifications (ACI 548.4, 1993).

The following requirements were followed and met for the WLP overlay mixtures:

- Compressive strength of 3000 psi for opening to traffic
- Slump between three to eight inches
- Maximum air content of 6.5%
- Minimum cementitious content of 658 lb/yd³
- Maximum water to cement (*w/c*) ratio of 0.40

(ACI 548.1, 1993)

The 3000 psi opening day strength was met by both of the WLP mixtures but one WLP mixture was able to achieve the strength several days ahead of the other.

All mixtures met the slump requirement. In some cases the mixtures had to be altered in order to meet the requirement. Changes to the mixtures include changing the *w/c* ratio or the amount of high range water reducing admixture (HRWR). All mixtures had air contents less than 6.5% and did not use air entraining admixtures. The concrete mixtures were designed with a minimum cementitious content of 658 lb/yd³ and a *w/c* ratio less than 0.4.

The following may be concluded:

- WLP1 had higher strength gain and a higher ultimate strength than SBR1 and SBR2. Improved strength gain would allow WLP1 to be in service before SBR1 and SBR2
- The abrasion coefficient of WLP1 was comparable to SBR1 and SBR2. WLP2 may have had an increased abrasion coefficient due to its high w/c ratio.
- Both WLP1 and WLP2 mixtures had chloride penetrability equivalent to the NC mixture according to the RCPT. SBR1 and SBR2 had the highest resistance to chloride penetration with “low” and “moderate” results, respectively.
- The WLP1 mixture met the requirements specified in ACI 548.4 to be used as an overlay. However, WLP2 had a lower performance than WLP1 in terms of abrasion, strength gain, ultimate strength, and in porosity.
- IR testing of the paints and cement mixtures displayed several similarities between the WLP and the SBR. The SBR1 and SBR2 cement mixtures displayed a difference in the spectra at 2400 cm^{-1} . These were also displayed during the single point testing.
- For paint to be used in construction, it must be tested for water and solid content. This will allow for opened paint containers to be used in concrete mixtures. The type of paint used may also change the properties of the concrete. A procedure must be established to determine which paints may be used.
- The WLP2 mixture contained a different paint and a different w/c ratio than WLP1. This combination lowered the properties desired in overlays including strength gain, ultimate strength, abrasion resistance, and tensile strength. Figure

29 demonstrated that the WLP2 mixture had larger micro and macro pores which could attribute to the lower performance.

- WLP has the ability to simulate several characteristics and LMC including compressive strength, tensile strength, abrasion resistance, and chloride resistance.
- WLP has the ability to improve normal concrete in properties important for overlays including ultimate strength, splitting tensile strength, and chloride resistance.

CHAPTER 4
PHASE 2 RESULTS: RECYCLING WASTE LATEX PAINT
IN RIGID PAVEMENTS

4.1 Overview

Rigid pavements are used for airports and highways. Rigid pavements must be designed to withstand repeated traffic loading. They have superior durability over flexible (asphalt) pavements. While rigid pavements are designed for a service life between 30 to 40 years, a flexible pavement has a service life between 15 to 20 years (FWA, 2006).

4.2 Tested Solid Content of Paint

The final results for the solid content were found after 56 days. Figure 30 demonstrates the change in solid content through time. The Styrene Butadiene Rubber (SBR) latex, used for phase 2, was found to have a solid content of 52% and waste latex paint (WLP) had a solid content of 56%. SBR had a published solid content of 47%. WLP has a published solid content value of 54%. The overall results demonstrate a difference less than 10% from the tested results to the published values.

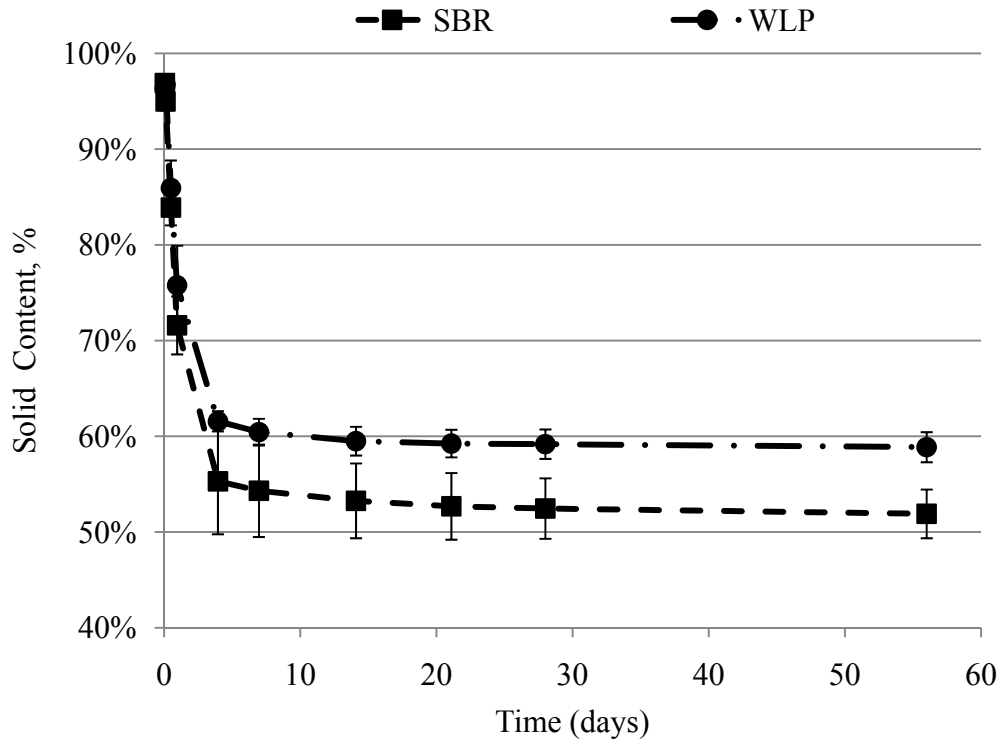


Figure 30 – Solid content of paint and latex used for phase 2

4.3 Fresh Properties

4.3.1 Slump

All mixtures had a slump less than the maximum amount of three inches. Due to the water reducing effects of SBR its mixture had to decrease the water to cementitious (w/cm) ratio to meet the slump requirement. Even though the SBR mixture had a w/cm ratio less than the NC or WLP mixtures, it was able to demonstrate the greatest slump. This natural water reducing effect of SBR was not demonstrated in the WLP mixture. The WLP mixture had the same w/cm ratio as the NC mixture but WLP had a slump 0.75 in. less than NC. Table 11 summarizes the fresh property results.

Table 11 – Fresh property results

Test	NC	SBR	WLP
Slump, in.	2 ± 0.5	2.25 ± 0.5	1.25 ± 0
Air Content, %	2 ± .5	0.5 ± 0	0.5 ± 0
Unit Weight, lb/ft ³	147 ± 0	147 ± 0.6	145 ± 1

4.3.2 Air Content

While NC had the highest air content at 2%, the latex mixtures had air contents less than 1%. Without an air-entrainment admixture the NC mixture was not able to reach an air content that would allow it to be resistant to freezing and thawing cycles. This susceptibility to freezing and thawing was exhibited in the surface scaling and the freeze-thaw testing. Although, SBR and WLP had air contents less than NC they both demonstrated superior performance during freezing cycles.

4.3.3 Adiabatic Temperature Change

The three figures had nearly identical results with a maximum peak being reached in the first 12 hours. Overall the WLP mixture had the highest and lowest temperature of the three mixtures. Figure 31 demonstrates the change in temperature through the first 48 hours. The mixtures had consistent temperatures after 48 hours.

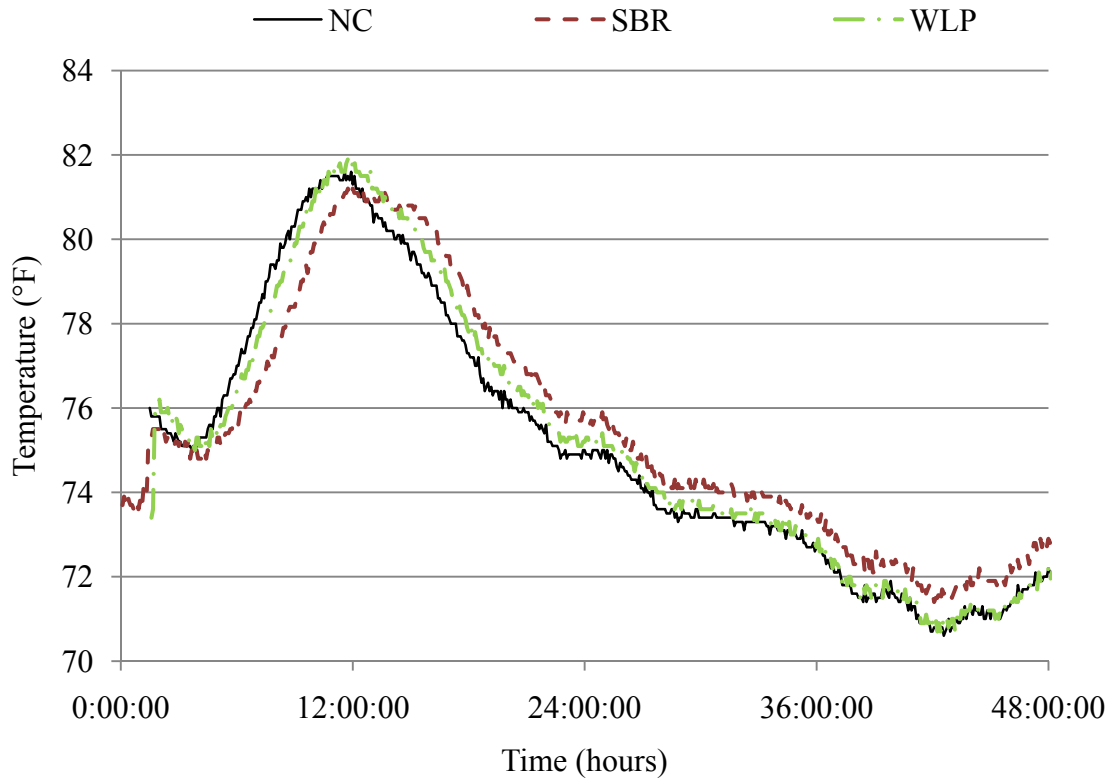


Figure 31 – Adiabatic Temperature Change

4.3.4 Unit Weight

As can be seen in Table 11, the three mixtures had unit weights similar to one another. While NC and SBR both had fresh unit weights of 147 lb/ft³, the WLP mixture had a fresh unit weight of 145 lb/ft³.

4.4 Hardened Properties

4.4.1 Compressive Strength

As seen in Figure 32, WLP and NC both had similar compressive strengths throughout the 28-day testing period and both finished with compressive strengths near 6000 psi. However, SBR had compressive strengths higher than both WLP and NC. This higher strength was consistently higher throughout the 28-days. SBR had a 28-day

compressive strength of 9700 psi. SBR's higher strength was due to its water reducing ability which allowed a w/cm ratio of 0.20.

The WLP-M mixture was created by decreasing the w/cm ratio of WLP from 0.35 to 0.30. By decreasing the w/cm a significant improvement can be seen in compressive strength. The final compressive strength of WLP-M is above the 6000 psi requirement. The WLP-M mixture is about 1000 psi higher than NC and WLP.

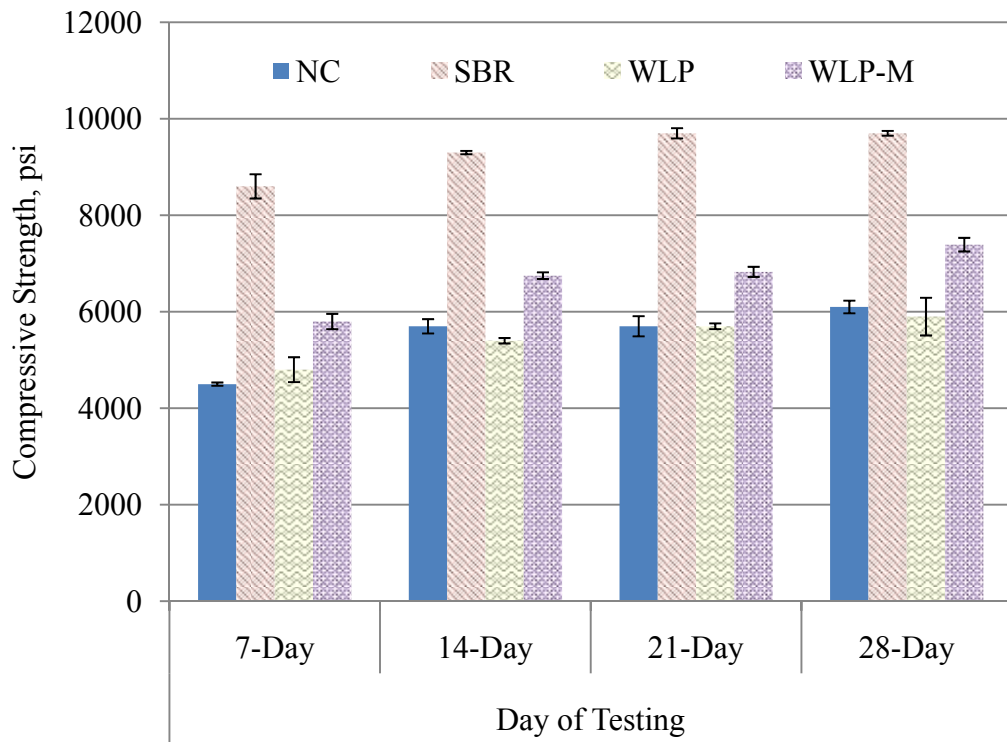


Figure 32 – Compressive strength gain through 28 days

4.4.2 Splitting Tensile Strength

While WLP had the lowest splitting tensile strength of three mixtures at 490 psi, SBR had the highest tensile strength at 740 psi. WLP was not able to simulate the ability of SBR to improve the splitting tensile strength of concrete. The splitting tensile strengths for mixtures can be compared in Table 12 and Figure 33.

The WLP-M mixture was able to improve tensile strength over the WLP mixture.

There is no statistical difference between WLP-M and SBR.

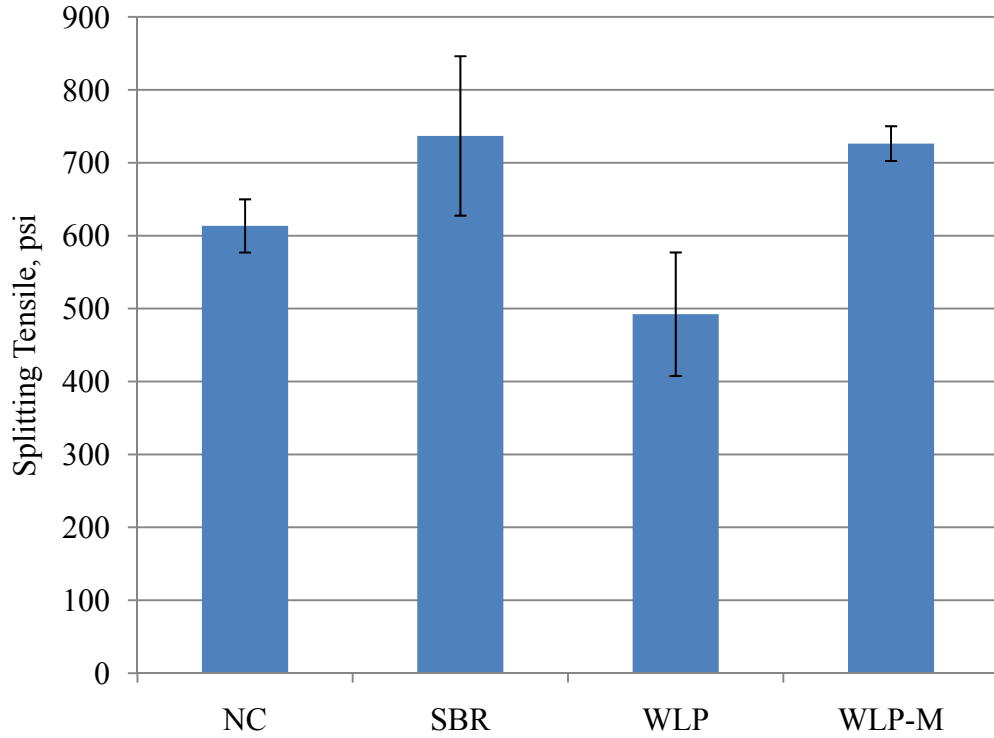


Figure 33 – Splitting tensile results at 28 days

Table 12 – Mechanical properties

Mixture	Compressive Strength, psi				Splitting Tensile Strength, psi	Static Modulus of Elasticity, psi	Modulus of Rupture, psi
	7-Day	14-Day	21-Day	28-Day	28-Day	28-Day	180-Day
NC	4500	5700	5700	6100	610	4,300,000 ± 0	860 ± 16
SBR	8600	9300	9700	9700	740	4,500,000 ± 0	1160 ± 36
WLP	4800	5400	5700	5900	490	3,650,000 ± 0	910 ± 32

4.4.3 Static Modulus of Elasticity

Table 12 displays the results for the static modulus of elasticity. SBR exhibited the highest modulus of elasticity. WLP was not able to simulate the improved property.

4.4.4 Flexural Strength

Testing for flexural strength displayed similar modulus of rupture strength for NC and WLP. SBR had the highest modulus of rupture with a total strength of 1160 psi. All mixtures were capable of exceeding pavement flexural requirements ranging from 150 psi to 500 psi (FWA, 2006).

Figure 34 exhibits the deflection of the beam throughout the loading process. The NC mixture displayed the greatest deflection throughout its loading. NC demonstrated similar final deflection as WLP but had a greater total load. Although WLP was not able to simulate the strength of SBR, it was able to simulate the elasticity.

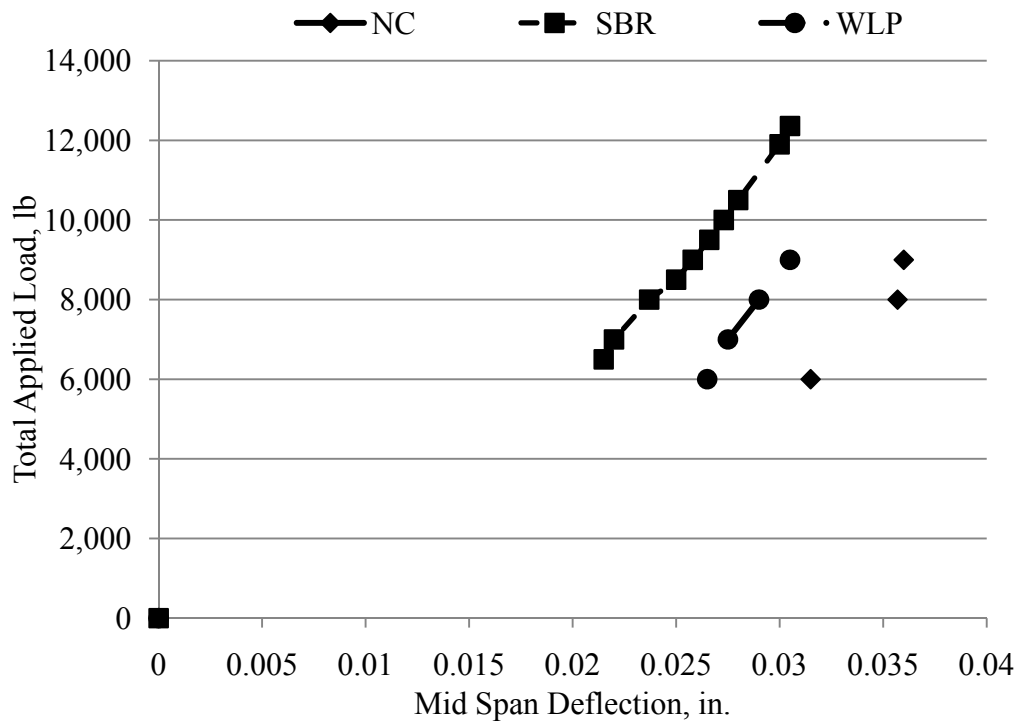


Figure 34 – Mid span deflection of beam vs. loading

4.5 Durability Properties

4.5.1 Rapid Chloride Penetrability Test

Table 13 summarizes the rapid chloride penetrability test results (RCPT). NC and WLP had high penetrability ratings but WLP had a lower penetration depth. WLP displayed a penetration depth of 1.05 in. while NC had a penetration depth of 1.46 in. WLP had a total passed charge of 1000 coulombs less than NC. Although NC and WLP had ratings of high, WLP demonstrated an enhanced resistance to chloride ion penetration than NC. SBR had the greatest resistance to the chloride ion penetration. SBR had 2660 coulombs pass through the sample during testing and this gives SBR a moderate susceptibility rating to chloride ion penetration. SBR also had the lowest penetration depth with only 0.5 in. of chloride penetrating the sample. The physical penetration depth can be seen in Figure 35. The chloride penetration in the figure is average distance from the top of the sample to the darker region.

Table 13 – Rapid chloride penetrability test and penetration results

Mixture	Passed Charge, coulombs	Penetrability Evaluation, ASTM C1202	Penetration Depth, in.
NC	7435	High	1.46 ± 0.21
SBR	2660	Moderate	0.5 ± 0.07
WLP	6470	High	1.05 ± 0.39



Figure 35 – Images of chloride penetration depth on RCPT samples

4.5.2 Resistance to Rapid Freezing and Thawing

The durability factor can be seen in Table 14. WLP, at 61.9, had the highest durability factor followed by SBR, at 57.5. Due to NC's low relative modulus of elasticity and early termination its durability factor decreased to 9.5.

Figure 36 displays the changes in transverse frequency in the tested samples. The figure demonstrates a slight increase for the WLP and SBR mixtures throughout the testing period. The NC mixture is considered failed at 130 cycles due to a decrease in transverse frequency greater than 30%.

As can be seen in Figure 37, NC deteriorated under freeze-thaw conditions. The specimen failed after nearly 50 cycles according to the 0.10% maximum elongation requirements. WLP and SBR mixtures demonstrated the ability to resist a 0.10% length change after 300 cycles. The change in length can be seen in Figure 38 and Figure 39.

Table 14 – Durability factor of freezing and thawing samples

Mixture	Relative Modulus of Elasticity (P)	Number of cycles at failure (N)	Number of cycles to be tested (M)	Durability Factor (DF), ASTM C 666
NC	22	130	300	9.5
SBR	57	300	300	57.5
WLP	62	300	300	61.9

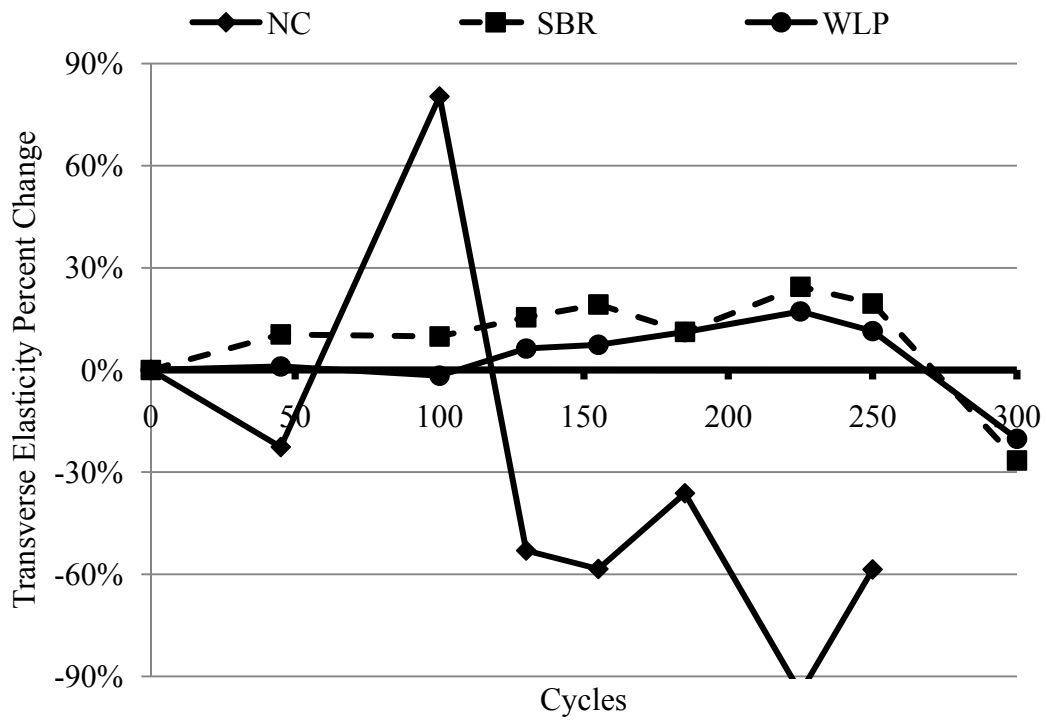


Figure 36 – Transverse elasticity test of freeze-thaw samples



Figure 37 – Images of freezing and thawing samples

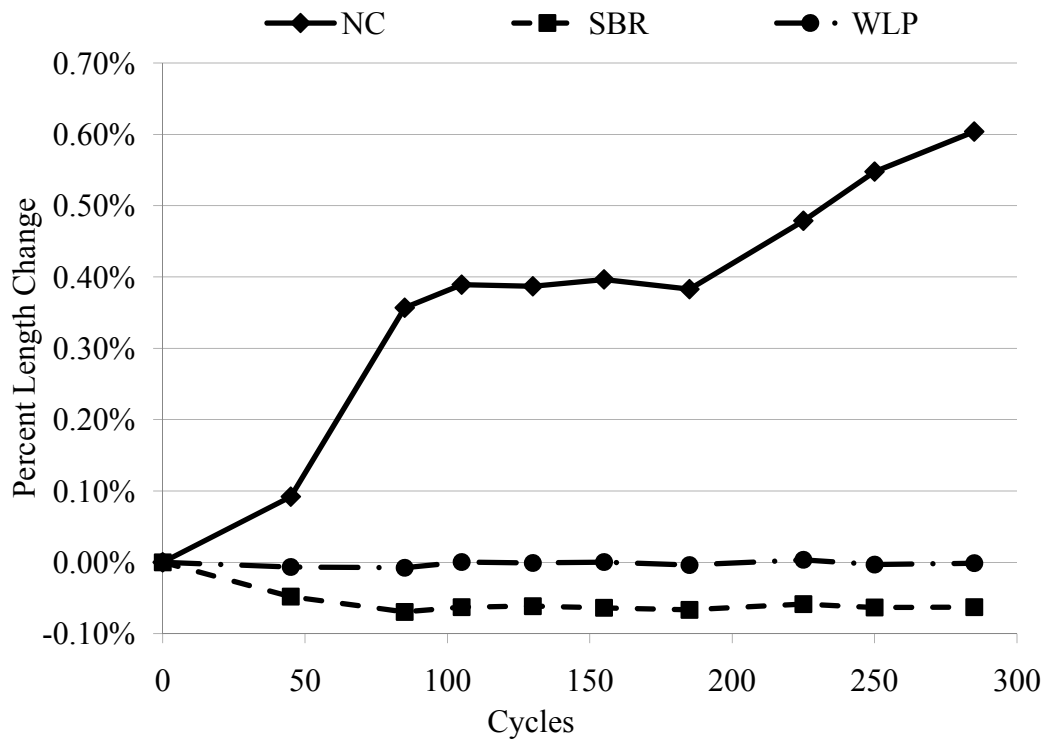


Figure 38 – Change of length from freeze-thaw samples

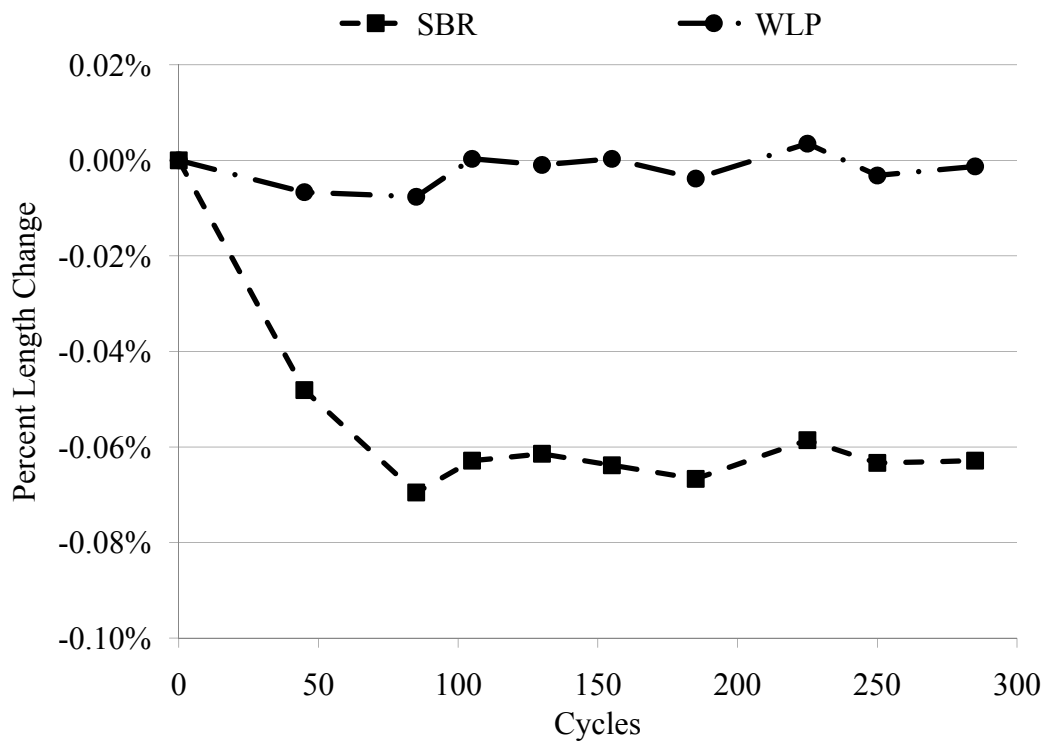


Figure 39 – Change of length from freeze-thaw samples (SBR and WLP only)

4.5.3 Resistance to Surface Scaling by Deicing Chemicals

Table 15 displays a visual rating of 1 for SBR and 2 for the WLP concrete mixture. However, NC received a visual surface scaling rating of 5. Figure 40 demonstrates that NC had significantly larger surface scaling throughout testing. NC deteriorated until failure at 30 cycles. SBR and WLP demonstrate the ability to improve surface scaling of normal concrete. Although, the SBR mixture had a visually superior surface, WLP had less recorded surface scaling as exhibited in Figure 41. Figure 42 displays the final physical deterioration of the three samples.

Table 15 – Surface scaling results

Mixture	Visual Scaling Rating	Total Scaling, oz
NC*	5	5.322
SBR	1	0.740
WLP	2	0.599

*NC mixture failed at 30 days

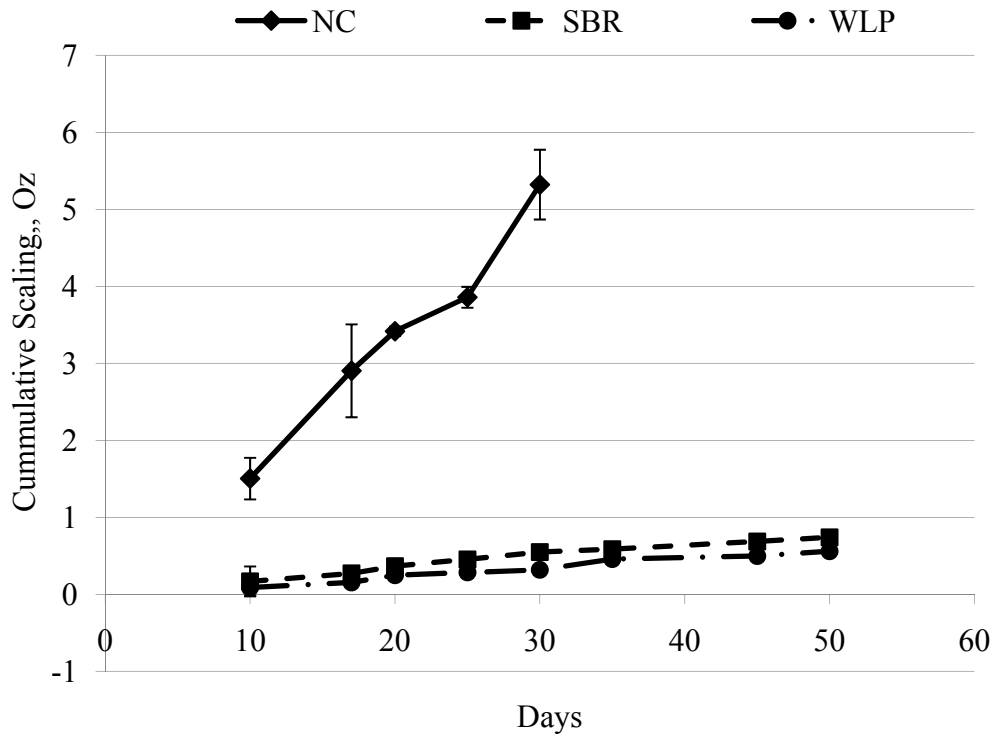


Figure 40 – Cumulative surface scaling

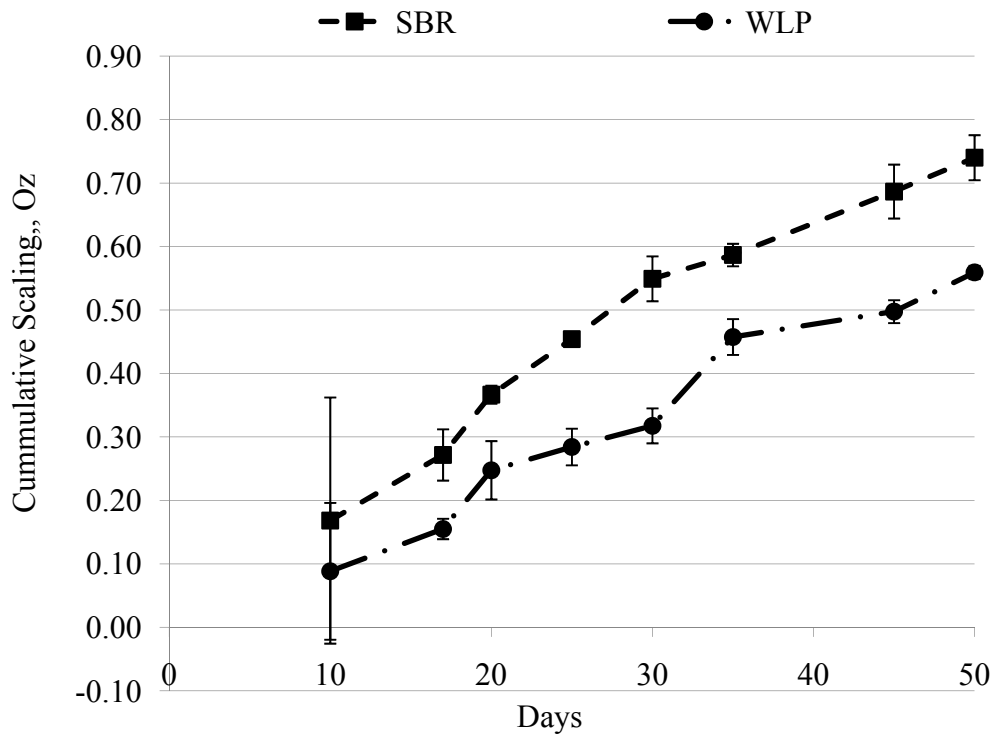


Figure 41 – Cumulative surface scaling for SBR and WLP only



Figure 42 – Images of surface scaling samples (from left to right: NC, SBR, WLP)

4.5.4 Abrasion Resistance Test

The three mixtures had similar abrasion coefficients. However, on average, SBR had the lowest volume abraded and lowest surface area. Table 16 shows the results for the abrasion testing and Figure 43 displays the samples after testing. The figure demonstrates the decreased surface area and volume for the SBR mixture.

Table 16 – Abrasion resistance results for phase 2

Mixture	Volume Abraded, in ³	Surface Area, in ²	Abrasion Coefficient, in ³ /in ²
NC	0.15 ± 0.10	2.99 ± 1.50	0.05 ± 0.01
SBR	0.08 ± 0.03	1.78 ± 0.44	0.04 ± 0.01
WLP	0.10 ± 0.04	2.02 ± 0.78	0.05 ± 0.01



Figure 43 – Abrasion samples after testing (from left to right: NC, SBR, WLP)

4.6 Conclusion

Several tests were completed to compare a general rigid pavement concrete mixture with a WLP rigid pavement mixture. Several tests and standards were completed to see if a WLP mixture could meet standards met by regular portland cement concrete. The following recommendations were followed for the WLP rigid pavement mixtures:

- Slump between one to three inches
- Water to cementitious (w/cm) ratio less than 0.41
- Cementitious material content of 840 lb/yd³
- Fly ash replacement of 25%
- Compressive strength of 6000 psi at 28 days
- Modulus of Rupture between 150 to 500 psi

(Delatte, 2009; FWA, 2006)

Mixtures were proportioned to meet slump requirements between one and three inches. Also, mixtures were designed with a w/cm ratio less than 0.41. A minimum cementitious content of 840 lb/yd³ was used along with a 25% fly ash replacement. The 25% fly ash replacement was used because of similar replacement used by the Nevada Department of Transportation (NDOT).

The only requirement not surpassed by WLP was compressive strength. WLP was 100 psi from reaching the 6000 psi requirement. As demonstrated by WLP-M, a decrease in the w/c ratio and using a high range water reducing admixture (HRWR) can increase strength and maintain workability.

The modulus of rupture for all mixtures surpassed the 150 to 500 psi recommendation for general rigid pavements.

Fresh, mechanical, and durability properties were tested in phase 2. Several conclusions can be made from phase 2. These conclusions include:

- WLP concrete does not demonstrate the same improved workability as SBR in concrete.
- WLP concrete exhibits the ability to resist freezing cycles without using air-entraining admixtures. Surface scaling and freeze-thaw testing demonstrated that WLP was able to have similar or improved properties than SBR concrete.
- Although WLP had superior results over NC in freeze-thaw and surface scaling tests, NC could improve by the addition of air entraining admixture.
- WLP had lower mechanical properties than the SBR mixtures.
- All SBR and WLP mixtures had improved chloride resistance results compared to NC.

CHAPTER 5
PHASE 3 RESULTS: RECYCLING WASTE LATEX PAINT
IN PERVIOUS CONCRETE

5.1 Overview

Pervious concrete is used to recharge groundwater and reduce stormwater runoff. Pervious concrete has a dependence on a strong cementitious paste to avoid aggregate separation. Waste latex paint (WLP) may improve the cementitious paste strength due to improvements in concrete with the addition of WLP. This section will study the ability of recycling WLP in pervious concrete.

5.2 Unit Weight of Pervious Concrete

Figure 44 displays the fresh unit weight of the pervious concrete along with the hardened density. NC and 5% WLP exhibit an increase in unit weight from the fresh density to the hardened density. The next three mixtures display a decrease in hardened unit weight. The decrease in hardened unit weight could be a sign of a weaker cementitious paste surrounding the aggregate. The weaker paste would allow aggregate to be lost between fresh density and hardened density measurements. Tennis *et al.* (2007) state common hardened densities to be within the range of 100 lb/ft³ to 125 lb/ft³. The 20% WLP mixture was the only mixture with a density less than 100 lb/ft³.

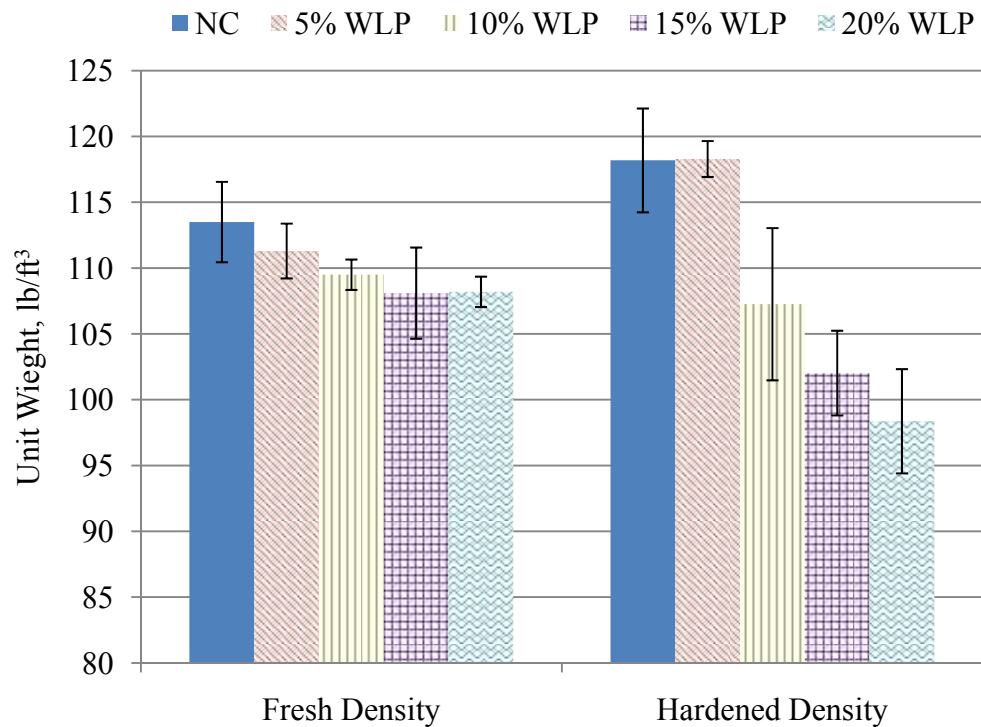


Figure 44 – Unit Weight of Concrete

5.3 Hardened Properties

5.3.1 Compressive Strength

Figure 45 demonstrates the compressive strength and splitting tensile strength of the NC and WLP mixtures. A decrease in strength was found with increasing percentages of latex paint. The increase from 5% WLP to 10% WLP decreased 7-day compressive strength, 28-day compressive strength, and 28-day splitting tensile strength by over 50%. The addition of 5% WLP decreased the compressive strength for 7- and 28-day testing by less than 10% compared to NC.

Tennis *et al.* (2007) stated that pervious concrete can have a compressive strength ranging from 500 psi to 4000 psi. NC, 5% WLP, 10% WLP, NC+Fiber,, and 5% WLP+Fibers were the only mixtures able to achieve the minimum compressive strength.

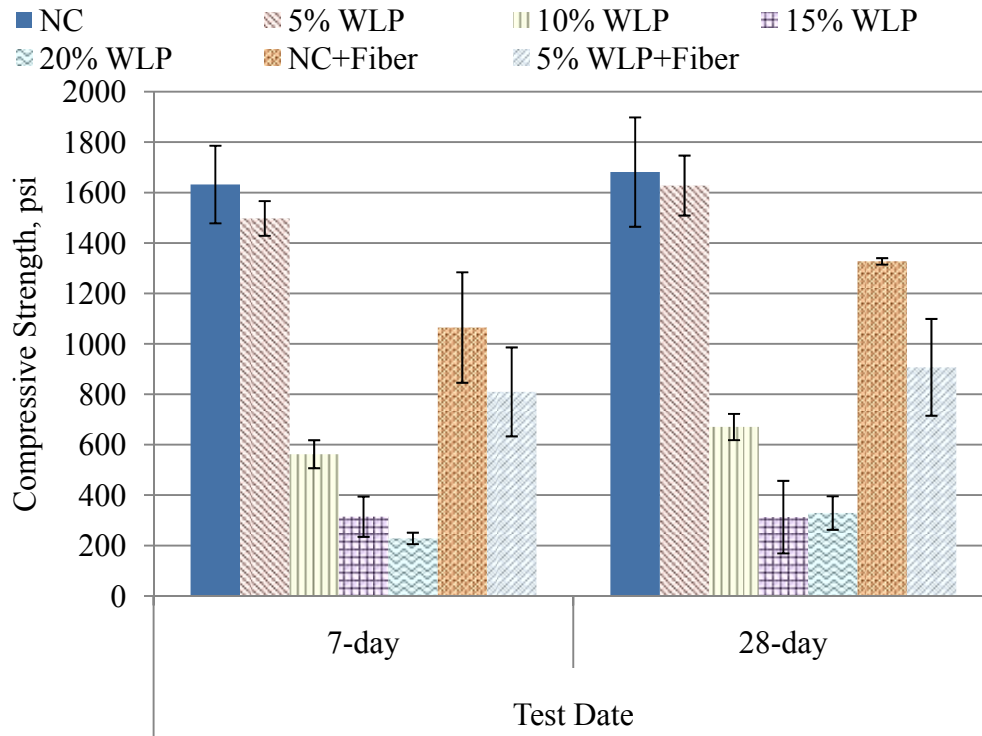


Figure 45 – Mechanical Properties of Pervious Concrete

Figure 46 displays the 7-day compressive strength of all mixtures including mixtures with fibers and dry cured mixtures. The figure exhibits a 40% decrease in strength for both mixtures with fibers. The dry cured samples had mixed results. The 5% WLP mixture decreased in strength by 32%. However, the 20% WLP mixture increased in strength by over 100%. Concrete is generally cured in a curing room to improve strength. For best results, latex-modified concrete (LMC) is dry cured. The 5% WLP mixture could have an insignificant amount of paint and therefore would improve strength by moist curing. However, the 20% WLP mixture, with a larger quantity of latex, would benefit from the dry curing.

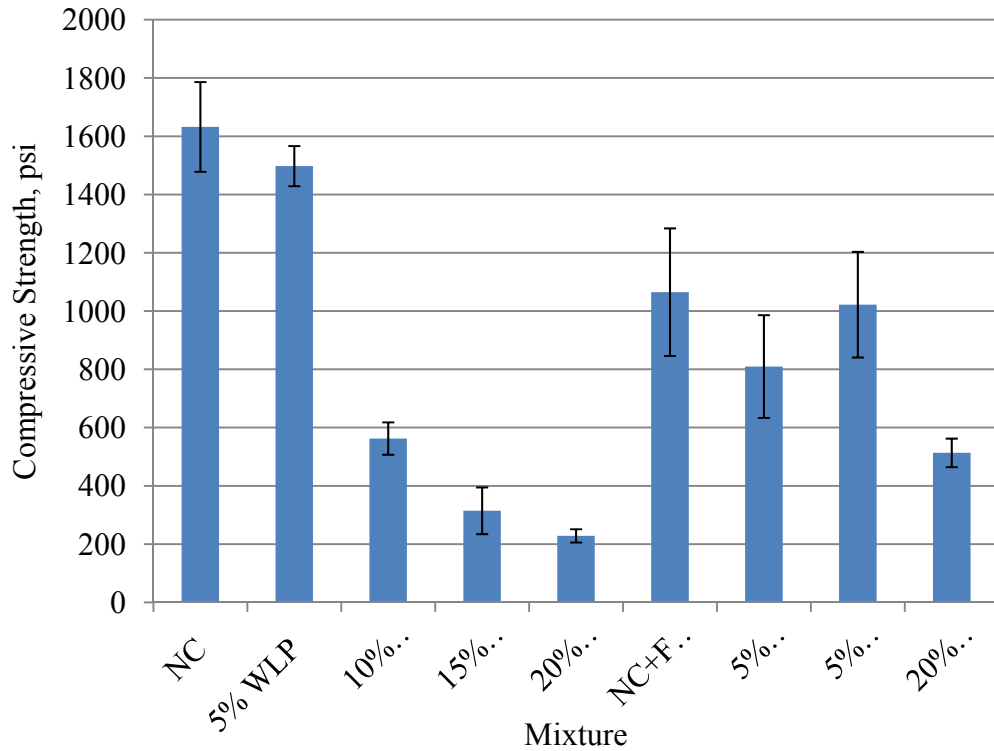


Figure 46 – 7-Day compressive strength of all mixtures including dry cured mixtures

5.3.2 Splitting Tensile Strength

Figure 47 displays the splitting tensile strength results. There is a significant decrease in tensile strength with an increase of WLP. Both mixtures containing fibers decreased in tensile strength. The NC mixture had the greatest tensile strength. Therefore, the addition of WLP or fibers did not improve the tensile strength in pervious concrete. The decrease in tensile strength for NC+Fiber and 5% WLP+Fiber could be due to the short length of the fiber.

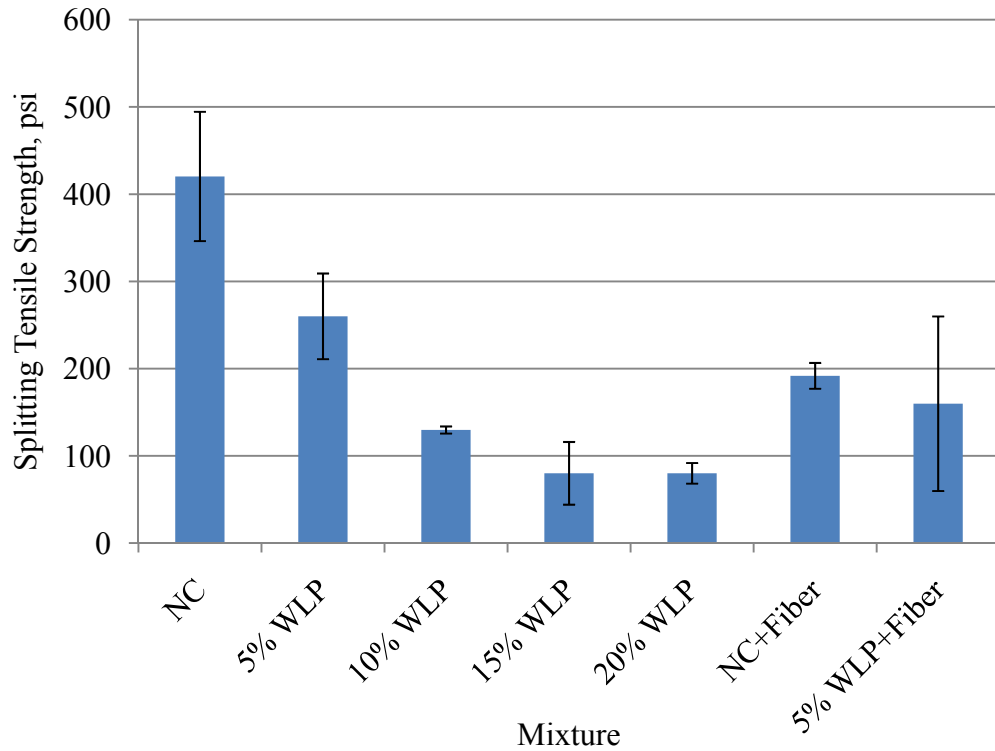


Figure 47 – Splitting tensile strength of pervious concrete

5.4 Freeze-Thaw

Figure 48 displays the freeze-thaw results for the pervious concrete. The 10% WLP, 15% WLP, and 20% WLP mixtures all failed within 100 cycles. The 5% WLP mixture did not fail until after 250 cycles. The fiber mixtures were able to improve the resistance to freezing and thawing. NC, NC+Fiber, and 5% WLP+Fiber displayed the greatest resistance to freezing and thawing.

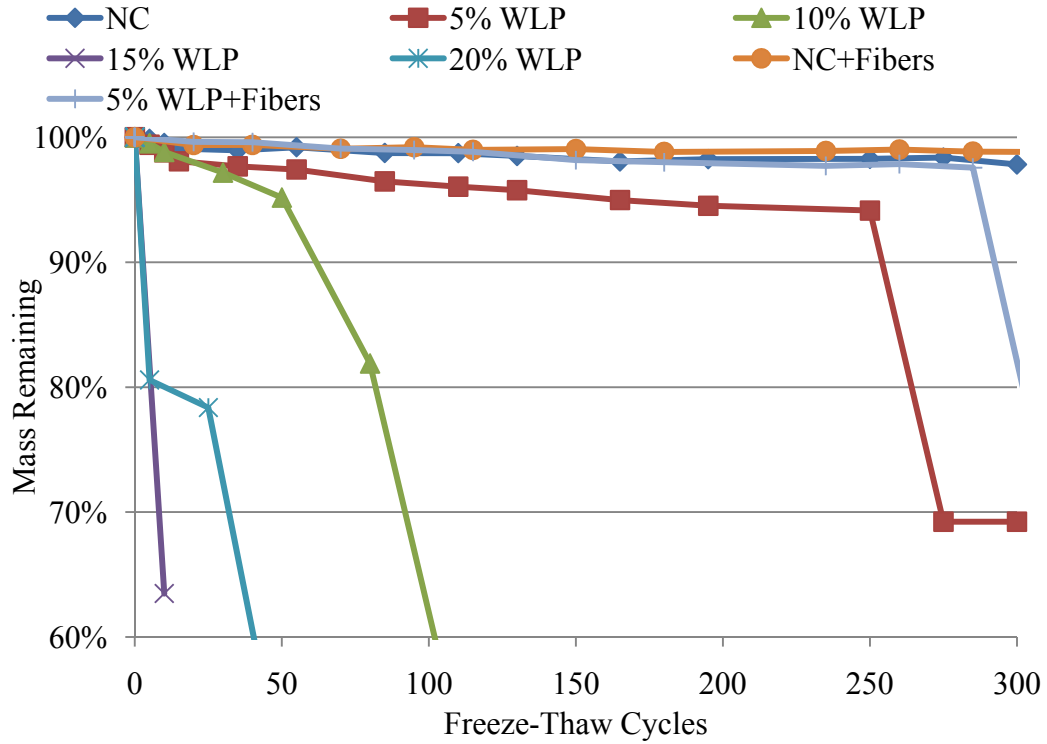


Figure 48 – Freeze-thaw results for pervious concrete

5.5 Pervious Concrete Testing Results

5.5.1 Porosity

Figure 49 displays a trend of increasing porosity with increasing WLP. WLP is the only mixture to have an average porosity less than NC. The increase in porosity can be related to the decrease in unit weight for mixtures containing WLP.

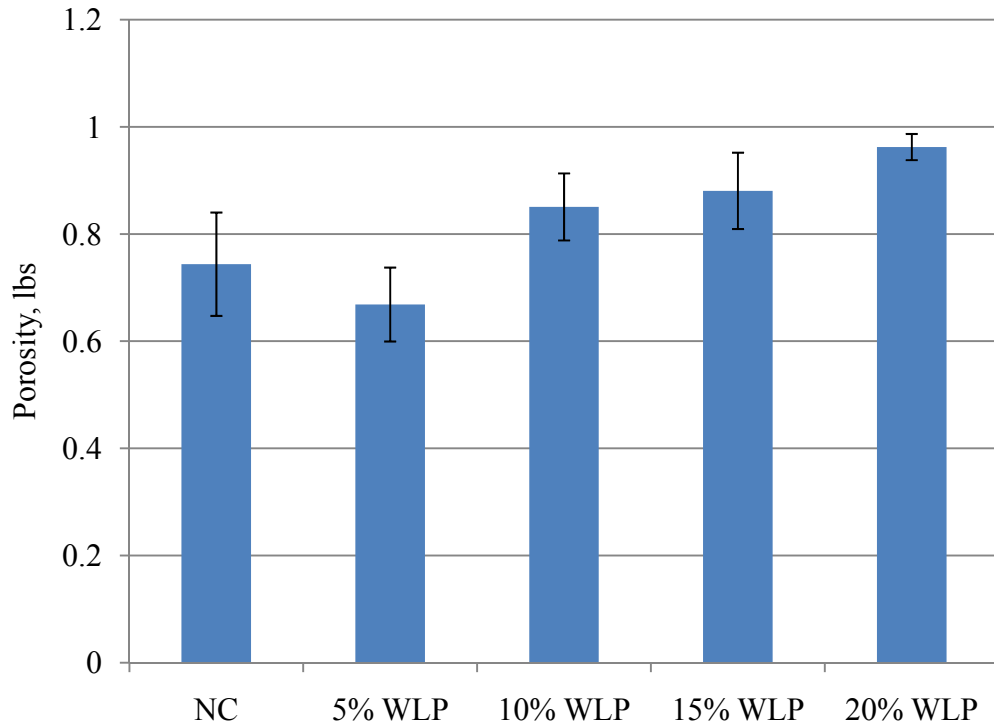


Figure 49 – Porosity of pervious concrete

5.5.2 %Void-Usable

The %Void-Usable, Figure 50, demonstrates an increasing void content with increasing WLP. NC has usable voids between the 5% WLP and 10% WLP void content. The 20% WLP mixture was the only sample to have useable voids greater than the designed void content of 24%.

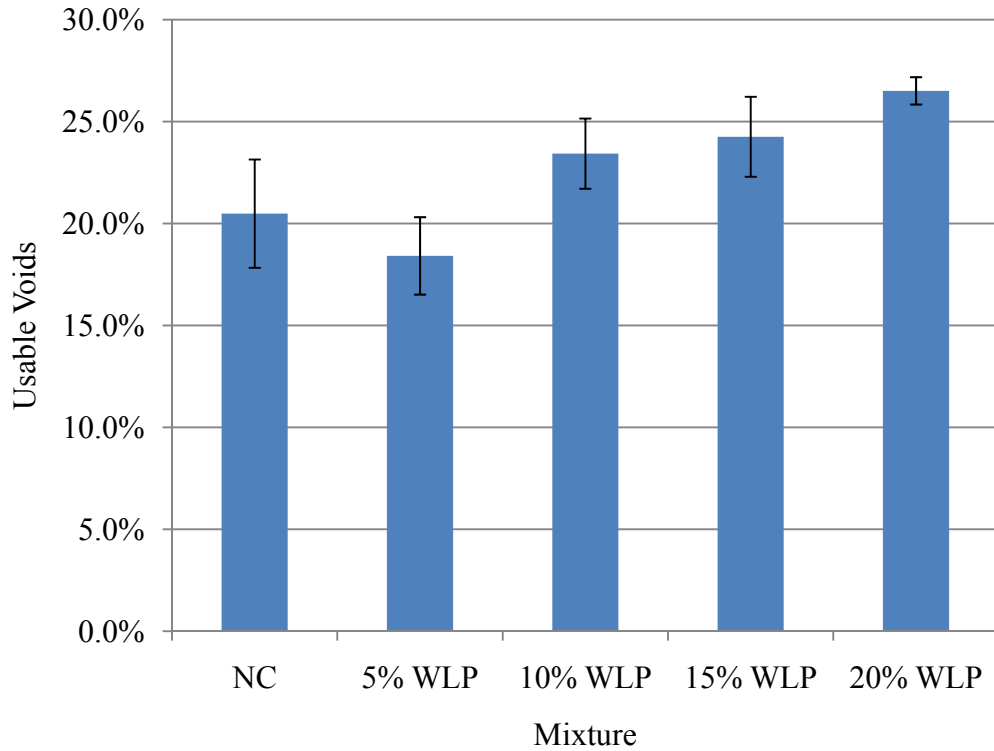


Figure 50 – %Voids-Usable

5.5.3 Infiltration Rate

Figure 51 displays the infiltration rate of the pervious concrete samples. NC had an infiltration rate of 6.7 gals/sq. ft./min. which was less than all mixtures except for the 5% WLP mixture. The infiltration rate increased with higher amounts of WLP. This trend is similar to the decreasing hardened unit weight seen in Figure 44. The lower density concrete had increased voids which allowed a larger infiltration rate and a larger porosity. Tennis *et al.* (2007)\ state that infiltration rate averages between 3-8 gal/ft²/min but higher rates have been seen in laboratory testing. NC, 5%, and 10% are all near the average infiltration rate.

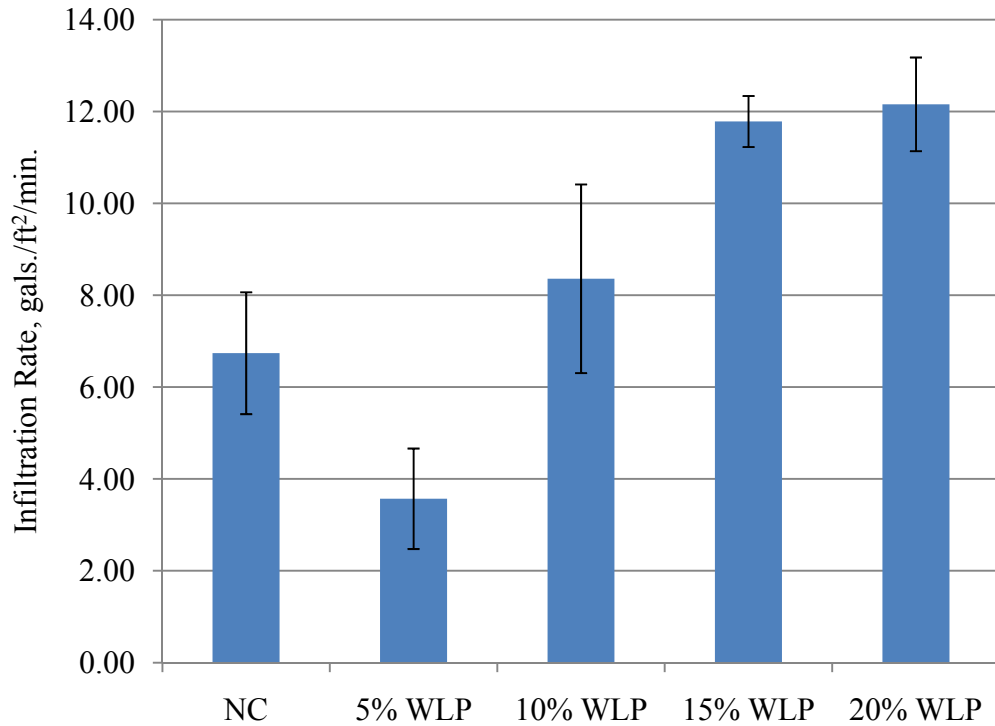


Figure 51 – Infiltration rate of pervious concrete

5.6 Conclusion

Several mixtures were created to test the ability of recycling WLP in concrete. The following suggestions and recommendations were followed for the WLP pervious concrete mixtures.

- Voids between 15% to 25% in hardened concrete
- Density between 100 lb/ft³ to 125 lb/ft³
- Permeability between 3 gal/ft²/min to 8 gal/ft²/min
- Compressive strength between 500 psi to 4000 psi
- Cementitious materials between 450 to 700 lb/yd³
- Aggregates between 2000 to 2500 lb/yd³
- *w/c* ratio between 0.27 and 0.34
- Aggregate:cement ratio between 4 to 4.5:1

- Fine:coarse ratio between 0 to 1:1

(Tennis *et al.*, 2007)

The density and useable voids requirement was not met by the 20% WLP mixture. All mixture met or surpassed the permeability average value between 3 gal/ft²/min and 8 gal/ft²/min.

The compressive strength was only met by the NC, 5% WLP, and the 10% WLP mixtures. Also, the mixtures containing fibers and dry curing met compressive strength requirements.

All mixtures were created to meet specification requirements including cementitious content, total aggregates, and *w/c* ratio.

The mixtures were tested for unit weight, compressive strength, tensile strength, and resistance to freeze-thaw. Also, several tests were conducted on the samples to find their pervious properties. The following conclusions can be made:

- An increase in paint decreases the compressive strength of concrete.
- There is a significant decrease (over 50%) in compressive and tensile strength for mixtures with WLP replacement at or above 10%.
- There is a decrease in unit weight with an increase of WLP replacement.
- The 5% WLP mixture was the only mixture to have less usable voids and a decreased infiltration rate than NC. The infiltration rate and the useable voids increased with an increase in WLP.
- A pervious concrete mixture containing a polymer to cementitious ratio of 5% has the mechanical properties necessary to simulate mechanical properties found in

normal pervious concrete. However, the 5% mixture has a lower infiltration rate and less usable voids than normal pervious concrete.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This study on recycling waste latex paint (WLP) in concrete consisted of three phases. The first phase determined the ability to replace commercial latex with WLP in concrete for overlays. The second phase aimed at recycling waste latex paint in rigid pavement concrete and to find similarities between WLP concrete and styrene-butadiene rubber (SBR) latex concrete. Finally, the third phase studied the effects of using WLP in pervious concrete.

Four goals were created for the project. The following goals were stated in chapter one:

1. Mixtures containing WLP will be created to meet the requirements and specification for overlays, rigid pavements, and pervious concrete.
2. The properties of the concrete mixtures will be compared with concrete containing commercial latex and to standard concrete.
3. The properties of the WLP concrete will be analyzed using infrared spectroscopy on the WLP and the WLP-cement binder.
4. Recommendations will be provided for each WLP concrete created and for the general use of WLP in concrete.

6.1 Goal #1 – Meeting Specifications and Recommendations

All phases created used WLP mixtures that met requirements, suggestions, or recommendations. However, in some phases there was a decrease in performance or alterations were needed for the mixtures.

6.2 Goal #2 – Performance of WLP to SBR in Concrete

A latex-modified concrete (LMC) mixture was created in phase 1 and 2 to compare the properties of the WLP mixtures to a styrene butadiene rubber (SBR) latex mixture.

Phase 1 had two WLP and SBR mixtures. One WLP mixture had higher compressive strengths and one had lower compressive strengths than the SBR mixtures. Similar mix reactions were found for splitting tensile testing. The SBR mixtures had superior abrasion resistance. The SBR mixtures also had better RCPT results than the WLP mixtures.

WLP performed similarly to SBR in several of the phase 2 tests. It had improved freeze-thaw resistance and resistance to surface scaling. WLP had lower results in compressive strength, splitting tensile strength, and modulus of rupture. SBR was superior in the rapid chloride permeability test.

6.3 Goal #3 – Infrared Spectroscopy

The cementitious paste mixtures had similar results for SBR1, SBR2, WLP1, and WLP2 with the only major difference occurring with the percent transmittance. These mixtures all had similar peaks at the same wavelengths. The NC mixture did not have a peak near 2900 cm^{-1} that the SBR and WLP mixtures contained. Other than the peak at 2900 cm^{-1} , the NC mixture was similar to the other mixtures.

6.4 Goal #4 – Recommendations

Overall, it is recommended that a study be conducted using dried WLP in concrete. Using dried WLP would remove the need to find the solid content of the paint. Furthermore, testing with wider variety of WLP is suggested. In phase 1, several

differences where seen from WLP1 and WLP2 results. Large differences could not be seen in the infrared spectroscopy results of the individual paints or of the paints mixed with cement.

For further testing in WLP concrete overlays and rigid pavements it is recommended that continuous abrasion testing be completed. Several methods exist for measuring abrasion resistance and this characteristic is needed for a successful overlay. It is recommended that overlay mixtures in future test be completed with cementitious replacements including fly ash, micro silica, and blast furnace slag. Also, the study should include an increasing amounts of WLP used for replacement.

For continuing studies with WLP pervious concrete the author recommends testing the replacement of cement with WLP instead of replacing aggregate. This could have two immediate impacts on pervious concrete. First, it would create mixtures with nearly identical theoretical fresh unit weights. Secondly, it could create a stronger mixture due to the increase of aggregates.

For future studies a maximum polymer to cementitious (p/cm) ratio of 10% is suggested and a 5% p/cm ratio is recommended. Tests that could be continued would include testing flexural strength, shrinkage, sulfate resistance, resistance to abrasion, water quality, and setting time. Finally, it is recommended that a complete study with dry cured WLP pervious concrete be conducted to find any improvements with higher p/cm ratio concrete.

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VITA

Graduate College
University of Nevada, Las Vegas

Oscar Inez Quiroz

Degrees:

Bachelor of Science in Engineering, Civil Engineering, 2009
University of Nevada, Las Vegas

Special Honors and Awards:

Harold and Mayme Stocker Scholarship
Graduate and Professional Student Association Grant

Publications:

- Quiroz, O, and Said, A. (2011). Economical bridge overlays using waste latex paint. American Concrete Institute Special Publication, 278, 1-16.
- Said, A., Quiroz, O., and Hatchett, D., (2011). Recycling waste latex paint in bridge overlays with added value. [In progress].
- Said, A., Quiroz, O., and Hatchett, D.. (2011). Recycling waste latex paint in rigid pavement concrete. [In progress].

Thesis Title: Recycling Waste Latex Paint in Concrete Overlays, Rigid Pavements, and Pervious Concrete

Thesis Examination Committee:

Chairperson, Dr. Aly Said, Ph.D., P.E.
Committee Member, Dr. Samaan Ladkany, Ph.D., P.E.
Committee Member, Dr. Ying Tian, Ph.D., P.E.
Graduate Faculty Representative, Dr. David Hatchett, Ph.D.,