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# Developing Green, Highly Flowable, Rapid Set, High-Performance Concrete for Pavement Patch Repair

Kejin Wang
*Iowa State University*, kejinw@iastate.edu

Gilson Lomboy
*Iowa State University*, grlomboy@iastate.edu

# Developing Green, Highly Flowable, Rapid Set, High-Performance Concrete for Pavement Patch Repair

**Abstract**

A high-performance mortar (HPM) containing a large amount of industrial by-products such as fly ash, silica fume, and limestone fines was developed for rapid repair of concrete pavements. The HPM development included three major steps.

1. Development of the mortar mixture proportion based on the optimal hydration of binder and particle packing of the mortar system. In this step of the study, all mortar materials were systematically proportioned, and the obtained mixtures were tested for flowability, rate of hydration, set time, and strength development. The optimal mixture proportion was then selected as the HPM, as it displayed good self-consolidating ability and achieved 1-day compressive strengths greater than 6,000 psi.

2. Investigation of the mechanical properties of the new HPM, including compressive and flexural strength, elastic modulus, and slant shear and pull-off strengths of patch-substrate bonds tested at 1, 3, 7, and 28 days. In this step, the properties of the HPM were evaluated in comparison with those of a commercial repair material: the rapid-set concrete (RSC). Two types of substrates representing old concrete were used for patching repair. One was made of a typical pavement mixture (C-3WR-C20), and the other was a high-strength pavement concrete mixture (O-4WR).

3. Investigation of the durability properties of the newly developed HPM compared to those of the RSC. Durability properties included cyclic freeze-thaw (F-T) resistance, permeability, and shrinkage behavior.

The results indicated that the newly developed HPM possesses excellent self-consolidating ability: highly flowable and non-segregating. Although there was delayed setting, the compressive strength of the HPM exceeded 6,000 psi at 1 day, approximately 25 percent higher than that of the RSC. At 28 days, the HPM reached 10,000 psi, while the RSC was about 7,000 psi. The HPM also displayed extremely low chloride permeability (18 coulombs) compared to the RSC (2,550 coulombs) and excellent F-T durability without the requirement for air entrainment. The F-T durability factor of HPM was kept around 100% throughout the standard F-T test, while the F-T durability factor of RSC reduced to 80% at the end of the F-T test. However, the HPM exhibited noticeably higher autogenous shrinkage and slightly lower free drying shrinkage than the C-3WR-C20 mixture, while the RSC had a little/no shrinkage during the 56-day test period. Addition of a small amount of micro-steel fibers (70 pcy) slightly reduced the shrinkage of the HPM.

Further studies on fatigue and shrinkage cracking behavior of the HPM are recommended.concrete.

**Keywords**

concrete pavement patches, high-performance mortar, limestone fines, rapid repair, patching mortar, mortar, silica fume, high performance concrete, fresh concrete

**Disciplines**

Civil Engineering

**Comments**

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tech transfer summary

**This project showed that a high-performance mortar can be achieved for rapid repair of concrete pavements using a high volume of industrial by-/co-products such as fly ash, silica fume, and limestone fines.**

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**RESEARCH PROJECT TITLE**
Developing Green, Highly Flowable, Rapid Set, High Performance Concrete for Pavement Patch Repair

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**PRINCIPAL INVESTIGATOR**
Kejin Wang, Professor
Civil, Construction, and Environmental Engineering, Iowa State University
515-294-2152 / kejinw@iastate.edu

**CO-PRINCIPAL INVESTIGATOR**
Gilson R. Lomboy, Postdoctoral Research Associate
Civil, Construction, and Environmental Engineering, Iowa State University

**MORE INFORMATION**
www.intrans.iastate.edu/

**MTC**
**Iowa State University**
**2711 S. Loop Drive, Suite 4700**
**Ames, IA 50010-8664**
**515-294-8103**

The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC). Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

MTC's research focus area is State of Good Repair, a key program under the 2012 federal transportation bill, the Moving Ahead for Progress in the 21st Century Act (MAP-21). MTC research focuses on data-driven performance measures of transportation infrastructure, traffic safety, and project construction.



## Background

The United States has an aging transportation infrastructure that is requiring extensive maintenance. According to a survey by The Road Information Program, 32 percent of major roads in the US are in either poor or mediocre condition (TRIP 2012).

Rapid repair of the deteriorated roads is essential to avoiding the inconvenience of commuters and disruption of daily business. The repaired pavements must be strong and durable to meet service requirements and extend their service lives. For these demands, use of high-performance concrete (HPC) as a repair material is a very attractive option.

HPC has been increasingly used for transportation structures, especially bridge decks, because of its high early strength (approximately 4,000 psi at 24 hours), high workability, and high durability. Recently, research has revealed that ultra-high-strength concrete (UHSC) or ultra-high-performance concrete (UHPC) can be produced using quartz and quartzite powders. Such concrete has very good flowability and excellent strengths (22,000 psi at 28 days).

## Problem Statement

Unfortunately, the existing UHPC is often specially formulated and packaged with particular materials, and it is expensive and difficult to be directly produced by users. In addition, most existing UHPC is not designed to have features for concrete repair, which not only includes rapid set and early compressive strength but also excellent workability, bond strength, shrinkage, and freeze-thaw (F-T) resistance.

## Project Objectives

- Study the chemical and physical interactions between limestone fines, cementitious materials, and chemical admixtures
- Develop a mix design methodology for a high performance mortar (HPM), based on the optimization of the chemical and physical particle interactions
- Evaluate the key mechanical and durability properties of the HPM
- Investigate the applicability and performance of the HPM for concrete repair

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## Approach

The approach to the development of a new high-performance mixture was based on the chemical interactions and particle packing of concrete materials. The materials studied mainly included portland cement (PC), fly ash (FA), limestone fines (LF), silica fume (SF), and river sand (RS). In addition, a high-range water reducer was used to improve the self-consolidating ability of the concrete.

The rationale was that these individual materials have different chemistry and particle size distributions and could integrate and compensate each other to form a new material with optimal chemistry and density. By synergizing the attributes of these materials and tailoring their mix proportions, the new high-performance mixture would possess the ability to self-consolidate and have high early strength, excellent bond strength with substrates, and long-term durability.

## Methodology

Development included three major steps:

1. Development of the mortar mixture proportion based on the optimal hydration of binder and particle packing of the mortar system. In this step of the study, all mortar materials were systematically proportioned, and the obtained mixtures were tested for flowability, rate of hydration, set time, and strength development. The optimal mixture proportion was then selected as the HPM, as it displayed good self-consolidating ability and achieved 1-day compressive strengths greater than 6,000 psi.

2. Investigation of the mechanical properties of the new HPM, including compressive and flexural strength, elastic modulus, and slant shear and pull-off strengths of patch-substrate bonds tested at 1, 3, 7, and 28 days. In this step, the properties of the HPM were evaluated in comparison with those of a commercial repair material: the rapid-set concrete (RSC). Two types of substrates representing old concrete were used for patching repair. One was made of a typical pavement mixture (C-3WR-C20), and the other was a high-strength pavement concrete mixture (O-4WR).

3. Investigation of the durability properties of the newly developed HPM compared to those of the RSC. Durability properties included cyclic freeze-thaw (F-T) resistance, permeability, and shrinkage behavior.

## Key Findings

- A high-performance mortar (HPM) can be achieved for rapid concrete repair using a high volume of industrial by-/co-products such as limestone fines, fly ash, and silica fume.

- Particle packing has a significant influence on the early age strength of the newly developed HPM, which was analyzed using the modified A&A model (Funk and Dinger 1994). In addition to their pozzolanic properties, proper silica fume and fly ash replacements for portland cement can help adjust particle packing and improve the workability and strength of the mortar. In addition to serving as fine aggregate or filler, limestone fines also accelerate hydration of cementitious materials in the HPM.

- Sandblasted and grouted surfaces provide the best performance for bonding of a rapid repair material to a mature substrate. Differently, repaired concrete without sandblasting and/or grouting showed lower pull-off and slant shear strength in the present study. Slant shear strength values are generally higher than direct pull-off strength.

- The F-T durability factor of the HPM stayed around 100 percent throughout the standard F-T test. Whereas, the RSC showed significant mass loss during the F-T test, and its F-T reduced to about 80 percent at the end of the F-T durability test.

- The permeability of the HPM is extremely low (18 coulombs), which may contribute to its high F-T durability. Whereas, the permeability of the RSC is much higher (2,550 coulombs).

- During moist curing, the HPM absorbed very little water and shrunk, while the RSC and C-3WR-C20 substrate mixtures absorbed much more water and swelled. Under a sealed condition, the RSC displayed little to no autogenous shrinkage, while the C-3WR-C20 displayed intermediate and the HPM displayed significantly high autogenous shrinkage. Under a drying condition, the RSC displayed low drying shrinkage, the HPM displayed much higher drying shrinkage, and was followed by the C-3WR-C20 mixture. As a result, the HPM had a higher total shrinkage than the C-3WR-C20, while the RSC had a small amount of total shrinkage. The addition of the micro-steel fibers (70 pcy) slightly reduced the shrinkage of the HPM.

- The set times of the HPM were about 2.5 hours longer that those of the C-3WR-C20. However, the delayed set times didn't affect the 1-day strength development of the HPM. The RSC set very quickly: 69 minutes for initial setting and 73 minutes for final setting.

## Implementation Readiness and Benefits

- The newly developed rapid repair HPM is highly workable, strong, and durable.
- The HPM possesses an excellent self-consolidating ability that is highly flowable, non-segregating, and requires no additional consolidation during casting.
- The compressive strength and modulus of rupture of the HPM at 1 day are comparable to the corresponding properties of conventional pavement concrete at 28 days. This suggests that the new rapid repair mixture is applicable for patch repair (requires compressive strength) and full-depth pavement repair (requires both compressive and flexural strength).
- The new repair material is likely to be able to withstand fatigue stresses similar to a conventional concrete. Bond performance under repeated loading is yet to be determined.
- In this study, with proper surface preparation and maturity, the bond under shear and tension was shown to be strong.
- The HPM is of excellent F-T durability, without the requirement for air entrainment.

The HPM uses a high volume of fly ash, silica fume, and limestone fines, the by-products of power plants and aggregate quarries. The project could have transformable impacts on increasing available resources for pavement repair and maintenance, decreasing road construction time, reducing motorists' vehicle repair and operating costs, and reducing traffic congestion costs (wasted time and fuel).

## Future Research

To investigate the properties of the repair material under repeated loading, a patch may be applied on the tension side of a beam and subjected to repeated loads.

This study also revealed an important discovery regarding shrinkage behavior: the pore structure of the concrete materials and not the amount of water evaporated primarily controls the materials' shrinkage behavior. Further study is needed on the pore structure of the repair materials as well as on the cracking potential of the HPM.

Results of the RSC (rather than the HPM) on F-T durability showed poor or moderate performance, which opens the question for further investigation of other rapid repair materials' durability performance. Granting that repair materials only need to last as long as the remaining life of the concrete being repaired, the durability of the rapid repair materials still needs to be known.

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