

Investigation of Material Improvements to Mitigate the Effects of the Abrasion Mechanism of Concrete Crosstie Rail Seat Deterioration

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Abstract: Rail seat deterioration (RSD) continues to be identified as one of the primary factors limiting concrete crosstie service life in North America. RSD refers to the degradation of material at the contact interface between the concrete crosstie rail seat and the rail pad that protects the bearing area of the crosstie. Industry experts consider abrasion to be a viable mechanism leading to RSD. A lack of understanding of the complex interactions affecting the severity of abrasion has resulted in an empirical design process for concrete crossties and fastening systems. The objective of this study is to quantify the abrasion resistance of concrete rail seats by using a variety of concrete mix designs and other materials relevant to the rail industry. To simulate the abrasion mechanism of RSD, a small-scale test for abrasion resistance (SSTAR) was designed by researchers at the University of Illinois at Urbana-Champaign (UIUC). Data obtained from the SSTAR will help the rail industry mechanistically design concrete crossties by improving the current understanding of the performance of various concrete abrasion mitigation approaches. Preliminary results show that abrasion mitigation approaches such as the addition of metallic fine aggregates (MFA), steel fibers, and the application of coatings improve the abrasion resistance of concrete specimens. DOI: [10.1061/\(ASCE\)TE.1943-5436.0000616](https://doi.org/10.1061/(ASCE)TE.1943-5436.0000616). © 2013 American Society of Civil Engineers.

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Introduction

To meet the increasingly stringent design and performance requirements because of increasing axle loads and cumulative gross tonnages from heavy-haul freight operations, along with increased high-speed inter-city passenger rail development, improvements in concrete crosstie designs are needed. These improved designs are especially critical on joint heavy-haul freight and high-speed passenger rail infrastructure, where loading demands are highest, track geometric requirements are most rigorous, and track occupancy time is at a premium.

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Improvements in concrete crosstie and fastening system designs also help address the need to reduce track maintenance windows, thereby gaining rail capacity. Before these advancements are realized, several design and performance challenges must be overcome, including rail seat deterioration (RSD).

RSD refers to the degradation of material at the contact interface between the concrete crosstie rail seat and the rail pad (Kernes et al. 2011b). RSD has been identified as one of the primary factors limiting concrete crosstie service life in North American heavy-haul freight infrastructure (Zeman 2010; Van Dyk et al. 2012). RSD can lead to problems that include fastening system wear and track geometry defects such as loss of cant and gauge widening that can lead to unstable rail conditions and/or derailments (Zeman et al. 2009). RSD is difficult to detect and repair without lifting the rail and removing the rail pad through a labor-intensive and costly repair process that results in track outages, traffic disruptions, and increased operating costs. A primary maintenance challenge facing the rail industry is the lack of compatibility between life cycles of infrastructure components. If the life cycles of the materials that compose the rail seat and fastening system are not sufficient to match the life cycle of the rail, interim repairs of the rail seat may be necessary.

Previously, RSD research and industry design practices have focused on mitigating the wear of concrete through pad-design improvements and various fastening system design modifications, with very little focus on concrete mix-design enhancements (Kernes et al. 2011b; Moody 1987). Going forward, additional RSD research should focus on improving the abrasion resistance of concrete materials and the materials used in the manufacture of fastening system components. This research focuses on the development of stronger, more durable materials in the concrete crosstie rail seat and the use of various protective surface

treatments. Such measures can prevent or delay the onset of RSD and increase the service life of the rail seat.

Background

Through previous research on RSD, the University of Illinois at Urbana-Champaign (UIUC) has identified five possible mechanisms having the potential to contribute to RSD. The feasible mechanisms are abrasion, crushing, freeze-thaw cracking, hydraulic-pressure cracking, and hydro-abrasive erosion (Joh et al. 2010; Zeman et al. 2009). Of these mechanisms, hydraulic-pressure cracking and hydro-abrasive erosion were investigated at UIUC and found to be feasible mechanisms resulting in RSD (Zeman 2010; Choros et al. 2007; Bakharev 1994). According to another study, RSD resembled damage that is typically caused by abrasion, with hydraulic-pressure cracking and freeze-thaw cracking also being identified as possible contributors (Bakharev 1994). The work described in this paper seeks to build on previous research by focusing on the abrasion mechanism of RSD.

Abrasion is defined as the wear of a material as two or more surfaces move relative to one another (Kernes et al. 2011a). Abrasion is a progressive failure mechanism and occurs when (1) cyclic motion of the rail base induces shear forces, (2) shear forces overcome static friction, (3) the rail pad slips relative to the concrete, (4) strain is imparted on concrete matrix, and (5) the harder surface cuts or ploughs into the softer surface (Kernes et al. 2011a). The abrasion mechanism of RSD is further complicated and potentially accelerated because of the occurrence of three-body wear. Three-body wear occurs as a result of an abrasive slurry (e.g., abrasive fines and water) that often exists in addition to the two interacting surfaces [i.e., rail seat and rail pad (Dwyer-Joyce et al. 1994)].

To understand the interactions leading to abrasion, a small-scale test for abrasion resistance (SSTAR) was designed and implemented. The SSTAR also helped in understanding the effect of various abrasion mitigation approaches such as concrete mix-design improvements and surface treatments on the abrasion resistance of concrete crosstie rail seat. The focus of this paper is to investigate methods to mitigate the abrasion mechanism of RSD based on experiments performed on the SSTAR.

Abrasion Mitigation Approaches

As a part of the efforts to improve the abrasion resistance of concrete by improving materials used in the rail seat, many abrasion mitigation approaches were evaluated using the SSTAR. The following description provides background information on the theory and rationale behind selecting these abrasion mitigation approaches.

Air content is believed to have an effect on the abrasion resistance of the concrete rail seat. Air is typically entrained in structural concrete to prevent cracking because of repeated freeze-thaw cycles and can be expressed as the air void volume in the concrete microstructure. Industry experts have questioned the use of air entrainment in concrete crossties citing the possible adverse effect on the abrasion resistance of the rail seat. According to the published literature related to concrete materials, the abrasion resistance of concrete is directly related to its compressive strength (Witte and Backstrom 1995; Hadchti and Carrasquillo 1988). Also, concrete compressive strength is inversely related to the air content (Mindess et al. 2003). Therefore, one would expect that the abrasion resistance of concrete would decrease with increasing air content. However, the trade-off between the abrasion resistance

of concrete and air content is not properly understood. UIUC researchers have investigated air entrainment using the SSTAR to determine if there is an optimum air content at which the need for abrasion resistance is balanced with appropriate freeze-thaw considerations.

To bound the complex problem that stems from a multitude of mix-design permutations, the air content of a given concrete mixture design was varied by selecting graduated dosages of air-entraining admixtures (AEA). The three AEA dosages that were selected for this study were

- No AEA: Eliminating the AEA from the concrete mixture resulted in an air content of 2.2% as measured by ASTM C173,
- Control specimens: Adding a moderate amount of AEA resulted in an air content of 3.5%, which is recommended by the American Railway Engineering and Maintenance-of-Way Association (AREMA 2012) for freeze-thaw durability, and
- Additional AEA: Adding a dosage of air entrainment that is higher than the dosage of the control mix design resulted in an air content of 6%, which is the recommended average air content for medium/severe environmental exposure conditions by the American Concrete Institute (ACI) (Mindess et al. 2003).

The North American railroad industry has recently increased its use of surface coatings as an abrasion mitigation approach. Epoxy coatings are being used as a preventive RSD mitigation measure. As an example, one major Class I railroad has incorporated the use of epoxy coating into its design specifications for all new concrete crossties. Other Class I railroads are using polyurethane coatings as an RSD repair approach. Preliminary qualitative results from revenue testing have shown that surface coatings can result in improvements to the abrasion resistance of rail seat. However, more research needs to be conducted on the engineering principles behind surface coatings to maximize their potential to mitigate the abrasion mechanism of RSD.

Self-consolidating concrete (SCC) is a type of high-performance concrete that exhibits low resistance to flow and moderate viscosity that allows fresh concrete to be placed and compacted properly when extensive reinforcement exists or traditional compaction methods are not available (Khayat 2000). The abrasion resistance of self-consolidating concrete was evaluated because of the advantages of lowering the water:cement ratio and high workability, which are known to be factors favoring abrasion resistance of concrete (Mindess et al. 2003; Gencel et al. 2011). Also, SCC does not require compaction, which can possibly increase the production rate of concrete crossties while decreasing the production cost.

The abrasion resistance of fiber-reinforced concrete (FRC) was evaluated based on the understanding that FRC has the ability to control cracking. Microcracking is suspected to occur in the rail seat because of freeze-thaw cycles and hydraulic pressure (Mindess et al. 2003; Bakharev 1994; Gencel et al. 2011). Because FRC may have the potential to mitigate microcracking, we tested FRC to investigate its ability to resist abrasion.

Metallic fine aggregates (MFAs) are fine metallic shavings that increase the local hardness of the concrete surface. MFAs have been used by pavement manufacturers as an abrasion mitigation approach and are known to possess significant strength properties (Wiley 1909; Gencel et al. 2011). Additionally, metallic coarse aggregate toppings have been used locally in the rail seat area and tested in revenue service as an RSD mitigation technique (Philip J. McQueen Corporation 2006). Preliminary anecdotal results from field testing of MFAs have shown an improvement in the abrasion resistance of concrete. By evaluating MFAs in this study, we were able to validate the results from the preliminary field testing.

Methodology

A prioritized list of abrasion mitigation approaches was developed based on the opinions of industry experts, results from the latest industry research and testing aimed at RSD mitigation, and literature in the domain of abrasion resistance of concrete materials (Shurpali et al. 2012). Previous work on abrasion resistance of concrete involved testing of abrasion mitigation approaches that were being evaluated for their abrasion resistance by the concrete material industry (Shurpali et al. 2013). However, the current experimentation reflected more recent RSD mitigation approaches being researched and used in revenue service by the North American concrete crosstie industry. The specimens were prepared by concrete crosstie manufacturers to minimize the variability in casting methods and to obtain concrete mix designs that were representative of current industry practices.

Small-Scale Test for Abrasion Resistance

Motivation

When investigating component-level behavior within the system, limitations to large-scale abrasion resistance testing, which typically requires relatively more time and resources to operate, can present significant challenges. These challenges limit the breadth, depth, and effectiveness of a parametric study to identify ways of mitigating the abrasion mechanism in RSD. The aforementioned limitations and lessons learned from the design of previous tests led UIUC researchers to the development of the SSTAR. The SSTAR was designed with the following characteristics and attributes: (1) ability to isolate the abrasion mechanism, (2) ability to quantify the abrasion resistance of various concrete abrasion mitigation approaches, (3) simple and economical operation, and (4) ability to conduct short-duration tests that will facilitate the collection of large volumes of data.

The SSTAR was designed to be similar to the current industry-standard abrasion tests, with modifications incorporated to represent some elements of RSD in the field (Turkish Standards Institution 2009; BSI 1990). The SSTAR is not completely representative of field conditions for several reasons that must be controlled (to the extent feasible) and understood when interpreting data. One difference is the continuous, rotational loading of concrete in the SSTAR as opposed to cyclic loading under normal field conditions. Another difference is that the interaction between steel and concrete that occurs in SSTAR is different from the interaction between polymer materials and concrete as seen in the field. Nevertheless, the SSTAR is a simplified tool that aims to provide quantitative results that compare the abrasion resistance of various abrasion mitigation approaches. Furthermore, it should not be considered a system-level test, rather, a qualification test for concrete rail seat materials prior to full-scale or revenue testing. Moreover, the SSTAR allows researchers to quickly obtain large amounts of data, which is critical in constructing an empirical model of rail seat wear, one of the objectives of this research project.

Test Setup

The SSTAR was constructed by modifying a lapping machine that is typically used to sharpen tools or create flat, smooth surfaces on machined metal parts and polish rocks in the realm of geotechnical engineering (Fig. 1). The lapping machine is comprised of a revolving steel plate with concrete specimens loaded in three counter-rotational rings that rest on top of the plate. The three rings are held in place by small rubber wheels attached to the main frame. This allows the circular specimens to revolve around their center while still maintaining the same position relative to the revolving lapping

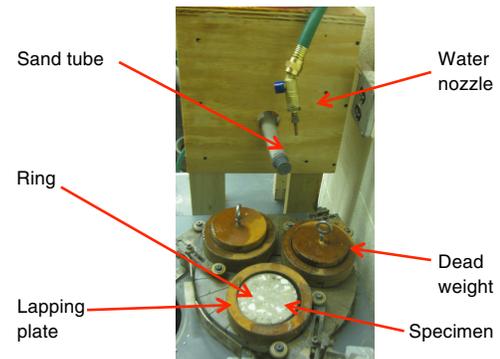


Fig. 1. SSTAR setup and abrasive slurry conveyance equipment

plate. A dead weight weighing 2 kg (4.5 lb) is placed on top of each specimen to provide a normal load. To represent the influence of three-body wear, an abrasive slurry of water and sand is applied to the lapping plate throughout the test at a uniform rate to abrade the concrete surface that mates against the lapping plate. Water is delivered to the lapping plate through a plastic tube with a valve that is used to control the flow rate. A raised wooden platform was constructed to support a sand storage container. Holes were drilled at the bottom of the sand storage container and the wooden platform to ensure proper alignment.

Test Protocol

To ensure confidence in the test results, nine specimens (or replicates) were tested for each abrasion mitigation approach. It should be noted that the abrasion resistance test was conducted after curing the concrete for 28 days. First, the concrete specimens were marked to identify the wearing surface (the as-cast surface). Also, locations where thickness readings were to be taken were marked. Initial thicknesses at the four marked locations were obtained using a vernier caliper. Three specimens were then placed in the lapping machine rings, the dead weight was applied, and the test was started. At the same time, an abrasive slurry of water and manufactured sand was introduced into the specimen-lapping plate interface. The manufactured sand used in this research is Ottawa sand and has a gradation of 20–30, which indicates that the sand particles pass through a nominal sieve-opening size of 841 μm and retained on a nominal sieve-opening size of 596 μm . The total test duration was 100 min, with thickness measurements taken at regular time intervals.

After testing, the wear depth (the difference between initial and final thicknesses taken at every time step using vernier calipers) was plotted with respect to testing duration to represent the progression of abrasion with time (wear rate curves). The wear rate is used as a metric to quantify abrasion resistance of concrete instead of weight and/or volume loss. This is done to counter the variability induced by the weight/volume loss measurements because of absorption of water by the concrete specimens during testing. Further details regarding the rationale behind the development of the test, test apparatus construction, specimen production, test protocol, and preliminary results from previous testing were published in Shurpali et al. 2012.

Results and Discussion

Specimens containing 3.5% air by volume are called *control specimens*. The differences in abrasion resistance of concrete specimens are measured relative to the control specimens. Also, all comparisons between abrasion resistances of control specimens and other abrasion mitigation approaches are done at the end of the

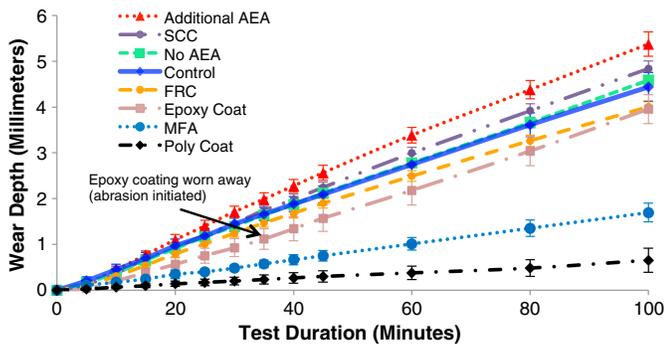


Fig. 2. Wear rate curves of various abrasion mitigation approaches

Table 1. Concrete Mix Designs for Specimens with Varying Air Contents

Details of mix design	Units	No AEA (2.2% air)	Control (3.5% air)	Additional AEA (6% air)
Batch volume	m ³	3.82	3.82	3.89
Cement	kg	1,352.20	1,383.91	1,383.90
Coarse aggregate	kg	4,004.52	3,986.40	4,058.90
Fine aggregate	kg	3,216.30	3,216.30	3,270.70
Metal fiber	kg	0.00	0.00	0.00
Actual water	kg	530.28	552.99	575.70
Air entrainment	mL	0.00	1.11	1.63
HRWR	mL	11.95	11.95	12.30

Note: HRWR = high range water reducing admixtures.

test (i.e., after 100 min). The wear rate is defined as the ratio of the change in wear depth over the testing duration and is depicted by the slope of wear rate curves in Fig. 2. As the wear curves shift downward towards the *x*-axis (i.e., wear rate decreases), the corresponding abrasion mitigation approach shows higher abrasion resistance. Each data point represents the average wear depth value obtained from nine specimens. Error bars representing two standard errors (both positive and negative) in wear depth are shown on all the data points. The concrete mix designs of various abrasion mitigation approaches can be found in Tables 1 and 2. Also, the compressive strength data of each abrasion mitigation approach are presented in the form of a bar chart in Table 3.

Air Content

Data from the SSTAR appear to support the hypothesis that abrasion resistance of concrete is directly correlated with the compressive strength. It was observed that the compressive strength of specimens with additional AEA (6% air content) was 28% less than that of specimens without any AEA (2.2% air content) (Fig. 3). This reduction in compressive strength probably led to a 15% decrease in abrasion resistance of specimens with additional AEA compared with specimens without AEA.

Table 2. Concrete Mix Designs for Specimens with other Abrasion Mitigation Approaches

Details of mix design	Units	FRC	MFA	SCC	Epoxy coat	Polycoat
Batch volume	m ³	2.30	3.82	2.67	3.82	3.82
Cement	kg	810.90	1,383.91	1,112.11	1,383.91	1,383.91
Coarse aggregate	kg	2,382.80	3,986.40	2,582.10	3,986.40	3,986.40
Fine aggregate	kg	1,902.60	3,216.30	2,147.22	3,216.30	3,216.30
Metal fiber	kg	60.00	0.00	0.00	0.00	0.00
Actual water	kg	375.85	552.99	465.18	552.99	552.99
Air entrainment	mL	1.19	1.11	0.32	1.11	1.11
HRWR	mL	7.15	11.95	10.88	11.95	11.95

Note: HRWR = high range water reducing admixtures.

Table 3. Compressive Strength and Change in Abrasion Resistance of Various Abrasion Mitigation Techniques

Abrasion mitigation technique	Compressive strength (Mpa)	Change in abrasion resistance (%)
No AEA (0% Air)	67.6	-3.4
Control (3.5% Air)	72.3	—
Additional AEA (6% Air)	52.9	-2.2
Self-consolidating concrete (SCC)	68.2	-9.0
Metallic fine aggregate (MFA)	72.3	62.0
Fiber-reinforced concrete (FRC)	63.0	10.0
Polyurethane coat	72.3	85.0
Epoxy coat	72.3	11.0

Also, there was no significant difference in the abrasion resistance of control specimens relative to specimens cast without AEA. This can be explained from the fact that there was only a 6.5% reduction in compressive strength of control specimens (72.3 Mpa) relative to specimens without AEA (68 Mpa). This is probably due to the fact that air is naturally entrapped in the concrete matrix during mixing and consolidation, even when no AEA is added during casting.

Surface Coatings

Data from the SSTAR show that epoxy coating delayed the onset of abrasion and resulted in an 11% increase in abrasion resistance relative to the control specimens. The epoxy coating developed cracks; after which, it quickly disintegrated and added to the abrasive slurry. This phenomenon can likely be attributed to the hardness of the epoxy coating layer as observed while testing. After the epoxy coating wore away, the abrasion of concrete material started, and the wear rate of the specimens was similar to that of the control specimens. This is evident from Fig. 2 where the epoxy coating is completely worn after 35 min. After the coating was lost, the wear rate increased from 0.03 mm/min to match the wear rate of control specimens at 0.05 mm/min.

Data from SSTAR showed that the polyurethane coating exhibited the least abrasion of all of the mitigation measures. It was observed that the specimens with polyurethane coating showed 85% higher abrasion resistance compared to the control specimens. In some instances, the polyurethane coating remained intact throughout the duration of the test. One reason that the polyurethane coating may have performed better than epoxy coating is that it was observed to be significantly softer than the epoxy coating.

Self-Consolidating Concrete

It was observed that SCC did not improve the abrasion resistance of concrete and showed a 9% reduction in abrasion resistance relative to the control specimens. This reduction in abrasion resistance is

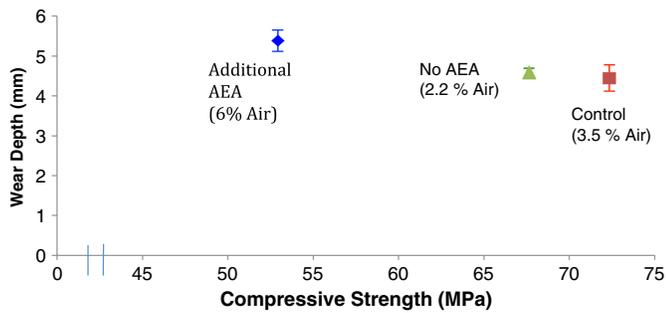


Fig. 3. Effect of compressive strength on abrasion resistance

likely related to the 5% decrease in compressive strength of the SCC specimens compared to the control specimens.

Fiber-Reinforced Concrete

Results from the SSTAR showed that there was an improvement of 10% in the abrasion resistance of FRC specimens relative to control specimens. It was observed that the corrugated metallic fibers seemed to protect the concrete material from abrasion in two ways: (1) by anchoring the surrounding concrete material and (2) by acting like a physical barrier to further abrasion.

Metallic Fine Aggregate

The MFA specimens exhibited exceptional abrasion resistance, and minimal wear of concrete was observed at the end of tests. The MFA specimens had the second best abrasion resistance after the polyurethane-coated specimens, showing a 62% increase in abrasion resistance as compared to the control specimens. These results are in agreement with the literature and limited anecdotal evidence related to the field performance.

Table 3 summarizes the percentage change in abrasion resistance of various specimen types relative to the control specimens. A negative sign before the numbers in the last column indicates a reduction in the abrasion resistance (greater depth of wear) relative to that of the control specimens.

Statistical Comparison of Wear Rates

The authors developed a first-order autoregressive model (AR1) to model the wear behavior of the concrete specimens. This model was developed because an ordinary regression model (or ordinary least squares (OLS) method) with time as the independent variable is not suitable for describing time-series data for two reasons. First, the time-series observations are usually dependent. This is true in the context of this research, as periodic wear-depth measurements are taken on the same specimen, resulting in the wear measurements being dependent on wear measurements taken previously. Second, forecasting future values entails extrapolation of historical data for which regression models are not suitable and can lead to inaccurate forecasts (Miller and Wichern 1977).

Numerical Example

A statistical modeling example in the next section illustrates a comparison of relative abrasion resistance of control specimens (CONT) and FRC specimens (FRC).

Step 1: Model Development

The model was developed using the following equation:

$$Y_{ij} = \beta_1 T_{ij} + \beta_2 D_{ij} T_{ij} + \varepsilon_{ij}$$

Table 4. Autoregressive Parameter Estimates

Variable	Degrees of freedom	Estimate	Standard error	<i>t</i> -value	$P_r > t $
$X_1 (\beta_1)$	1	0.0505	0.000697	72.36	<0.0001
$X_1 X_2 (\beta_2)$	1	-0.0085	0.001710	-5.01	0.0002

where Y_{ij} = wear depth at *i*th time period and *j*th replicate; β_1, β_2 = parameter coefficients; T_{ij} = *i*th time period for *j*th replicate; D_{ij} = dummy variable (0 = CONT, 1 = FRC); ε_{ij} = statistical error term at *i*th time period for *j*th replicate.

Three possible hypotheses exist when comparing relative abrasion resistances of FRC specimens and control specimens:

- If $\beta_2 = 0$, no difference of wear rate between CONT and FRC (null hypothesis).
- If $\beta_2 < 0$, wear rate of CONT is greater than FRC.
- If $\beta_2 > 0$, wear rate of CONT is less than FRC.

Step 2: Parameter Estimates and Interpretation

From Table 4, we can see that $\beta_2 < 0$, which indicates that the wear rate of CONT is greater than wear rate of FRC, showing that FRC improves abrasion resistance relative to control specimens. Also, we can conclude that there is a statistically significant difference between the abrasion resistances of the CONT and FRC specimens.

The preceding example illustrates three points: (1) the abrasion resistances of various specimens can be statistically compared over a period of time, (2) the abrasive wear rate that results from SSTAR testing can be described using a statistical model, and (3) wear depth can be extrapolated over a reasonable period of time.

Conclusions

SSTAR is capable of producing quantifiable abrasion of concrete specimens in an accelerated environment. Also, based on the results obtained from SSTAR, the experimental test setup proved to be a reliable alternative to existing abrasion resistance tests and provided repeatable data. This is illustrated in Fig. 2 where the error bars representing two standard errors do not indicate a wide scatter of data. The SSTAR could also establish the direct relation between abrasion resistance and compressive strength of concrete. Through experimental testing using the SSTAR, researchers at UIUC have successfully compared 21 abrasion mitigation approaches through material improvements to date. Also, a statistical model was developed to describe the abrasion mechanism of concrete. This was helpful in comparing the relative abrasion resistance of various abrasion mitigation approaches and predicting wear rates.

Data from SSTAR show that the abrasion resistance of concrete can be improved with the addition of steel fibers, application of polyurethane and epoxy coatings on the rail seat surface, and using MFAs in the rail seat. Increasing the air content appeared to have a negative effect on the abrasion resistance of concrete probably because of a reduction in the compressive strength of concrete. Surface treatments in the form of epoxy and polyurethane coatings improved the abrasion resistance of the specimens significantly. Polyurethane coatings performed significantly better than epoxy coatings, likely because of the differences in material properties such as hardness. Minimal wear was observed on the surface of the concrete specimens topped with MFAs upon completion of the abrasion tests. SCC showed no significant improvement in abrasion resistance despite the presence of elements of various effective abrasion mitigation approaches present within the SCC mix design.

Future Work

As a part of an effort to develop a simplified industry-standard abrasion resistance test for concrete crossties, data obtained from SSTAR will be correlated with the data from AREMA Test 6 (wear and abrasion) on the pulsating load testing machine (PLTM) at UIUC. AREMA Test 6 is the industry-standard crosstie and fastening system wear/deterioration test and is the only AREMA test that is capable of generating RSD. Ultimately, this research will help in formulating design recommendations for the industry to mitigate RSD from a material standpoint.

Further material experimentation will be conducted to understand the effect of various coating parameters like coating thickness, temperature, and curing method. Although MFA and FRC improved the abrasion resistance of concrete, more research must be done on the effect of harder metallic materials on the abrasion resistance of the softer rail pad.

Aggregate properties are critical to the abrasion resistance of concrete (Gencel et al. 2011; Frith et al. 2004). To study the effect of varying aggregate proportion on the abrasion resistance of concrete, the relative proportion of aggregate in the concrete mix will be varied. The coarse aggregate proportion in the mix will be changed without affecting the cement paste-to-aggregate ratio so as to not dilute the binding properties relative to the control specimens. Also, the water:cement ratio will be held constant to minimize the variation in the other properties of hardened concrete. In addition, an image analysis will be utilized to characterize the effect of variability in the area of coarse aggregate that is exposed on the abrasion resistance of concrete specimens as abrasion progresses (Chermant 2001). Another research project is underway at UIUC, which aims to evaluate the performance of high-performance concrete (HPC) mix designs in concrete crossties. This study will be conducted by testing a comprehensive array of samples to evaluate the durability of concrete crossties. Results from this project will supplement the conclusions from our study related to the abrasion resistance of various rail seat materials.

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