Investigation of the Impact of Abrasion as a Concrete Crosstie Rail Seat Deterioration (RSD) Mechanism

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ABSTRACT

To meet the demands of increasing freight axle loads and cumulative gross tonnages, and high-speed passenger rail development in North America, the performance and service life of concrete railway crossties must be improved. According to a railway industry survey conducted by the University of Illinois at Urbana-Champaign (UIUC), rail seat deterioration (RSD) was identified as one of the primary factors limiting concrete crosstie service life. While previous research at UIUC focused on the moisture-driven mechanisms of RSD, the purpose of this study is to define and characterize abrasion in order to understand the criticality of abrasion as a failure mechanism. Abrasion is widely considered to be a viable mechanism leading to RSD; nonetheless, a lack of understanding of the complex properties affecting abrasion has resulted in a highly iterative design process for concrete crossties and fastening systems. When combined with abrasive fines and water that penetrate into the rail seat and pad interface, the frictional forces and relative movement of the concrete crosstie and fastening system equate to a seemingly ideal situation for the occurrence of abrasive wear. This paper includes an investigation of the tribological properties at the interface of the rail seat and pad and preliminary results from an experimental evaluation of the parameters that are believed to affect the rate of abrasion. By identifying the parameters that contribute to RSD, UIUC's research will seek to mitigate the effects of abrasion with an overall goal of improving the performance of concrete crossties.

INTRODUCTION

Rail seat deterioration (RSD) is the term used to describe the degradation of material directly beneath the rail pad on the bearing surface of concrete crossties *(1).* The loss of material at the rail seat decreases the fastening system's clamping force on the rail and can lead to track geometry problems such as gauge widening and loss of cant (inclination of rail seat surface) *(1)*. These types of track defects increase the derailment risk by altering the ratio of lateral to vertical forces and consequently reducing the stability of the rail. As a result of the problems associated with RSD, the service life of many concrete crossties in service on demanding railway lines has been reduced.

In order to avoid the premature replacement of concrete crossties well before the design life has expired, several Class One railways are forced to include rail seat repairs in the capital maintenance plan to prevent track geometry problems. First identified in the 1980's, RSD continues to be a notable problem on North American freight railways as axle loads and rail life cycles increase *(1)*. Rail seat maintenance is relatively expensive because RSD is difficult to accurately detect and impossible to repair without lifting the rail and removing the pad. If the durability of the materials that compose the rail seat is not sufficient to last as long as rail steel in severe service conditions, then interim repairs of the rail seat may be necessary. Thus, increasing the performance and durability of the rail seat materials for concrete crossties is of paramount importance to meet the future requirements of increasing freight tonnages and high-speed rail development.

Familiar with the challenges associated with the durability of concrete crossties, members of the American Railway Engineering and Maintenance-of-Way Association (AREMA) committee on ties (Committee 30) formed a working group charged with identifying the primary causes and factors that contribute to RSD. The working group is composed of industry experts that represent various organizations including freight and passenger railways, suppliers, and research institutions. Table 1 summarizes the most recent work of the group, and represents the current industry understanding of RSD factors and causes *(1)*.

TABLE 1. Summary of Internal and External Factors Related to the Causes of RSD

	High Stresses at the Rail Seat	Relative Motion at the Rail Seat	Presence of Moisture	Presence of Abrasive Fines
Internal Factors	*Loss of proper rail cant* • Loss of material at rail seat • Loss of material at shoulder • Loss of clamping force *Contact area of pad* • Material properties and surface geometry of rail pad	*Looseness of fastening system (loss of clamping force)* • Loss of material at rail seat • Loss of material at shoulder • Yielded or fractured clips • Worn insulators *Scrubbing action* • Poisson's ratio of rail pad • Pad geometry • Confinement of pad	*Rail pad seal* • Material properties and surface geometry of rail pad • Looseness of fastening system • Wear of rail seat and rail pad *Concrete saturation* • Permeability of concrete and rail seat surface	*Rail pad seal* • Material properties and surface geometry of rail pad • Looseness of fastening system • Wear of rail seat and rail pad *Fines from wear of rail seat components*
External Factors	*High vertical loads* • Impact loads • Degraded track geometry *High L/V ratio* • Truck hunting • Over-/under-balanced speeds on curves • Sharp curves • Degraded track geometry *High longitudinal loads* • Steep grades • Thermal stresses in rail • Train braking and locomotive traction *Poor load distribution among adjacent* rail • Non-uniform track substructure • Non-uniform crosstie spacing • Degraded track geometry	*Uplift action* • Low stiffness of track substructure, higher deflections *Lateral action* • Truck hunting • Truck steering around curves (push and pull) • Over-/under-balanced speeds on curves • Sharp curves *Longitudinal action* • Steep grades • Thermal stresses in the rail • Train braking and locomotive traction	*Climate* • Average annual rainfall, days with precipitation, humidity, etc. • Average evaporation rate, etc. • Extreme daily or annual temperatures • Number of annual freeze/thaw cycles	*Environment* • Wind-blown sand or dust • Moisture to transport the abrasive fines under the rail pad *Track maintenance* • Ground ballast • Metal shavings from rail grinding or rail/wheel wear *Train operations* • Application of locomotive sand (especially on grades) • Coal dust and other abrasive commodities

Table 1 relates the primary causes that result in RSD - high stresses, relative motion, moisture, and abrasive fines - to internal and external factors, that affect the primary causes. Internal factors refer to aspects of concrete crosstie and fastening system design. Alternatively, external factors are directly related to track geometry, track maintenance, railway operations, climate, and environmental characteristics *(1)*. Table 1 illustrates the challenges associated with designing a concrete crosstie and fastening system to mitigate RSD by listing a variety of factors and causes that interact in complex processes that are difficult to analyze simultaneously.

MECHANISMS OF RAIL SEAT DETERIORATION

Previous and current research at the University of Illinois at Urbana-Champaign (UIUC) focused on an investigation of the complex physical processes, or mechanisms, that contribute to RSD. As a result of this work, five mechanisms have been identified that have the potential to deteriorate the materials at the rail seat. The RSD mechanisms include abrasion, crushing, freeze-thaw cracking, hydraulic-pressure cracking, and hydro-abrasive erosion *(2, 3, 4)*. Each of the mechanisms is briefly introduced below.

Abrasion is defined as the wear of particles on the rail seat surface as frictional forces act between the rail pad and the concrete rail seat, which move relative to one another. The abrasion mechanism, which will be described in detail in this paper, is the focus of current RSD research at UIUC. Another RSD mechanism, crushing, occurs when concentrated stresses on the rail seat exceed the strength or fatigue limits of the rail seat materials, resulting in localized damage of the rail seat surface *(4)*.

The three remaining RSD mechanisms are referred to as moisture-driven mechanisms because the physical process that damages the concrete at the rail seat is only possible when moisture is present in the concrete pore structure. Freeze-thaw cracking initiates when the tensile strength of concrete is exceeded by stresses due to volumetric changes of water in the concrete pore structure with variations in temperature *(2, 4)*. Hydraulic pressure cracking occurs when rail seat loads and surface water create pore pressure in the concrete *(5)*. Based on experimental laboratory testing performed at UIUC, pore pressures have the potential to exceed the concrete's tensile strength, resulting in micro-cracking and subsequent spalling *(5)*. Hydro-abrasive erosion, also called abrasive erosion or suspended particle erosion, refers to concrete wear through the action of flowing water *(1)*.

In Table 2, the five mechanisms are related to the causes of RSD that have been identified.

TABLE 2. Relevance of the Causes of RSD Related to Potential Concrete Deterioration Mechanisms

	Concrete Deterioration Mechanisms				
Causes	Abrasion	Crushing	Freeze-Thaw	Hydraulic Pressure	Hydro-Abrasive
High stresses at rail seat	✓	✓		✓	✓
Relative motion at rail seat	✓	✓		✓	✓
Presence of moisture	✓	✓	✓	✓	✓
Presence of abrasive fines	✓				✓

The current approach for the RSD investigation is to individually examine each mechanism by analyzing the parameters that affect it. Next, a variety of sources will be used to estimate the frequency with which those conditions occur in track. Then, the frequency of conditions that lead to each mechanism will be compared. Methods of mitigating the most critical mechanism (the one that has the highest probability of occurring in North America) should govern concrete crosstie rail seat and fastening system design *(6)*. Alternatively, multiple crosstie designs could be manufactured that are specific to the mitigation requirements for various internal and external RSD factors.

Based on expert opinion in the railway industry, abrasion has been selected as the next mechanism for detailed investigation in this study. Though abrasion is widely considered to be a viable mechanism that leads to RSD, a lack of understanding of the complex interaction of parameters that affect abrasion has resulted in a highly iterative process of concrete crosstie and fastening system design. When combined with abrasive fines and water that penetrate into the rail seat and pad interface (seat-pad interface), the frictional forces and relative movement of the concrete crosstie and fastening system equate to an ideal situation for the occurrence of abrasive wear.

Experimental evidence from existing AREMA laboratory wear and abrasion tests have produced wear on concrete rail seats that is similar in appearance to concrete crossties with deteriorated rail seats that have been observed on North American freight infrastructure. Additionally, RSD was originally called rail seat abrasion (RSA), likely due to the fact that the scrubbing action of the rail pad is visible during loading cycles and seems to correlate to the rubbing action that has been used to characterize the abrasion mechanism. However, as a result of a better understanding of RSD mechanisms, AREMA recently updated its Manual for Railway Engineering to refer to the degradation of materials at the rail seat as RSD, recognizing the multiple mechanisms that are capable of producing deterioration *(6)*. The mechanics of abrasion must be analyzed in order to better understand its influence as an RSD mechanism.

MECHANICS OF ABRASION AT THE RAIL SEAT

As wheel loads are transferred from the rail to the underlying pad and from the pad to the crosstie, shear forces act at the seat-pad interface. Slip occurs when the shear forces at the interface overcome the static friction between the bottom of the pad and rail seat. Each time slip occurs, strain is imparted into the concrete system. Over time, this strain exceeds the fatigue limit of the concrete material and a brittle failure occurs, dislodging individual particles of mortar paste. Initially, microscopic particles are worn away, resulting in a surface that appears polished or burnished *(T. Johns unpublished)*. After many loading cycles, enough particles can be degraded so that a noticeable depth of material is lost, yielding a rough, uneven rail seat.

Parameters Affecting Abrasion Mechanism

Based on the current understanding of the mechanics of abrasion, the primary causes that drive the process are high stresses, or contact pressures, and the motion that occurs between the pad and the rail seat. The primary factors influencing those causes, and the subsequent rate of abrasion, appear to be the contact properties of the materials at the seat-pad interface. Principles from tribology, an interdisciplinary field aimed at studying interacting surfaces in relative motion, can be applied to the investigation of abrasion in order to more effectively characterize the critical parameters. From tribology, we know that the amount of abrasive wear a surface undergoes is proportional to the normal force between the two surfaces and the amount of movement *(7)*. Additionally, the relative hardness of the interacting materials also affects the rate of wear *(7)*. Based on an extensive literature review, the contact pressure, types of motion specific to the seat-pad interface, and properties of materials at the interface present a set of unique problems which are discussed below.

Contact Pressures at the Rail Seat Interface

Quantifying the magnitude and distribution of pressures on the rail seat surface is critical to understanding the abrasion mechanism. Preliminary results from an experimental investigation of contact pressures at the seat-pad interface at UIUC have resulted in pressures up to 2,600 pounds per square inch (psi) *(8)*. For many rail pads, some portions of the pad are unloaded and transfer negligible loads to the rail seat surface.

In addition to experimental measurements conducted at UIUC, researchers at the Volpe Center tasked with investigating a 2006 derailment estimated rail seat pressures based on vertical and lateral forces calculated with the NUCARS model *(3)*. In this study, average rail seat pressures of 400 psi up to 16,400 psi were calculated *(3).*

Obtaining additional rail seat pressure distribution data is vital to understanding the demands on the rail seat. The pressure at the rail seat is a critical parameter of multiple mechanisms of RSD, including abrasion.

Types of Motion Leading to Abrasion

Through experimental testing and field observation, two types of motion have been observed at the seat-pad interface. First, compression of the pad, due to axial loading, leads to radial expansion of the pad. This type of motion will be referred to as compressive motion, and is also known as “Poisson’s effect”. This motion at the local contact asperities could cause wear of the concrete surface, possibly explaining RSD on tangent track where lateral loads are lower.

Second, translational motion occurs along the seat-pad interface due to lateral and longitudinal loads. High lateral to vertical (L/V) load ratios, such as those experienced on sharp curves, can result in forces that will cause the pad to translate laterally. Alternatively, movement can occur in the longitudinal direction due to the wave action of the rail as multiple wheels pass over the concrete crosstie, acceleration and braking, or thermal stresses in the rail. Because translational motion has the potential for larger displacements, this type of motion will be replicated in the laboratory test.

Properties of Materials at the Rail Seat Interface

Recognizing the materials that are present at the seat-pad interface and analyzing the behavior of all materials interacting at the interface is critical to understanding the abrasion process. For most concrete crossties in North America, the rail seat is initially composed of concrete mortar paste and air voids. The concrete mortar paste surface is composed of a matrix of cement grains that bond to one another as the cement is hydrated *(9)*. As RSD initiates and the cement paste is worn away, coarse and fine aggregate is exposed at the rail seat surface.

Regardless of the cement paste to coarse aggregate ratio at the rail seat, the concrete provides a brittle bearing surface that exhibits a limited amount of elastic behavior. As a result, the surface roughness and hardness are of primary importance to the outcome of the abrasion mechanism. The surface roughness refers to the variability of the profile of the rail seat surface. Alternatively, the surface hardness is the ability of concrete to resist local plastic deformations. For concrete, the roughness and hardness of the surface depend on the quality of the constituents used in concrete crosstie manufacture, the manufacturing methods or processes employed, and nearly every mechanical property of the hardened concrete *(4,10)*.

As mentioned previously, surface coatings of epoxies and urethanes are currently used to restore the rail seat surface in maintenance applications after rail seat surface material is deteriorated. Furthermore, at least one North American railway company is applying a surface coating to new concrete crossties as part of the production process in order to increase the durability of the rail seat. Fundamentally, epoxy and urethane materials are expected to exhibit behavior that is different than concrete in the rail seat environment, and these alternative materials are included in our investigation of the abrasion mechanism.

Initially, the rail seat surface is in direct contact with the rail pad. With a goal of attenuating and transferring wheel loads from the rail to the concrete crosstie, a large variety of materials have been used to construct rail pads for North American railway applications. Rubber, santoprene, ethyl vinyl acetate (EVA), polyurethane, reinforced nylons, and many other material combinations have been coupled with various pad geometries in an attempt to protect the rail seat while transferring loads *(4)*.

With respect to the abrasion mechanism, the most important property of the materials that compose the rail pad is the Poisson's Ratio of the pad, or the ratio of lateral strain behavior to vertical strain behavior. The Poisson's Ratio of rail pads is a material property that is correlated to the ability of the pad material to resist internal shear forces under axial compression. The lateral strain forces overcome static frictional forces at the rail seat interface causing slip, or localized movement. A pad with higher internal resistance to shear forces - a lower Poisson's Ratio - exhibits less movement at the contact interface. In addition to Poisson's ratio, pad hardness is significant for understanding the abrasion mechanism. Pad hardness refers to the local plastic deformation behavior of the materials that make up the pad. Plastic deformation of the pad at local contact asperities can potentially change the pressure distribution at the rail seat, resulting in more damaging pressures *(8)*.

In conjunction with the Poisson's ratio of the pad material, the geometry, loading distribution, and confinement of the pad affect the lateral elasticity, or deflection of the pad perpendicular to the normal load. Although the vertical elasticity, typically referred to as elasticity, of the pad is important for track stiffness and damping, the lateral elasticity of the pad is expected to be the most critical metric in analyzing abrasive behavior of pads on rail seat surfaces. Lateral elasticity directly relates to the amount of shear strain that occurs at the rail seat. A laboratory test to monitor the global lateral elasticity of the pad when measuring the vertical elasticity under compressive loading could be useful in understanding pad behavior and may lead to more prescriptive designs for rail pads in abrasive environments. Furthermore, mathematical models could be used predict the lateral elasticity of the pad and the shear strain that is transferred to the rail seat for various rail pad designs. Careful consideration of the lateral stiffness should be applied to pad design because of its influence on the abrasion mechanism.

While the rail pad plays a critical role in movement at the rail seat, external materials that enter into the seat-pad interface affect the contact properties. The frictional interface between the rail pad and the rail seat surface is significantly altered by the presence of moisture and abrasive fines that can penetrate into the interface when an effective seal is not achieved by the pad. Previous studies have shown that concrete surfaces experience significantly more abrasive wear when they are wet, possibly due to the weakening of mortar paste as it is exposed to moisture *(4, 11, 12)*. Similarly, the presence of fine materials in standard abrasion resistance tests has been shown to accelerate the rate of abrasion *(13, 14)*. In general, fine particles that are introduced to a frictional interface equate to greater volumes of wear at that interface *(15)*. According to the American Concrete Institute (ACI) Repair Manual, concrete will be abraded only if the abrading material is harder than the concrete *(16)*. Considering most rail pad materials are not harder than concrete, abrasive fines from locomotive sand, ground ballast material, coal dust, rail grinding, etc. can be expected to play a major role in abrasion at the rail seat. As a point of reference, silica particles that make up sand are harder than the hardest pad materials, the concrete rail seat, and premium rail steel *(17)*.

Experimental Methods of Investigating Abrasion

Developing experimental methods for gathering quantifiable data is critical to learning more about the abrasion mechanism due to the complex interactions contributing to RSD and difficulties in gathering field data. Beyond the abrasion resistance test that is described below, two simplified laboratory studies were performed at UIUC to learn about the contact properties of the materials at the seat-pad interface.

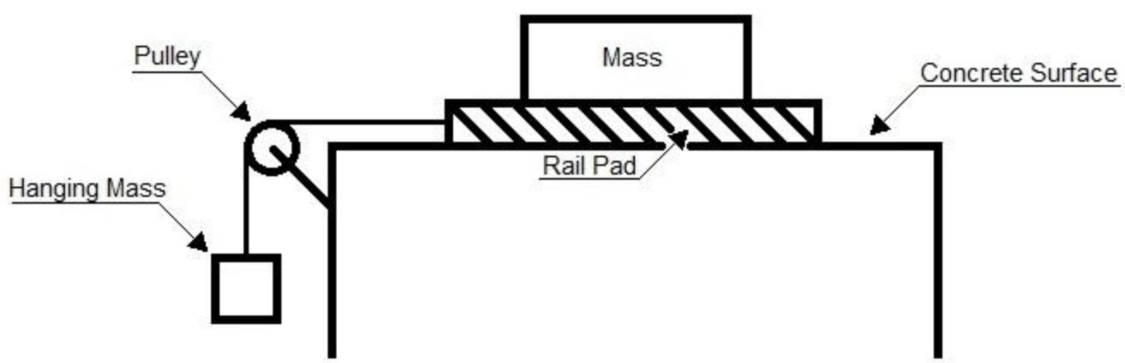
Estimating the Static Frictional Coefficient of Rail Pads on a Concrete Surface

The frictional properties of the seat-pad interface are critical to abrasion because frictional forces resist local movements of the pad. One important frictional property at the interface is the static coefficient of friction. As illustrated by the equation below, the magnitude of frictional forces is directly related to the normal force between the two bodies by the coefficient of friction.

$$\text{Frictional Force} = \mu N$$

In this equation, N stands for the normal force and μ represents the frictional coefficient. The static coefficient of friction is the ratio of the force perpendicular to contact required to accelerate a body from rest to the normal force between the two forces. The static coefficient of friction between a rail pad and a concrete surface was estimated with a laboratory experiment at UIUC. A pad was loaded with a known mass and placed on a relatively smooth concrete surface. A lateral force was applied to the pad by tying one end of string to the pad and the other end to a hanging mass. By mounting a pulley to the edge of the elevated concrete surface, the direction of the load provided by the hanging mass was transferred so that gravity could be used to provide the lateral load on the pad. Figure 1 shows a schematic diagram of the frictional coefficient test setup.

FIGURE 1. Test Setup to Estimate Static Frictional Coefficients of Rail Pads on a Concrete Surface



Three different rail pads were tested with four different surface conditions. The first pad was a 2-part polyurethane assembly with a flat bottom. In contrast, the second and third polyurethane pads had studded and dimpled geometry, respectively. Sand and water were applied to the interface to modify the surface conditions resulting in four cases: dry, dry plus sand, wet, and wet plus sand. Weight was added to the hanging mass until the pad moved. The weight of the hanging mass required to move the pad was divided by the weight of the loaded pad (normal force), resulting in the experimental static coefficient of friction. For each pad geometry and surface condition combination, 3 repetitions were conducted. The results from this investigation are shown in Table 3 below.

TABLE 3. Average Experimental Static Frictional Coefficients of Rail Pads on a Concrete Surface

Average Experimental Static Frictional Coefficient				
Geometry of Pad Bottom	Surface Condition			
	Dry	Dry + Sand	Wet	Wet + Sand
Flat	0.83	0.46	0.64	0.45
Studded	0.77	0.50	0.66	0.42
Dimpled	0.65	0.47	0.63	0.54

The introduction of sand and water to the interface between the pad and the concrete surface decreased the average static frictional coefficient for each trial, regardless of the pad geometry. Sand at the interface reduced the static frictional coefficient by an average of 36% while water reduced the frictional coefficient by 14%, as compared to the dry surface condition. The static frictional coefficient of the pad with a flat bottom was reduced at a greater rate than the pads manufactured with various geometries. The static frictional coefficient observed in this study will be compared to those measured in the abrasion resistance laboratory test that is explained below.

Estimating Rail Seat Surface Hardness with a Rebound Hammer

In addition to characterizing the coefficient of friction at the seat-pad interface, the hardness of the rail seat surface was investigated experimentally at UIUC. Hardness is a property that is used to describe the capacity of a surface to resist plastic deformation under point loads, simulating localized stresses at contact asperities. As the abrasion mechanism initiates due to stresses at local contacts, it is hypothesized that a harder surface would provide greater resistance to abrasive wear.

To validate the claim that a harder rail seat can be correlated to an increase in abrasion durability, the surface hardness of two concrete rail seat samples was evaluated with a rebound hammer. Two different sections of a full-scale concrete crosstie manufactured in North America were prepared and tested as separate experiments to compare the cement paste surface of a concrete crosstie with two alternative surface treatments. Specimen A had six distinct regions prepared by precision grinding wheels and one region that remained as cast, composed of cement paste. Specimen B had two distinct regions: half was coated with a high-viscosity repair epoxy and the other half remained as cast.

A rebound hammer, Schmidt type N-6 manufactured by Forney Testing Machines, was used to calculate dynamic rebound numbers for each distinct surface. The Schmidt hammer measures the height of the hammer mass after an impact with the testing surface. A softer material will experience more plastic deformation upon impact. Thus, less initial kinetic energy from the mass will be transferred to the rebound of the mass after impact resulting in a lower rebound number *(18)*.

The data was analyzed and average rebound numbers were calculated according to American Society of Testing Methods (ASTM) C 805. The data was used to prepare two quantitative plots comparing the average rebound values of the cement paste surface, ground surface, and epoxy-coated surface. Table 4 illustrates the results both specimens.

TABLE 4. Experimental Rebound Data for Rail Seat Surfaces A and B

Average Rebound Number			
Specimen A		Specimen B	
Cement Paste	33	Cement Paste	48
Ground (Exposed Aggregate)	43	Epoxy Coating	50

For Specimen A, the average rebound number for the cement paste surface was lower than the values for the ground surfaces. Similarly, the average rebound number for the cement paste surface was lower than the average for the epoxy-coated surface on Specimen B. It should be noted that the two specimens were not supported in the same way and had different thicknesses. Therefore, the results from the different specimens should not be compared. Further testing is needed to determine the validity of using the rebound hammer to measure rail seat surface hardness. Relative rebound data from future tests will be compared with results obtained from the investigation of abrasion resistance of concrete surfaces described below. These results will be further analyzed to determine if a correlation exists between hardness and abrasion.

CURRENT TESTING METHODS FOR ABRASION RESISTANCE

Abrasion resistance is a term used to describe a material's ability to withstand frictional contact forces and relative movement that have the potential to produce wear. Previous studies have illustrated that the abrasion resistance depends on the quality of materials used, manufacturing/construction practices, and mechanical properties of the finished concrete *(4, 10)*.

Increasing the abrasion resistance of the rail seat should be strongly considered as a way of improving the durability and performance of concrete crossties. A number of test methods have been used in North America to compare the relative abrasion resistance of rail seat materials. Previously, the tests have been specified by railways for quality control purposes and employed by crosstie manufactures for research and development purposes. The testing method that is utilized depends on the objectives of the test and can be typically divided into two categories; system tests and materials tests.

Currently in North America, the AREMA Test 6: Wear/Abrasion is the recommended method of determining if a rail seat and fastening system have the ability to resist RSD under repeated loads *(19)*. As a qualification test for new crosstie and fastening system designs, AREMA Test 6 was designed to represent severe service conditions when concrete ties are subjected to high lateral forces on a high-degree curve with moisture and abrasive sand present. Test 6 is the ideal test for studying the abrasion mechanism because it most closely represents the process that occurs on railway tracks in revenue service. Unfortunately, the test is expensive for prototyping because a full-scale crosstie and fastening system is required for each new design or material improvement. Additionally, the test takes between 10 and 15 days to complete, resulting in few data points.

Due to the time and cost of AREMA Test 6, several existing materials tests, standardized by the ASTM, were used in the concrete crosstie industry to evaluate the abrasion resistance of rail seats. The Revolving Disks Test (ASTM C 779 A), Dressing Wheels Test (ASTM 779 B), Ball Bearings Test (ASTM C 779 C), and a modified version of the Robinson Test (ASTM C 627) successfully produced mechanical wear on concrete surfaces and provided some relative abrasion resistance data. However, these tests are not representative of the abrasion mechanism at the rail seat interface because they were designed to represent abrasion due to foot traffic, steel wheels, or studded tires on industrial slabs or pavements. In general, these tests use some type of steel contact surface that is constantly rotating or rolling to cause abrasion on a horizontal surface. Although some of the tests offer the ability to add an abrasive slurry of fine particles and water, the primary parameters of the tests (pressure, motion, contact properties) are fundamentally different from the abrasion mechanism that is observed at the rail seat. For example, the continuous motion of the ASTM tests result in rolling friction or kinetic friction that is expected to produce frictional coefficients that remain at relatively static levels throughout the tests. In contrast, the frictional coefficient at the rail seat appears to be dynamic because of the wheel loading cycles and elasticity in the system that accelerate (move) the pad and then restore it to its original position. A dynamic friction loop is expected to occur where static friction will give way to kinetic friction and return to static friction under each loading cycle (wheel load). Combined with the natural variability in the tests, the standard abrasion resistance tests fail to facilitate the collection of qualitative data by means of a representative process.

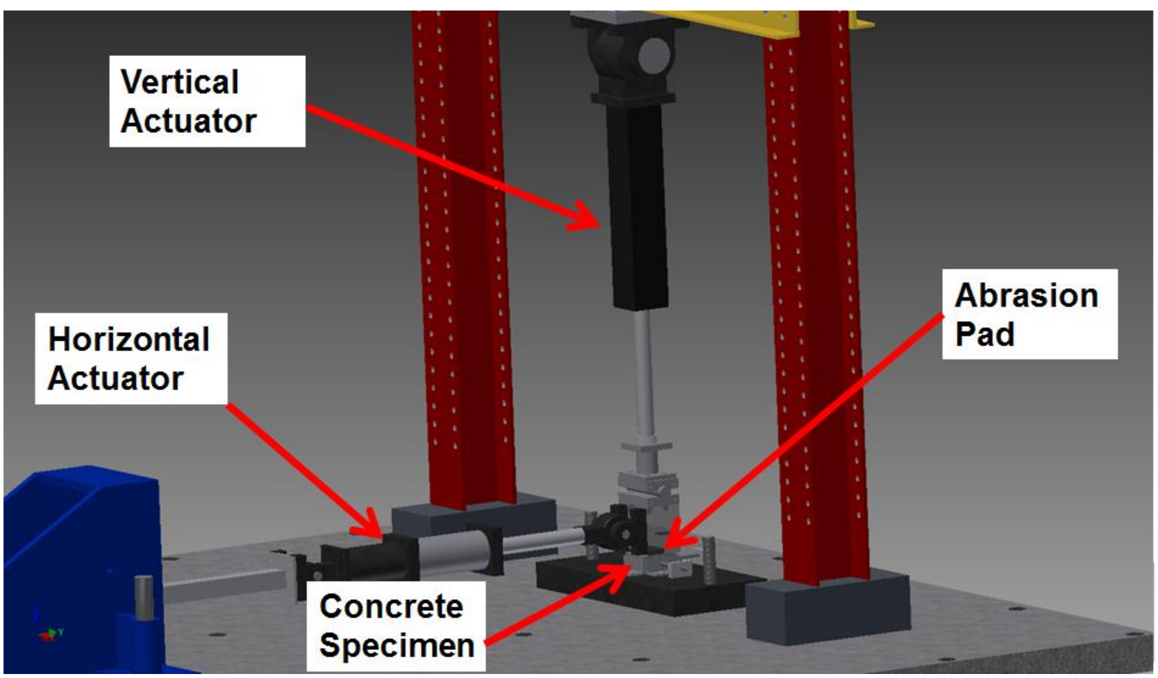
LABORATORY TEST SETUP AND PROCEDURE

A large gap exists between the full-scale system test (AREMA Test 6) and standardized abrasion resistance tests that have been used to evaluate rail seat surfaces. A laboratory test that is more representative of the rail seat abrasion mechanism than the ASTM standard tests and is easier to execute than Test 6 will be beneficial to the railway industry.

The study of abrasion requires observation of wear after many loading cycles so that the amount of actual deterioration and the rate at which wear occurs can be assessed. A novel laboratory test and procedure has been developed at UIUC to produce measurable abrasive wear of mock rail seat surfaces. This test is designed to isolate the parameters that are believed to affect the abrasion mechanism and facilitate the acquisition of quantitative and qualitative data for each parameter.

The test utilizes a horizontally mounted actuator to produce displacements of a pad relative to a concrete specimen while a static normal force is applied with a vertically mounted actuator. A 35 Kilopound (Kip) MTS servo-hydraulic actuator in displacement control provides the force needed to accelerate the pad perpendicular to the normal load and return the pad to its original position. Alternatively, a 110 Kip MTS servo-hydraulic actuator in force control provides a static normal force on the pad so that representative contact pressures are maintained. Both actuators are pinned to a steel loading head that houses the abrasion pad in a recessed cavity. Mock rail seat specimens that are 6” x “6” x 3” deep are fixed to the floor via a steel base plate and adjustable angle (L-bracket) supports. Water and abrasive fines may be added through a channel within the loading head that deposits the materials at the edge of the interface between the pad and the specimen. A 3-dimensional (3D) model of the test setup is shown in Figure 3.

FIGURE 2. Rail Seat Abrasion Resistance Test Setup



Replicating the translational movement at the rail seat during demanding track conditions and loading scenarios (e.g. loss of clamping force, high lateral and longitudinal forces, etc.) permits the analysis and study of the abrasion resistance of rail seat surfaces under variable conditions. Test parameters include the normal load (pressure), the amount of horizontal displacement of the abrading surface relative to the specimen, the moisture condition of the concrete specimen, and the type and amount of abrasive fines.

The displacements and forces are monitored in both the lateral and vertical direction for the duration of each test. The ratio of lateral forces to vertical forces will facilitate the collection of data related to the dynamic friction loop of the contact interface. Additionally, a 3D imaging system that utilizes a laser to map the physical position of objects in space will be used to determine the amount and position of abrasive wear that occurred on the rail seat specimens during testing.

INITIAL RESULTS AND CONCLUSIONS

Initial experience in characterizing the abrasion mechanism of RSD has yielded several observations. Current abrasion resistance tests fail to accurately capture field conditions and do not simulate the abrasion mechanism at the concrete rail seat surface. A more representative test for abrasion resistance will be beneficial for innovation in the industry A testing setup and protocol has been developed at UIUC that will facilitate the collection of more data, qualify materials for AREMA Test 6, and contribute to a better understanding of the abrasion mechanism.

The contact pressure, movement, and material properties at the seat-pad interface are parameters that are suspected to be critical to the abrasion mechanism. These parameters are being investigated in parallel with the abrasion resistance testing so that correlations can be made between the parameters and the abrasion mechanism.

Initial experiments show that the average static frictional coefficient is reduced due to the intrusion of abrasive fines and moisture at the interface. Also, the relative hardness of alternative rail seat surfaces was harder than as-cast concrete rail seats when measured with a rebound hammer. Analysis of these experimental data will advance the understanding of the abrasion mechanism of RSD. By identifying the factors that contribute to RSD, this research will seek to mitigate the effects of multiple RSD mechanisms, with an overall objective of improving the performance and service life of concrete crossties.

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TABLES

FIGURES