Extending the Lifetime of Mixer Paddles Used in the Production of a Low-level Radioactive Cementitious Waste Form – 15624

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ABSTRACT

The Saltstone Production Facility (SPF) at the Savannah River Site (SRS) immobilizes low-level radioactive salt solution as a cementitious waste form known as saltstone. The mixer used in the SPF is a "10-inch" Readco-Kurimoto continuous mixer with paddles fabricated from a high toughness steel. Saltstone is processed daily at a rate of 9.46E-03 m^3/s (150 gallons per minute) in a caustic and radioactive environment. The paddles have degraded much quicker than expected which limits production rates and increases outage times. Due to the high cost of the mixer and the limited maintenance due to the radioactive environment, a combination of material properties and paddle configuration must be employed to extend the lifetime of the paddles. This paper will discuss two wear tests conducted by the Savannah River National Laboratory (SRNL) to determine the optimum paddle configuration to reduce wear on the mixer paddles. The first wear test used the mixer design operated up to December 2011 as the baseline and the second test used the mixer design installed after December 2011 as its baseline. As a result of these tests, the SPF will be implementing a new paddle configuration in the mixer currently installed in the SPF process room.

INTRODUCTION

At the Savannah River Site (SRS), the Saltstone Production Facility (SPF) receives low level waste (LLW) salt solution from Tank 50H for treatment and disposal. At the SPF, the LLW is mixed with premix (a mixture of portland cement, blast furnace slag, and Class F fly ash) in a "10-inch" Readco-Kurimoto continuous mixer to produce fresh (uncured) saltstone that is transferred to the Saltstone Disposal Facility (SDF) for permanent disposition in the Saltstone Disposal Units (SDU).

The "10-inch" Readco-Kurimoto mixer installed in the SPF is a continuous co-rotating twin-screw mixer. The co-rotating shafts contain 28 intermeshing lens-shaped mixing paddles that have tight clearances between the paddles and the inside diameter of the barrel which promotes a "self-wiping" capability [1]. Also on the shafts are augers that provide the flow of premix into the paddles and they also have the tight clearance between the outside flight diameter and barrel. As shown in Fig. 1, the paddles on the co-rotating shafts are paired and off-set by 45 degrees. For the duration of this report, the paddles at each position in the mixer will be referred to as paddle pair and the respective position number. Numbering begins with the first paddle pair after the feed augers.

The SPF mixer contains shearing and conveying paddles (Fig. 1). The shearing paddles are flat and designed for mixing the constituents in the mixer. The conveying paddles have a helical curvature and are designed to help move the material through the mixer. Throughout this report, the shearing and conveying paddles will be referred to as flat and helical paddles, respectively.

To date, worn paddles in two SPF mixer have caused processing upsets and delays. In March 2011, dry feeds began backing up in the chute that feeds the "10-inch" Readco-Kurimoto continuous mixer. The dry feeds were setting off level indicators in the premix chute to the "10-inch" mixer during multiple days of processing. When the high level indicator is tripped, the SPF enters into shutdown. During troubleshooting of the process, the "10-inch" mixer was cleaned, inspected and wear was found in the area where the screw augers and the first set of mixing paddles meet (Fig. 2). The wear on the paddles eliminated the self-cleaning capabilities of the paddles and augers, leading to a build-up of grout between the paddles/augers and the barrel. This build-up acts as a restricting orifice which reduces the throughput capabilities of the premix as provided by the auger section of the mixer. Eventually after several shutdowns and mixer cleanings, the mixer was removed from service in December 2011 and replaced with a different mixer configuration [1].

In January 2013, a routine inspection of the new SPF mixer showed there was more wear on the mixer paddles below the liquid inlet than what was anticipated based on previous mixer inspections and testing at Savannah River National Laboratory (SRNL) (Fig. 3) [1]. As a result of this increased wear on paddles in the transition region of the mixer, SRNL was asked to evaluate the installed mixer paddle configuration to establish a wear baseline and propose alternate paddle and auger configurations to reduce the wear rate in the mixer [2]. The transition region is defined as the area in the mixer where the dry feeds first become wetted by the LLW salt solution at the liquid inlet but before the dry feeds are completely wetted at the desired water to premix ratio [1].

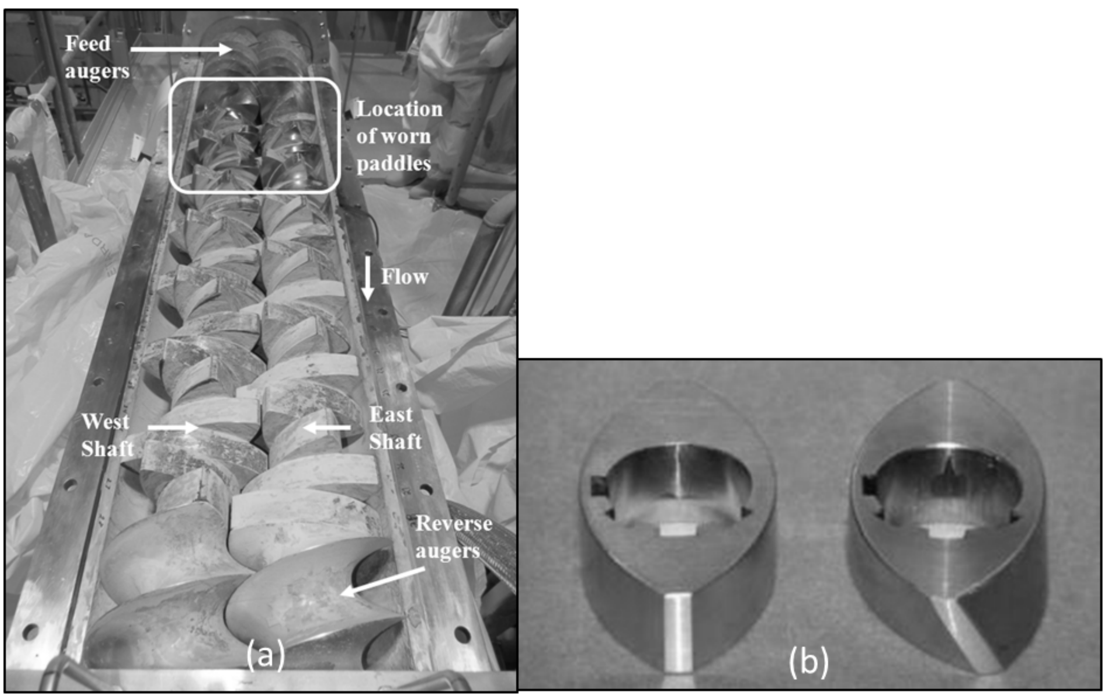

Fig. 1. (a) "10-inch" Readco-Kurimoto mixer installed in the SPF in December 2011 showing the feed augers, the co-rotating shafts with pairs of intermeshing mixing paddles, and location of worn paddles and (b) the two types of paddles shearing or flat (left) and conveying or helical (right) used in the mixer.

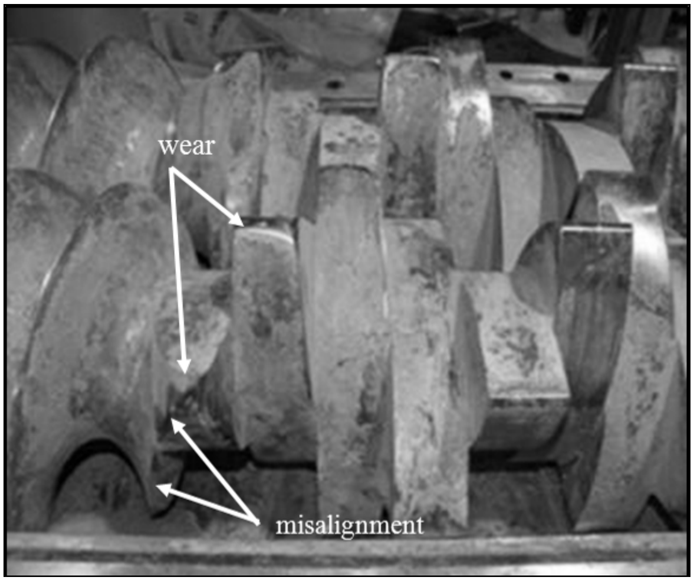

Fig. 2. Worn paddles in the “10-inch” mixer removed from service in December 2011 (note the misalignment of paddle 1 and the feed augers).

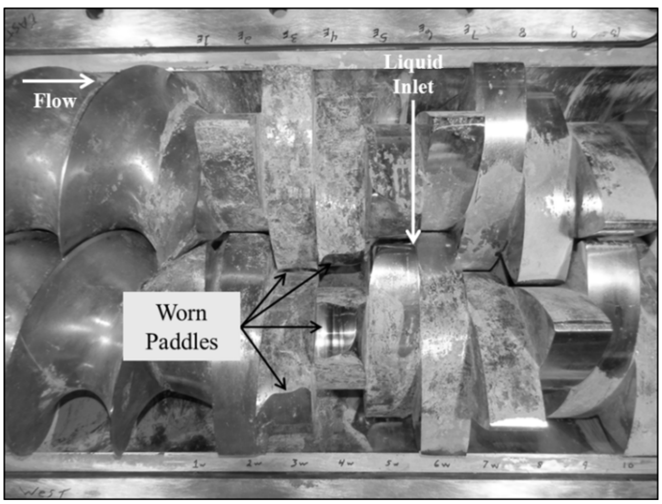

Fig. 3. Paddles 1 – 9 in the “10-inch” mixer after cleaning during the January 2013 inspection with worn paddle tips showing on paddles 3 and 4.

PADDLE CONFIGURATION TESTING

SRNL has developed a pilot scale system of the SPF at Savannah River Site (SRS) known as the Scaled Continuous Processing Facility (SCPF) [3]. The scaled system consists of a dry material feeder coupled to a Readco-Kurimoto “2-inch” co-rotating twin-screw continuous processor (mixer) which mixes the dry feeds with liquid supplied by a feed tank. Details of the unit operations of the SCPF as well as the scaling and comparisons between the “2-inch” and “10-inch” mixers are captured in other reports [1,3,4]. It should be noted that the current SPF mixer has 28 paddle pairs as part of the new design compared to 26 paddle pairs in the previous design. The “2-inch” mixer also contains 26 paddle pairs and cannot be changed to include more paddles. The difference of two paddle pairs between the “2-inch” and “10-inch” mixer will not impact the testing results and conclusions since the wear is localized to the paddle pairs directly after the feed augers. The paddle pairs are numbered in series starting at 1 after the feed augers and ending in 26 at the discharge of the “2-inch” mixer.

Two separate wear tests for each mixer configuration were performed. Wear test 1was on the mixer configuration removed from service in December 2011 [1], and wear test 2 was performed on the mixer configuration installed in December 2011[2]. Each test consisted of two sub-tests. Test a was the paddle configuration as installed in the SPF was tested to establish the baseline wear and test b was the SRNL recommended paddle configuration. Wear test 1a has flat paddles in positions 1 – 4 and paddle 1 is misaligned with the feed auger. Wear test 1b has a helical paddle aligned with the feed auger and paddles 2 – 4 are flat. For bot tests in wear test 1, the liquid inlet is over paddles 1 and 2. For wear test 2 tests, the mixer configuration was changed so the liquid inlet was moved over paddles 5 and 6. For wear test 2a, paddle 1 is a helical paddle misaligned with the feed auger and paddles 2 – 6 are flat. In wear test 2b, paddles 1 – 6 are helical and paddle 1 is aligned with the feed auger.

The “2-inch” mixer paddles are fabricated from 316 stainless steel. The paddles interest, referred to as wear paddles, were fabricated out of 6000 series aluminum in order to increase the paddle wear rate [5] and decrease the test run time, since 6000 series aluminum is a soft metal with low wear resistance. Each wear paddle was laser etched with a unique number to aid in reassembly and identification post testing.

Test Procedure

Both wear test 1 and wear test 2 wear preformed under the same operating conditions. The testing procedure started by filling the liquid feed tank and loading the dry feed hopper. The dry feed for the wear testing was a mixture of 45 wt % fly ash and 45 wt % blast furnace slag and 10 wt % cement. The liquid for the wear testing was process water. The SPF operates at a dry feed throughput of approximately 8.82 kg/s (35 ton/hour) with the maximum throughput capacity of 12.60 kg/s (50 ton/hr). For this testing, the dry feeder was run at a dry feed rate scaled to the maximum throughput capacity of the SPF “10-inch” mixer [6].

The liquid feed was started followed by the “2-inch” mixer and both were adjusted to their respective test conditions. The liquid feed rate was maintained to produce a 0.60 water to premix grout, similar to SPF operations. The mixer motor speed was set to 3.67 rotations per second (rps) (5.12 rps paddle speed) to provide maximum throughput for this testing. Grout production started when the dry material feeder was started. At the dry feed rate of 1.05E-01 kg/s (833.3 lbs/hr), a full hopper lasted about 1800 seconds. The hopper was reloaded as required to continue testing until the desired mass of processed dry feeds was reached. Once the test was completed, the system was put into a safe condition and the mixer was opened to remove the paddles for inspection. The mixer housing opens like a clamshell to fully expose the shaft for inspection, cleaning, or paddle replacement.

Following a test, the paddles were cleaned before inspection to remove simulant LLW grout residue. Residue was removed by soaking the wear paddles in concentrated nitric acid for 180 seconds. This process was carefully evaluated to verify residue removal with minimal aluminum removal. Numerous tests revealed that the aluminum lost during this process was relatively insignificant (> 0.001 grams) while the majority of the residue was removed.

Determination of Wear Rate

Mass loss was the primary measurement used to determine wear rate. In addition, the wear rate was measured by the change in critical dimensions of each paddle [1,2]. Prior to testing, each paddle was photographed, weighed and the dimensions were measured before the paddle as placed on the mixer shafts. The contour of each paddle was measured with a specially designed fixture consisting of a micrometer and a rotary table and the length, width, and height of each paddle was measured with a vernier caliper [1,2]. The paddle fixture measured the radial dimension of the paddle contour at various angular locations around the paddle. In addition, the contour measurements were taken at three locations along the thickness of the paddle: bottom, middle, and top. Readings were concentrated around the tips (90° and 270°) since it was expected that the majority of the wear would occur in those locations. The results of these measurements are documented in other reports [1,2].

RESULTS AND DISCUSSION

The total duration of each wear test was based on mass of dry feeds processed so that all the paddles were exposed to the same amount of material. The target dry feed mass for each wear test was 1360.7 kg of premix. Wear test 1a processed 1188.4 kg of premix and wear test 1b processed 1496.9 kg of premix [1]. Wear test 2a processed 1349.4 kg of premix and wear test 2b processed 1360.7 kg of premix [2].

Wear Test 1

The majority of the mass loss occurred on paddle 1 for both wear tests 1a and 1b. Paddle 1 is directly upstream of the liquid feed inlet, which enters the barrel above the paddle pair 2 on the right side (looking towards the motor). The paddle 1 area is where the dry feed transitions from dry to wet and is also the transition between the auger and first set of paddles. Fig. 4 shows the actual mass loss of the paddles 1 – 4 in wear test 1a and wear test 1b.

As shown in Fig. 4, the paddle mass loss at paddle 1 for wear test 1b is approximately 40% less than the mass loss of the paddles at the same location in wear test 1a. It is hypothesized that this is primarily due to the misalignment of the paddle pair 1 with the feed augers. Also, the dry feeds are more abrasive than the premix-water slurry and the augers and first set of paddles would be more exposed to un-wetted dry feeds than any of the other paddles in the mixer.

The mass loss of the paddle 2 (where the liquid feed enters the mixer) was approximately 50% less for wear test 1b than test 1a. At this stage in the mixer, the slurry has not been subjected to a lot of shear, so the material will be more viscous at the paddles 1 and 2 than at paddle 26 where it is discharged from the mixer. The flat paddles used in wear test 1a are designed to shear rather than convey material, so the viscous slurry has no directional force to move through the mixer other than additional material supplied by the augers. Therefore, it can be assumed the viscous mixture would reside in that location longer, causing more wear, than it would if a helical (conveying) paddle replaced the flat paddle. For wear test b, it is hypothesized that the viscous mixture is conveyed past the liquid inlet by the helical paddles, reducing the contact time with the paddles, resulting in a lower mass loss. The paddles at paddle 3 had comparable mass loss for both tests. The fourth paddles for wear test 1a had almost no mass loss. For wear test 1a, the fourth paddles showed a greater mass loss relative to paddle 3 for wear test 1b. This is likely because paddle 4 was the transition point from the helical paddle design to the flat paddle design in wear test 1b.

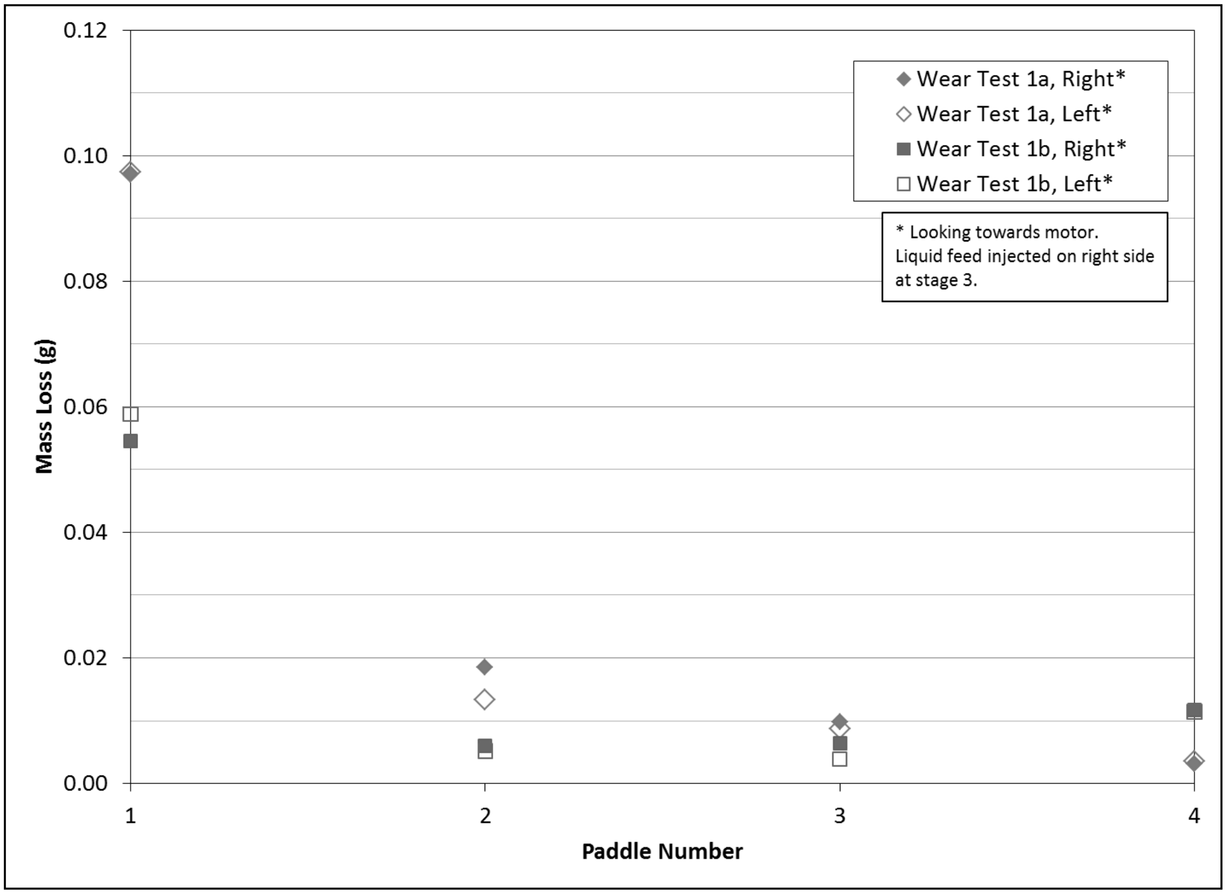

Fig. 4. Mass loss for paddle pairs 1 – 4 after wear testing in the SPF mixer configuration (1a) and the alternate helical paddle configuration (1b).

The wear results are supported by the deformation documented during visual inspection of each paddle after testing. As shown in Fig. 5, the flat paddles become more deformed in the transition region than the helical paddles in the same position.

Mixer Location	Wear Test 1a		Wear Test 1b	
	Left	Right	Left	Right
Paddle 1				
Paddle 2				

Fig. 5. Images of paddles 1 and 2, which had the most mass loss, after completion of wear test 1.

Wear Test 2

The majority of the mass loss occurred in paddle pairs 4 and 5 for the baseline wear test (2a) as well as the alternate helical configuration (2b) (Fig. 6). This is expected based on the wear observed in the “10-inch” SPF mixer. As shown in Fig. 3, the liquid inlet is centered over paddle pairs 5 and 6; however since the liquid wicks back towards the dry feed augers, the transition region occurs where the dry feeds are first wetted over paddle pairs 3 and 4 in the “10-inch” mixer. The flat paddles used in wear test 2a are designed to shear rather than convey material, so the viscous and abrasive grout in the transition region has no directional force to move through the mixer other than additional material supplied by the augers. Therefore, it can be assumed that the viscous mixture imparts more force on the paddles in the transition region, causing more wear on the shearing (flat) paddles than it would if a conveying (helical) paddle replaced the flat paddle due to the inherent design of the paddles (Fig. 1). For wear test 2b, it is hypothesized that the viscous mixture is conveyed through the transition region past the liquid inlet by the helical paddles, reducing the contact force and time with the paddles, resulting in a lower mass loss. The mass loss is presented as a wear rate in Fig. 6 which demonstrates how destructive the thick grout mixture is at paddle pairs 4 and 5 as opposed to the fully wetted grout over paddle pair 6 and the dry feed at paddle pairs 1 - 3. This is supported by the deformation documented during visual inspection of each paddle after testing. As shown in Fig. 6, the flat paddles become more deformed in the transition region than the helical paddles.

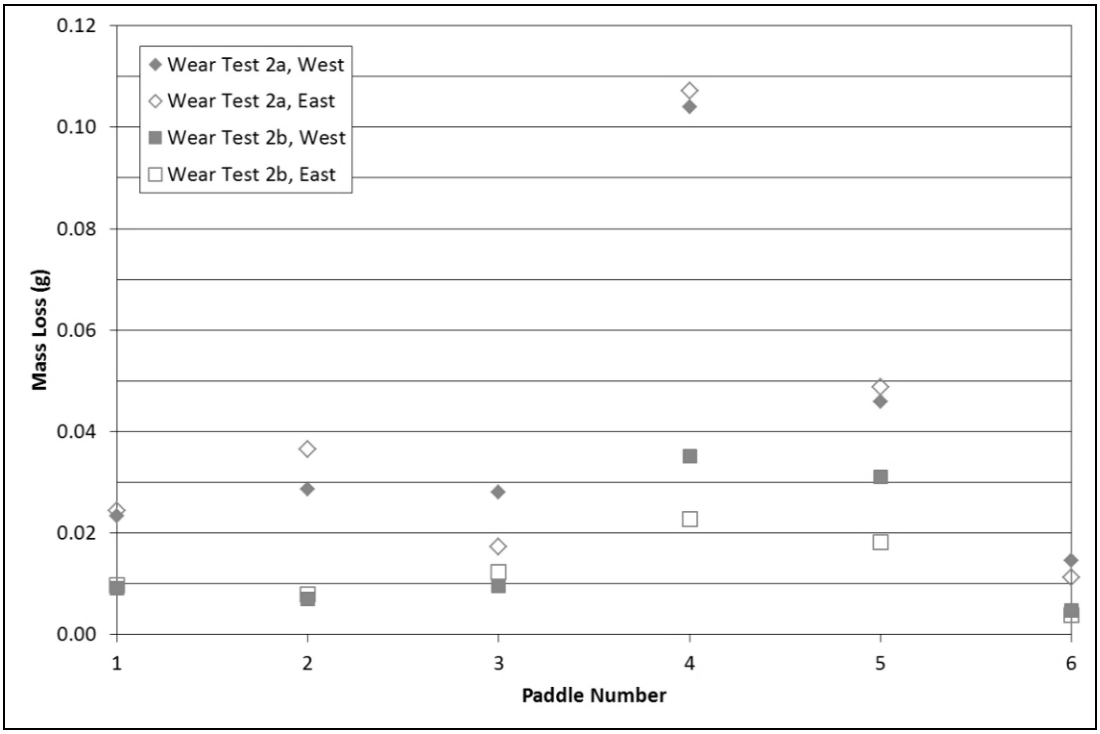

Fig. 6. Mass loss for paddle pairs 1 – 6 after wear testing in the SPF mixer configuration (2a) and the alternate helical paddle configuration (2b).

As shown in Fig. 7, the mass loss and subsequent wear rate on paddle pair 1 is more in wear test 2a than 2b. It is hypothesized that this is primarily due to the misalignment of the helical paddles with the augers in the current saltstone mixer. As demonstrated by this testing, as well as wear test 1, aligning paddle pair 1 in the mixer with the discharge of the feed augers reduces the wear on those paddles [1].

Mixer Location	Wear Test 2a – Flat Paddles		Wear Test 2b – Helical Paddles	
	East	west	East	West
Paddle 4				
Paddle 5				

Fig. 7. Images of paddles 4 and 5, which had the most mass loss, after completion of wear test 2.

CONCLUSIONS AND APPLICATION TO SPF

The Saltstone Production Facility has a “10-inch” Readco-Kurimoto continuous mixer that mixes the premix dry feeds and low-level waste salt solution to make fresh (uncured) saltstone. Inspection of the mixer in March 2011 and January 2013 showed significant wear on paddles immediately after the feed augers. A “2-inch” Readco-Kurimoto continuous mixer at SRNL was used to test alternate paddle configurations for use in the “10-inch” mixer to decrease the wear rate on the paddles. Two wear tests were conducted to investigate a method of reducing wear on the mixer paddles. Both tests used the baseline configuration installed in the SPF at the time of testing (wear test 1a and 2a) as well as the SRNL recommended paddle configuration (wear test 1b and 2b).

A soft metal with low wear resistance (6000 series aluminum) was used for the wear testing paddles to minimize run time while maximizing wear rate. For the paddle configurations tested using the scaled “2-inch” Readco-Kurimoto continuous mixer, with the first four or six paddles after the augers were replaced by the wear paddles and the remaining paddles were stainless steel. The remainder of the “2-inch” mixer was configured to mimic the SPF “10-inch” mixer to the extent possible.

The wear rate from wear tests 1a and 2a were approximately double the wear rate from wear test 1b and 2b for paddle pairs at the transition region. For both tests, there was little or no wear on paddle pairs before and after the transition region, indicating that the un-wetted and fully wetted premix materials cause less wear than the partially wetted premix. Additionally, inspection of the wear surface of the paddles showed more deformation on the flat paddles than the helical paddles which was consistent with the wear rates. Aligning of the auger discharge flight with paddle pair 1 resulted in a lower wear rate paddle pair 1 rather than having them misaligned with the feed augers.

Since the results of these tests have been provided to Savannah River Remediation (SRR) which operates the SPF, the “10-inch” mixer currently installed in the SPF has been retro-fitted with the SRNL recommended paddle configuration from wear test 2b. Processing of grout will begin in January 2015 and SRR engineering will monitor the performance of the mixer for any signs of wear.

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