

On the Suitability of ASTM 532 IIB Cr White Cast Irons for Erosion-Corrosion and Abrasion-Corrosion Applications

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ABSTRACT

In this paper, two commercial Cr white cast irons, conforming to ASTM 532 IIB (15CrMo) and ASTM 532 IIIA (27Cr) respectively, have been studied under slurry jet erosion, Coriolis scouring erosion, slurry sliding abrasion and slurry pot erosion-corrosion conditions. The results show that 15CrMo performs considerably better than the 27Cr counterpart under most of the test conditions but is only slightly better in the erosion-corrosion test. Based on analyses of various components of tribo-corrosion synergy and the testing results, it is suggested that it may be beneficial to more broadly use the 15CrMo white cast irons to replace the ASTM 532 IIIA higher Cr alloy in erosion-corrosion/abrasion-corrosion applications where the intensity of damage due to mechanical effect (pure erosion/abrasion) is severe such as in the handling of thick slurries.

Key words: Cr white cast irons; erosion; erosion-corrosion; abrasion-corrosion; tribo-corrosion; synergistic effect

INTRODUCTION

High chromium (Cr) white cast irons are widely used in oil sands and many mining operations. In slurry handling systems such as slurry pumps and cyclones, ASTM 532 IIIA white cast irons are the most commonly used grade. One of the main considerations for using such higher Cr content in applications involving combined corrosion and erosion or corrosion and abrasion attacks is to offer good corrosion resistance by imparting sufficient amount of Cr in the matrix ($\geq 12\%$). On the other hand, ASTM 532

IIB type of Cr white cast irons (typically 15 CrMo) are widely used in dry abrasion conditions. The microstructures of all of these alloys generally consist of about 25 volume % of hard chromium carbides (M_7C_3 type, ~1500 HV) in a hardened ferrous matrix (600-800 HV). The high abrasion and erosion resistance of Cr white cast irons is derived mainly from the composite microstructure where the hard Cr-carbide is harder than the most common abrasives in mining, silica or quartz, and protects the matrix from severe wear. In the meantime, the matrix provide support to the carbide so that microchipping of the carbide particles is minimized. An ideal microstructure for optimal wear resistance should contain high volume fraction of hard and tough carbide and a strong/hard matrix. Here, “strong matrix” does not simply mean high hardness/strength but rather means that it can withstand the wear attacks under given situations. For example, it may mean that the matrix has both sufficient corrosion and wear resistance when used under combined wear and corrosion conditions. While the compositions and properties of the M_7C_3 carbide in Cr white cast irons may vary to some degree depending on the overall chemical compositions of the alloy, their variabilities are not as broad as possible for the matrix. Thus, improving the wear performance of such materials relies heavily on optimizing the chemistry and physical metallurgy of the matrix.

In ferrous alloys, Cr is an α -phase forming element. High Cr and high Cr/C ratios in the Cr white cast irons tend to reduce the concentration of carbon (C) dissolved in the matrix after heat treatment and thus promote the formation of low carbon martensite. It is known that low carbon martensite generally has less pure abrasion and/or erosion resistance than high carbon martensite. From the extensive testing results obtained in our lab over the past 20 years or so, it has been observed that ASTM 532 IIB white cast irons generally have better abrasion and slurry erosion performance than ASTM 532 IIIA white cast irons in none-corrosive environments [1]. Now that Cr white cast irons containing much less alloying elements also have better wear resistance, a natural question arises: Is it possible to extend their use to substitute the more highly alloyed version in certain erosion-corrosion or abrasion-corrosion conditions? If so, what are the conditions?

To address some of these questions, in this paper, two commercial Cr white cast irons, conforming to ASTM 532 IIB (15CrMo) and ASTM 532 IIIA (27Cr), respectively, have been studied using slurry jet erosion, Coriolis scouring erosion, slurry sliding abrasion and slurry pot erosion-corrosion tests. Conditions under which the substitution of higher Cr alloy can be considered by the lower Cr version of white cast irons will be discussed.

MATERIALS AND TESTING METHODS

2.1 Materials

Two commercial Cr white cast irons have been selected for this study. The material information is provided in Table 1. The 27Cr alloy is a typical Cr white cast iron used in slurry pumps for oil sands applications while the 15CrMo samples were taken from a laminate product where the Cr white cast iron is brazed on a steel backing. Both materials had been heat treated per their respective production conditions by the manufacturers.

Table 1 *Materials used in the study.*

Sample	Material	HRC	Chemical compositions, wt%						
			C	Cr	Ni	Mn	Si	Mo	Fe
27Cr	ASTM 532 IIIA	60.1	2.9	27.2	0.8	0.98	0.54	0.08	Bal
15CrMo	ASTM 532 IIB	64.0	3.6	16.8	0.25	0.67	0.59	1.36	Bal

When plotted over the Fe-Cr-C ternary phase diagram (Figure 1), the compositions of these two studied alloys can be seen to be near-eutectic with almost the same distance to the eutectic line U_1 - U_2 , indicating that they would have similar eutectic carbide volume fractions, although the carbon concentration of the 15CrMo alloy is considerably higher than that in 27Cr.

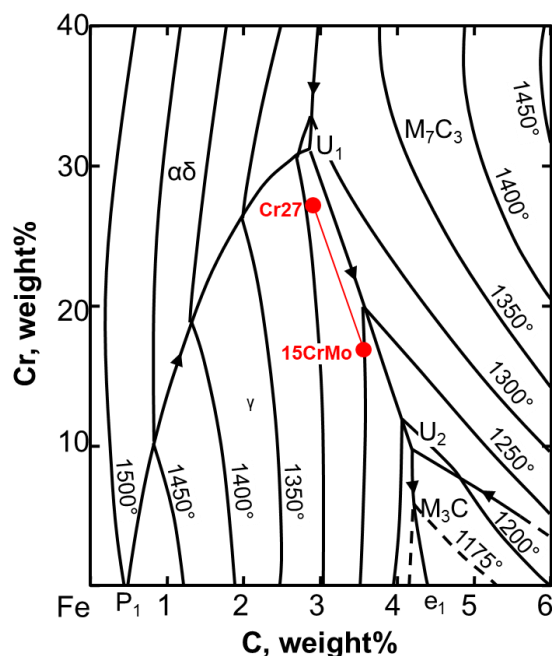


Figure 1: Compositions of the studied alloys plotted on the FeCrC ternary diagram (extracted from reference [2]).

2.2 Test Equipment and Conditions

The two materials have been evaluated under various wear and erosion conditions, including slurry jet erosion, Coriolis slurry erosion, slurry sliding abrasion, slurry pot erosion-corrosion, and slurry sliding abrasion-corrosion. The testing methods and test conditions are highlighted below.

2.2.1 Slurry jet erosion test

Figure 2 shows a schematic diagram of the slurry jet erosion (SJE) tester at the National Research Council Canada (NRC). In the tester, a slurry jet exiting a nozzle impacts the surface of the test specimen to cause erosion. The jet is created by using an air-operated pump circulating the slurry from the slurry reservoir. The test specimen is clamped in a holder which can be adjusted to provide a selected slurry impingement angle. The slurry flow rate is maintained by a computer controlled electronic valve that controls the flow of compressive air driving the pump. The NRC SJE test assesses material resistance to slurry attack at various impingement angles and has been shown to be a convenient and reproducible technique [3, 4].

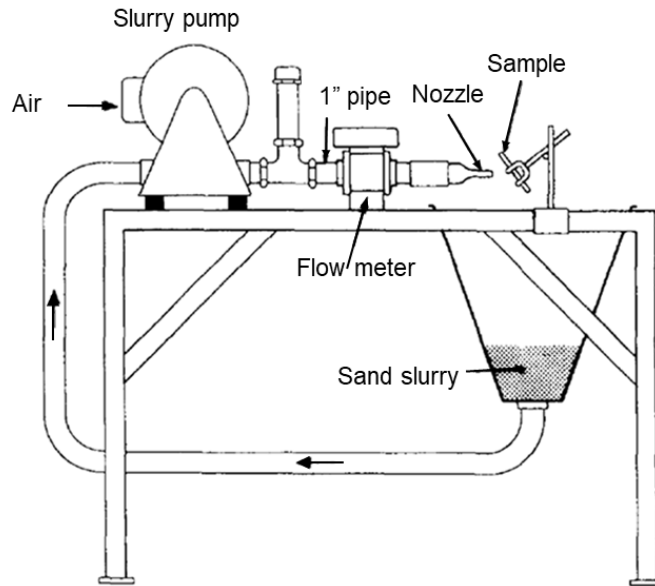


Figure 2: Schematics of the NRC slurry jet erosion test rig.

2.2.2 Coriolis slurry erosion test

The Coriolis slurry erosion tester was first introduced in 1984 [5] and was further developed by NRC [6–8] to allow the use of flat plate specimens and the accurate measurement of the cross-sectional area of the eroded track. The Coriolis erosion method is particularly suitable for evaluating materials involved in handling slurries at locations where solid particles tend to impact the wear surface at a very low impingement angle. The data obtained from Coriolis erosion test have been shown to correlate well with field experience for wear in slurry pumps [9, 10].

The Coriolis erosion test rig (Figure 3) consists of a diametrically grooved rotor, which rotates at a preselected speed. A pre-mixed slurry is fed into the center of the rotor at a controlled constant rate and is then expelled along the two slurry channels/grooves in the rotor under centrifugal force (F_{cent}) and flows over the test specimen surface. During this centrifugal flow, the Coriolis force (F_{cor}) acts to force the slurry against the specimen surface and turbulent flow in the slurry causes the erodent particles to impact on the specimen surface at low impact angles ($<5^\circ$).

In the current study, the rotor speed was 5000 rpm, giving a slurry flow velocity in the range from 14 to 24 m/s across the length of the test specimen surface depending on the distance from the center of rotation. The slurry was 10 wt% AFS 50–70 silica in tap water and the slurry feed rate was 60 ml/s. The slurry was not re-used after exiting the rotor. The wear volume loss was measured using a laser profilometer. A relative erosion resistance (RER) was calculated by dividing the volume loss of annealed 1018 steel reference specimen by the volume loss of the test specimen under the same testing conditions:

$$RER = \frac{\text{Volume loss of 1018 steel}}{\text{Volume loss of test specimen}} \quad (1)$$

The higher the RER number, the more erosion resistant the material is under this test condition.

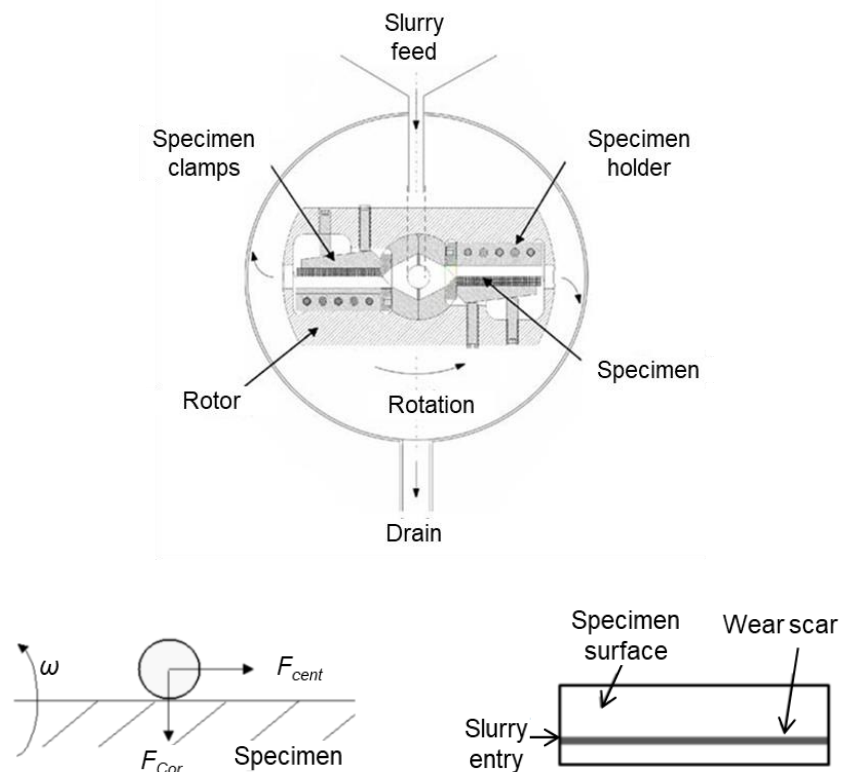


Figure 3: Schematics and principles of the Coriolis erosion test rig.

2.2.3 Slurry sliding abrasion test

A Miller tester (Figure 4) constructed in conformity to the ASTM G75 standard [11] was used to evaluate the slurry abrasion response (SAR) of materials following the ASTM G75 standard procedures. In the test, a wear specimen is loaded against a neoprene rubber lap on the bottom of a slurry bath and slides in a reciprocating motion at a speed of 48 rpm (revolutions per minute). The stroke length of the sliding is 203.2 mm (8"). Three consecutive 2 hr runs are conducted in each test and the cumulative mass loss, M (in mg), as a function of sliding time, t (in hr), is recorded. The SAR number is calculated according to the following expression [11]:

$$SAR = 18.18 \left(\frac{dM}{dt} \Big|_{t=2hr} \right) \left(\frac{7.58}{\rho_{sample}} \right) \quad (2)$$

where ρ_{sample} is the density of the material under investigation.

SAR number is essentially a volume wear rate at 2 hr's sliding. The higher the SAR number, the higher the wear rate of the material is.

For the SAR number test, the slurry used was 50wt% AFS 50-70 silica sand in distilled water.

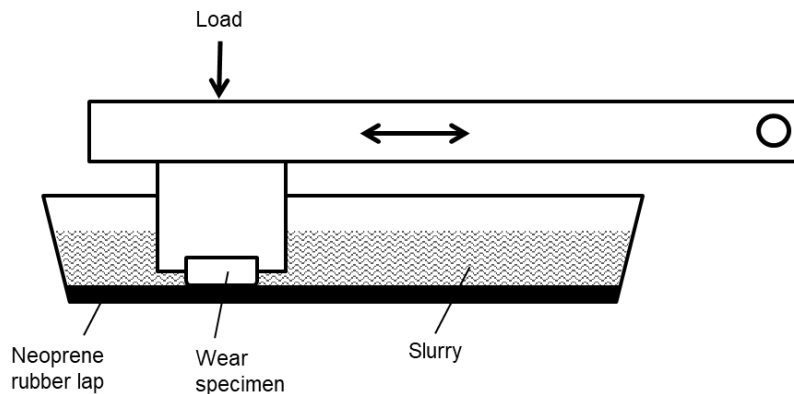


Figure 4: Schematics of the slurry sliding abrasion (Miller) test rig.

2.2.4 Slurry pot erosion-corrosion (SPEC) test

The erosion-corrosion synergy was studied in a slurry pot erosion–corrosion (SPEC) test system. The setup of the tester is shown in Figure 5. The main components of the unit consist of a 4 L glass vessel, neoprene-lined impeller which is rotated to impel the slurry against the static test surfaces, heating/cooling system and a Gamry PC4/750 potentiostat for electrochemical and erosion-corrosion synergistic analysis.

The test specimen has a test surface area of 18 mm × 10 mm which was polished to 1 µm diamond suspension prior to the experiments. All specimens were mounted in epoxy, leaving only the test surface exposed to the testing environment. An electrical contact was attached to the specimen requiring electrochemical assessment/control before embedding in epoxy. Temperature is an important factor affecting corrosion and also erosion-corrosion processes and is controlled by using a water bath surrounding the slurry pot.

The test conditions for erosion–corrosion assessment are as follows.

- Slurry composition: 35 wt% 16-30 mesh Filter (silica) sand + 3.5 wt% NaCl solution
- Slurry temperature: 45 °C
- Impeller rotation speed: 900 rpm
- Test duration: 6 hr

The erodent impact velocity at the 900 rpm impeller rotation speed was in the range of 0.8-2.8 m/s as measured using 20-25 mesh glass beads and annealed pure copper following a technique described in [14, 15].

Distilled water was used for preparing the 3.5% NaCl solution in making the slurries and was left in open air for at least 24 hr before being used. Test was conducted at 45°C because this is the most typical slurry temperature in the Canadian oil sands operations (tailings and hydrotransportation).