MgO-C REFRACTORIES FOR STEEL LADLES SLAG LINE

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ABSTRACT

The current results of laboratory tests used for characterizing four MgO-C ladle slag line bricks from different suppliers are presented and discussed. Combining the laboratory results with the industrial performance helped to define a criterion for the selection of refractories for steel ladles. The results indicated, for the evaluated conditions, that the thermomechanical behavior is one of the most important characteristics to enhance the industrial performance for slag line lining.

The selection criteria of MgO-C bricks for ladle lining can also be a valuable tool for the development of novel products, taking into account the particular aspects of each steelmaking plant.

I. INTRODUCTION

Usiminas Steel Plant No. 2 holds 20 ladles with a capacity of 160 t per unit, lined with MgO-C bricks in the slag line (152 mm), Al_2O_3-MgO-C bricks in the barrel area (152 mm) and Al_2O_3-C bricks at the bottom (229 mm).

Since the late '90s, Usiminas steelworks has intensified efforts to increase the life of steel ladle lining. The main focus has been on MgO-C bricks for slag line which represents a critical region in terms of performance. The outcome of this improvement can be split in three potential benefits: (i) wear uniformity and reduction of refractories consumption, (ii) increase of the operational availability of the ladles, and (iii) maintenance of the steel quality.

In this context, Usiminas developed a laboratorial characterization schedule for four MgO-C bricks from different suppliers, in order to establish a criterion for selecting refractories for steel ladles. Although, resin bonded MgO-C is the most common brick for ladle slag line in Brazil, two of the studied bricks were pitch bonded.

The correlation between the laboratory and industrial performance defined the most important parameters when selecting MgO-C for steel ladles.

II. EXPERIMENTAL PROCEDURES

The samples for physical and chemical properties were taken out of four commercial MgO-C bricks denominated MC1-MC4. Compositions MC3 and MC4 are resin bonded, whereas the others are pitch bonded materials. The x-ray diffraction and microstructural characterization were carried out on samples coked at 500°C for 5 h. The apparent porosity was obtained on cylindrical sample (50 mm x 50 mm) coked at 800°C, 1200°C and 1400°C for 5 h. The samples were vacuum saturated with kerosene for these measurements. Oxidation resistance tests were carried out at 1400°C for 30 min in samples (25 mm in diameter x 40 mm in height) coked at 1400°C for 5 h. The tests were performed in a tubular electrical furnace where a holding device promoted rotary and translation movements in the samples. The oxidation index was measured by the ratio between the final and initial carbon content [1]. Three point flexural strength was measured on 25 mm x 25 mm x 150 mm bars under nitrogen atmosphere at 800°C, 1200°C, 1400°C and 1500°C. The samples were kept at testing temperature for 30 min before loading application. Rotary slag tests were carried out on samples measuring (88 mm; 68 mm) x 30 mm x 190 mm at 1650°C for 6 h. The slag composition is presented in **Table 1**. The corrosion index was determined by the ratio between the cross section area after and before testing.

Table 1. Chemical composition of slag (wt.%)

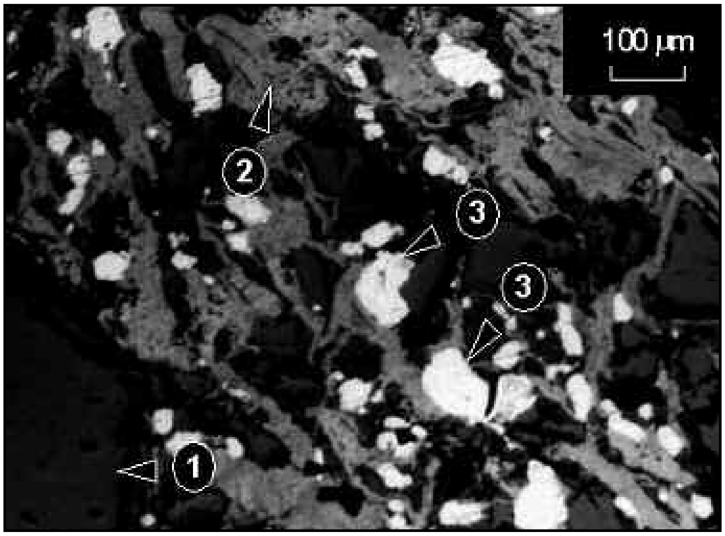
CaO	SiO_2	Al_2O_3	MgO	MnO	Fe_2O_3
45.30	6.19	34.50	6.77	0.80	4.12

Thermal shock testing was carried out in an induction furnace at 1560°C. A prismatic sample (40 mm x 40 mm x 160 mm) was partly immersed in the steel and maintained at testing temperature for 60s. Following, the sample was cooled in water for 15s and then in air. The thermal cycling (heating and cooling) was repeated three times. Thermal shock damage was evaluated by the size and number of cracks generated in the samples. The tests were performed based on technique developed by Ichikawa et al.[2]. A damage scale between 1 (lower damage) and 5 (higher damage) was set for comparison purposes.

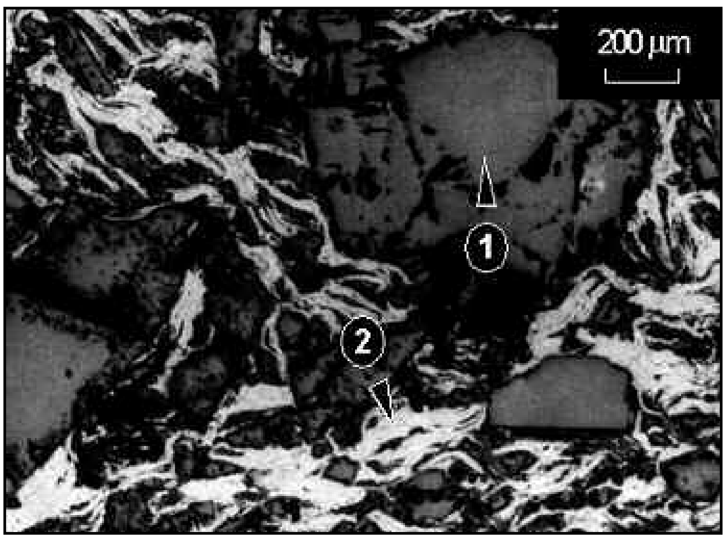
III. RESULTS AND DISCUSSION

The x-ray diffraction results indicated the presence of periclase and graphite in all the samples, nevertheless Al was only present in compositions MC1 and MC3 (**Figure 1a**). In addition, other metallic antioxidants were not observed in bricks MC2 and MC4 (**Figure 1b**) when analyzed by optical microscopy.

The apparent porosity was substantially influenced by the coking temperature mainly for compositions MC2 and MC4 which were Al-free (**Figure 2**). No variation in the apparent porosity of the bricks MC1 and MC3 between 1200°C and 1400°C was verified, suggesting the presence of reaction products associated with Al. According to Yamaguchi et al.[3], $Al_2O_{3(s)}$ and $C_{(s)}$ (**Equation 1**),



a)



b)

Figure 1 Photomicrographs of the samples MC3 (a) and MC4 (b) after coking at 500°C for 5 h: MgO (1), graphite (2) and Al (3).

as condensed phases, resulting of different reactions involving Al, can fill the open pores and thus reducing the apparent porosity.

$$2Al_{(g)} + 3CO_{(g)} \Leftrightarrow Al_2O_{3(s)} + 3C_{(s)} \qquad (1)$$

The combination of the oxidation index with the carbon loss at 1400°C (**Table 2**) was an important aspect to understand the oxidation resistance behavior.

These results showed that the oxidation index values of the bricks MC2 and MC4 are quite similar. However, they differ in terms of absolute carbon loss value at 1400°C. The structural degradation due to oxidation, such as the increase of porosity and decrease of mechanical strength, was superior in brick MC4, which holds higher apparent porosity than the MC2. According to Aneziris et al.[4], the isotropic phase of the coke residue resulted by the resin bond-

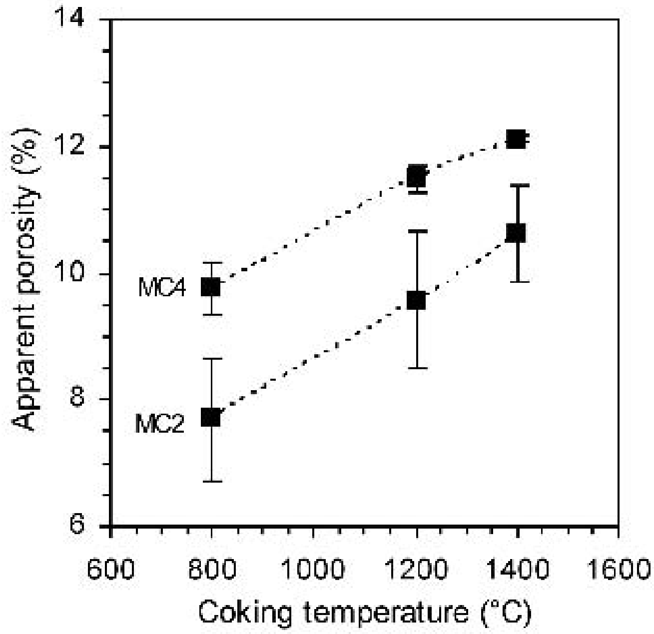


Figure 2a. Apparent porosity as a function of coking temperature.

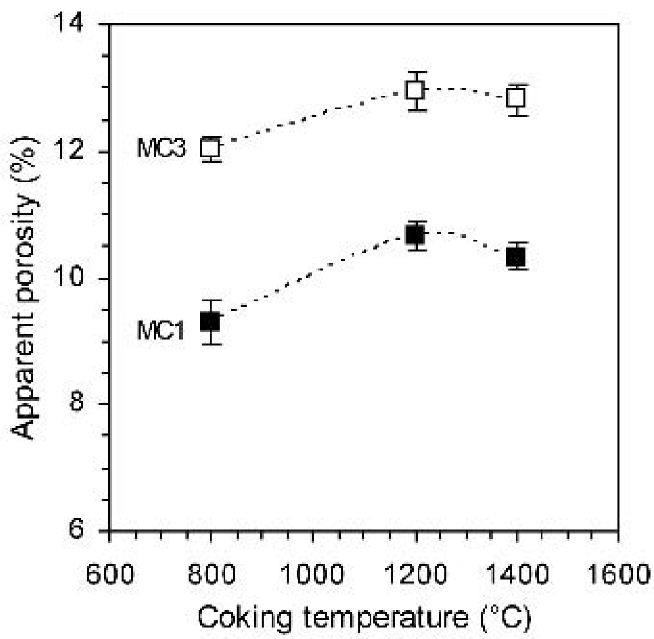


Figure 2b. Apparent porosity as a function of coking temperature.

Table 2. Carbon loss and oxidation index at 1400°C after 30 min in air

Bricks	Carbon (Initial)	Carbon loss (1400°C)	Oxidation index (1400°C)
	(wt.%)		(%)
MC1	11.8	8.6	73
MC2	11.0	8.5	77
MC3	13.8	8.5	62
MC4	14.1	11.0	78

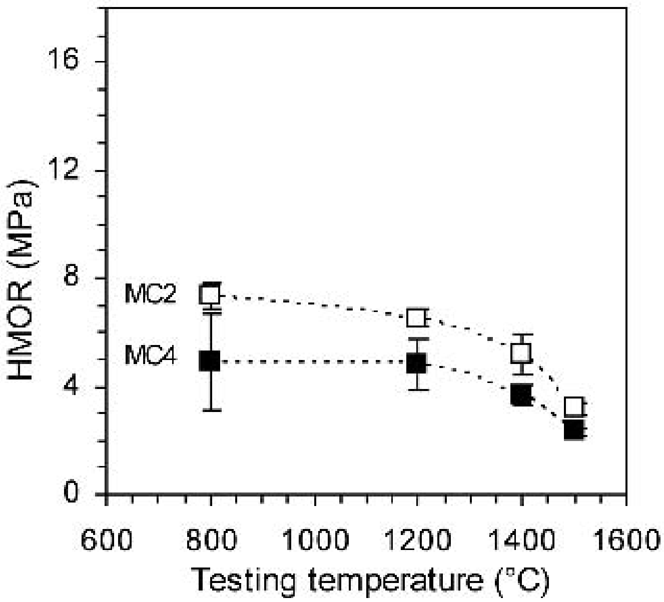


Figure 3a. Hot modulus of rupture (HMOR)..

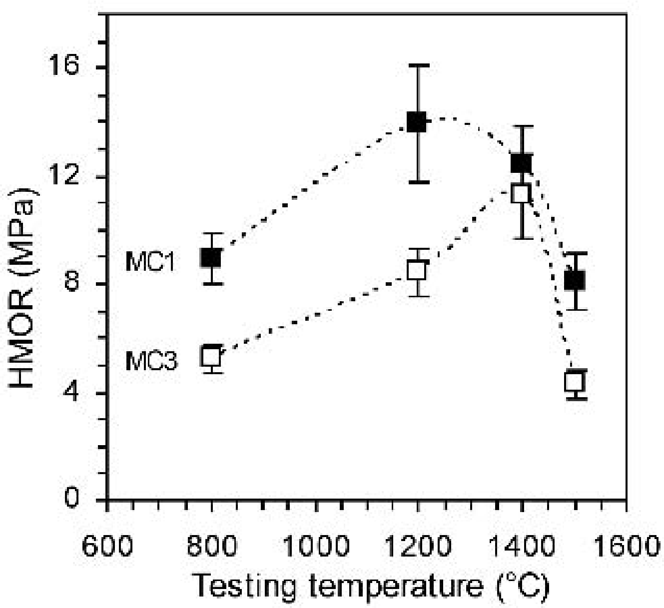


Figure 3b. Hot modulus of rupture (HMOR).

ed refractory leads to a higher likelihood to oxidation and thermomechanical stress.

Distinct behaviors in terms of flexural strength at high temperature (**Figure 3**) were verified. As a general trend, the strength of the bricks containing Al (MC1 and MC3) increased up to approximately 1400°C, but then dropped sharply at 1500°C. Additionally, a lower strength of the Al-free bricks (MC2 and MC4) and a mechanical strength decrease above 1200°C were observed. These results match with the literature [5], which points out that metallic

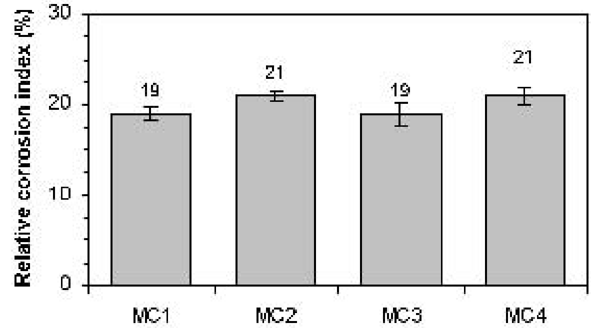


Figure 4. Relative corrosion index of the MgO-C bricks.

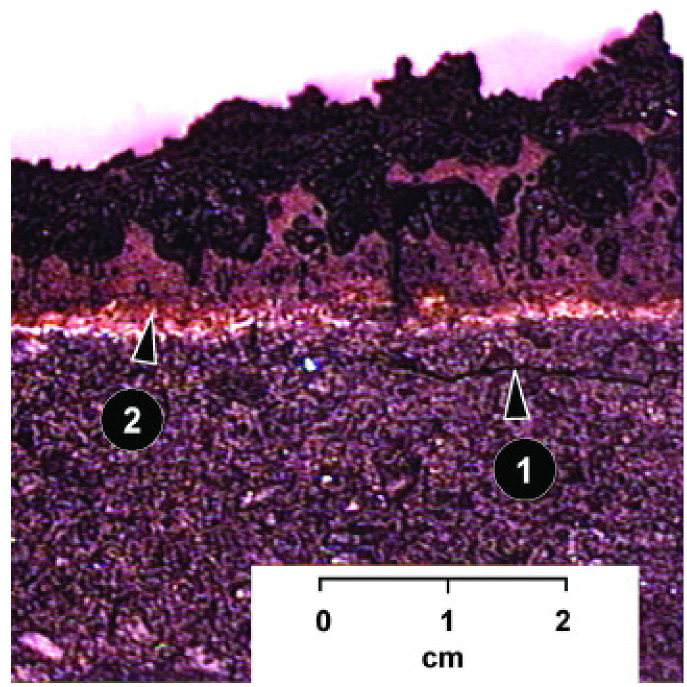


Figure 5. Cross section of the brick MC1 after slag corrosion test: crack (1) and slag (2).

antioxidants can improve the mechanical strength of MgO-C refractories.

Although these bricks were designed taking into account different concepts and approaches, the slag corrosion indexes were similar (**Figure 4**). For brick MC1, cracks parallel to the hot face were observed in samples just after slag testing (**Figure 5**). In addition, expansion and crack generation in compositions MC1 and MC3 after slag testing and laboratory environment exposure for four days were observed. The effect was attributed to $Al_4C_{3(s)}$ hydration as point out in the literature [6].

According to Evans et al. [7], the main factors that contribute to lining thermal stress are the preheating practice, the thermal cycling and the ladle shell and lining design (**Figure 6**). Generally,

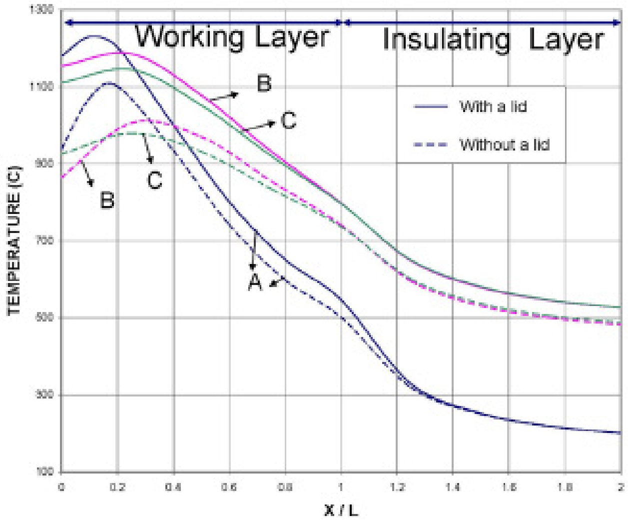


Figure 6. Usiminas' ladle showing the deformation in the radial direction.

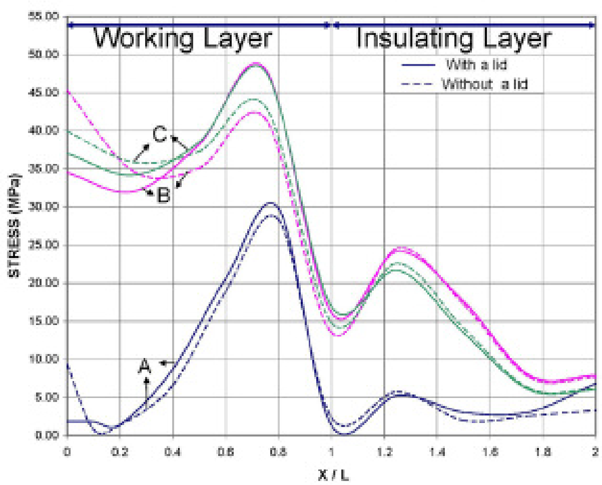


Figure 7. Longitudinal cross section of samples after thermal spalling test: metal infiltration (1).

carbon containing refractories are selected taking into account its high thermal conductivity and low thermal expansion in order to undergo to the thermal cycling.

Evaluating the thermal shock performance of the slag line bricks it is not an easy task, because of carbon oxidation and their excellent thermal spalling resistance. Ichikawa et al. [2] developed an appropriate evaluation method that has allowed a better understanding of the thermal shock behavior of these compositions. **Figure 7** presents the longitudinal cross section of brick samples after thermal spalling test. The paths of the cracks were highlighted by a stereoscope and image analysis.

Bricks MC2 and MC4 showed inferior thermal spalling damage, whereas MC1 and MC3 presented greater damage by thermal spalling.

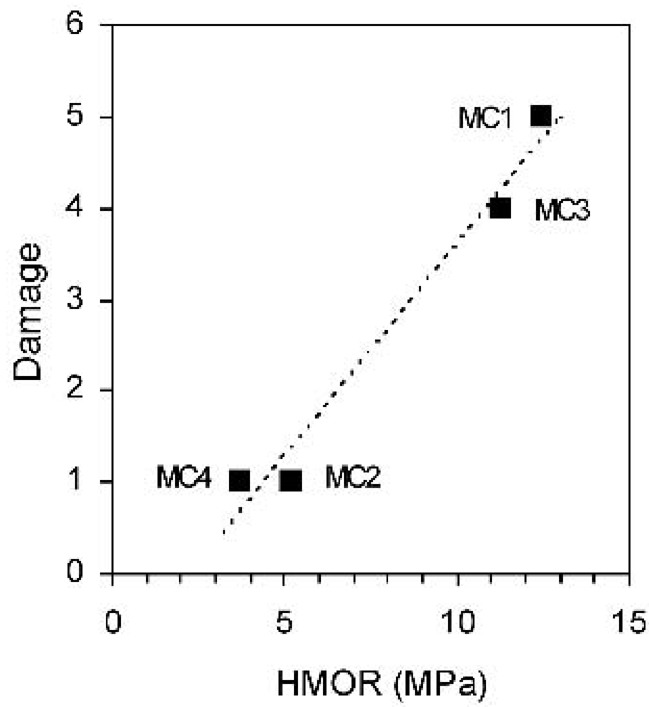


Figure 8. Behavior of the thermal shock resistance as a function of the HMOR (1400°C).

According to Hasselman's [8] thermal shock theory, the driving force for crack propagation is proportional to the stored elastic energy in the body at onset of fracture. Therefore, refractory materials with high thermal shock resistance present high values of fracture energy (γ_{wof}) and low values of stored elastic energy at fracture. Elastic energy at fracture initiation is dictated by the σ^2/E ratio [9]. Because of the difficulties of evaluating γ_{wof} of carbon containing refractories at high temperature in controlled atmosphere, in this study only the correlation between thermal shock damage and flexural strength at 1400°C was considered (**Figure 8**). This temperature is usually associated to isotherms verified behind the hot face.

IV. INDUSTRIAL RESULTS

Assuming as performance index the specific consumption of refractories, MC2 lining has shown superior performance, followed by MC1, MC3 and MC4.

Considering the traditional evaluation method for this class of materials, based on mechanical strength, oxidation, and corrosion, brick MC2 would not be the best material for slag line of steel ladle. In such case, why has this composition presented superior industrial performance? Combining the laboratory tests results provided a better understanding of this question. The results indicated that, if slag corrosion resistance and oxidation resistance requirements are fulfilled, the superior spalling resistance and low mechanical strength at high temperature could be the key properties.

In principle, thermal stress and mechanical stress (from shell deformation) could be better dissipated by the refractories with those characteristics. On the other hand, brick MC4 showed high thermal shock resistance and low HMOR, although, the carbon oxidation of this composition was pronounced in laboratory and industrial trials (**Figure 9**),

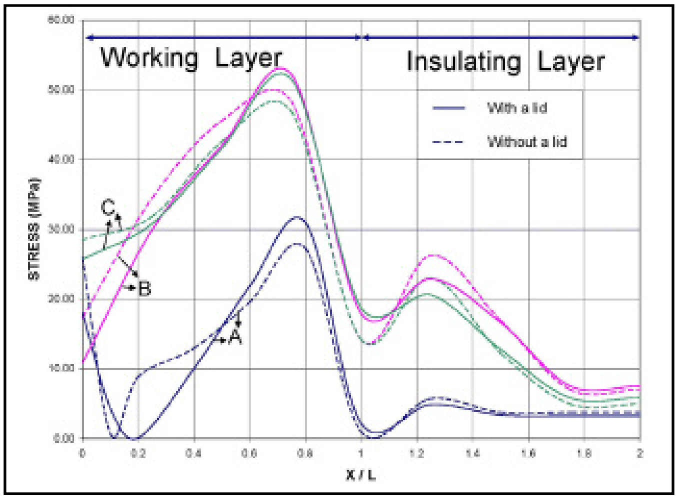


Figure 9. Photograph of the slag line lining after 80 heats showing the carbon oxidation of the brick MC4.

Figure 10. Photograph of the slag line lining (MC2) after 107 heats.

which affected its performance. The degradation caused by decarburization was lower in the brick MC2 (**Figure 10**).

In addition, the performance of the bricks MC1 and MC3 was also influenced by crack formation behind the hot face.

V. CONCLUSION

Associating the laboratory evaluations and the industrial testing resulted in a better criterion for selecting MgO-C bricks for steel ladle slag line. In general, for the studied conditions, it was observed that the resistance to mechanical and thermal stresses is one of the most important characteristics for refractory lining designing. The superior performance at industrial scale of brick MC2 it is believed to be associated to its high thermal shock resistance and low mechanical strength at high temperature, which resulted in a more compliant structure. Additionally, this composition presented an acceptable oxidation and slag corrosion resistance.

VI. ACKNOWLEDGMENTS

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Correction

In my July/August RA News article about China, in the 1983 and 2005 photos of the Pudong area of Shanghai (pg. 6), I incorrectly identified the river as the Yangtze. Gordon Snyder of Bricmont has noted that the correct name of the river is the Huangpu.