AVALIAÇÃO DAS PROPRIEDADES DE REDUÇÃO-DEGRADAÇÃO E DE AMOLECIMENTO E FUSÃO DA CARGA USADA NO AF2 DA TERNIUM ARGENTINA*

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Resumo

Durante 2017, a operação do AF#2 da Ternium Argentina exigiu alterações da basicidade binária em uma ampla faixa entre 2.0 a 2.7 e no teor de MgO. Esta faixa de trabalho motivou o estudo das propriedades metalúrgicas do sinter e sua interação com outros componentes materiais da carga do Alto-Forno. Além disso, foi testado e analisado a influência de duas qualidades diferentes de granulado. Para entender os efeitos da composição química, um conjunto de testes de redução-desintegração foram desenvolvidos. Aliando com perfis isotérmicos (ISO 4696-1), perfis variáveis de temperatura e composição de gás, com intuito de simular a redução no AF. As propriedades sob alta temperatura também foram avaliadas por meio de ensaios de amolecimento e fusão, compondo a carga sinter, pelota e minério granulado. Utilizando amostras de sinter de diferentes basicidades e teores de MgO. Os resultados obtidos e sua influência no comportamento dos altos-fornos são analisados no presente trabalho.

Palavras-chave: sinterização, alto-forno, amolecimento.

EVALUATION OF REDUCTION-DEGRADATION AND SOFTENING-MELTING PROPERTIES OF BURDEN USED AT TERNIUM ARGENTINA BF2

Abstract

During 2017 Ternium Argentina BF#2 operation required changes in binary slag basicity in a wide range between 2.0 to 2.7 and in the MgO content. This working range motivated the study of the metallurgical properties of sinter and its interaction with other components of blast furnace iron burden materials.

Also, it was tested and analized the influence of two different lump ore qualities.

In order to understand the effects of chemical composition, a set of reduction-desintegration tests were designed, with isothermal profiles (ISO 4696-1) and variable temperature and gas composition profiles. Properties at high temperature were also evaluated through softening-melting point tests, over sinter, pellet and lump ore mixtures, using sinter samples of different basicity and MgO content.

Test results and their influence on the blast furnace behavior are analyzed in the present paper.

Keywords: sinter, blast furnace, softening

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1 INTRODUCTION

The fines generated by the ferrous raw materials during reduction in the upper part of the blast furnace have a significant effect on its permeability and as a consequence, on fuel consumption and productivity.

Sinter and lump ore are the principal contributors to the generation of these fines because of their physical and metallurgical properties.
On the other hand, as the burden descends, it increases its temperature until it reaches the softening and melting point, generating an area of greater resistance to the gas flow. This area, called cohesive zone, depends on the chemical composition of the raw materials and their interaction, among other properties.

This paper seeks to deepen the knowledge on the influence of chemical composition of sinter over the fines generation after reduction at low (550 ºC) and high (900 ºC) temperature, as well as during the softening and melting process in order to help choosing the right basicity index. In addition, two qualities of lump ore with different chemical composition were evaluated as a part of the mixture.

In the literature, it is concluded based on laboratory tests that the behaviour of sinter melting can be improved with mixing with pellet or lump (1). Most researchers investigated the metallurgical properties of sinter and pellets individually and mixtures with different proportions. A few researchers have included lump ore in their investigation in order to be evaluated individually (2) and mixed with sinter (3). Also previous studies (4) have tried to understand the influence of increasing lump ore and sinter participation in the burden, but not the influence of different lump ore qualities.
Mixtures used in these papers differ in material proportions and quality with the iron burden used at Ternium Argentina BF2. In the present work, the influence of sinter basicity together with high lump ore participation were tested, taking in consideration that present day lump ore qualities differ from those used in the past.

2 DEVELOPMENT

2.1 Samples: Mixtures design

Four mixtures were evaluated, consisting of five raw materials: one pellet, two lump ores (A and B) and three sinter qualities (BI2 1.7, 2.0 and 2.7) which were produced at Ternium Argentina pilot scale plant. The proportion of each raw material is constant, 23 % pellet, 39 % lump and 38 % sinter, varying the chemical composition of the sinter and the lump ore, as shown in table 1. The design of the mixtures was based on ferrous burden used at Ternium Argentina Blast Furnace 2.

Table 1. Mixtures

	Pellet	Sinter			Lump	
		BI 1.7	BI 2.0	BI 2.7	A	B
Mix 1	x	x			x	
Mix 2	x		x		x	
Mix 3	x			x	x	
Mix 4	x		x			x

• Mixtures 1, 2 and 3 were designed to evaluate the influence of the sinter binary basicity (%CaO / % SiO_2): 1.7; 2.0 and 2.7, respectively.
• Mixtures 2 and 4 were designed to evaluate the influence of the lump chemical composition: A and B.

The chemical compositions of the individual materials are detailed in Table 2.

Table 2. Pellet and **lump ore** chemical composition

	Fe(%)	CaO(%)	MgO(%)	SiO2 (%)	Al2O3 (%)
Pellet	66,1	2.29	0.06	2.35	0.41
Lump A	66,0	-	-	3.29	1.03
Lump B	66,1	-	-	5.82	1.00
Sinter 1.7	55.3	10.50	1.70	6.20	1.90
Sinter 2.0	53.2	12.50	2.30	6.20	1.90
Sinter 2.7	48.7	16.80	2.70	6.20	1.90

2.2. Methodology

In order to evaluate the fines generation after reduction, two different methodologies of reduction were used.

2.2.1. Methodology 1. Reduction using fixed gas temperature and composition.
Based on ISO 4696-2: Iron ores for blast furnace feedstocks - Determination of low-temperature reduction-disintegration indices by static method - Part 2: Reduction with CO and N_2.

The raw materials mix was reduced at 550ºC, for 30 minutes, in a reducing atmosphere (70% N_2 + 30% CO).

2.2.2 Methodology 2. Reduction with variable profiles of temperature and gas composition.
The different mixtures in the oxide state were reduced with variable gas temperatures and compositions, shown in table 3.

Table 3. Reduction conditions, Method 2.

time (min)	Temperature (°C)	N_2 (%)	CO (%)	CO_2 (%)
30	500-700	60	20	20
30	700-900	60	30	10
60	900	60	30	10
15	900-1000	60	40	0
45	1000	60	40	0

The reactor used in both methodologies is described in ISO 4696.

The mixtures reduced under both methodologies are subjected to the action of a micro-drum (also described in ISO 4696). They are rolled for 30 minutes at 30 rpm. After that, the reduced material is sieved to evaluate the fines generated.

The properties at high temperature are evaluated by softening, melting and percolation test. This test consists of placing the previously reduced mixture according to methodology 2, table 3, between two layers of coke, in a graphite reactor. A sample of 500 g of mixture is heated up to 1600 ºC, with a nitrogen flow. Figure 1.

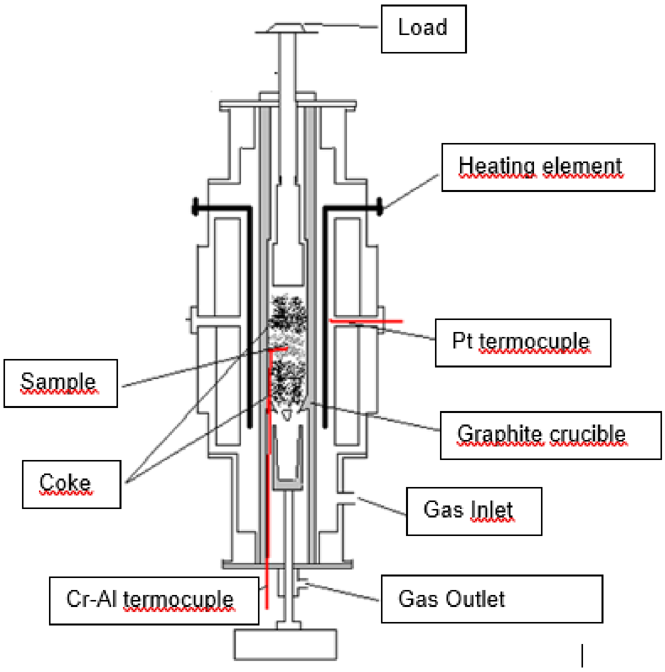

Figure 1. Softening, melting and percolation equipment.

As the temperature is increased, different parameters are recorded: pressure, percolated material, (collected in a graphite cup in the bottom of the crucible, over a scale) and the contraction of the mixture.
Figure 2 shows a typical curve obtained from the parameters recorded during the test. Table 4 explains the obtained test results.

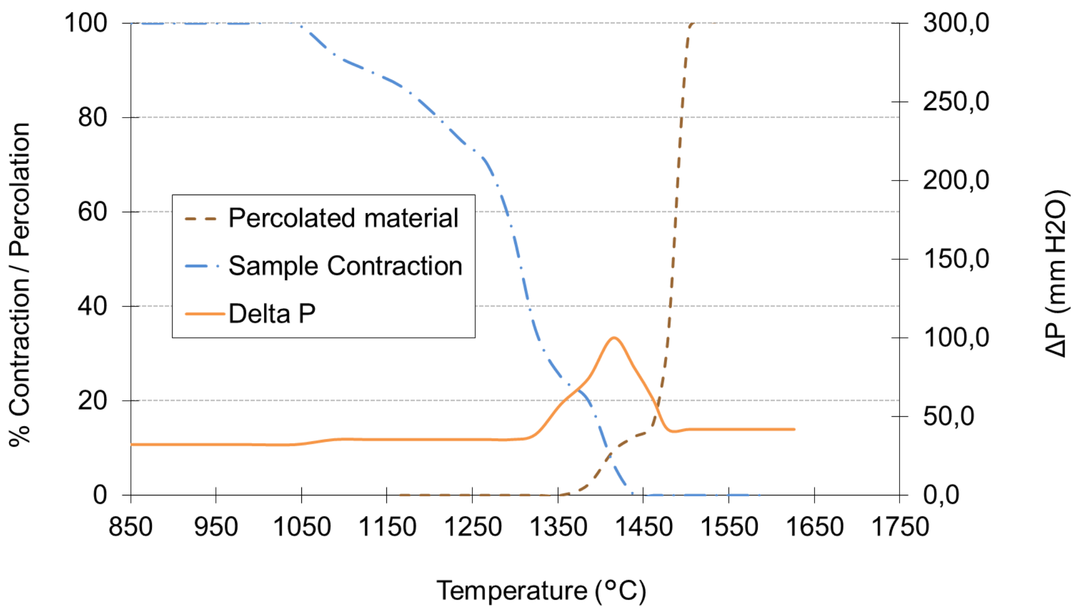

Figure 2. Pressure, Sample contraction, and Residual material during the test.

Table 4. Softening, Melting and Percolation Results.

TS	Beginning of the cohesive zone: sudden increase in the delta P curve.
TP max.	Temperature at maximum pressure drop.
TC100	Temperature at 100% contraction
TID	Temperature at percolation beginning (1 % of percolation)
TC100 – TS	Cohesive zone range
P max.	Maximum pressure drop
MR1600	Non-percolated material at 1600 ºC
RI	Indirect reduction percentage
PC	Delta P/ contraction rate at TP max.

2.3. Results

2.3.1. Fines generation after reduction

Tables 5 and 6 show the results of the fines generation after reduction at low and high temperature.

Table 5. Fines generation according to Methodology 1.

time (min)	Mix 1	Mix 2	Mix 3	Mix 4
% <6,3 mm	34,2	31,5	23,8	36,8
% < 2,83 mm	14,4	14,0	11,0	17,0
% < 0,5 mm	5,0	4,6	3,9	6,0

Table 6. Fines generation according to Methodology 2.

time (min)	Mix 1	Mix 2	Mix 3	Mix 4
% <6,3 mm	33,5	26,5	23,7	31,0
% < 2,83 mm	14,8	11,3	10,8	13,9
% < 0,5 mm	5,0	4,3	4,9	4,9

2.3.2. Softening, melting and percolation results.

Table 7 shows the results of the softening, melting and percolation test.

Table 7. Softening, Melting and Percolation Results.

	Mix 1	Mix 2	Mix 3	Mix 4
TS	1339	1295	1340	1305
TP máx.	1407	1395	1418	1382
TC100	1445	1443	1517	1426
TID	1377	1389	1419	1382
TC100 - TS	107	148	178	121
P máx.	65	104	90	109
MR1600	0	9,0	18	8
RI	57	56	56	55
PC	1	1,2	1,1	1,3

2.3. Discussion

It is observed that the increase of sinter basicity causes a decrease in the degradation of the reduced sample at low and high temperature. Figure 3 shows this tendency for fines <6.3 and <2.8 mm, for both analyzed methodologies.

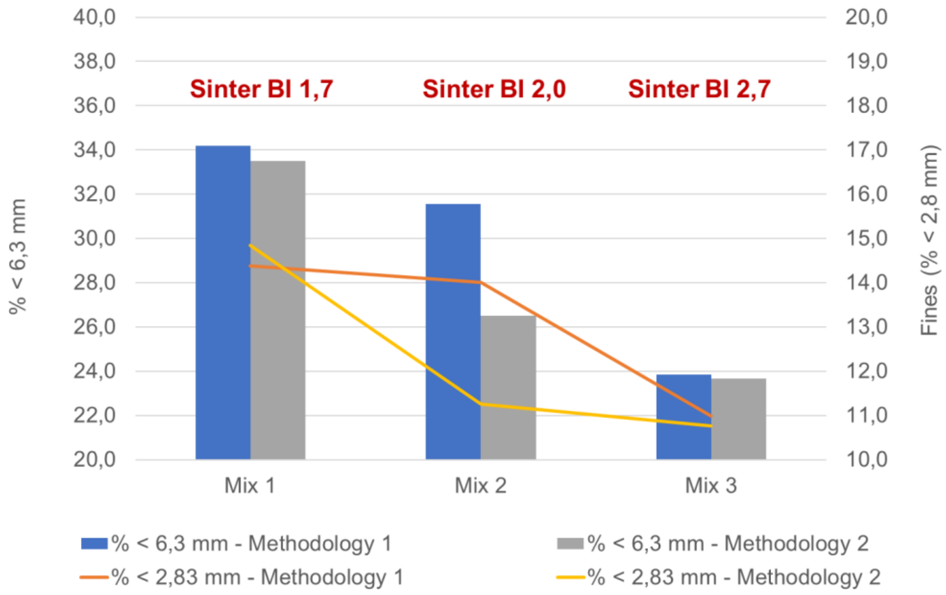

Figure 3. Mixtures disintegration vs Sinter basicity.

The mixture that includes Lump Ore B, with higher silica content, generates more fines, as obtained by both methodologies. Figure 4.

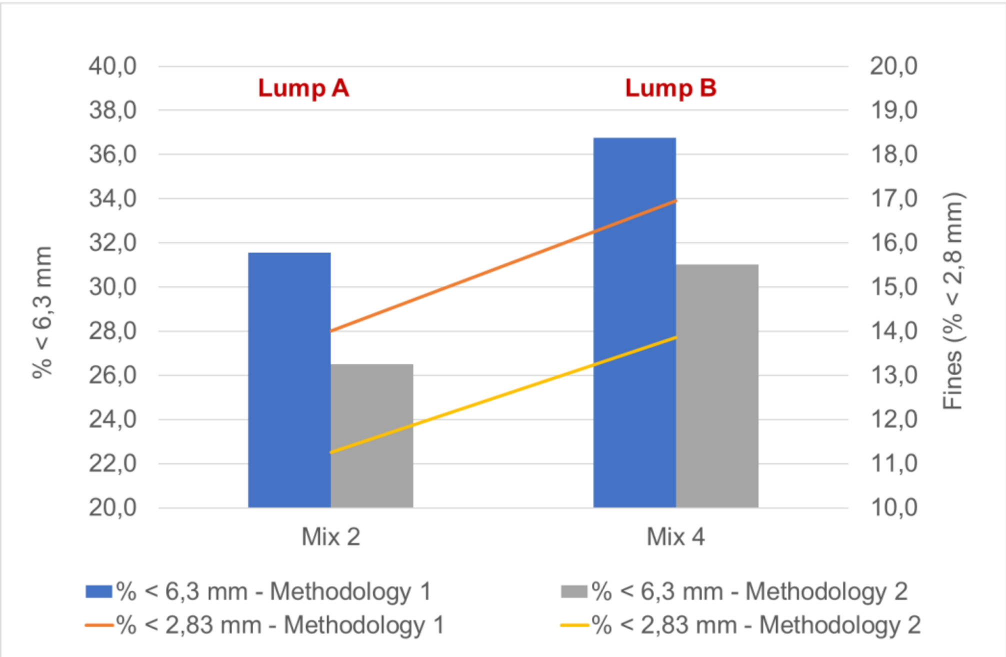

Figure 4. Mixtures disintegration vs Lump quality.

As the basicity of the sinter increases, it is observed an increase of the low permeability zone and unmelted material at 1600 ºC. Figure 5.

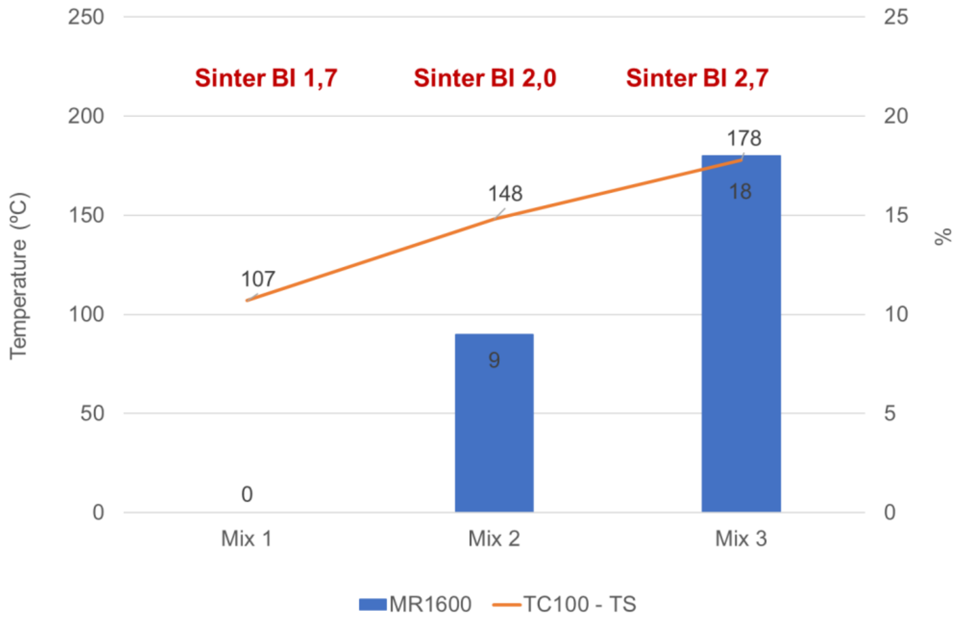

Figure 5. High temperatures properties vs sinter basicity.

In previous high temperature studies over sinter samples individually analysed, the same trend was observed, Table 8.

Tabla 8. Softening, melting and percolation results on sinter samples.

	TC100 - TS (ºC)	MR1600 ºC (%)
Sinter IB 2.0	123	39.2
Sinter IB 2.5	>345	79
Sinter IB 3.0	>350	85

Comparing the results of the mixtures and of the sinter samples evaluated individually, the beneficial interaction between the different materials of the burden that benefit the melting conditions is evidenced by decreasing the thickness of the low permeability zone and the remaining material at 1600 ºC.

The use of Lump Ore B in the mixtures decreases the thickness of the low permeability zone. No appreciable differences were observed in the remaining material at 1600 ºC, Figure 6.

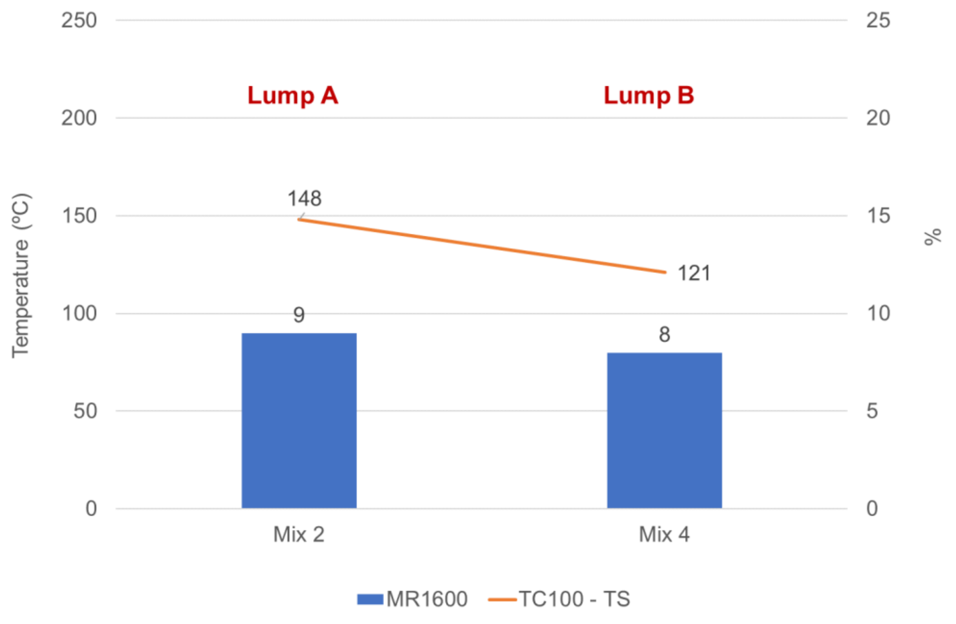

Figure 6. Effect of lump **ore** on high temperature properties.

The smaller thickness of the cohesive zone and the tendency to less non-percolated material in Lump Ore B is related to the higher SiO2 content in this material that favors the formation of more fluid slag with better percolation.
An increase of the sinter basicity, decreases the amount of fines generated after reduction due to less degradation of the mixture because of a higher slag volume. However, the thickness of the cohesive zone and the remaining material increases because of deterioration of softening-melting properties. As observed in Figure 7, there could be a sinter basicity index value in which a balance between both effects could optimize the design of the burden and therefore improve blast furnace operation.

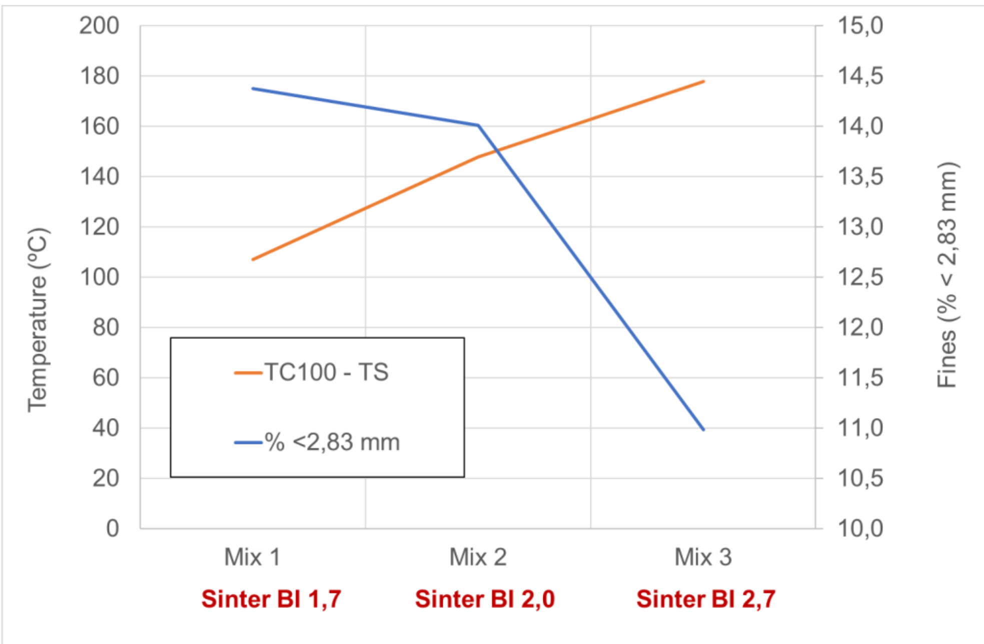

Figure 7. Effect of sinter basicity on degradation and high temperature properties

In figure 8, it is shown the relationship between RDI and BI using actual industrial plant results in a period of 2.5 years. In secondary axes the Laboratory results for Softening-melting tests were added to represent the thickness of cohesive zone. It is observed that reducing BI below 2 could reduce the lower permeability zone but would increase RDI. At present, Ternium Argentina Sinter basicity target has been varied between 2.1 to 2.2, a decision that involved these results and final BF slag composition targets, considering fluxes consumption at the BF.

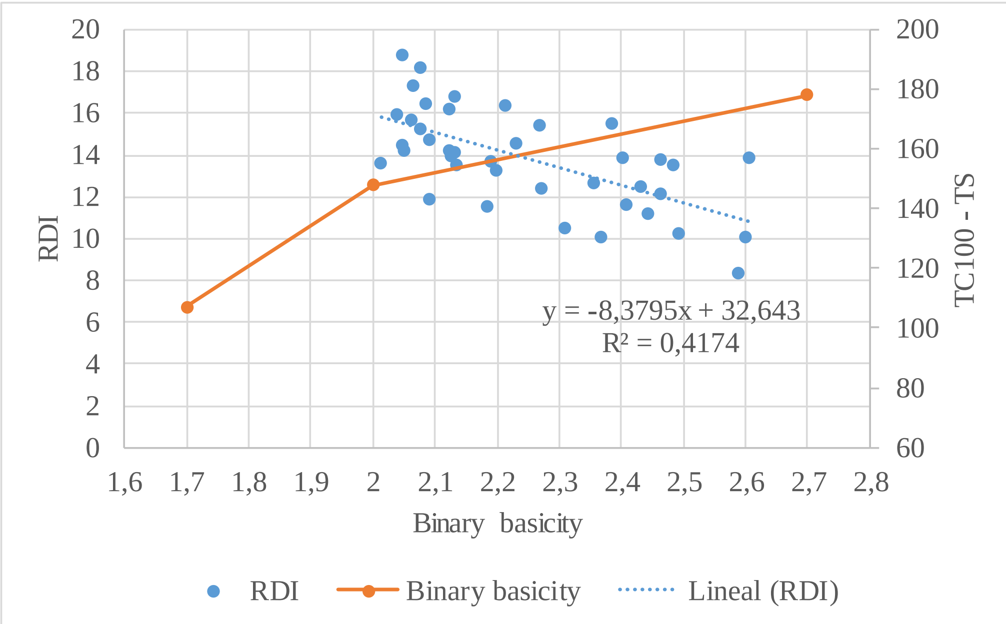

Figure 8. Effect of sinter basicity on degradation using real plant data and high temperature properties

Similar results were found by Pandey et all (5). It has observed that factors favouring RDI are detrimental to Softening-Melting properties, as a result, with decrease/improvement in RDI, Softening-Melting properties deteriorated. Therefore, a balanced approach is necessary to optimise the RDI and Softening-Melting properties.

The same analysis can be done for the two lump ores A or B. Lump A with lower RDI due to its effect on the generation of fines in the shaft and its influence on the permeability and burden descent as can be seen in Figure 10.

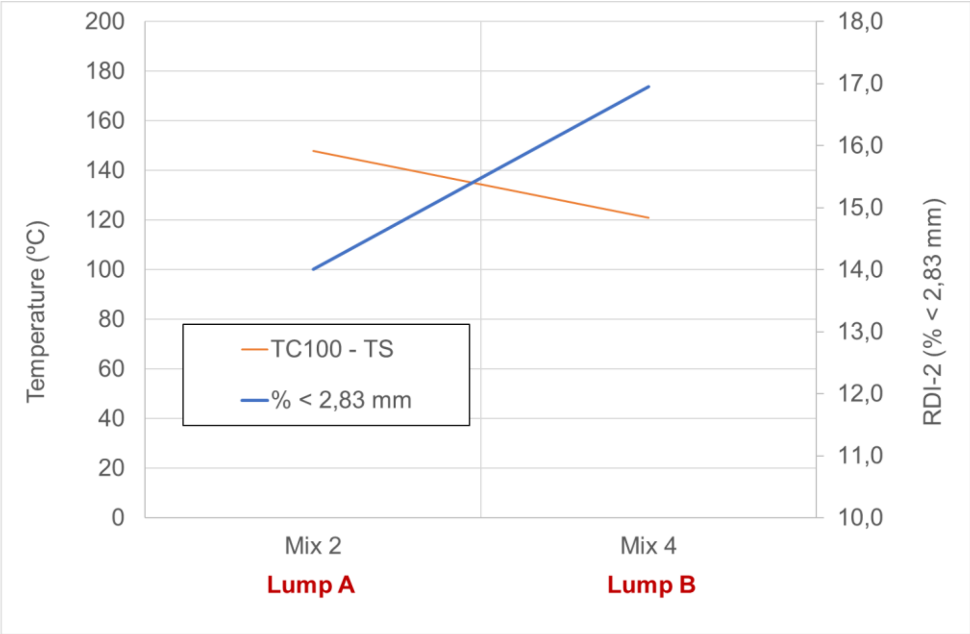

Figure 10. Effect of lump on degradation and high temperature properties.

3 CONCLUSION

The results of this work help estimate the relationship between ranges of IB and ranges of properties at low and high temperature. As it was discussed, there could be a basicity index value in which a balance between its effects over degradation and softening-melting behaviour could optimize the design of burden and improve blast furnace operation.

To select the basicity index of sinter for a blast furnace in operation other factors must be taken into account such as the final composition of the slag for each IB, the need to add basic fluxes to guarantee desulfurization, the percentage of sinter charged in the blast furnace in order to estimate how much a change in these properties will proportionally affect and other issues of the particular operation such as the productivity and permeability of the blast furnace.

In particular, results were applied to choose a BI target for sinter at Ternium Argentina for the actual burden. Any future important change in burden material or qualities should lead to a new evaluation of these properties.

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