PRE DRYING OF RIO TINTO CORUMBA'S LUMP IRON ORE FOR DIRECT REDUCTION[1]

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Abstract

Rio Tinto Corumbá developed physical and metallurgical evaluation of Corumbá lump in direct reduction through laboratory research and industrial test works has produced highly promising results. The present work presents the principal laboratory studies that have led to the development of the pre-treatment of drying the ore before use in industrial direct reduction reactors. The purpose of the first studies was to verify the effect of the natural moisture of the ore and of the sample after drying, on the generation of fines due to the thermal effect (decrepitation). The results showed that drying the ore has a strong effect in the decreasing fines from the thermal shock in the decrepitation test, reducing the occurrence of decrepitation by 80%. The laboratory reduction tests also presented a marked effect from drying the ore, reducing by more than 60% the fines generated in the reduction process. In basket tests in the industrial furnace, the decrease in reduction fines when the ore was pre-dried was clearly evident. The result of the laboratory test showed a direct relationship with the industrial basket test. Experiments in rehydrating the dried lump showed that after drying had eliminated the natural moisture of the ore, it was not reabsorbed when the lump became wet. Maybe due to the great porosity of the ore to superficial water that penetrates in the cavities and pores, this water is also eliminated with facility. When the ore pile is left for some days, the superficial water drains away and the ore returns to the same condition after drying. The laboratory studies allowed the development of the potential of Corumbá lump. After drying, its performance is compatible with its use in the direct reduction process. The laboratory test developed by Rio Tinto Corumbá presented an excellent relationship with the basket test in the industrial furnace, providing an important method for metallurgical evaluation of the ore and a reliable tool for the planning of shipments to customers.

Key words: Ore; Iron ore; Metallurgy; Direct reduction.

PRÉ—TRATAMENTO DE SECAGEM DO LUMP DE MINÉRIO DE FERRO DA RIO TINTO CORUMBÁ PARA REDUÇÃO DIRETA

Resumo

A Rio Tinto Corumbá através de pesquisas laboratoriais e testes industriais de avaliação física e metalúrgica do lump mostraram resultados altamente promissores para seu uso na redução direta. O presente trabalho apresenta os principais estudos laboratoriais que levaram ao desenvolvimento do pré-tratamento de secagem do minério antes de seu uso nos reatores industriais de redução direta. Os primeiros estudos de secagem do lump objetivaram verificar a influência da umidade natural do minério e da amostra depois de seca, na geração de finos pelo efeito térmico (crepitação). Os resultados mostraram que a secagem do minério tem forte influência na diminuição dos finos provenientes do choque térmico no ensaio de crepitação, reduzindo em 80% a ocorrência da crepitação. Os ensaios laboratoriais de redução também apresentaram efeito marcante da secagem do minério, reduzindo em mais de 60% os finos gerados no processo de redução. Nos ensaios de cesta no forno industrial, foi claramente visível a diminuição dos finos gerados na redução quando o minério é previamente seco antes de ser enfornado. O resultado do ensaio de laboratório mostrou uma relação direta com o teste de cesta realizado industrialmente. Os experimentos de re-hidratação do lump seco mostraram que, uma vez eliminada a umidade natural do minério na secagem, esta não é reabsorvida quando o lump é molhado. Talvez devido à grande porosidade do minério a água superficial, que penetra nas cavidades e poros, é também eliminada com facilidade. A pilha em repouso por alguns dias, escoa a água superficial e o minério retoma à mesma condição após secagem. Os estudos de laboratório permitiram o desenvolvimento da potencialidade do lump da mina de Corumbá. Após secagem, o minério da Rio Tinto Corumbá apresenta desempenho compatível com seu uso no processo de redução direta. O ensaio de laboratório desenvolvido na Rio Tinto Corumbá apresentou uma relação excelente com o teste de cesta praticado pela siderurgia, constituindo um importante instrumento na avaliação metalúrgica do minério e numa ferramenta segura para o planejamento dos embarques aos clientes.

Palavras-chave: Minério; Minério de ferro; Siderurgia; Redução direta.

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1 INTRODUCTION

Rio Tinto Corumbá is located in Corumbá, in the state of Mato Grosso do Sul, in the Pantanal region, very close to the border with Bolivia.

Rio Tinto Corumbá currently supplies mainly the Argentinean market and also Europe, Asia and the Middle-East, with lump for coke blast furnaces, and direct reduction steel production. Recent laboratory research and industrial tests evaluating the physical and metallurgical characteristics of this lump, showed highly promising results for its use in direct reduction.

Rio Tinto Corumbá is currently at a production rhythm of 2.0 Mty, with a short term expansion project aiming to reach 12.5 Mty, in order to attend the demand of the market. Mid-term project studies to reach 15 Mty are being developed, in view of the development of a steel centre in the region of Corumbá, and the growth that is being observed in the international steel industry.

Despite the fact that the lump has been used at Acindar – Argentina, from 1993 to 1996, the quality factor that made its continuous use difficult in the direct reduction, was the great quantity of fines generated during the reduction process, in the sponge iron production.

Two main factors are the cause of these fines: firstly, the disintegration due to thermal effect, decrepitation; and secondly, the transformation of the hematite into magnetite during the reduction, when the crystalline phase mutation occurs, with a volume expansion of the pieces of ore, which cause internal fissures and cleavage, consequently generating fines, due to reduction.

These efforts were finally rewarded when recent laboratory studies showed that the drying of the ore prior to its use, can reduce the generation of fines due to thermal effect, to over 80%, and the total decrease of fines generation during reduction, to approximately 60%.

The results of the laboratory tests were confirmed through industrial tests performed at the Argentinean steel producers Siderca and Acindar.

For use in blast furnaces, this ore presents a different behaviour. The blast furnace is a natural dryer and when the ore reaches the critical regions of temperature and reduction, the ore is already dry and its performance is the same as if it were dried outside the furnace.

This work presents the main laboratory tests that brought to the development of the drying treatment prior to its use in the industrial reactors of direct reduction.

2 RIO TINTO CORUMBÁ MINERAL DEPOSITS

2.1 Characterístics of the Deposit

The iron ore of Rio Tinto Corumbá derivates from the weathering of a thick package of jaspilite rocks, which are responsible for the conservation of the heights that reach 900 m above the Pantanal flatland.

The column of ferriferous sequence has a thickness of 270 meters, divided into 11 stratigraphical units, representing different cycles of ferruginous sediment deposit. The chemical and physical characteristics of these units are constant along the whole deposit.

However, a strong anisotropy takes place in the vertical axis, which founded the division of the deposit into stratigraphical units. This is a characteristic of paramount importance for the deposit, as it allows a very coherent forecast of the products that will be generated by the extraction. This premise is fundamental to the planning of the extraction, which is performed selectively, by unit.

The supergene enrichment of the jaspilite sequences can reach up to 35 meters of depth along the slopes of the elevations, being a function of the inclination of the layers, of the geomorphology, and the stratigraphical horizon involved, i.e. the coat of ore covers the elevations superficially and integrally.

As shown schematically in Figure 1, the ore covers the elevations as an orange peel, although, with variable thickness.

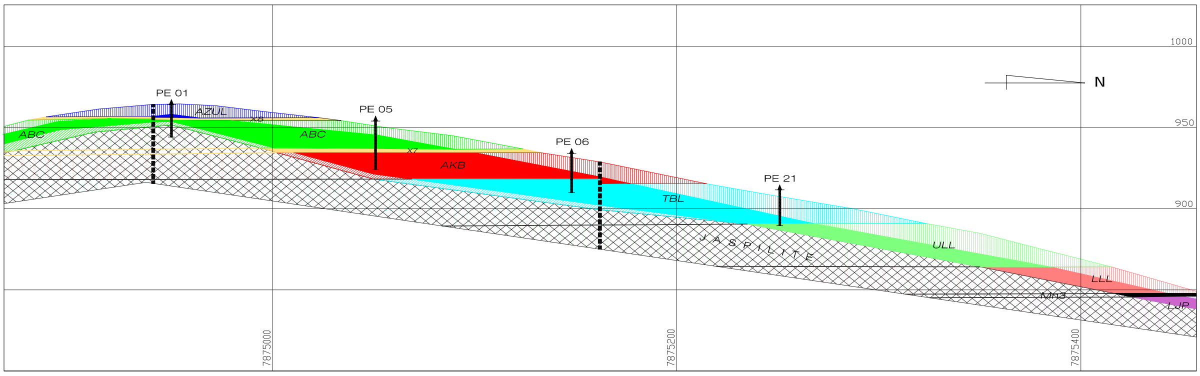

Figure 1 – Stratigraphical Layer along the hill.

Due to the intense fracturing rate, Rio Tinto Corumbá's ore is extractable by simple scraping, without need of explosives for its removal.

The planning always considers the extraction on different fronts, located in different zones and stratigraphical units, to minimize variations in the quality of the lump and guarantee constant quality shipments to the client. The lump of each unit is produced and transported to the port, where it is stocked in individual piles for later blending with lump of other units, depending on shipment specifications.

2.2 Characteristics of the Direct Reduction Lump

The quality of the lump varies from one stratigraphical unit to another. Each unit's product has its advantages and disadvantages. In order to benefit totally from its resources, Rio Tinto Corumbá has to extract and beneficiate the different units selectively, and blend the lump at the port, assuring shipments with an approximately constant quality.

By stratifying the deposit in layers of different characteristics, nature gave planning a powerful tool for quality control.

The lump, primary product of the mine, presents a chemical, physical and metallurgical quality, in accordance with the specifications of the clients, and its typical characteristics and deposit average, are shown in Table 1.

Table 1 – Typical Characteristics of Rio Tinto's DR lump.

Elements	%	Physcal tests	%	Metallurgic tests	%
Fet	67.50	Tumbler rate (ISO)	88.0		
SiO2	1.70	(% > 6,35 mm)		Reductibility (JIS)	63 - 65
Al2O3	0.90	Abrasion rate (ISO)	5.5	Metalization (Midrex)	96.0
P	0.052	(% < 0,50 mm)		Reduction Fines (Midrex)	13.7
LOI	0.90	Decrepitation (ISO)	1.2	(% < 6,35 mm)	
Mn	0.020	(% < 6,35 mm)		S Release in S in ppm (IAS)	9.2
K2O	0.020	Appearant Density	2.2		
Na2O	0.016	Moisture (ISO)	4.0		

For the use in direct reduction, the quality factor that made its continuous use difficult was the high amount of fines generated during the reduction process, in the production of sponge iron.

Two main factors are the cause of these fines: firstly, the disintegration due to thermal effect, decrepitation; and secondly, the transformation of the hematite into magnetite during the reduction, when the crystalline phase mutation occurs, with a volume expansion of the pieces of ore, which cause internal fissures and cleavage, consequently generating fines, due to reduction.

Rio Tinto Corumbá has always been studying the mechanisms of these phenomena in its laboratory. The decrepitation is a phenomenon of great contradictions and some specialists state that it is variable depending on the time, as no repeated rates are found.

At Rio Tinto Corumbá, during the many studies performed in 1996, the conclusion was reached that decrepitation is an independent variable, as no correlation with other parameters were verified.

Ever since that time, 12 years ago, countless and exhaustive research programmes were made on the main variables of the reduction process, of its handling and stocking, of the characteristics and peculiarities of each kind of ore that is found at the mine, of every stratigraphical layer, of every zone of the mineralized package, etc.

3 STUDIES ON DRYING LUMP FOR DIRECT REDUCTION

3.1 Thermal Effect

The thermal disintegration of the lump was first studied in the early 60's, especially for the use in blast furnaces.

Researchers believe the thermal disintegration is due to two kinds of mechanisms. First, when the hard and compact hematite contains 1% to 2% of combined water deriving from iron oxides hydrated with goetite or lepidocrosite, the goetite is dehydrated at approximately 350ºC, and the increase of water vapor pressure due to the difficulty of its ejection, generates the rupture of the material. Even ores which are considered as non hydrates do actually have hydrated phases, which are distributed as thin incrustations in their interior.

When heated, the decomposition of these phases takes place, producing water vapor. Even very small incrustations become critical at higher temperatures.

The second mechanism would be caused by the defoliation in parallel layers, caused by thermal expansion. The hematite expands in an anisotropic way, resulting in the disintegration into preferential plans.

In light of this information Rio Tinto Corumbá promoted innumerous studies on the subject, and came to the conclusion that the decrepitation is an independent variable, as no correlation with other parameters were verified.

As to the ore of Corumbá, the mechanism that best explains the thermal disintegration is the crystallization water, or intrinsic moisture, associated with the tiny incrustations in the interior of the iron ore.

The first studies on the drying of the lump aimed to verify the influence of the natural moisture of the ore and the sample after having been dried, on the generation of fines by thermal effect (decrepitation). Three types of ore were used, corresponding to the different stratigraphical layers, and four different temperatures were used for the thermal shock of the samples.

Temperatures: 1000ºC, 900ºC, 800ºC e 700ºC

Samples: GHI, ABC and TBL.

Moisture: sample at natural moisture and dry sample at 105ºC for 7h.

The samples were placed on a stainless steel tray, which was placed into the furnace preheated to the temperature of the test. When reaching the test temperature, the sample was kept there for 30 minutes, before it was removed, cooled, and screened. This procedure followed the ISO standard of decrepitation, adapting only the temperature variation for the test.

The results of these experiments are shown in Table 2 and Figure 2.

Table 2 – Effect of the drying on fines generated by thermal effect

Layer	**Moisture**	**Temperatures (ºC)**			
		700	**800**	**900**	**1000**
TBL	**Natural (3,5%)**	**13,4**	**15,3**	**15,2**	**17,1**
	Dry	**1,1**	**5,6**	**7,5**	**10,8**
ABC	**Natural (3,8%)**	**12,7**	**17,9**	**21,2**	**24,2**
	Dry	**5,2**	**9,0**	**9,2**	**15,1**
GHI	**Natural (3,9%)**	**9,9**	**12,0**	**12,1**	**13,6**
	Dry	**1,6**	**3,0**	**5,6**	**6,3**
LUMP TOTAL	**Natural (2,2%)**	**10,5**	**14,8**	**16,0**	**15,7**
	Dry	**2,3**	**4,0**	**7,3**	**10,0**

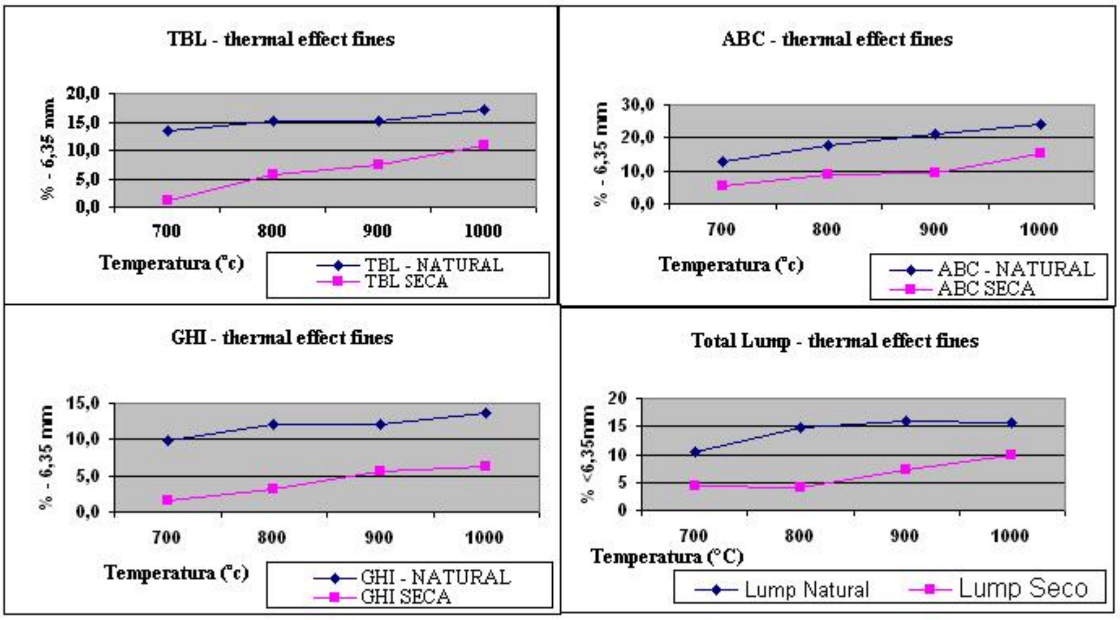

Figure 2 – Graphics of the effect of the drying on fines generated by thermal effect.

The results presented in Table 2 and Figure 2 showed that the drying of the ore has a strong influence on the reduction of the fines resulting from thermal shock.

The temperature also presented remarkable influence, as a more significant disintegration of the lump occurred as the temperature increased from 700ºC to 1,000ºC.

3.2 Reduction Tests in Laboratory and Industrial Tests

3.2.1 Laboratory

In the process of reduction of the iron ore, the mutation from crystalline phase, when the hematite (Fe_2O_3) is compact and hexagonal, into magnetite (Fe_3O_4), when it is cubical and of centered face, an important quantity of fines are generated.

This mutation of crystalline phase causes volume expansion, with fissures and micro-cleavages in the material. During the motion of the load inside the direct reduction reactor, the material disaggregates, generating fines in the process.

At the laboratory at Rio Tinto Corumbá, with the use of a Linder furnace, a test procedure was developed, which allows evaluating the fines generated during reduction, for the different ores that are found at the deposit.

Table 3 presents a summary of the procedure of the RDI-DR test.

An enormous quantity of tests was performed, detailing all layers or stratigraphical units of each zone of the mineralized package and of the different morphological types. These studies made it possible to get to know previously the metallurgical quality during the planning of a lot/convoy of ore for exportation, which is normally compound by an adequate mixture of the layers.

Table 3 – Summary of the procedure of the test on disintegration by reduction, at Rio Tinto Corumbá.

RDI-DR	
Description	RDI-DR
Weight of the sample (dry)	500 g
Size distribution Strip	19,0 a 25,4 mm
Reduction Furnace	Linder
Furnace Temperature	870ºC
Reduction Temperature (tube)	850ºC
Reduction Time	60 min
Reduction Gas Midrex	64% H2 + 36% CO
Gas Output N2 during heating	1,0 L/min
Reduction Gas Output	15,0 L/min
Gas Output N2 during cooling (2,0 min)	1,0 L/min
Micro Drum RDI	30 rpm, 30 min.
Results AT and DT	% < 6,35 mm % < 3,35 mm
Linder furnace heated at 870ºC, place tube with dry sample, applying N2. During heating to 850ºC. Keep during 10 minutes for temperature equalization. Start reduction applying reduction gas, completing the test in 1h. Apply N2 for two minutes and withdraw tube from furnace to cool down at room temperature.	
Test Sample: Compound proportionally types: compact dense + cavity dense + tabular dense + hematite porous.	

3.2.2 Industrial basket test

The ore lot that consisted of the “trial cargo” for industrial test was compound from the direct reduction quality lump piles of the layers, previously identified.

Steel factories normally perform preliminary tests with the ore that will go into the furnace, through small stainless steel baskets which go into the furnace together with the load in the reactor. After this process, the baskets are recovered at the output of the reactor and the ore is taken to the laboratory for analysis.

Picture 03 shows the basket tests: the preparation of the baskets; the baskets ready to go into the reactor; opening the baskets after the reduction process; and the sponge iron of the lump.

Figure 3 - Basket tests, performed at the direct reduction industrial reactor.

3.2.3 Laboratory and industrial results

Table 4 presents the comparative results between the laboratory test at Rio Tinto Corumbá and the basket tests, performed with samples of the ore sent for direct reduction industrial test.

Table 4 – Effect of the drying on the results of fines generated during reduction (laboratory and industrial)

Fines generated during reduction % < 6,35 mm				
Laboratory – **DRY** sample			Industrial test (Basket Test)	
GHI	8,0		**Natural** 2,8% natural moisture	35,0
E	12,9			
AZUL	16,8		**Pre-dried** 0,3% residual moisture	17,5
ABC	12,0			
TBL	19,0		**DRY**	12,0
Industrial sample	11,7			
Industrial sample = mix of the layers in accordance with “trial cargo” plan				

The results in Table 4 show the values of the fines generated in each stratigraphical layer that were part of the industrial test lot, and the result of the test performed on the shipment sample. Comparatively, the results of the basket tests in the industrial reactor are also shown, with natural sample (moisture 2.8%), sample with 0.3% of residual moisture from the drying, and totally dry sample.

It is clearly visible how the generation of fines during the reduction process decreases, when the ore is dried prior to be placed in the furnace.

The result of the laboratory test showed a direct relation with the basket test that was performed industrially.

These results give the company an important sureness as to the supply of ore to direct reduction plants. They show that the dried ore from Corumbá, is perfectly commercial for the process, and the laboratory test assures the possibility to foresee the behaviour of the lump as to fines generation during the reduction process.

The industrial test with the lump from Corumbá showed that the fines that are produced during the test followed the indications of the basket test, maintaining the already known correlation rates between the tests and the furnace operation.

3.3 Rehydration of Dried Ore

Following the drying studies of the lump a question arose, as to the behaviour of the dried ore when exposed to rain during transport or stocking. Would it absorb the moisture again, and would the problems of fines caused by moisture return?

Again, a series of laboratory tests were conducted to verify whether the dried ore would reabsorb the natural moisture. Samples of 100Kg for each layer involved in the studies were dried to 0% of residual moisture and subsequently stocked outdoors.

The piles went through two types of hydration processes:

1º - The dried ore pile was wet with a hose during an eight-hour shift, simulating rain, and then the pile was left to rest, measuring the moisture every two days.

2º - After being dried the ore was submerged in water for 24 hours, simulating a ship cellar with rain water. Then, the ore was stocked and left to rest, measuring the moisture every two days.

The results of these experiments are presented in the graphics of Figures 4 and 5. After losing its natural moisture, the ore does not rehydrate again. The moisture that was detected in the absorption of rain water is just superficial and percolates through the pores of the ore and drains naturally when the lump is left to rest.

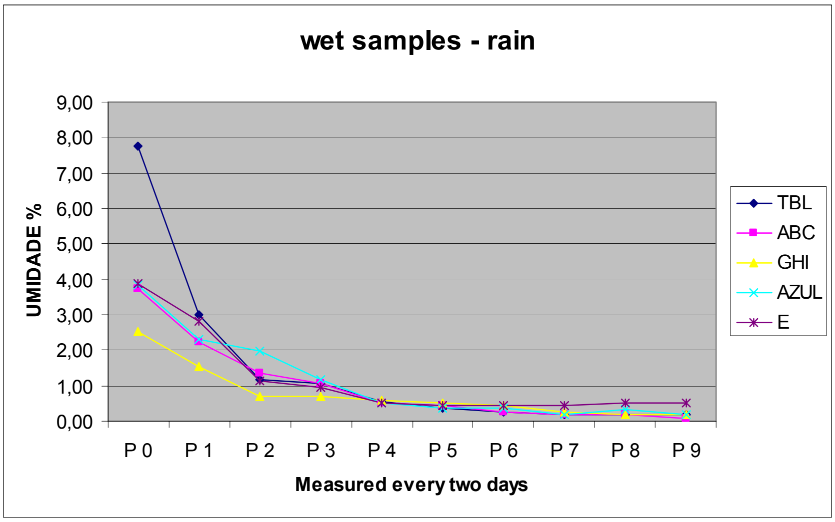

Figure 4 – Rehydration tests of the lump after drying. Samples simulating rain period.

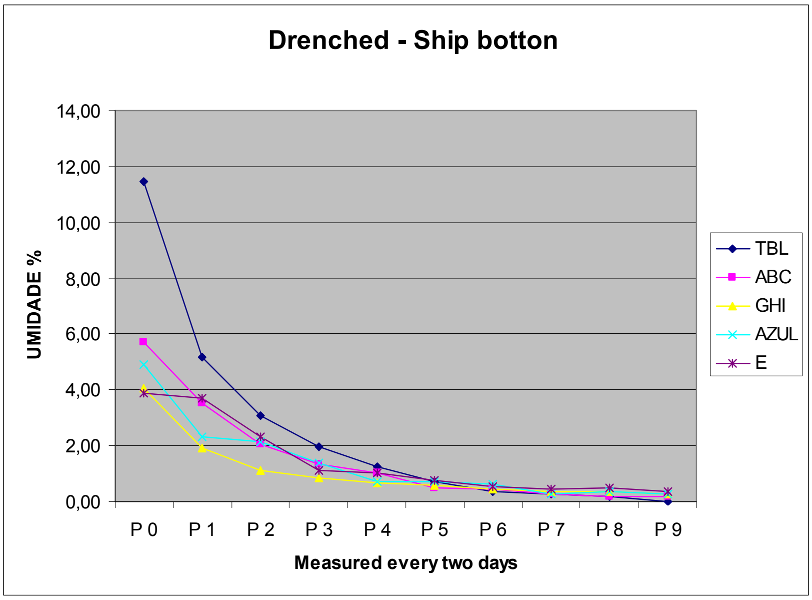

Figure 5 – Rehydration Tests of the lump after drying. Drenched samples simulating ship transport.

Also, some basket tests were performed in the direct reduction industrial furnace, using the dry lump (105ºC for 7 hours), comparatively with wet lump to verify the direct influence of the superficial water, simulating rain period. Considering that there would be no time to stock the material for draining of the superficial water, what would the influence of this water be on the fine generation during reduction process? Once dried, the ore was wet with a water spray, simulating rain and another portion was wet leaving the ore inside a container, which was submerged in water for 1 hour, to drench.

Immediately after, the samples were placed in baskets in the furnace, to perform the test.

The results showed that the superficial water due to rain does not influence the disintegration process of the ore in the reduction process. The drenched sample showed a slight increase in fine generation, but nothing compared to the natural moisture of the ore.

Table 5 presents the results of the basket tests with dry ore and with wet ore simulating rain, in case there is no time to stock the material for draining of the superficial water.

Table 5 – Results of industrial basket tests with dry ore and with wet ore.

	Basket 1 to 8		Basket 9 to 16		Basket 17 to 24	
QUALITY	RIO TINTO DRY	PELLET	RIO TINTO DRY	RIO TINTO SPRAY	RIO TINTO DRY	RIO TINTO DRENCHED
FINES % < 6,35mm	15,34	5,15	16,26	17,24	16,67	19,25
TOTAL FE	94,60	92,66	94,60	94,60	94,60	94,60
FE°	90,38	87,92	90,08	90,02	90,78	90,63
METALIZATION	95,54	94,88	95,23	95,16	95,97	95,81
% C	1,02	2,20	0,72	1,14	0,93	1,32
GANGA	3,18	3,78	3,39	2,95	3,38	2,95

4 CONCLUSIONS

The studies performed by Rio Tinto Corumbá on the pre-drying treatment of the lump meant for direct reduction, made it possible to conclude that:

1- The drying of the ore has a strong influence on the decrease of fines generated by thermal shock during decrepitation tests, as shown in Table 02 and in Picture 02.

This decrease showed an important gain, recording an average difference of 80% of the fines smaller than 6.35 mm when the ore went through a thermal shock at the critical temperature of 700º.

2- The temperature also presented remarkable influence, as greater disintegration of the lump occurred when the temperature of the thermal shock went from 700ºC to 1,000ºC.

3- In Table 04, it is clearly visible how the generation of fines during the reduction process decreases, when the ore is dried prior to be placed in the furnace. The industrial basket tests, showed a fall of 50% of fines, when the ore was pre-dried, with a remaining moisture rate of 0.3%, and even greater fall, of 65%, when the ore was completely dried.

4- The experiments on rehydration of dried lump showed that, once the natural moisture of the ore is eliminated, it is not reabsorbed when the lump is wet. Perhaps due to the great porosity of the ore, the superficial water, which penetrates in cavities and pores, is also easily eliminated. The pile left to rest for a few days drains the superficial water and returns to the same post-drying condition.

5- The basket tests performed in the direct reduction industrial furnace with samples that were wet simulating rain, showed that the ore did not reabsorb its natural moisture and that the superficial water does not influence the fine generation in the reduction process. The excess of water in the drenched sample showed a slight influence on fines, but far from being comparable with the influence of the natural moisture of the ore.

6- The laboratory test developed at Rio Tinto Corumbá, presented an excellent relation with the basket test performed by the steel industry, representing an important instrument in the metallurgic evaluation of the ore and a safe tool for the planning of the shipments to the clients.

The laboratory studies also allowed developing the potentiality of the lump from Corumbá. After drying, the ore from Rio Tinto Corumbá presents a performance that is compatible with its use in the direct reduction process.

Following these studies, Rio Tinto implanted a Drying Plant in Corumbá, and is exporting DR lump to some clients in the Middle-East.

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