THE USE OF REFRACTORY WASTES ON THE MOLDING SANDS IN A CASTING PROCESS

Christian Egidio da Silva, christianegidio@gmail.com
Instituto Tecnológico de Aeronáutica (ITA), 12.228-900, São José dos Campos, SP, Brasil
Gerdau Aços Especiais, 12.442-260, Pindamonhnaganba, SP, Brasil

Luiz Carlos Silidônio Júnior, lui.junior@gerdau.com.br
Rogério Regis Dias de Camargo, rogerio.camargo@gerdau.com.br
Paulo Henrique Ribeiro de Oliveira, paulo.ribeirodeoliveira@gmail.com
Amir Rivaroli Júnior, amir.rivaroli.@gerdau.com.br
Gerdau Aços Especiais, 12.442-260, Pindamonhnaganba, SP, Brasil

Abstract.*The present work was developed to understand the influence of using refractory wastes on the molding sands properties. After knowing the real influence on the properties it is possible do define the proportion of using residual wastes to save money and to reduce the wastes generation. It was applied a design of experiments with three factors and three levels to optimize the tests. They were performed grain size analysis and mechanical testing. It was used a typical #40/50 quartz silica sand and #200 silica to prepare the mixtures. The refractory wastes used in these tests were collected from the process and the mixtures were prepared considering the DOE planned. The results showed that it is possible to use the refractory wastes on the sand mixture replacing up to 50% of #200 silica without risks for the casting. It was observed that the properties did not change up to that specific quantity of refractory waste. The replacement of #200 silica by the refractory wastes reduces almost 7% of total preparation costs. The use of refractory wastes on the molding process promote a reduction on the wastes generation and its costs.*

Keywords*: refractory, casting, wastes, recycling, sand*

1. INTRODUCTION

The quality of a product is the result of a combination of factors. If that combination is suboptimal, quality will suffer and the company will lose as a result of rework and repair (Bass, 2007).

The best operations' decisions are the result of a strategic thought that consists in conducting several experiments, combining relevant factors in different ways to determine which combination is the best (Bass, 2007). This process is known in statistics as Design Of Experiment (DOE). Due to several factors which affects the quality level of the products and services, it is necessary to know how the input factors and their interactions affect the response variable.

In accordance to Robles Júnior (2003), the new worldwide competition way requires that the companies to be compromised with continue and complete product, process and manpower improvement. The methods are necessary to conduct all the company in a correct direction in order to reach the goals. Silva (2002) shares the same thought about the contemporaneous competition, technology and management rules which requires a lot of changes on the way to measure and manage its business. In this context, the investment on training and process improvement become fundamental and necessary to the company success.

In accordance with Laszlo (1997) it is assumed by top management that quality improvement related to the products and services offered raises the cost of operation above the current levels. This view is not merely simplistic, but it is erroneous. It is based on the assumption that improvements inherently involve higher expenditures. It can be simply demonstrated that not all quality improvements carry higher price tags – higher efficiency may be obtained, in some cases by simplifying tasks, thereby reducing costs. Moreover, for in certain cases of quality improvements, the added costs associated with the quality improvement are outweighed by the financial benefits derived from the changes – the cost of conducting design reviews may be considerably less than complications arising from design errors.

The quality cost approach is based on the balancing of the cost of assuring quality against the costs associated with problems attributed to a lack of quality. The goal of quality improvement is to minimize inefficiencies and waste. The savings could be translated into added margin that increases shareholder value, and/or the savings could be passed along to the customers in the form of a price reduction (Laszlo, 1997).

The present work was developed to understand the influence of refractory wastes on the molding sands properties and other casting characteristics. After knowing the real influence on the properties it is possible do define the ideal proportion of refractory wastes on the casting sand to save money and to reduce the wastes generation.

2. THE CASTING PROCESS

2.1. General description

The casting process consists on a metal melting and its pouring inside a mould. This mould normally is manufactured with sand. It is used inside the mould a pattern which will reproduces the item to be cast during the molding process. After having packed the sand in the molding flask, the pattern is removed and the resulted shape is finished off. The molten metal is poured into the moulds. There are many process parameters which shall be controlled during and after casting to guarantee a good product: sand mould hardness, temperature of moulds, dressing density, dressing thickness.

The mould is allowed to cool and after the metal solidification and the total cooling it is carried out the piece stripping. In this step the piece is stripped off from the mould.

Immediately after its stripping, the pieces are submitted to a non destructive inspection (X-Ray, ultrasonic testing, magnetic particle, penetrating liquid, microscopic analysis) to check the existence of discontinuities and to evaluate the integrity of obtained piece.

On the sequence the pieces are submitted to a heat treatment and after concluding this operation, they are conducted inspections like hardness and residual stress measurements.

Finishing these inspections the machining process started. It is common to conduct some audits on the machining steps during the process to guarantee that all the real dimensions are in accordance to the specified parameters. After concluding this machining it is performed a final inspection – ultrasonic inspection, hardness measurements and magnetic particle – and the piece is read for shipment.

2.2. Requirements for the casting sands

The molding sands must comply with the follow requirement: thermal and dimensional stability to high temperatures, good size particles, appropriate morphology and distribution, chemically stable when in contact with the molten metal, free of low melting temperatures particles, free of products which generate gases, presents suitability with the raw materials, low cost. The overall properties are a function of sand/additive mineral constituent characteristics.

The kind of sand and its size distribution affect directly properties like refractoriness, permeability and sand expansion. The mechanical resistance of mould is influenced by the additive percentage and its mixture. The surface quality of a casted piece depends on the grain size and its distribution: thinner sands conduct to a better surface finishing but reduce the sand permeability and require more additive due to its higher specific area. The purity grade is an important characteristic of sands because influences directly the refractoriness properties and affects the use of certain additives types.

3. MATERIALS AND METHODS

3.1. Sand preparation

The sand used in the present experiment was prepared in laboratory in accordance to CEMP-182 (2003), but using the same preparation methodology used to the production. They were prepared different batches using a *ML-7* equipment manufactured by *Mesterlide*, each one with a specific raw material proportion. The standard batch was prepared exactly equal to that used on the production. As a function of that reference, it was planned a Design of Experiments. The mixing time was adjusted to the laboratory conditions.

It was defined a Design of Experiments of 3 factors and 3 levels to evaluate the real influence of each raw material and its interaction on the properties of one specific sand type in order to approve the use of refractory wastes.

The standard batch was based on the standard production proportion and contains the following constituents and quantities: #40/50 quartz silica (400g) and #200 silica (50g). Additionally to these constituents, normally it is used “natural sodium bentonite” (28.5g), “dextrine” (4g), “iron oxide” (8g) and “water” (20g).

The main objective of this experiment was to reduce the #200 silica consumption through its replacement by a specific waste generated in the process. This waste is a refractory powder too fine, which was obtained after cutting all kinds of refractory bricks and tubes. These bricks and tubes are used to prepare casting ladles, wall furnace and other pieces which are exposed directly to molten metal.

The chemical compositions of “refractory waste” and of “typical silica #200” are on Tab. 1. Additionally it is possible to see that the refractory waste presents a great Al_2O_3 content, what could contribute to a higher resistance to temperature for the mold.

	SiO_2	Al_2O_3	TiO_2	MgO_2	CaO	Na_2O	K2O
Typical #200 silica quartz sand	99,97%	-	-	-	-	-	-
Refractory waste	55,35%	39,90%	0,98%	0,17%	0,09%	1,27%	1,16%

Table 1. Chemical composition of refractory waste and typical #200 silica quartz sand.

The sand batches were prepared as follows:

(a) They were weighs the raw material specified on the experiment.
(b) Following the design of experiments planning all the raw material were put on the mixer to start the drying mixture.
(c) After concluding 120s of mixing it was added the water content in accordance to the standard proportion of process. All the materials remain in mixing during this addition.
(d) On the sequence, after transferring all the water content to the mixer, the mixture remains in mixing for more 180s to guarantee a perfect homogenization. Concluding this additional time, the sand is ready to start the laboratory tests.

3.2. Design of experiments

Table 2 presents the design of experiments used to the present study. They were planned reductions of 7.5% and 15% on the standard Silica #40-50 content, which were considered levels “0” and “-1”, respectively. The standard process condition (400g) was considered level “+1”. It was still focused a reduction between 50% and 100% on the standard Silica #200 amount. This reduction will be performed through its replacement by refractory wastes.

	Level		
Parameter	-1	0	+1
Silica #40-50	340g	370g	400g
Silica #200	0	25g	50g
Refractory waste	0	25g	50g

Table 2. Parameters and levels analyzed for the mold painting process.

3.3. Laboratory testing

3.3.1. Grain size analysis

They were used the following sieves, in accordance to ABNT standard: #6 (3.35mm), #12 (1.79mm), #20 (0.85mm), #30 (0.60mm), #40 (0.42mm), #50 (0.30mm), #70 (0.21mm), #100 (0.15mm), #140 (0.107mm), #200 (0.075mm) and #270 (0.053mm) and bottom. The tests were conducted using as reference the document CEMP–081 (2003).

3.3.2. Dry tensile strength tests

They were manufactured 3 samples per batch in accordance to the document CEMP-162 (2003). It was used a sand universal machine to perform the testing, manufactured by *Dietert Detroit Product*.

3.3.3. Dry and green compression strength tests

They were manufactured 3 samples per batch for the “dry compression testing” and 3 samples per batch for the “green compression testing”. The manufacturing and the testing were performed in accordance to the documents CEMP-060 (2003) and CEMP-066 (2003). It was used a sand universal machine to perform the testing, manufactured by *Dietert Detroit Product*.

3.3.4. Compacting tests

It was manufactured 1 sample per batch in accordance to the document CEMP-065 (2003). It was used a specific compacting machine to perform the testing, manufactured by *Dietert Detroit Product*.

3.3.5. Dry and Green hardness tests

They were manufactured 3 samples per batch for the “dry hardness testing” and 1 sample per batch for the “green hardness testing”. The samples were positioned on a plan base and they were taken the hardness measurement. They were used specific durometer to perform the both hardness testing. These different equipments were manufactured by *Dietert Detroit Product*.

3.3.6. Humidity tests

It was analyzed 10-20g of material per batch in accordance to the document CEMP-105 (2003). It was used an infra-red equipment to perform the testing, manufactured by *Gehaka Ltda*.

4. RESULTS

4.1. Grain size analysis

The main information concerning the mesh of refractory waste and typical quartz sand are on Tab. 3. The AFS module for the refractory waste is too fine (#237), close to that specified to the aggregate (Silica #200), what suggests that the refractory waste can be used to replace the typical silica #200.

	Concentration	AFS Module	Fine content (#200 + #270 + Bottom)
Typical #40-50 quartz sand	93,10%	40,6	0,00%
Refractory waste	79,55%	237,54	84,93%

Table 3. Main information concerning the refractory waste and typical quartz sand mesh.

4.2. Dry tensile strength tests

Figure 1 show that an increasing on the constituents conduct to a reduction on tensile strength. So, the tensile strength is affected by the changing on its contents.

Comparing the experiments, it is possible to see that when is used 50% of refractory waste instead silica #200 the tensile strength maintain its result. The overall tensile strength behavior to “silica #200” and “refractory waste” were quite similar. When it is increased the refractory replacement, the dry tensile strength results drops too much.

These results suggest that it is possible to use 50% of refractory waste on the sand mixture without risks to the casting process. It is necessary to comment that when it is used the refractory waste instead the silica #200 the tensile strength level was higher than to that viewed to the experiment with 50% of silica #200.

After analyzing the interactions “silica #40-50” to “silica #200” and “silica #40-50” to “refractory waste”, it is noted that the results present similar behavior with a little favorable condition to the “refractory waste”. When it is maximized the use of refractory wastes the tensile strength drop by half.

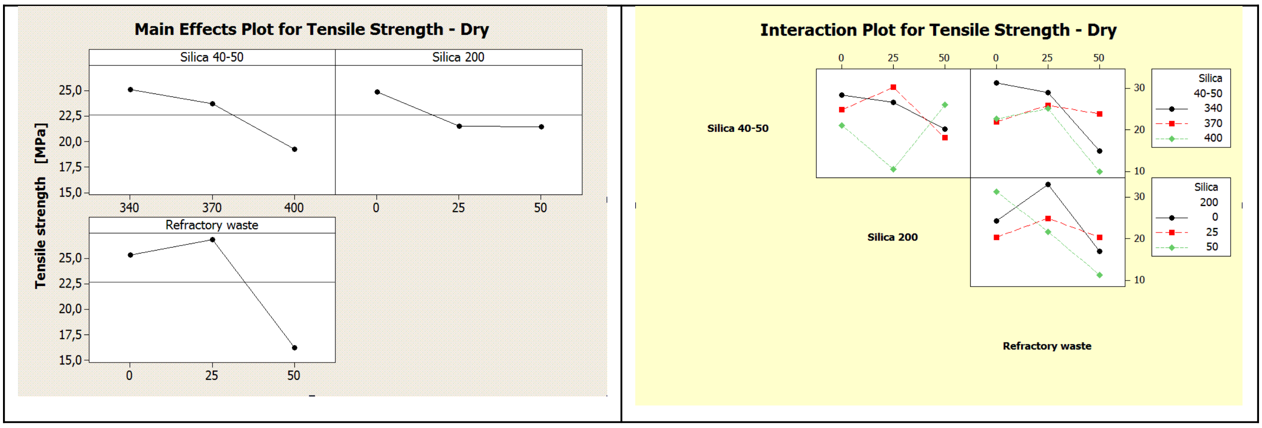

Figure 1. Main effects and interaction plots for dry tensile strength.

4.3. Dry and Green compression strength tests

Figure 2 show no significant changing on the results when it is used 50% of refractory wastes in the mixture for the “dry testing”. When the refractory amount is increased on the mixture the compression strength drops and its decreasing is expressive. So, the compression strength is affected by the changing on its contents.

The Fig. 2 still show that the green compression strength decreased more than for dry compression strength. But the behavior observed is too similar to the “dry testing”.

These results suggest that it is possible to use 50% of refractory waste on the sand mixture without risks to the casting process. It is necessary to comment that when it is used the refractory waste instead the silica #200 the compression strength level was higher than to that viewed to the experiment with 50% of silica #200.

After analyzing the interactions “silica #40-50” to “silica #200” and “silica #40-50” to “refractory waste”, it is noted that the results until 50% of replacement present similar behavior with a little favorable condition to the “refractory waste”. When it is maximized the use of refractory wastes the tensile strength drop by half.

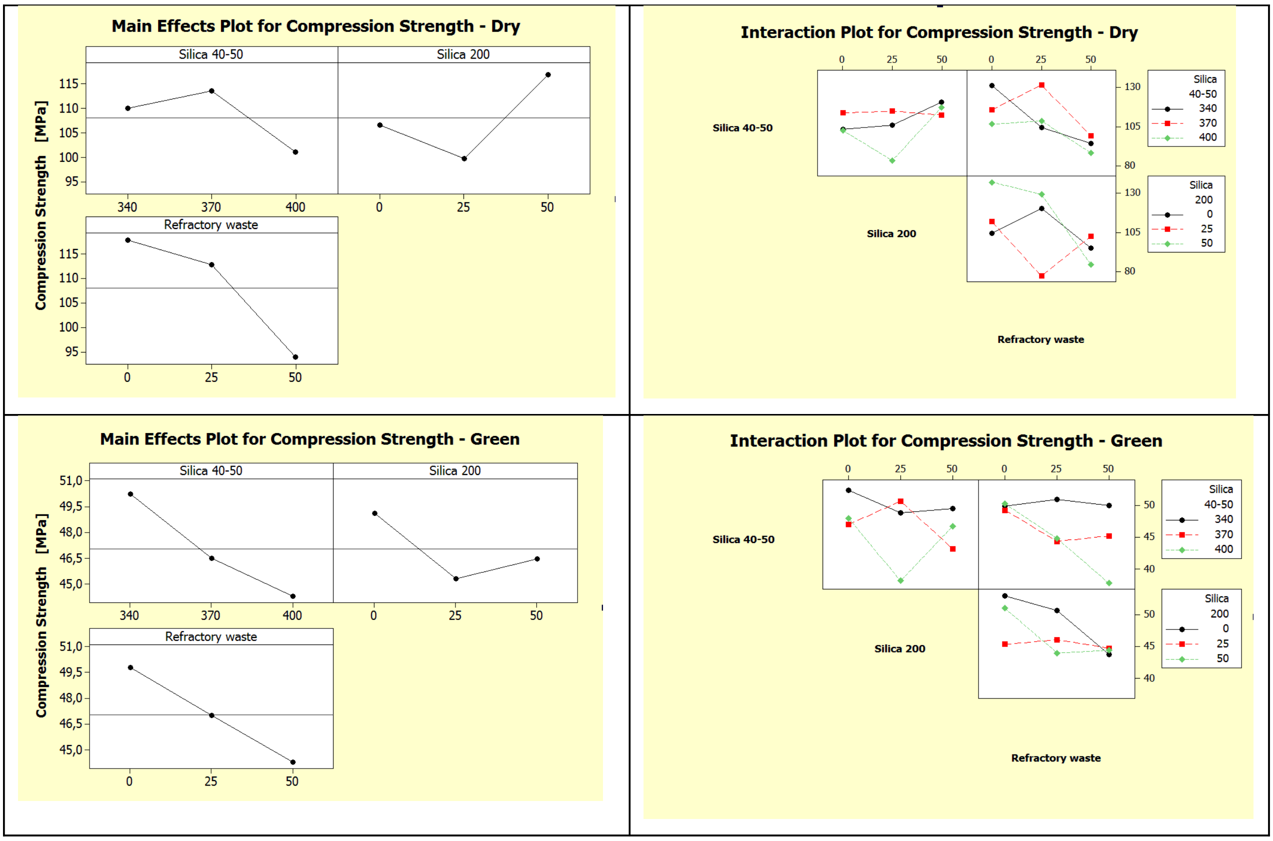

Figure 2. Main effects and interaction plots for dry and green compression strength.

4.4. Compacting tests

Figure 3 show no significant changing on the results to the extreme experimental levels ("-1" and "+1"). This behavior was similar to the both graphs ("refractory wastes" and "silica #200"), which suggest that the replacement of silica #200 by refractory wastes doesn't affect the result.

Considering that this test is a comparative analysis, there aren't differences between the results.

It is noted that for the experimental intermediate level ("0" level) the compacting percentage results drop. Considering that for this level (50% of silica #200 and 50% of refractory wastes) it will be present on the mixture three different particle sizes (silica #40-50, silica #200 and #237 refractory wastes), it could be expected the occurrence of any packing failure between its particles. Sometimes the particles are in perfect contact but in many cases it is possible that there isn't a morphological homogeneity between the particles which will conduct to a packing failure. Because that, in terms of compacting, it is better the use of 100% of refractory waste to avoid this occurrence.

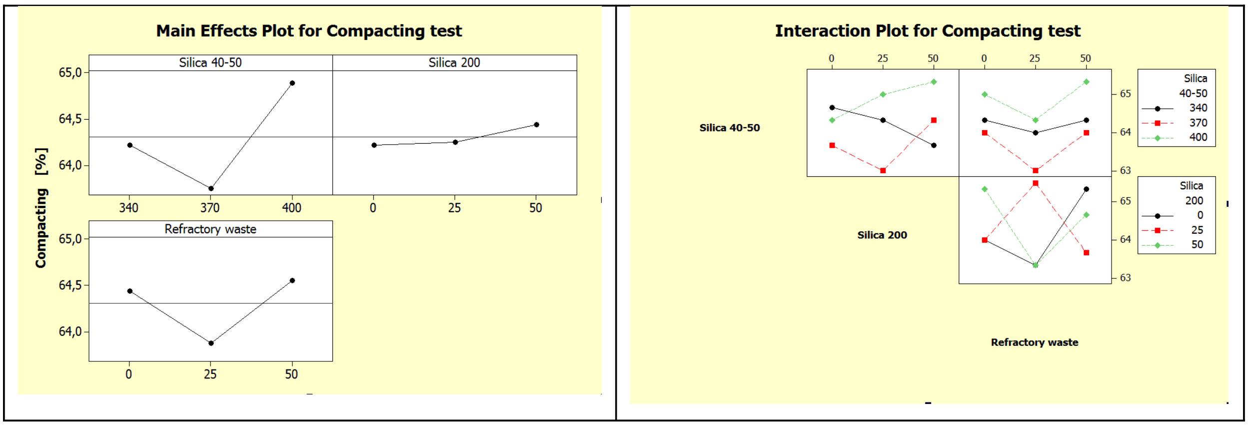

Figure 3. Main effects and interaction plots for compacting test.

4.5. Dry and Green hardness tests

Figure 4 shows no significant changing on the results for “silica #200” for the both tests (dry and green) independent of its content.

It was observed that for “refractory wastes” the green hardness maintained the same results independent of its content. It was still noted that the dry hardness decreasing with a refractory content increasing. But it is necessary to clarify that the hardness results for 50% of refractory wastes content are similar to that obtained to silica #200, which suggests that it is possible to use 50% with refractory wastes without any property detriment.

Comparing the interaction plots with a mixture of 50% of refractory waste and 50% of silica #200, it is noted that the hardness results are higher when they were used refractory wastes.

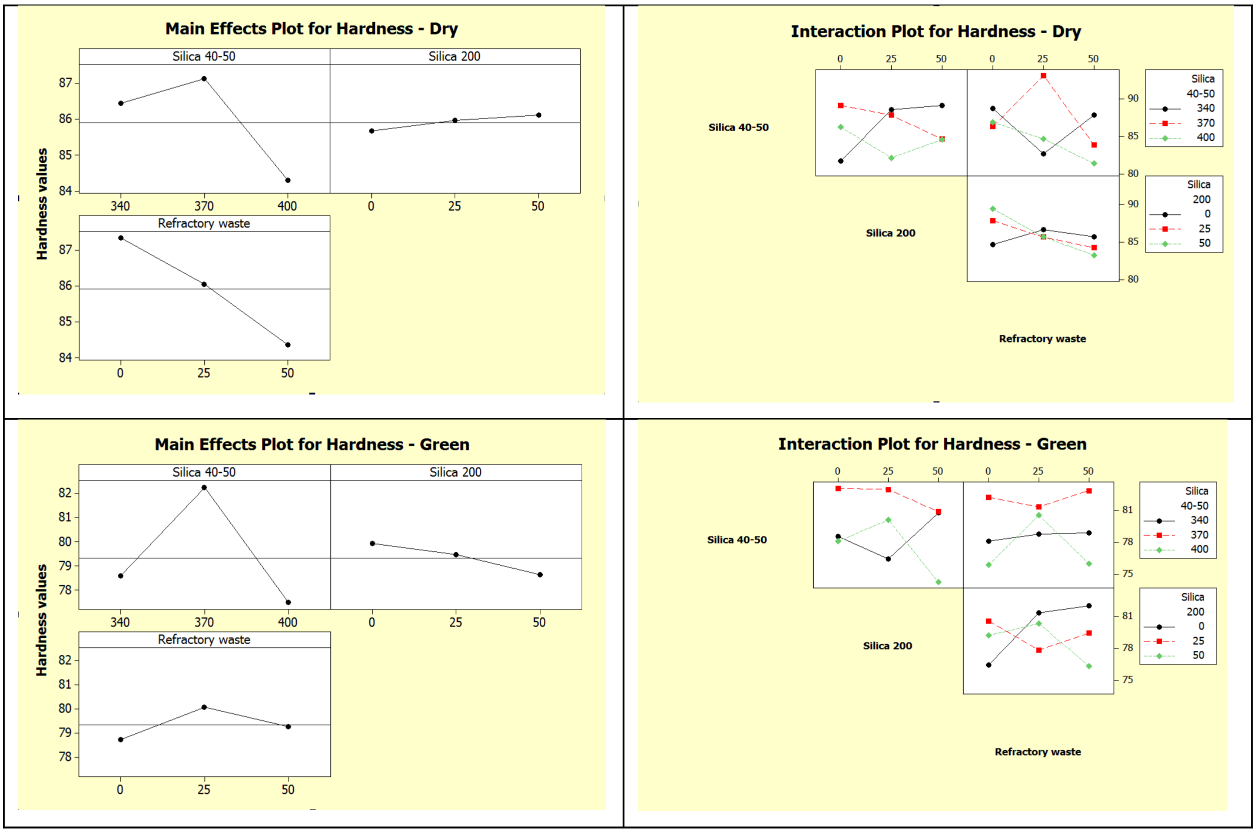

Figure 4. Main effects and interaction plots for dry and green hardness.

4.6. Humidity tests

Figure 5 shows no significant changing on the results for “refractory wastes” experiments, which suggest that a 100% replacement is possible. It is noted that for “silica #200” the changing on its content could impact on the humidity result.

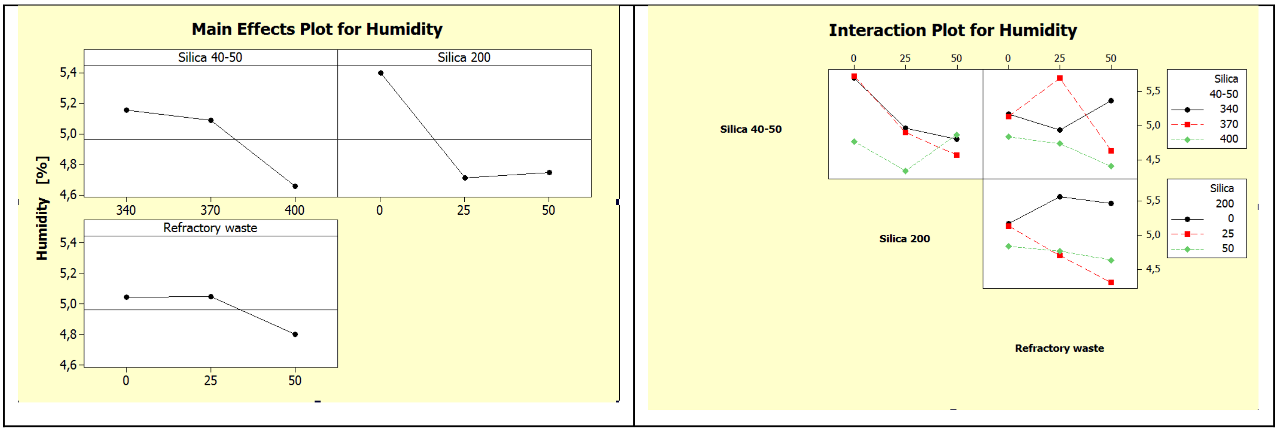

Figure 5. Main effects and interaction plots for humidity.

4.7. Relationship between the parameters

Figure 6 shows that there is a direct correlation between “dry tensile strength” and “dry compression strength” (see the arrow on the graph showing that tendency). The results point out to the follow relation: dry compression = 2.6 x tensile strength. So these both parameters can be used satisfactorily to analyze the mixture behavior.

There isn’t correlation between “dry compression strength” and “green compression strength”. So it must be careful with the use of “green compression” to avoid erroneous understanding. The results are too close independent of its values, which suggest that “green compression” isn’t a trustable data. Considering that, it is recommended the use of “dry compression strength”.

They were not found correlations between “dry compression strength” or “green compression strength” and “humidity”, which suggest that humidity cannot be used as the unique analysis parameter.

There isn’t correlation between “compacting” and “green hardness” or between “dry hardness” and “green hardness”. These results reinforce the need to be careful on the use of “green hardness”, because this test could not be totally correct.

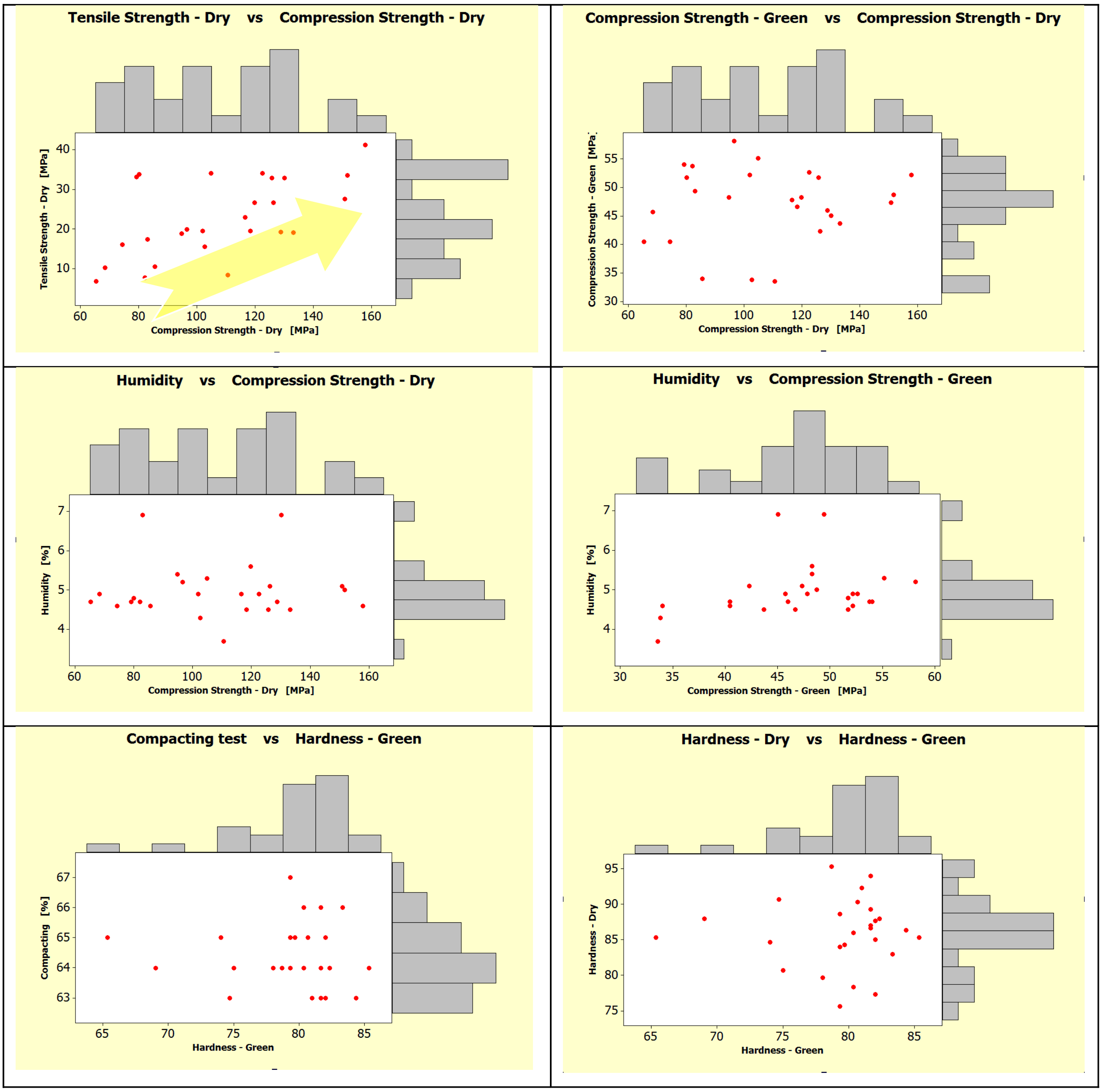

Figure 5. Relationship between parameters.

5. CONCLUSION

The mechanical testsresults suggest that the "refractory wastes" could be used on the preparation of sand used in a casting process replacing until 50% of "silica #200", without risks for the casting.

This alternative allows reducing the total cost of sand preparation because the reduction on the "silica #200" consumption. It is still possible to save money because the residues won't to be sent to graveyard. The waste can be used in the process.

The total replacement of "silica #200" by "refractory waste" is not advisable. Additional tests and a real casting must be conducted to evaluate this possibility.

The results indicate that it is possible to perform this replacement, which could reduce the total preparation cost about 7% (R$ 45,000.00 per year).

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