Characterization of No-Bake Phenolic-Isocyanate and Furanic Binders in Different Base Metal Casting Sands

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ABSTRACT

This paper presents test results for silica and corundum base metals casting sands. Standardized tests were carried out to understand physical and mechanical properties of the metal casting sands and molding mixtures prepared with these refractory bases. Grain distribution, grain size, grain shape classification, moisture content, pH, LOI, Weibull distribution tensile test, permeability, and roughness are the properties that have been evaluated. Tensile, permeability, and roughness tests are carried out with different molding mixtures changing base sand and Phenolic-isocyanate and Furanic binders. The results of the tensile test were adjusted to a Weibull distribution. Weibull modulus of each molding mixture and the strength at a probability of failure of 63% is obtained. The permeability and roughness results were subjected to ANOVA and t-test. Regular grains contributes to increase strength of molding mixture while permeability is not affected by time and amount of binder.

KEYWORDS

ANOVA Analysis and T-Test, Corundum, Molding Mixture, Silica Sand, Weibull Distribution

I. INTRODUCTION

The molding mixture is the result of the combination between base refractory sand and chemical binder. The analysis of base sand and molding mixture is of great importance for the foundry industry because its quality influences the production process of metal castings products (Dańko et al., 2015). However, a great variety of base sands and chemical binders makes it difficult find the best mixture combination. The choice of the molding mixture is considered correct when it does not present problems during the casting process and produces parts with a good quality. Chemical binder no-bake molding is usually applied in foundry industry with two representative molding systems PUNB (phenolic urethane resin) and FA (furan resin), both are commonly used in foundry processes that varies depending on the size of the casting, chemical composition of the material to be cast, reuse of base sand, among others (Lucarz et al., 2019). Depending on the type of base sand, type of binder and quantity of binders, the properties and characteristics between one and another molding mixture may substantially vary. Variations can positively or negatively affect the casting process.

DOI: 10.4018/IJMMME.299042 *Corresponding Author

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In this research, the effect of base sand characteristics such as grain distribution, grain size and grain shape classification, moisture content, pH and LOI on tensile strength, permeability and roughness are investigated. In addition, the present study evaluates the behavior of the molding mixture by adjusting the tensile strength results to a Weibull distribution as recommended for ceramic like materials (Li et al., 2017) (Basu et al., 2009). Additionally, by means of ANOVA and T-Test analysis, the effect of time and quantity of binders on the permeability of various molding mixtures was assessed. Similarly, the effect of the base sand, type of binders, amount of binders and brand of binders on the roughness of various molding mixtures is analyzed. These analyzes are important because the quality of the base sand and molding mixtures has a great influence on the production of castings.

II. MATERIAL AND METHOD

A. Materials

For the development of this research, types of silica sands from two different suppliers (Sierra Central and Sibelco) is uses. Another, corundum base sand from a third supplier (Cast Ball from Mineração Curimbaba) is also studied. A summary of the main characteristics of these base sand is presented in Table 1. On the other hand, phenolic-urethane (PUNB) and furanic resin (FA) are the chemical binders applied in the research due to their widespread use.

The molding mixtures to be evaluated are shown in Table 2. In the table the abbreviation PUNB means Phenolic-urethane No Bake System and the abbreviation FA means Furan Resin. Characteristics such as grain size, amount of fine powder, moisture content, pH and LOI, were determined based on procedures given in the Mold & Core Test Handbook from AFS.

The classification of the grain shape is carried out based on Figures 1, 2 and 3. According to the AFS 1107-12-S procedure, the shape of the different base sands is as follows: Sibelco silica sand and Sierra Central silica sand have a subangular shape and Corundum Cast Ball has a rounded shape.

Table 1. Characteristics of the base sands used

| Base sand            | Grain Size AFS index | Amount of fine powder (%) | Moisture content (%) | pH  | LOI (%) |
|----------------------|----------------------|---------------------------|----------------------|-----|---------|
| Silica sand Sierra Central | 39,42                | 0,34                      | 0,02                 | 7,15| 0,3     |
| Silica sand Sibelco  | 56,09                | 2,18                      | 0,05                 | 7,08| 0,55    |
| Corundum Cast Ball   | 51,46                | 1,94                      | 0,01                 | 6,84| 0,03    |

B. Molding mixture

The molding mixtures made for the production of traction and permeability specimens were made with the different base sands shown in Table 1, different type of binders (PUNB and FA), different amounts of binder as shown in Table 2. The process for making tensile and permeability specimens is carried out in accordance with the GB / T2684-2009 standard.

The compositions of Tables 3, 4 and 5 correspond with the amount of binders used for the elaboration of each molding mixture seen in Table 2. It should be stated that the binders come in parts, so one must mix the parts in order to fully form the binder. Tables 3 and 4 show the amount of parts for PUNB systems: Total resin 1% of the total amount of base sand, Part I 55% of the total resin, Part II 45% of the total resin and Part III 1% or 5% of Part I. Part III is a very small amount which must be mixed separately with Part I (100 gr Part I and 1 to 5 gr of Part III are recommended). This interpretation also applies when the amount of resin is 1.4% with the percentages for said
concentration. Similarly, using the FA (furan resin) molding system, Table 5 shows the composition used that mentions: 1% resin of the total amount of base sand, catalyst 35% of the total amount of resin. In the same way, it would be interpreted for 1.4% resin.

In the case of the present study, 800 grams of base sand was used to prepare the traction test pieces and 1000 grams to make the permeability test pieces. The binders used for each base sand are shown in Tables 6 and 7.

According to the GB/T2684-2009 standard, the process for the elaboration of the molding mixture using phenolic-urethane resin was as follows: place the base sand in the mixer, add the mixture Part I and Part III (previously prepared according to the recommendations given previously) and mix for 1 min, finally add part II and mix for 1 minute and immediately make the traction or permeability specimens. Using furan resin to make the molding mixture, the procedure was as follows: place base sand in the mixer, add catalyst and mix for 1 min, add resin and mix for 1 minute and immediately make the traction or permeability specimens. (Li et al., 2017)

III. RESULTS AND DISCUSSION

A. Tensile strength adjusted to a weibull distribution

The Weibull distribution is an indicator of the variability of the resistance of materials resulting from the distribution of defects of different sizes in the structure of the material. The fit of tensile strength data to a Weibull distribution has several steps:
Figure 2. *Silica sand Sierra Central, magnification x20.*

Figure 3. *Silica sand Sibelco, magnification x20.*
1) Calculation of coefficient of variation with the tensile strength data of 6, 12, 18, 24 and 20 specimens excluding 2 minimum and maximum strength values (24 specimens). The coefficient of variation is used to determine if the data obtained are adequate for statistical analysis, a coefficient of variation of less than 15% is necessary (Mitra, 2008). Finally, the elaboration of 24 specimens is chosen and to exclude 2 maximum and 2 minimum resistance values for each molding mixture. This step must be done only once with the tensile strength data of the first molding mixture to know how many tensile specimens should be made.

2) Elaboration of 24 tensile specimens with each molding mixture shown in Table 2 for two polymerization times (2 and 4 hours), calculate the coefficient of variation of each one with 20 data previously excluded 2 minimum and 2 maximum resistance values (total 24 tested specimens). Twenty four tensile specimens were made for each molding mix, a total of 720 tensile specimens were made for all molding mixtures.

3) With 20 data selected from each molding mixture, with the help of a spreadsheet, it is ordered from lowest to highest and each resistance value is related to the value of a probability estimator, this probability is called “probability of failure F(V)”. The probability estimator chosen is shown in equation (1) where “i” is the position of the resistance value when it was ordered from lowest to highest and “n” the amount of resistance data. (McDowell & Amon, 1992) (Mitra, 2008)

4) Finally, equation (2) and equation (3) are used to calculated the logarithm of the resistance and the probabilistic estimator. With the data obtained, the graphic “equation (2) vs. equation (3)” of each molding mixture is made. The Weibull modulus and resistance with a probability of failure “F (V)” of 63% of each molding mixture at different polymerization times were obtained. (McDowell & Amon, 1992)

\[ F = \frac{i - 0.5}{n} \]  

(1)

| Type of binder | Binders brand | Sand Brand | Amount of binders |
|---------------|---------------|------------|-------------------|
| PUNB          | SQ            | Silica sand Sierra Central | 1%               |
|               | SQ            | Silica sand Sibelco | 1%               |
|               | SQ            | Corundum Cast Ball | 1%               |
|               | Mancuso       | Silica sand Sierra Central | 1%               |
|               | Mancuso       | Silica sand Sibelco | 1%               |
|               | Mancuso       | Corundum Cast Ball | 1%               |
| FA            | SQ            | Silica sand Sierra Central | 1%               |
|               | SQ            | Silica sand Sibelco | 1%               |
|               | SQ            | Corundum Cast Ball | 1%               |

Table 2. Molding mixtures for tensile and permeability specimens.
Table 3. Composition of molding mixtures with punb (phenolic-urethane) system and sierra central silica sand or corundum cast ball.

| Composition for molding mixtures with PUNB system |
|--------------------------------------------------|
| Total resin (Part I+II+III) | 1% | 1.40% |
| Part I | 55% | 50% |
| Part II | 45% | 50% |
| Part III | 1% | 1% |

Table 4. Composition of molding mixtures with punb (phenolic-urethane) system and sibelco silica sand.

| Composition for molding mixtures with PUNB system |
|--------------------------------------------------|
| Total resin (Part I+II+III) | 1% | 1.40% |
| Part I | 55% | 50% |
| Part II | 45% | 50% |
| Part III | 5% | 5% |

Table 5. Composition of molding mixtures with fa systems (furan resin) and sierra central, sibelco silica sand or corundum cast ball.

| Composition for molding mixtures with FA system |
|------------------------------------------------|
| Resin | 1% | 1.40% |
| Catalyst | 35% |

Table 6. Brand of binders and base sands used for the elaboration of molding mixtures with phenolic-urethane resin.

| Binders brand | Base sand | Binders PUNB | Part I | Part III | Part III |
|---------------|-----------|--------------|--------|----------|----------|
| Mancuso       | Corundum Cast Ball | Resin Rapidur | B727   | Catalyst Medium Slow C3 400 |
|               | Silica sand Sierra Central | Resin Rapidur A733 |   | Catalyst Fast C 550 |
|               | Silica sand Sibelco |   |   | Catalyst Fast C 550 |
| ShengQuan     | Corundum Cast Ball | Resin SQ 101 HB |   | Catalyst Slow NP 103E |
|               | Silica sand Sierra Central | Resin SQ 102 HB |   | Catalyst Fast NP 103 |
|               | Silica sand Sibelco |   |   | Catalyst Fast NP 103 |
Table 7. Brand of binders and base sands used for the elaboration of molding mixtures with furan resin.

| Binders brand | Base sand          | Resin     | Catalyst |
|---------------|--------------------|-----------|----------|
| ShengQuan     | Corundum           | SQM 305A | GS03     |
|               | Cast Ball          |           |          |
|               | Silica sand Sierra Central |     |          |
|               | Silica sand Sibelco |           |          |

B. Permeability results evaluated by anova and t-test analysis.

Permeability is the ability of the molding mixture to allow the circulation of gases through it, allowing the escape of gases during the casting of liquid metal and during the cooling process. Low permeability values produce defects related to poor gas evacuation in the casting. (Aminnudin et al., 2020)

Permeability specimens are made with each molding mixture shown in Table 2 and tested at 2, 4 and 24 hours of polymerization time. Six permeability specimens were made for each molding mixture, a total of 90 permeability specimens were made for all molding mixtures. The representation of the data obtained was done with box and whisker diagrams because for each polymerization time 6 permeability specimens were tested, these data can be seen in Figure 10, Figure 11 and Figure 12.
Figure 5. Weibull distribution tensile strength of molding mixtures made with silica sand Sibelco and phenolic urethane binder.

Figure 6. Weibull distribution tensile strength of molding mixtures made with corundum Cast Ball and phenolic urethane binder.

Figure 7. Weibull distribution tensile strength of molding mixtures made with silica sand Sierra Central and furan resin.
The obtained permeability data were subjected to an ANOVA analysis to accept or reject the following null hypothesis:

- There is no influence of time on permeability (null hypothesis 1).

For the evaluation of this hypothesis, data that have the same base sand, type of binders and brand of binders were chosen. The results of this analysis are shown in Table 9. In addition, the permeability data obtained were subjected to a T-test analysis to accept or reject the following null hypothesis:

- There is no influence of the amount of binder on permeability (null hypothesis 2).
Table 8. **Weibull modulus and resistance with a probability of failure of 63%**

| Molding System | Molding Method | Wear Surface | Amount of Wear (mm) | Weibull Modulus (σ) | Resistance for P (%) |
|----------------|----------------|--------------|---------------------|---------------------|---------------------|
| **SQ**         | Silica and Sinted Central | 1%           | 2 PUNB-SC-SQ1% 2    | 20.18 0.28          |                     |
|                |                |              | 4 PUNB-SC-SQ1% 4    | 11.47 0.95          |                     |
|                |                |              | 2 PUNB-SC-SQ1% 4    | 14.44 0.4           |                     |
|                |                |              | 4 PUNB-SC-SQ1% 4    | 17.04 0.51          |                     |
|                | Silica and Sheldow | 1%           | 2 PUNB-SC-SQ1% 2    | 16.15 0.18          |                     |
|                |                |              | 4 PUNB-SC-SQ1% 4    | 19.4 0.33           |                     |
|                |                |              | 2 PUNB-SC-SQ1% 4    | 17.19 0.52          |                     |
|                |                |              | 4 PUNB-SC-SQ1% 4    | 11.17 0.49          |                     |
|                | Cornedum Cast Ball | 1%           | 2 PUNB-SC-MA1% 2    | 29.93 0.25          |                     |
|                |                |              | 4 PUNB-SC-MA1% 4    | 15.6 0.51           |                     |
|                |                |              | 2 PUNB-SC-MA1% 4    | 18.59 0.51          |                     |
|                |                |              | 4 PUNB-SC-MA1% 4    | 20.9 0.44           |                     |
| **Mascon**     | Silica and Sinted Central | 1%           | 2 PUNB-MC-MA1% 2    | 11.58 0.22          |                     |
|                |                |              | 4 PUNB-MC-MA1% 4    | 9.3 0.29            |                     |
|                | Silica and Sheldow | 1%           | 2 PUNB-MC-MA1% 2    | 19.38 0.93          |                     |
|                |                |              | 4 PUNB-MC-MA1% 4    | 15.51 0.54          |                     |
|                | Cornedum Cast Ball | 1%           | 2 PUNB-MC-MA1% 2    | 11.89 0.51          |                     |
|                |                |              | 4 PUNB-MC-MA1% 4    | 19.02 0.55          |                     |
| **FA**         | Silica and Sinted Central | 1%           | 2 FA-SC-SQ1% 2      | 19.89 0.49          |                     |
|                |                |              | 4 FA-SC-SQ1% 4      | 19.52 0.46          |                     |
|                |                |              | 2 FA-SC-SQ1% 4      | 16.05 0.58          |                     |
|                | Silica and Sheldow | 1%           | 2 FA-SC-SQ1% 2      | 16.48 0.41          |                     |
|                |                |              | 4 FA-SC-SQ1% 4      | 12.99 0.46          |                     |
|                |                |              | 2 FA-SC-SQ1% 4      | 14.28 0.49          |                     |
|                |                |              | 4 FA-SC-SQ1% 4      | 14.83 0.51          |                     |
|                | Cornedum Cast Ball | 1%           | 2 FA-SC-SQ1% 2      | 17.95 0.41          |                     |
|                |                |              | 4 FA-SC-SQ1% 4      | 21.05 0.43          |                     |
|                |                |              | 2 FA-SC-SQ1% 4      | 14.27 0.49          |                     |
|                |                |              | 4 FA-SC-SQ1% 4      | 23.83 0.56          |                     |
Figure 10. Permeability of molding mixtures made with corundum Cast Ball and phenolic-urethane (PUNB) or furan (FA) binders.

Figure 11. Permeability of molding mixtures made with silica sand Sierra Central and phenolic-urethane (PUNB) or furan (FA) binders.

Figure 12. Permeability of molding mixtures made with silica sand Sibelco and phenolic-urethane (PUNB) or furan (FA) binders.
Table 9. Results of ANOVA analysis performed with a level of significance $\alpha = 0.05$. The influence of time on permeability is evaluated (null hypothesis 1)

| Type of binders | Binders brand | Sand Brand | Amount of binders in percentage of sand | probability resulting from ANOVA analysis |
|-----------------|---------------|------------|----------------------------------------|------------------------------------------|
| PUNB            | SQ            | Sierra Central | 1%                                    | 0,32                                     |
|                 |               |            |                                        |                                           |
|                 | SQ            | Sibelco | 1%                                    | 0,54                                     |
|                 |               |            |                                        |                                           |
|                 | SQ            | Cast Ball | 1%                                    | 0,82                                     |
|                 |               |            |                                        |                                           |
|                 | SQ            | Sibelco | 1%                                    | 0,92                                     |
|                 |               |            |                                        |                                           |
| Mancuso         | Sierra Central | 1% | 0,24                                  |
| Mancuso         | Sibelco | 1% | 0,64                                  |
| Mancuso         | Cast Ball | 1% | 0,82                                  |

Table 10. Results of the T-Test analysis to evaluate “null hypothesis 2” of molding mixtures made with Cast Ball corundum

| Polymerization time | Type of binders, brand and quantity of binder to compare |
|---------------------|--------------------------------------------------------|
|                     | PUNB SQ 1% y 1,4% | FA SQ 1% y 1,4% |
| 2 hours             | 0,149          | 0,474          |
| 4 hours             | 0,104          | 0,415          |
| 24 hours            | 0,052          | 0,390          |

Table 11. Results of the T-Test analysis to evaluate “null hypothesis 2” of molding mixtures made with silica sand Sibelco.

| Polymerization time | Type of binders, brand and quantity of binder to compare |
|---------------------|--------------------------------------------------------|
|                     | PUNB SQ 1% y 1,4% | FA SQ 1% y 1,4% |
| 2 hours             | 0,127          | 0,217          |
| 4 hours             | 0,203          | 0,170          |
| 24 hours            | 0,098          | 0,270          |
For the evaluation of this hypothesis, data that have the same base sand, type of binders and binder brand were chosen. The results of this analysis are shown in Table 10, Table 11 and Table 12. ANOVA and T-test are well know statistical tools used to identify if certain factors have a significant effect on the final result. Anova analysis is used to compare the mean of 3 or more data sets while T-Test is used to compare the mean of only 2 data sets.

C. Roughness Results Evaluated by Anova and T-Test Analysis

In the roughness test, permeability specimens of each molding mixture (15 in total) were evaluated to measure its roughness, the equipment used was an Elcometer 224/2 roughness tester with type P1 probe. 10 measurements were performed on each specimen, with these data ANOVA and T-test analysis was performed to evaluate the following null hypotheses:

a. There is no influence of the type of sand on the roughness (null hypothesis 3); Data are chosen from different base sands that maintain the same type of binders, brand and amount of binder
b. There is no influence on roughness when the amount of binder varies (null hypothesis 4); For the evaluation of this hypothesis, data were chosen that maintain the same base sand, type of binders and the binder brand.

Table 12. Results of the T-Test analysis to evaluate “null hypothesis 2” of molding mixtures made with silica sand Sierra Central.

| Polymerization time | Type of binders, brand and quantity of binder to compare |
|---------------------|--------------------------------------------------------|
|                     | PUNB SQ 1% y 1,4%                                      |
|                     | FA SQ 1% y 1,4%                                       |
| 2 hours             | 0,158                                                  |
|                     | 0,214                                                  |
| 4 hours             | 0,410                                                  |
|                     | 0,127                                                  |
| 24 hours            | 0,102                                                  |
|                     | 0,469                                                  |

For the evaluation of this hypothesis, data that have the same base sand, type of binders and binder brand were chosen. The results of this analysis are shown in Table 10, Table 11 and Table 12. ANOVA and T-Test are well know statistical tools used to identify if certain factors have a significant effect on the final result. Anova analysis is used to compare the mean of 3 or more data sets while T-Test is used to compare the mean of only 2 data sets.

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a. There is no influence of the type of sand on the roughness (null hypothesis 3); Data are chosen from different base sands that maintain the same type of binders, brand and amount of binder
b. There is no influence on roughness when the amount of binder varies (null hypothesis 4); For the evaluation of this hypothesis, data were chosen that maintain the same base sand, type of binders and the binder brand.

Figure 13. One-way ANOVA analysis diagram for roughness results of molding mixtures made with silica sand Sierra Central. (MathWorks, 2019)
There is no influence on roughness when the binder brand varies (null hypothesis 5); For the evaluation of this hypothesis, data were chosen that maintain the same base sand, type of binder and amount of binder.

The data obtained were graphed using a one-way ANOVA analysis diagram such as those shown in Figures 13, 14 and 15. The evaluation of these hypotheses was made using a significance level $\alpha = 0.05$ for ANOVA and T-test analysis.
Table 13. Average rugosity

| Identification code of molding mixture | Average rugosity (um) |
|---------------------------------------|-----------------------|
| PUNB-SC-SQ1%                          | 230,8                 |
| PUNB-SC-SQ1,4%                        | 221,1                 |
| PUNB-SI-SQ1%                          | 198,4                 |
| PUNB-SI-SQ1,4%                        | 219,4                 |
| PUNB-CB-SQ1%                          | 226                   |
| PUNB-CB-SQ1,4%                        | 273,8                 |
| PUNB-SC-MA1%                          | 247                   |
| PUNB-SI-MA1%                          | 240                   |
| PUNB-CB-MA1%                          | 249,6                 |
| FA-SC-SQ1%                            | 314,3                 |
| FA-SC-SQ1,4%                          | 316,3                 |
| FA-SI-SQ1%                            | 342,5                 |
| FA-SI-SQ1,4%                          | 269,4                 |
| FA-CB-SQ1%                            | 295,5                 |
| FA-CB-SQ1,4%                          | 314,8                 |

Table 14. Results of ANOVA analysis calculated with a significance level $\alpha = 0.05$ to evaluate the “null hypothesis 3”.

| Type, brand and amount of binders | Probability resulting from ANOVA analysis |
|----------------------------------|------------------------------------------|
| PUNB-SQ-1%                       | 0.65                                     |
| FA-SQ-1%                         | 0.68                                     |

Table 15. Results of the T-Test analysis to evaluate “null hypothesis 4”.

| Base sand                         | Probability resulting from T-Test analysis |
|-----------------------------------|-------------------------------------------|
|                                   | PUNB SQ 1% y 1,4%                          | FA SQ 1% y 1,4%                           |
| Silica sand Sierra Central        | 0.7751                                    | 0.9684                                    |
| Silica sand Sibelco               | 0.5164                                    | 0.1008                                    |
| Corundum Cast Ball                | 0.1338                                    | 0.0705                                    |

Table 16. Results of the T-Test analysis to evaluate “null hypothesis 5”.

| Base Sand                          | Probability resulting from T-Test analysis |
|------------------------------------|-------------------------------------------|
| 1% PUNB ShengQuan y Mancuso binder brand |                                           |
| Silica sand Sierra Central         | 0.6753                                    |
| Silica sand Sibelco                | 0.2334                                    |
| Corundum Cast Ball                 | 0.4597                                    |
D. Discussion

Table 1 shows the AFS index of each of the base sands used in this work. Sierra Central Silica Sand has an AFS 39.42 Index, Sibelco AFS 56.09 Silica Sand and Cast Ball AFS 51.46 Corundum. According to its AFS index, all base sands can be applied in the manufacture of castings. The maximum recommended fine powder content is 1%, above this amount the strength of the molding mixture begins to decrease or a greater amount of catalyst is needed to harden the molding mixture because the fine powder consumes the binder (Aminnudin et al., 2020)(Holtzer & Kmita, 2020). Table 4 shows the effect of fine powder on the amount of catalyst, this effect is better appreciated in type of binders where the catalyst has very small amounts, Table 4 shows that a greater amount of catalyst was needed to harden the molding mix due to the high content of fine powder in Sibelco silica sand. With corundum Cast Ball, this problem did not exist despite its high content of fine powder because corundum is an acidic sand that promotes the polymerization reaction.

For a correct activation of binders, a moisture content of less than 0.2% is recommended, above this amount the polymerization reaction is affected, becomes slow or can stop completely. Also, a high moisture content can decrease the strength of the molding mixture.(Holtzer & Kmita, 2020)

Additionally, pH of the base sand is related to the type and amount of catalyst to be used. With neutral base sands, there is no problem when using rapid polymerization reaction catalysts, slow polymerization reaction catalysts or using different amounts of catalyst as long as you work within the recommended parameters. Highly alkaline sands can neutralize the acid catalyst, slowing or stopping the polymerization reaction. Acid sands accelerate the polymerization reaction, sometimes the polymerization reaction is so fast that it does not allow the manufacture of tensile specimens, permeability specimens, or molds (Holtzer & Kmita, 2020). With acid sands, it is recommended to reduce the amount of catalyst or use a slow-reaction polymerization catalyst. Table 6 shows the different catalysts used for the silica and corundum sands. To know in more detail, the demand for the type and quantity of catalyst, it is recommended to carry out the ADV or acid demand test.

Figures 1, 2 and 3 show the shape of the base sand grains used in this work. Silica sand Sierra Central and Sibelco are subangular and Cast Ball corundum is round. Regular grain shapes reduce binder consumption for adequate strength because less binder is necessary to form a homogeneous layer around the grain of sand. For the same amount of binder, greater resistance is obtained with regular grains and less resistance with irregular grains. In addition, round grains increase the permeability of the molding mixture, subangular grains provide intermediate permeability, and angular grains have the lowest permeability due to their ease of compaction (Petrus et al., 2020)(Aminnudin et al., 2020).

Figures 4, 5, 6, 7, 8 and 9 show the tensile strength results adjusted to a Weibull distribution of all the molding mixtures shown in Table 2, at 2 and 4 hours of polymerization time, these graphs show the dispersion of tensile strength data that depends on the size distribution and number of defects in the structure of the molding mixture (Zhang et al., 2020). Therefore, the fewer defects the molding mixture has, it supports a greater stress, in contrast if the molding mixture has a large number of defects, it supports less stress.

Table 8. shows that the strength values vary between 0.22 (MPa) and 0.63 (MPa). The highest resistance with the PUNB molding system was obtained with Sierra Central silica sand and 1.4% quantity of binders with 0.51 (MPa). On the other hand, the highest resistance with the FA molding system was obtained with Sierra Central silica sand and 1.4% of the amount of binders with 0.63 (MPa). This result is attributed to the curing time, which with furanic resin is longer than with phenolic-urethane resin.

In addition, Table 8 shows Weibull modulus of each molding mixture. This modulus varies between 9.76 and 37.5 indicating a varied presence of defects in the structure of the specimens made with different molding mixtures because when the Weibull modulus has small values it means a dispersed distribution of defects but when the Weibull modulus has high values, the distribution of defects becomes homogeneous (Sharma & Penumadu, 2020).
Figures 10, 11 and 12 show the permeability values obtained and it can be seen that high permeability is obtained with Cast Ball corundum (round grains and AFS 51.46 index), medium permeability with Sierra Central silica sand (subangular grains and index AFS 39.42) and low permeability with Sibelco silica sand (subangular grains and AFS 56.09 index). The permeability is a function of the AFS index and the grain shape, although the AFS index of Sierra Central silica sand is lower than the AFS index of Corundum Cast Ball, the highest permeability is achieved with corundum due to the round shape of your grains.

Tables 9, 10, 11 and 12 show the results of the ANOVA and T-Test, it is shown that the resulting probability value is greater than the significance level ($\alpha = 0.05$), therefore the proposed null hypotheses are accepted. That is, the time and the amount of binder do not affect the permeability. Permeability does not vary as a function of time, because time affects the hardening of the molding mixture (polymerization reaction), which is directly related to tensile strength. In addition, the amount of binder does not affect permeability because it is used in very small quantities which do not reduce the spaces between sand grains allowing the free passage of air (Aminnudin et al., 2020).

Table 13 shows the average roughness of each molding mixture, the values presented seem to show variations among themselves, but to know if these variations are due to a specific factor or are simple statistical variations, an ANOVA or T-test analysis must be carried out, such as those shown in tables 14, 15 and 16 to accept or reject various null hypotheses.

Tables 14, 15 and 16 show the probability values resulting from the ANOVA and T-test analysis. These values show that the null hypotheses for roughness must be accepted. Therefore, the type of sand, amount of binder and brand of binder does not affect roughness. The roughness of a molding mixture is related to the surface quality of a casting. In the case of molding mixtures made with chemical binders, there are no notable differences between the roughness achieved with one or another base sand because in the base sand market it is a matter of having standard values of AFS indices between 35 and 60 (medium sand). In addition, roughness depends on the surface quality of the part model where the molding mixture is placed.

**IV. CONCLUSIONS**

The molding mixture (sand base-binders set) is a fundamental part of the casting process because the molding mixture allows all types of castings to be shaped. Therefore, excellent properties such as good resistance, high permeability, low consumption of binder, homogeneous grain of sand base, good affinity with binders, among others, are required.

High amounts of fine powder and moisture content decrease the strength of the molding mixture or require more catalyst to harden the composition. On the other hand, regular grains contribute to increase the resistance. This can be appreciated in Table 1 and 8.

The pH of a base sand is related to the type and amount of catalyst that must be used, the pH level can speed up or slow down the polymerization reaction (hardening of the molding mixture).

The tensile strength results conform to a Weibull distribution because the size distribution and number of defects present in the molding mix vary the strength. Therefore, when the molding mixture has fewer defects, it supports a greater stress, in contrast if the molding mixture has a large number of defects, it supports less stress.

The defects present in the molding mixture have two main sources: defects present in the structure of the base sand grain and defects present during the joining of sand grains by means of the binder (there are very small areas in the sand grain that were not covered by the binder). These defects are typical of the base sand, they are always present during the process of making the molding mixture and can only be minimized with routine inspections of the sand and following recommendations from binder suppliers.

The Weibull modulus calculated varies between 9.76 and 37.5 indicating a varied presence of defects in the structure of the specimens made with different molding mixtures from a sparse
distribution to a more equitable distribution of defects. In view of the fact that the weibull modulus is related to the variation of the resistance, the higher its value, the less variation between the results is obtained. Thus, an improvement of 284.22% is obtained using silica sand with furanic resin than with phenolic-urethane resin.

The permeability does not depend on the polymerization time or the amount of binders. The permeability depends on the AFS index, grain distribution and grain shape of the base sand.

The roughness of the base sands used in this work does not have a significant difference when the base sand, quantity or brand of binders varies. Roughness is related to the AFS index and grain distribution. In the molding sands used in the foundry industry there is no great difference among one or another base sand because the base sands available in the market are manufactured within a specific AFS index (average size AFS index between 35 and 60) for mixtures of chemically bonded molding. In addition, roughness depends on the surface quality of the part model where the molding mixture is placed.

FUNDING AGENCY

Open Access Funding for this article has been covered by the authors of this manuscript.

ACKNOWLEDGMENT

The present research is possible thanks to Company Fundireciclar and its board of directors for kindly providing materials, supplies and access to its facilities. We also thank Escuela Politecnica Nacional for funding part of the research through grant project PIS-20-03.
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