Brazilian Journal of Development

# Characterization of the Amazon river sand for the casting of parts in the naval industry

# Caracterização da areia do rio Amazonas para fundição de peças na indústria naval

DOI:10.34117/bjdv5n10-266

Recebimento dos originais: 20/09/2019
Aceitação para publicação: 21/10/2019

**Raimundo Nonato Alves da Silva**
Mestre em Gestão pela Universidade do Vale do Itajaí – UNIVALI
Instituição: Universidade do Estado Amazonas – UEA/Deptº. de Enga de Materiais e Programa de Doutoral em Engenharia Metalúrgica e de Materiais, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal
Endereço: Rua Dr. Roberto Frias, s/n 4200-465 Porto, Portugal
E-mail: rnasilva@uea.edu.br

**José Costa de Mâcedo Neto**
Doutor em Engenharia Química pela Faculdade de Engenharia Química – UNICAMP
Instituição: Universidade do Estado Amazonas – UEA, Deptº. de Engª de Materiais do PPGEM/EST/UEA
Endereço: Av. Darcy Vargas, 1200. Manaus – AM, 69050-020
E-mail: jotacostaneto@gmail.com

**Solenise Pinto Rodrigues Kimura**
Doutora em Engenharia Química pela Faculdade de Engenharia Química – UNICAMP
Instituição: Universidade do Estado Amazonas – UEA, Deptº. de Engª de Materiais do PPGEM/EST/UEA
Endereço: Av. Darcy Vargas, 1200. Manaus – AM, 69050-020
E-mail: solenisekimura@yahoo.com.br

**Bruno Mello de Freitas**
Mestre em Engenharia Mecânica pela Universidade Federal do Rio de Janeiro – UFRJ
Instituição: Universidade do Estado Amazonas – UEA, Deptº. de Engª de Materiais do PPGEM/EST/UEA
Endereço: Av. Darcy Vargas, 1200. Manaus – AM, 69050-020
E-mail: bfreitas@uea.edu.br

**João Carlos Martins da Costa**
Mestre em Ciência e Engenharia de Materiais Universidade Federal do Amazonas – UFAM
Instituição: Universidade do Estado Amazonas – UEA, Deptº. de Engª de Materiais do PPGEM/EST/UEA
Endereço: Av. Darcy Vargas, 1200. Manaus – AM, 69050-020
E-mail: jcarlosmartins.89@gmail.com

**Márcio da Silva Rabbi**
Mestre em Metalurgia pela Universidade Federal do Rio de Janeiro (UFRJ)
Instituição: Programa de Doutoral em Engenharia Metalúrgica e de Materiais, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal

Endereço: Rua Dr. Roberto Frias, s/n 4200-465 Porto, Portugal
E-mail: msrabbims@yahoo.com

**Marcionilo Neri da Silva Júnior**
Mestre em Ciências e Engenharia de Materiais pela Universidade de São Paulo (USP)
Instituição: Universidade Federal do Amazonas – UFAM, Deptº. de Engª de Mecânica
Endereço: Av. General Rodrigo Octávio Jordão Ramos, 1200. Manaus – AM, 69067-005
E-mail: marcionilo@ufam.edu.br

**ABSTRACT**

Concern about the environment is rising exponentially, mainly due to the availability of resources such as energy and raw materials. However, to preserve the environment, the foundry industries should contribute significantly to reducing the impacts generated by these activities, due to the high consumption of energy and raw materials, generating environmental impacts associated mainly with the generation of waste. Therefore, there is a great need to look for new alternatives for more sustainable production. Currently, in the city of Manaus, we have some foundry companies that use the Amazon river sand as raw material. Sand collection is nearby the city where there is a large concentration of sedimentary material. This paper presents the physical and chemical characterization of river sand through laboratory tests and tests. The results show sand that does not require chemical resin due to its refractory characteristics, because it is very thin and abundant, presents an opportunity to use in the melting of low melting alloys such as aluminium (Al), copper (Cu), among others, thus providing a very low cost. In the practical test, there was no sand washing, e.g., it was used in natura, and they have fluxing materials such as iron ($Fe_2O_3$) and titanium ($TiO_2$), materials that decrease the melting point of the material. In the sintering temperature tests, we have seen that the material has a low melting point compared to other types of feedstock having the same application (sand casting).

**Keywords:** Sustainable, Sand Moulding, Amazon River, Casting, Characterization.

**RESUMO**

A preocupação com o meio ambiente está aumentando exponencialmente, principalmente devido à disponibilidade de recursos como energia e matérias-primas. No entanto, para preservar o meio ambiente, as indústrias de fundição devem contribuir significativamente para reduzir os impactos gerados por essas atividades, devido ao alto consumo de energia e matérias-primas, gerando impactos ambientais associados principalmente à geração de resíduos. Portanto, há uma grande necessidade de procurar novas alternativas para uma produção mais sustentável. Atualmente, na cidade de Manaus, temos algumas empresas de fundição que utilizam a areia do rio Amazonas como matéria-prima. A coleta da areia fica nas proximidades da cidade onde há uma grande concentração de material sedimentar. Este artigo apresenta a caracterização física e química da areia do rio através de testes e testes laboratoriais. Os resultados mostram que a areia que não requer resina química devido às suas características refratárias, por ser muito fina e abundante, apresenta uma oportunidade de uso na fundição de ligas de baixo ponto de fusão, como alumínio (Al), cobre (Cu), entre outras, proporcionando assim um custo muito baixo. No teste prático, não houve lavagem de areia, por exemplo, foi usada in natura, e eles têm materiais em fluxo, como ferro ($Fe_2O_3$) e titânio ($TiO_2$), materiais estes que diminuem o ponto de fusão do material. Nos testes de temperatura de sinterização, vimos que a areia tem um baixo ponto de fusão em comparação com outros tipos de matéria-prima com a mesma aplicação (fundição em areia).

**Palavras-chave:** Sustentável, Moldagem em Areia, rio Amazonas, Fundição, Caracterização.

## 1. INTRODUCTION

The foundry industry has great importance in Brazilian and the world's economy, supplying its products to several sectors, especially the automotive. Among the manufacturing processes, the sand moulding process is more widely used for the production of metal parts (Bala and Khan, 2013).

The problem in this sector is a large amount of wasted sand discarded from the current smelting process, and there is the requirement of the regulatory organs for disposition in industrial landfills and recycling of these materials due to some chemical substances present in the mixture of these sands, which generates significant expenditures for the industries. When it is not possible to further reuse in the foundry it is removed from the foundry and termed as waste foundry sand (WFS) (Siddique *et al.*, 2010). Organizations must cultivate a management culture to foster the goal of being green and sustainable. We live in a moment of great changes, to leave the traditional, to allow innovation in the process of foundry to a greener level. Together with cost reductions, we can reach ecological improvements (Gigante, 2010). Some researchers in the field of alternative development are looking for new materials for the foundry industry where they can determine the suitability for casting production (Acharya *et al.*, 2014). Until now, recovery and recycling are the best environmental solutions to save raw materials and to reduce the amount of waste (Zanetti and Fiore, 2003). It is important to understand that many recent techniques and products attract the industry's attention as global research scales increase, greatly amplifying the environmental consequences, meaning you have to search for new outputs that nature offers (Dalquist and Gutowski, 2004). However, most of these have a focus on the determination of the refractory properties and are used as a binder in moulding sand. The Amazon has the largest hydrographic basin, and the sand of the amazon river has a high content of salt and fine sand, and it is sought to use in the processes where the current sand (synthetic sand) does not allow a great surface finish which will consequently reduce the cost with deburring, machining and even discarding operations, since this type of sand only needs water for its mixture, and it can be reused several times. For this, the first step to be taken is the characterization and the determination of the physical-chemical properties of this sand through a methodology of tests according to the regulating norms. After this process technological tests will be done, allowing for the visualization of surface finish results of the cast and fluidity of the material heated by the sand mould of the Amazonian river.

This study will reveal if it is possible to use this sand for casting aluminium alloys. Therefore, the importance of this project for future research in the casting of parts becomes crucial for technological development.

## 2. EXPERIMENTAL

### 2.1 METHODS AND MATERIALS

The company uses this river sand in the casting process of propellers (aluminium and copper) for boats, rudders and small parts destined to naval casting. After collecting the materials and the norms for the elaboration of tests, they were studied in the characterization and determination of the properties of the material to be analysed. As Bala and Khan (Bala and Khan, 2013) point out in their article "Characterization of beach/river sand for foundry application, to characterize a foundry material, the following tests are required: granulometry, moisture, fire loss, chemical analysis, determination of the sintering temperature and Permeability analysis. The tests that were carried out in this study followed ABNT (Brazilian Association of Technical Standards) and CEMP (Commission for the Study of Raw Materials). The goal of the test is to eliminate water by controlled heating and verification of the mass difference. This essay was prepared according to CEMP-105 norm (Fundição., 2003b). The sample weighed between 10g and 50g, in a previously tared container. Samples were placed in an oven between 105°C and 130°C for approximately 3 hours. After cooling in the desiccator, the samples were weighed. The result is expressed as a percentage, with an accuracy of 0,01 and is obtained with the following Equation 1:

$$U = \frac{(\mathrm{Mpf+Ma}) - (\mathrm{Mpf+Mr})}{\mathrm{Ma}} \, x \, 100 \qquad \text{(Eq. 1)}$$

**Granulometry.** To determine the granulometry, the ideal for this test would be dry particle size distribution, which consists of passing the material through a sequence of standard sieves according to the ABNT norm, but due to the high concentration of clay in the material, the use of the pipette method was recommended. This methodology is used by Embrapa - a Brazilian company of agricultural research. This methodology is based on the fall velocity of the particles that compose the soil. Five samples were made, each containing 20g of material in each beaker. The time for vertical displacement in the soil suspension with water was fixed after the addition of a chemical dispersant (soda or Calgon). A volume of the suspension deposited in the beaker is pipetted, to determine the clay that is dried in an oven and then weighed. The coarse fractions (fine and coarse sand) are separated by sieve, oven dryness and weight to obtain the respective percentages. The silt corresponds to the complement of the percentages for 100% of the material. It is obtained by differentiating the other fractions concerning the original sample.

X-ray Fluorescence. The basic principles of X-ray fluorescence spectrometry analysis consist of applying a source of high energy radiation (gamma radiation or X radiation) that causes the reaction of the atoms of the substance that we intend to analyse (Beckhoff *et al.*, 2007). For this essay, 3 samples were supplied, sprayed in eppendorf flasks with their identifications and duly packed for the Crowfoot Group of X-ray methods. For each sample, with the aid of a 10,000 Kgf press, fine-particle pellets of uniform granulometry were prepared, the composition of which contained 1,000g of the sample, homogenized with 4,000g of $H_3BO_3$ of high purity in agate mortar. All samples were analysed in triplicate. The analysis was performed on Rigaku-brand X-ray fluorescence (WD-XRF), Model Supermini with a palladium tube, 200s exposure time, with the power of 200W. The conditions were adjusted taking into account the sample matrix and the sample holder. All elements were identified by their Kα and/or Kβ energies (K. Janssens, 2003). The analysing crystals LIF 200, PET and RX25 were used. In this equipment, the SC and PC detectors were available and used in the analysis of these samples.

X-ray diffraction. Three samples were supplied, sprayed in eppendorf flasks with their identifications and duly packed for the Crowfoot Group of X-ray methods. Each sample was pressed in its aluminium sample port with the help of a glass slide because it was an amorphous material and therefore did not interfere with the analysis result. The samples were analysed by X-ray diffraction (XRD) in polycrystalline samples with Shimadzu® XRD 6000 equipment, CuK α radiation, 40 KV, 30 mA, 2.0 0 / min speed, 0.020 0θ steps, with scanning between 3 and 90. From the diffraction data, and with the help of tabulated values, it was possible to obtain the identification of the different phases present in the sample. To calculate the crystallinity of the material, the following methodology was used according to equation 2:

$$x = \frac{1}{\frac{(1 + K \times La)}{Lca}}$$

(Eq. 2)

In this formula, it is assumed that the total intensity of the crystalline part of the sample is Icr, that the amorphous part is Ia, and K is the constant that relates the scattering intensity of the amorphous part.

## 2.2 RESULTS AND DISCUSSION

Practical tests were carried out in the foundry laboratory on a cylindrical spur gear with 120 mm diameter, following the following steps: compacting the sand and adjusting the model inside; positioning the feed and climb channel models (followed by their removal); metal casting and shakeout of the part. In addition to the materials mentioned above, a crucible with a capacity of 1.2 L was used, a wooden box for forming the mould and a muffle furnace for melting the material. The use of refractory material, which would involve the piece, was dispensed with since there was an intention to study the possible defects in the piece with the lack of it, since the possibility of failure would be less with the presence of them. Table 1 shows the material that was used in the test.

Table 1. Materials used

| Material | Application |
|---|---|
| Aluminium alloy AA5052 | Metal |
| Amazon river sand | Material |
| Brand polystyrene: styroform | Construction of the model |

After shakeout and cooling the part, it was possible to visualize defects on the surface of the casting. These anomalies are characterized by small voids that provide an aspect of deformation in the part. This phenomenon occurred with the aggregation of sand in the part. Shrinkage of the cast gear may also be observed. In Figure 1 this fact can be verified in the reduction of the dimensions in Table 2, confirming the reduction of the volume that occurred during the casting process.

Table 2. Difference of measurements between model and cast

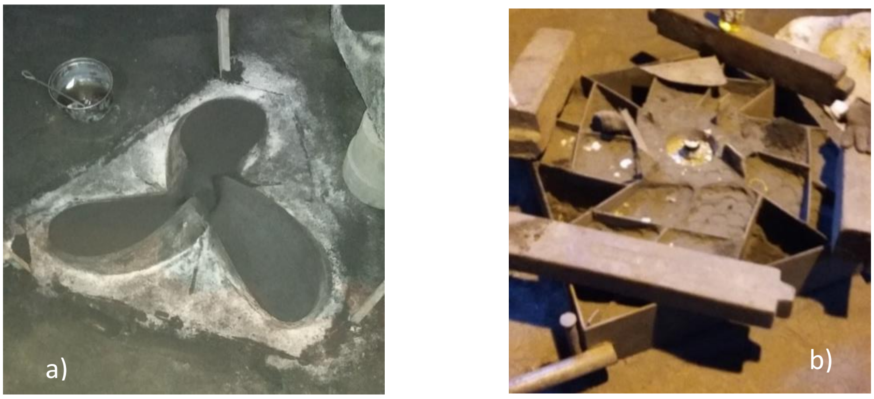
| Material | Application |
|---|---|
| Aluminium alloy AA5052 | Metal |
| Amazon river sand | Material |
| Brand polystyrene: styroform | Construction of the model |

Figure 1: (a) polystyrene model and (b) aluminium part AA5052

This type of phenomenon can be linked to the lack of use of refractory material, which would involve the part during the process, as this would facilitate the escape of gases to the sand and protect the part in such a way that there is low adherence of sand to the surface of the casting. However, currently, the sand of the Amazon River is used in the manufacture of aluminium and company

'Fundição Barbosa of nautical products Ltda., Manaus city. Figure 3, examples of boat propellers cast with sand from the river.

Figure 3: (a) Cast of a propeller. (b) Propeller Model (courtesy Fundição Barbosa Ltd.)




**Loss to fire.** Three (3) samples of material from the Amazon River were tested for better result evaluation. The norm used for the test was CEMP-120 (Fundição., 2003a). After the results were collected, a mean was obtained between results. With this, we observed that the samples had a loss of approximately 5.6% of organic matter. A high value compared to the results of fire loss of materials that have similar applications. Knowing this information is important because of the concentration of organic matter influencing the quality of the final parts, which can generate defects in the surface finish of the cast piece caused by the gases of the organic matter.

**Moisture content.** Three samples were used as well. A mean was obtained between sample results. The result was approximately 8.73% moisture content. The moisture content of the base material for casting is a very important variable for the performance of this material in the process, being harmful due to the non-cohesion and adhesion between sand and clay particles. However, the result of this test. does not influence the process of the casting pieces manufacturing, since the material does not undergo any kind of mixing with another refractory element, except water.

**Sintering temperature.** The result of the sintering test provided information on the temperature at which the material begins to undergo fusion. According to the test, the material begins to undergo fusion at a temperature of 1100°C. Four samples were sintered by the calcination method. The first sample was subjected to a temperature of 1000°C, the second sample was subjected to a temperature of 1050°C, the third one to 1100°C and the fourth one to a temperature of 1200°C. After the samples were passed through the muffle oven, they were analysed under a microscope with an increase of 40. With this result we can select the type of ferrous or non-ferrous material that can be leaked in the mould made with this Amazonian Ground of floodplain material and as a consequence obtain a minimum loss mould material**.**

**Granulometry.** To evaluate this characteristic, the pipette method based on the Embrapa - Brazilian Agricultural Research Corporation methodology was used. The main goal of this test is to determine the percentage of sand, clay, and silt present in the samples. In Table 4, it is indicated the result in a percentage of each mineral present in the sample. For the determination of the fractions of clay, silt, and sand we used 20g of the floodplain material of the Amazon river. The essay was performed according to the Embrapa methodology

Table 4: Percentage of Materials present in the sample.

| Mineral | [wt%] |
|---|---|
| Final sand | 34,78 |
| Coarse sand | 0,40 |
| Clay | 32,67 |
| *Silte* | 32,15 |

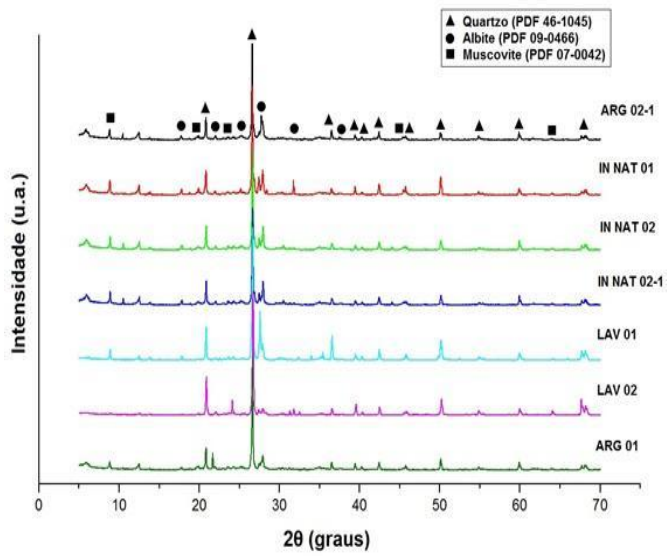
As it can be observed, the sample has high values of clay and silt, minerals that are considered contaminants for the mixing process with resins and catalysts in the industries. Another fact that we can cite is that the greater the presence of fine particles such as clay and silt, the less permeability of the mould, i.e., more defects will arise. However, this material is prepared for moulding only with the addition of water in its composition. The water only serves to bind the clay and silt particles with the grains of sand. Another aspect that we can raise is the percentage of final sand present in the sample. According to researchers in the field, fine sand is ideal to give a better surface finish in the cast.

**Fluorescence of X-rays**. For all samples, the same chemical elements were observed: Si (silicon), Na (Sodium), P (Phosphorus), Al (Aluminium), K (Potassium), Ca (Calcium) and Fe (Iron). There is a very large concentration of CaO (Calcium Oxide) and $K_2O$ (Potassium Oxide). Another point that we can mention is the presence of silicon dioxide that acts as a refractory element in the casting process. However, X-ray fluorescence analysis also showed the presence of fluxing materials, such as iron ($Fe2O_3$) and titanium ($TiO_2$), that is, materials having a low melting point, making it impossible to study for materials that have a high melting point such as steel and cast iron, metals that are widely used in metallurgy.

**Diffraction of X-rays.** Through the X-ray diffraction (XRD) analysis, the samples were submitted with the purpose of identifying their ceramic mineral compounds and thus to identify if there were actually refractory compounds. In Fig. 4 we can visualize the diffractograms of the samples analysed.

Figure 4: Diffractograms of analysed samples

**Intens**




**20 (degrees)**

In all of the analysed samples, we identified the argillo-minerals of the groups of Quartz ($SiO_2$), Albite ($NaAlSi_3O_8$) and Muscovite ($KAl_2Si_3AlO_{10}$ $(OHF)_2$). In the LAV 02 sample, the Muscovite phase was not identified at angles between 7° and 9°, however, in all other samples, it was possible to see this phase. The same behaviour of the sample LAV 02 is possible to see in the angles near 17º and 18°, and there is no presence of the Albite phase. In other samples, it was possible to observe this phase, even though in some samples this peak had the lowest intensity.

The phase of the quartz clay group appeared with great intensity in all samples at the angle of approximately 27°, this behaviour of silicon dioxide ($SiO_2$) is consistent with studies (Oliveira, 2012; Kim et al., 2016; Wang, Li, Du, Tang, et al., 2016; Wang, Li, Du, Yang, et al., 2016). The refractory compound Albite is also present in approximately 30°, with this behaviour being similar to Mulita ($Al_2O_3SiO$). This analogy was also described in the work of Kim and Oliveira(Oliveira, 2012; Kim et al., 2016). These refractory ceramic compounds are extremely important because their presence guarantees the application in sand casting moulds, and these peaks corresponding to JCPDS cards and these groups of clay minerals were discussed in others works (Wang, Li, Du, Tang, et al., 2016). Because of this analysis, it can be concluded that the natural raw material contains all the components for the application of this work, however, it is worth stressing that it is interesting to do the washing with the sieving to remove organic matter and compounds with Coarser grades. However, no further washing of the material is recommended because, according to its cleaning, parts of the refractory materials such as Albite ($NaAlSi_3O_8$) no longer appear and the other compounds already appear with a lower intensity. This is noticeable in other samples with different behaviours of intensity and the presence of the compounds of Quartz ($SiO_2$) and Albite ($NaAlSi_3O_8$) and Muscovite ($KAl_2Si_3AlO_{10}$

(OHF) 2 are important since their structure contains the presence of silicon oxides and this gives the most refractory behaviour.

## CONCLUSION

In the collected material from the river there was a minimum concentration of sand, fundamental for its refractory characteristics. In the fire loss test, the material presented an expressive loss of organic material. This occurred because the one sample of the material was not treated after the collection of the river.

Due to the high concentration of fine minerals (clay and silt), it can cause defects in the part, such as porosity, lack of gas output, poor finishing, and a consequence is the generation of more costs concerning the final piece.

In the diffraction test, that is, X-ray fluorescence, it was possible to know the chemical characteristics of this material, where its diffraction was evaluated, and regardless of the preparation of the raw material before the casting process, it can be used washed or in natura.

The material has the same mineralogical phases, and only one washing is recommended for the removal of the organic material. The samples (washed or in natura) present fluxing materials such as iron (Fe2O3) and titanium (TiO2), materials that decrease the melting point of the material. The result of the sintering temperature, it was observed that the material has a low melting point compared to other types of raw material having the same application (melting).

Therefore, the material under study does not have the necessary characteristics for use in other conventional casting processes (such as steel), however, it can be used for several years in small companies located in the city of Manaus, Amazonia to cast aluminium parts , copper and brass.

## ACKNOWLEDGMENTS

This research has been carried out thanks to the support of LabMatPro from the Universidade do Estado do Amazonas - UEA in partnership with the Crowfoot Group of X-Ray Methods in Manaus.

## REFERENCES

ACHARYA, S.; VADHER, J.; ACHARYA, G. A Review on Evaluating Green Manufacturing for Sustainable Development in Foundry Industries. **International Journal of Emerging Technology and Advanced Engineering**. Volume 4, Issue 1, p.232-237, January 2014. ISSN 2250-2459.

BALA, K. C.; KHAN, R. H. Characterization of beach/river sand for foundry application. **Leonardo journal of sciences,** v. 12, n. 23, p. 77-83, 2013.

BECKHOFF, B. et al. **Handbook of practical X-ray fluorescence analysis**. Springer Science & Business Media, 2007. ISBN 3540367225.

DALQUIST, S.; GUTOWSKI, T. Life cycle analysis of conventional manufacturing techniques: sand casting. ASME 2004 International Mechanical Engineering Congress and Exposition, 2004, American Society of Mechanical Engineers. p.631-641.

FUNDIÇÃO., A. B. D. **CEMP 120: Determinação da perda ao fogo**: ABIFA São Paulo 2003a.

**______. CEMP Nº105: materiais para fundição - determinação do teor de umidade**: ASSOCIAÇÃO BRASILEIRA DE FUNDIÇÃO. 2003b.

GIGANTE, G. How can we become a practical green foundry industry? **International Journal of Metalcasting,** v. 4, n. 3, p. 7-15, 2010. ISSN 1939-5981.

KIM, E.-H. et al. Development of a high-temperature mold process for sand casting with a thin wall and complex shape. **Thin Solid Films,** v. 620, p. 70-75, 2016. ISSN 0040-6090.

OLIVEIRA, C. Influência do Teor de Feldspato Espodumênio e Albita na Sinterização de Uma Massa Cerâmica Triaxial. **São João del-Rei, UFSJ, Programa de Pós-Graduação em Engenharia Mecânica**, 2012.

SIDDIQUE, R.; KAUR, G.; RAJOR, A. Waste foundry sand and its leachate characteristics. **Resources, Conservation and Recycling,** v. 54, n. 12, p. 1027-1036, 2010. ISSN 0921-3449.

WANG, K. et al. Preparation, thermal analysis and mechanical properties of in-situ Al2O3/SiO2 (p)/Al composites fabricated by using zircon tailing sand. **Materials & Design,** v. 99, p. 303-313, 2016. ISSN 0264-1275.

WANG, K. et al. Thermal analysis of in-situ Al2O3/SiO2 (p)/Al composites fabricated by stir casting process. **Thermochimica Acta,** v. 641, p. 29-38, 2016. ISSN 0040-6031.

ZANETTI, M. C.; FIORE, S. Foundry waste recycling in moulding operations and in the ceramic industry. **Waste management & research,** v. 21, n. 3, p. 235-242, 2003. ISSN 0734-242X.