DEVELOPMENT OF REFRACTORY COATING APPLIED TO EPS PATTERN LOST FOAM PROCESS

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Abstract. *The lost foam process employs an expanded polystyrene pattern placed in unbounded silica sand. When the melting metal is pouring, the pattern vaporizes and the metal reproduces the cast geometric form. As the sand is unbounded and no core is needed, the process cost is reduced. However, in order that EPS can be substituted by the molten metal is necessary to support the sand during the brief interval between the gasification and replacement of pattern. As such, the EPS pattern with a refractory coating must support the sand some seconds until mold filling. A critical factor of this process is the refractory coating paint. It is the objective in this paper to develop a refractory coating and to investigate it application in aluminum casting foundry. The preliminary experiments shows that the developed coating made with colloidal silica, zirconia and maranil, presented good results with excellent superficial casting finish.*

Keywords: *Lost foam; Refractory coating; Aluminum foundry.*

1. INTRODUCTION

The lost foam casting process was developed and patented by Shroyer (1958). It was used a pattern of expanded polystyrene (EPS), supported by bonded sand (green sand) in a mold flask, that was vaporized by the molten metal during pouring. The molten metal replaces the pattern foam, accuracy duplicating the entire pattern characteristic. This process is known as the full mold process.

Because of porosities problems generated by the pattern decomposition, the process was not intensively used.

After, Flemings (1964) used unbounded sand with the process. This is known nowadays as lost foam casting process (LFC) or EPC (evaporative pattern casting).

The principles of the lost foam casting process are now generally well known and applied in industries, Foseco (1982, 1986, 1989).

With the development of the EPC process, the formation of porosities defect was studied until obtaining positive results, with good casting quality. An example is the combined EPC process with the vacuum sealed molding Process (V-process). The vacuum applied to EPC mould draws the decomposed gases and improves the casting quality, Kumar *et al* (2009).

The pattern for the foundry EPC process is made of expanded polystyrene injected at a die especially projected. After it production, the pattern is coated with a covering or refractory paint. This covering is the critical point of whole process.

Firstly, it should support, for an interval of time, the molten liquid metal, impeding that the fast pattern evaporation cause the mold erosion, damaging the geometry of the cavity, causing defective castings. Secondly, it should have good permeability allowing that the gases formed by the pattern evaporation can be evacuated for the sand that surrounds it.

After the protection covering, the pattern is let to dry and later put in the sand mold and compressed by vibration. The employed sand in the molding is unbounded, allowing the reutilization and continuous use, only with cooling after each pouring.

Figure 1 shows the principle of the process.

Figure 2 schematizes the reaction that occur at the interface between the liquid metal that is pouring and the polystyrene pattern, where happens the process of substitution of EPS for the metal.

In a study on the reaction of the molten metal and the pattern, Shivkumar *et al* (1995), was shown that the degradation of the pattern results in the formation of gases, approximately 40%, e viscous residue, partially depolymerizaded, 60%. The composition of the gaseous products consists of styrene, benzene and other hydrocarbons, Mehta et al (1995). The fraction of the viscous residue it would increase with the temperature until a certain value that turns constant, above 650ºC. The viscous residue consists predominantly of dimer, trimer, tetramer and other oligomers, Shivkumar (1994). This viscous residue may penetrate the pores in the coating and will eventually undergo further depolymerization to yield gaseous products. These gases are then transported into the sand.

According to Ferreira (1999), the lost foam casting advantages are numerous and most evident. In this process, there is neither mold partition line, nor is necessary the use of cores. The molding boxes of only one piece are easily manipulated.

The use of both non agglomerated and unbounded sands turns the process both economical and easy of controlling. The equipment for sand processing requests little maintenance. It is necessary less sand and it can be reused without recycling, which is an advantage in ecological terms.

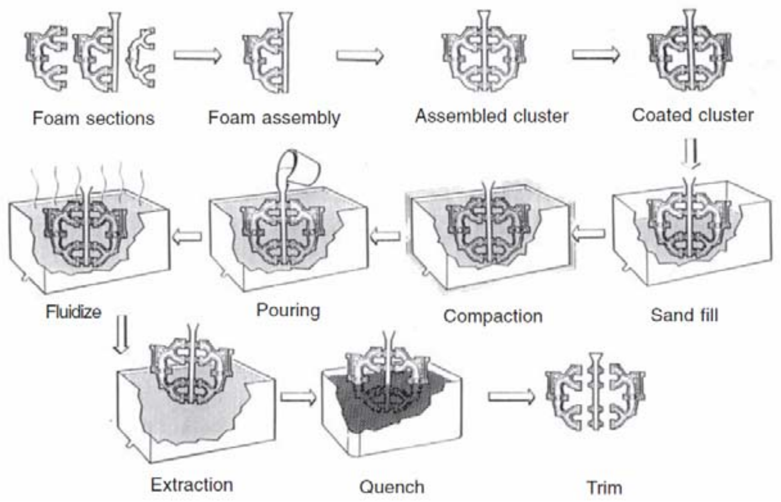


Figure 1. The lost foam casting process, Brown (2000).

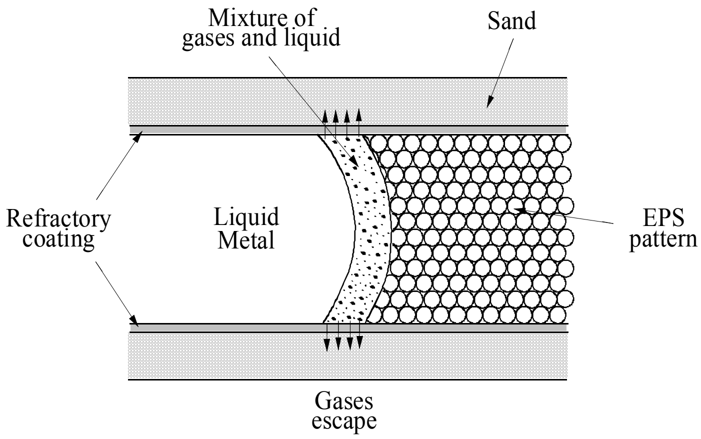


Figure 2. Schematic of the foam degradation process (Shivkumar and Gallois, 1987).

One of the most important steps in this process is the coating. The coating is applied to the surface of the pattern, to produce a smooth, and acceptable surface finish of the casting. It also provides the rigidity of the pattern that minimizes the pattern shape distortion during the mold compaction, Ballmann (1998).

The coating should have a good wettability for foam materials and should be durable and flexible during handling the patterns, Clegg (1985).

There are several kinds of evaporative pattern coating with different thermo-physical characteristics, which are specially designed to meet number of requirements of the EPC process, Acimovic *et al* (2003).

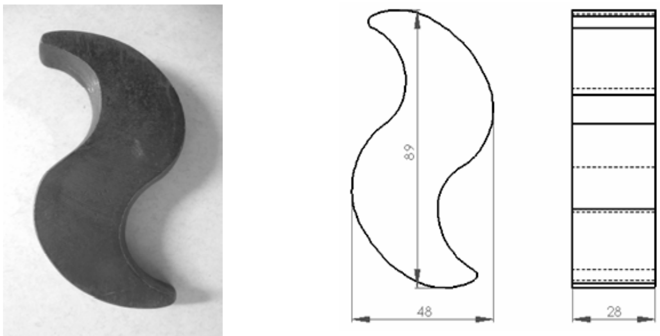
In agreement with the literature, only a limited number of works were made to improve the characteristics of the coating material and to develop new refractory. Among the employed products are mentioned: zircon flour, kaolin, talc, silica, mullite, (Dieter 1965, Acimovic *et al* 2003, Kumar *et al* 2009).

It is the objective in this paper to develop a coating for expanded polystyrene pattern that fills out the necessary requirements to obtaining good quality aluminum castings.

2. MATERIALS AND METHODS

The design of the chosen piece for pattern production was the brake system of heavy vehicles. The choice is due to the fact of the same presents geometric characteristics as curves, sharp borders, and a thickness of 28 mm that makes possible the verification of several parameters in the efficiency of the process as well as in the final structure of the piece.

Figure 3 shows the original piece and their dimensions.



(a) (b)

Figure 3. Geometry of the piece used in the experiments.

To avoid shrink hole formation in the piece, it was used a riser that was calculated using the Chvorinov rule (1940), or module rule. The calculated volume of the piece was 70.747.47 mm^3 and the riser volume corresponding of 12.271,87 mm^3.

Pieces were cut separately using a hot wire, Fig. 4, and later mounted and assembled with glue of polivinila acetate in solution of alcohol. The employed polystyrene in the experiments was employed in commercial isolation for transport of equipments. Figure 5 shows the mounted and ready pattern to receive the refractory coating.

Figure 4. Equipment used for the EPS cut.

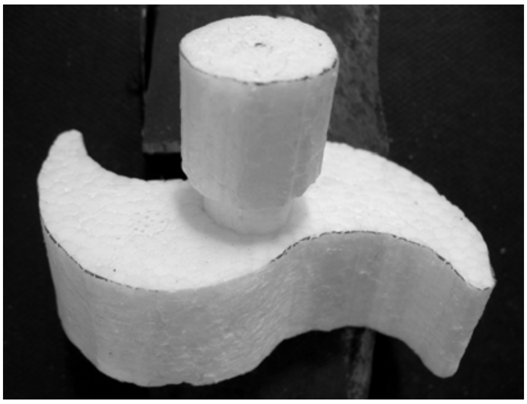


Figure 5. Pattern obtained in EPS.

The key point to obtaining success in the experiments is an effective coating. The refractory slurry to cover the EPS pattern should present a viscosity stable and capable of wetting the model. The slurry should be applied only on an uniform layer, Kumar et al (2009). To form the slurry, calcined alumina and zirconia were tested as refractory, colloidal silica and bentonite as bonding, and Disponil SN (dodecilbenzeno sulfonate of lineal sodium with 49-52% actives/solids tenor) as tensactive. In the composition of the colloidal silica with alumina, the obtained results were not satisfactory, once the alumina was not dissolved completely in the colloidal silica.

The tests with bentonite didn't obtain success in view of bentonita agglomeration, independent of the binder used. The composition that presented better results was the mixture of colloidal silica, zirconia and Disponil SN.

The employed zirconia in the experiments is composed of 65,5% of oxide of zirconium, 33% of silica, 0,05% of iron and 0,10% of titanium.

For obtaining the slurry, was used a precision balance, 0,001 grams, for weighting of the components. Several compositions were tested, the one that presented best results was 300 g of zirconita, 86 ml of colloidal silica and 17 g of Disponil SN. Initially, 86 ml of colloidal silica was put in a recipient, afterwards, 300 g of zirconita was added. To avoid the formation of agglomerates and bubbles, the zirconia was added little by little and the mixture was always maintained agitated for a mixer, Fig. 6.

Figure 6. Mounted system to maintain the agitated slurry mixture.

After the addition of the zirconia and colloidal silica, the mixture was in agitation for 24 hours, for a complete dissolution of the zirconia. In the sequence, the Disponil SN was added little by little to avoid agglomeration. They were added to the mixture 17 g of this component, maintaining the mixture in agitation for more 48 hours, being obtained homogeneous refractory slurry. After prepared the slurry, the pattern was immersed and let to dry to the air for 24 hours. The employed sand for the production of the mold was analyzed to determine the fineness according to AFS (American Foundry Society) (1978). The fineness found was AFS = 113.58 which classifies the sand as fine. The composition of the employed aluminum alloy in the tests, analyzed by optical emission spectrometry, is shown in Tab. 1. It is an alloy type Al-10%Si. The alloy was melted in resistance furnace in the temperature of 750ºC.

Table 1. Chemical composition of the used alloy.

Element	Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Pb	Ti	Al
%	10.55	0.633	0.114	0.0547	0.0174	0.105	0.0106	0.008	0.155	0.0103	remaining

To pour the piece, the same was put in a box with vibration compressed sand. According to Fig. 7, the surface of the riser was free to make possible the pouring. The choice of the pouring for the riser had as objective eliminates the making of the runners, to facilitate the pouring, in spite of not normal practice in foundry.

Figure 7. Mold ready to be poured.

3. RESULTS AND DISCUSSION

The EPS pattern was dipped in the slurry to be obtained the total coating of the surface. It is observed that bubbles didn't appear in the pattern surface, which impeded the formation of areas with a deficient slurry coating. After the refractory bath, the model came in the way shown in Fig. 8.

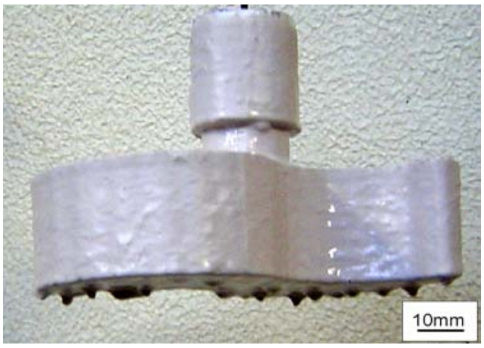
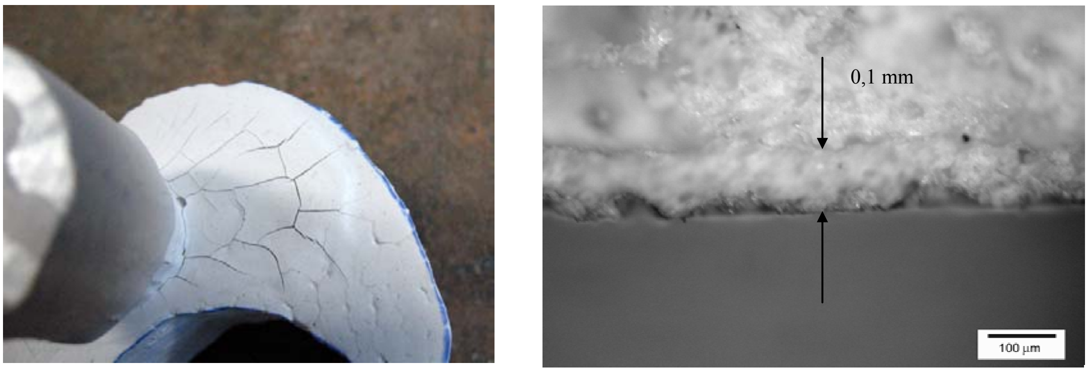


Figure 8. EPS pattern covered with the refractory slurry.

After drying, the refractory covering presented cracks that didn't commit the complete covering of the surface of the pattern, Fig. 9. The medium thickness of the layer covering was between 0,1 and 0,15 mm, Fig. 9b. This result is in agreement with Sands and Shivkumar (2003) that consider a typical thickness between 0,1 and 0,2 mm.



(a) (b)

Figure 9. (a) Aspect of the refractory coating after drying, and (b) coating thickness.

Griffiths and Davies (2008) say that this value is typically 0.5 mm. In agreement with both references, the thickness of the layer is fundamental in the mold pouring in function of the permeability. Figure 10 shows the influence of the refractory layer thickness in permeability for three commercial paints.

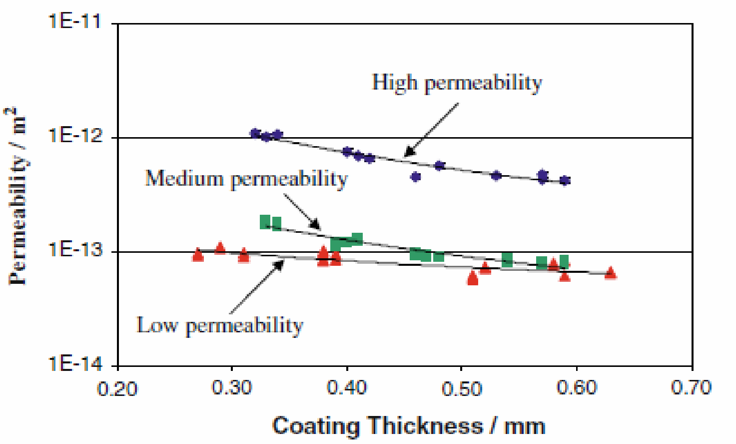
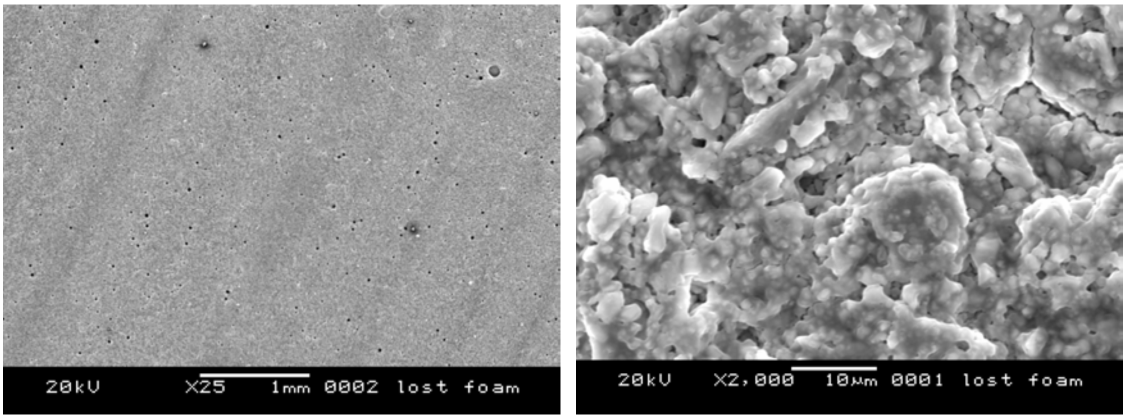


Figure 10. Measured permeability values of three commercial lost foam pattern coatings, for a range of coating thicknesses, Griffiths and Davies (2008).

Figure 11 shows the refractory coating SEM images. In smaller magnification, Fig. 11a, is verified the good consistence and uniformity, with the presence of micro pores. Fig. 11b with increase magnification shows the good agglomeration of the base constituents. Figure 12 shows the coating EDS basically composed of Si and Zr.



(a) (b)

Figure 11. SEM images of the refractory coating.

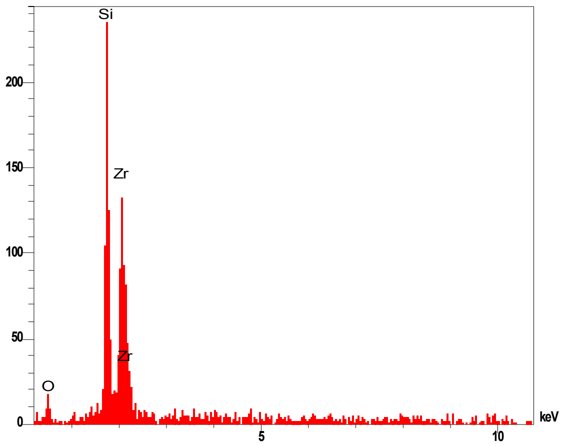


Figure 12. EDS refractory coating.

The slurry dries made possible the handling of the model without happening detachment, even after the molding.

Figure 13 shows the casting as extracted of the mold. It can be noticed the refractory layer in the surface of the casting, that is removed easily with the use of a brush of hard fiber.

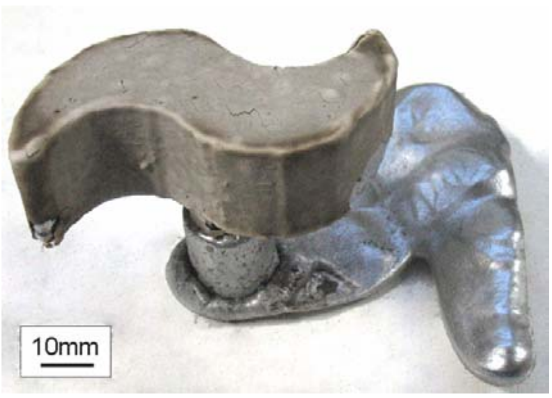


Figure 13. Casting after pouring and solidify.

Figure 14 displays the superficial aspect of the casting after cleaning. As it can be seen, the surface of the casting is a faithful reproduction of the final EPS pattern used. As it is EPS of low quality, in the moment of production there was not the total compacting of the "pearls" that were reproduced in the foundry casting. The flaws among the "pearls" are the own model employee's defects and not of the covering type.

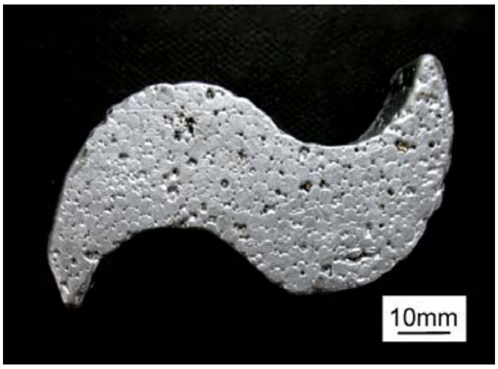


Figure 14. Superficial finish of the casting after cleaning.

To verify the occurrence of internal porosities, the casting was cut longitudinally close of the surface and sanded to sandpaper of granulating 1200. Figure 15 display that the piece didn't present internal porosities being very compact. What is noticed in the picture is the shrinkage presence in the connection area of the riser with the casting. This shrinkage is owing to the section of riser choking that caused a "hot point" solidifying last.

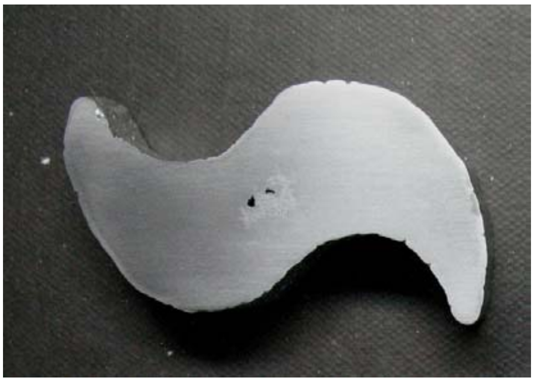


Figure 15. Sanded casting showing the absence of pores of great dimensions.

The prepared casting was submitted to attack with Tucker reagent to verify the type of formed structure using the process lost foam, Fig. 16.

Figure 16. Casting crystalline structure obtained by the lost foam process.

As it can be observed in the picture, occurred the formation of equiaxed grains during the solidification of the casting. This structure is typical of solidification in sand mold, in addition, exits a refractory layer that block the fast cooling of the casting. Also, the chemical compositions of the employed aluminum alloy close to the eutectic point, with a very small solidification interval, Fig. 17. In the left extremity of the piece the grains are more refined, as probable consequence of a faster cooling in function of the finer thickness. In the central area of the piece the crystals are larger due to a slower cooling, as result of the larger thickness of the piece.

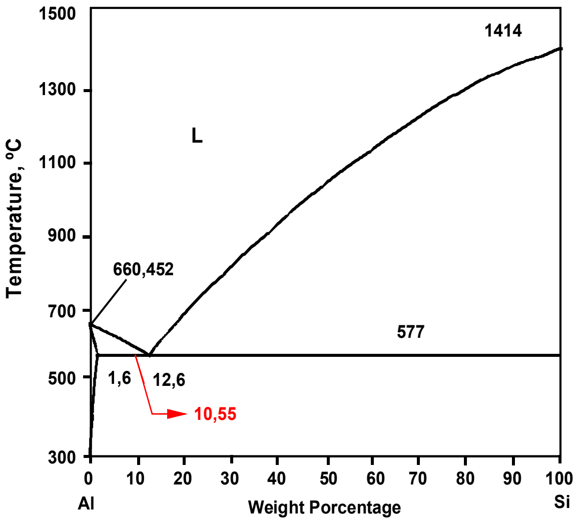


Figure 17. Al-Si phase diagram.

4. CONCLUSIONS

The results obtained in the experiments shows that the employ of the composition of the elements zirconia, colloidal silica and Disponil SN, in controlled proportions, form a refractory covering of good quality in the lost foam process foundry. The formed slurry perfectly wets the surface of the pattern, forming a uniform layer of small thickness that supports the temperature of the aluminum alloy to the complete vaporization of the polystyrene pattern, and allows the evacuation of the gases without causing porosities. The coating maintains the superficial finish of the pattern that is maintained in its original characteristics. Because it is an experimental work, several parameters still need to be identified, as for instance, the measure of the permeability of the covering, its degree of mechanical resistance, the gases that are formed during the disaggregation of the pattern, among others.

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