www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES
of
FOUNDRY ENGINEERING
DOI: 10.1515/afe-2016-0055
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

DE GRUYTER OPEN

ISSN (2299-2944)
Volume 16
Issue 3/2016

83 – 88

Silica-Kaolin Mix Effect on Evaporative Pattern Castings Surface Roughness

B.V. Omidiji *, R.H. Khan, M.S. Abolarin
Obafemi Awolowo University, Ile-Ife, Nigeria
Federal University of Technology, Minna, Nigeria
*Corresponding author. E-mail address: bvomidiji@gmail.com

Received 15.03.2016; accepted in revised form 13.06.2016

Abstract

The influence of the refractory coating which is a mixture of silica flour and kaolin on the surface roughness of the plate castings produced using evaporative patterns had been considered in this work. The kaolin was used as a binder and ratio method was employed to form basis for the factorial design of experiment which led to nine runs of experiments. Methyl alcohol at 99% concentration was used as the carrier for the transfer of the coating to the surface of the patterns. Pouring temperature was observed as a process parameter alongside the mix ratios of the coating. Attempts were made to characterize the refractory coating by using two methods; differential thermal analysis (DTA) and X-ray diffraction. Attempt was also made to characterize the casting material. Gating system design was done for the plate casting to determine the correct proportions of the gating parameters in order to construct the gating system properly to avoid turbulence during pouring of liquid metal. A digital profilometer was used to take the measurements of the surface roughness. It was observed that the mix ratio 90% silica flour-10% kaolin produced the lowest value of the surface roughness of the plate castings and had the lowest material loss in the DTA test. The pouring temperature of 650°C produced best casting.

Keywords: Pattern, Coating, Roughness, Carrier, Binder, Temperature

1. Introduction

Evaporative Pattern Casting (EPC) Process which is a relatively new form of sand casting makes use of evaporative patterns buried in the sand mould to produce castings. Instead of coating the mould as it is done in traditional sand casting method, the evaporative patterns are coated with refractory materials otherwise known as pattern coating. The evaporative pattern is usually made of polystyrene foam.

The refractory layer coating formed on the foam pattern has been recognized as a critical factor to good quality castings [1]. It was posited that the coating determines the flow of the evacuation of evolved gases during casting [2]. For a high permeable coating, it is observed that the gas front velocity increases linearly with the pouring temperature. It had been observed that mould filling times decreased with permeability of the coatings [3].

For a given temperature, filling times can double according to the type of coating used. If the gaseous and liquid pyrolysis products are not released through the coating in a timely manner, the gas pressure in the kinetic zone increases until it exceeds the metallostatic pressure. The gases escape through the molten metal discontinuously and form defects in the castings.

On the contrary, if the pyrolysis products are released too fast, local pressure drops are sufficiently high to cause sand collapse. The coating layer is then not supported by gas or metal pressure and can no longer bear the weight of the sand. This leads to surface collapse defects. An ideal pattern coating must allow gaseous and liquid foam degradation products to be transported out of the casting in a timely and balanced manner. Variables such as coating material, , viscosity, liquid absorption capability, coating thickness and gas permeability affect the quality of casting. There is no standard method to measure and control liquid absorption and gas permeability. To produce good quality castings, consistent coating properties including wettability, permeability and viscosity should be maintained [4]. In a recent development, additional binders and chemical agents have been applied to produce a reactive coating. It reacts with the surface immediately to produce the required properties when heated by the molten metal. The coating layer can be easily removed from the casting after it cools down.

As regards the particle size of the refractory coating [5 and 6] had recommended 200 meshes (75μm) in their researches. In reality the particle size can be reduced to 65μm. This gives good surface finish to the castings produced with it. The surface roughness obtained in the castings when the coatings are used is subject to the type of casting method employed. With ceramic investment casting process, [7] obtained 2 μm surface roughness value but with sand casting method between 10 μm and 50 μm was obtained [6].

In this study, ratio method had been employed to produce refractory material. Samples were characterized using differential thermal analysis (DTA) to determine the rate of material loss. X-ray diffraction of the Silica sand was done to determine the composition. Atomic Absorption Spectroscopy (AAS) method was used to determine the composition of the kaolin.

The ratio method combined with pouring temperature which is the temperature at which the molten metal was poured into prepared moulds, considered as process parameters gave nine runs of experiments. The pouring temperature was taken at three levels, 650 °C, 700 °C and 750 °C.. Gating system was designed (parting line gating method) to introduce the molten metal into the prepared moulds. The chemical composition of the Al-alloy was done to show the kind of material been cast.

2. Materials and Methods

2.1. Development of the Refractory Coating

Materials used were silica and kaolin due to their availability and high refractoriness. The silica sand was sourced from Isasa River at Ipetumodu, Osun State, Nigeria. The Kaolin was taken from clay deposit at Ipetumodu, Nigeria. The silica sand sample was washed severally with water to get rid of clay, slit and other contents that may reduce the refractoriness of the sand. It was sun-dried and processed in a grinding mill to reduce the surface area of the grains. This brought the grains sizes to about 70 μm before it was sieved to further obtain fine grains at 65 μm. Mechanical sieve shaker was employed for the sieving process. For coating of patterns, grains obtained are used [6 and5]. Methyl alcohol at 99% concentration was the carrier employed as solvent or reducer in the coating to facilitate the transfer of the refractory particles to the surface of the patterns When the carrier evaporates, a refractory solid left on the surface of the pattern acts as a barrier between the sand and molten metal. The binder used was the kaolin whose function was to bind the refractory particles together.

2.2.Chemical Composition of the Al-Alloy and Kaolin

The chemical composition of the Al-alloy is presented in Table 1. It is an Al-Si alloy because all other alloying elements are negligible in % composition. The composition of the kaolin sample is presented in Table 2. Atomic Absorption Spectrophotometry (AAS) method was used to determine the chemical analysis of the clay sample (kaolin) used.

Table 1.
Chemical composition of the Al-alloy [10]

Element	Si	Mg	Fe	Cu	Mn	Cr	Ni	Zn	Ti	Pb	Al
%	1.96	0.31	0.33	0.58	0.095	0.015	0.026	0.515	0.02	0.05	Balance

Table 2.
Chemical composition of clay

Chem. Comp.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2
% Comp	55.91	29.91	1.91	0.2	0.4	1.9	0.2	0.9

2.3. Design of Experiments (DOE)

Design of Experiment (factorial design) was employed to apply the coating on the patterns. This led to nine runs of the experiments. The design is presented in Figure 1. The mixture ratios (of the silica flour and kaolin) 90% -10%, 85%-15% and 80%-20% were employed. A stepped block was used to test the effect of the zircon coating on the surface roughness of the castings [5] but a plate casting was employed in this experiment. The gating and feeding systems was designed for the plate casting using gating ratio 1:2:4 (sprue: runner: ingate) which is non-pressurised [9]. This excludes turbulence in the flow of the molten metal. The thickness of the coating on the pattern was between 1.5mm and 2mm. It was difficult to keep the thickness of the coating constant because of the manual spraying method employed in the application of the coating on the patterns (Figure 2). Care was taken to avoid touching any part of the sprayed portion. Since the alcohol used as carrier evaporated within seconds, the patterns were buried inside the moulds immediately to prevent the coating from peeling off. Mould employed here was a sand mould. The moulding material was sourced from Osun River in Osogbo. One flask was used for moulding.

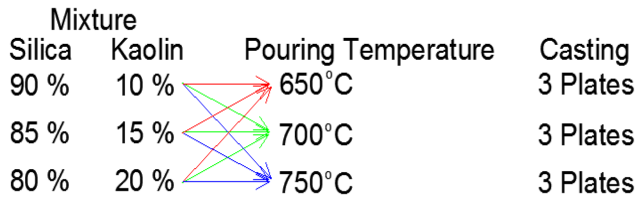

Fig. 1. Mixture ratios/ Design of Experiment

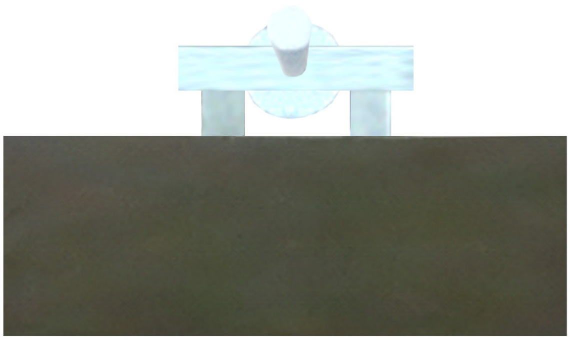

Fig. 2. Coated Plate Pattern

2.4.Characterization of the Refractory Coating

Effect of temperature on the powder mixtures containing silica flour and binder which was kaolin was determined using Differential Thermal Analysis (DTA) in the range from ambient temperature 20 °C to 1000 °C. The mineralogical composition of the silica sand was investigated with the aid of X-ray diffractometer (XRD) model 10 Monochromatic CuKa radiation (wavelength λ= 1.5406) produced by Radicon limited. Fine grain of sand was obtained by passing the sand through a 425µm sieve size. The fine grain sand was exposed to the X-ray beam from an X-ray generator running at 25kV and 20 mA. The scanning regions of the diffraction were 16-72° on the 2θ angle.

2.5. Measurement of the Surface Roughness of the Castings

The surface profiling of the nine plate castings that were produced by the application of the various mixture ratios of the refractory material developed using the factorial design of experiment was done by Surface Profilometer. Samples were place under the stylus of the profilometer The stylus was instructed to move on the surfaces of the samples to feel the deviations (hills and valleys). An Arithmetic Average (AA) method was then employed to determine the surface roughness of the castings as presented in equation 1 [8].

$$Ra = \int_0^{L\infty} \frac{|y|}{Lm} dx \qquad (1)$$

where:
R_a = arithmetic mean value of roughness, µm;
y = the vertical deviation from nominal surface (converted to absolute value), µm;
L_m = the specified distance over which the surface deviations are measured.

2.6. Gating System Design for Aluminum Alloy Plate

A plate of dimension 250mmx100mmx10mm is presented in figure 3. Using the dimensions, the volume is determined. By employing properties of the plate the mass, pouring rate of the melt, pouring time and choke area are determined.

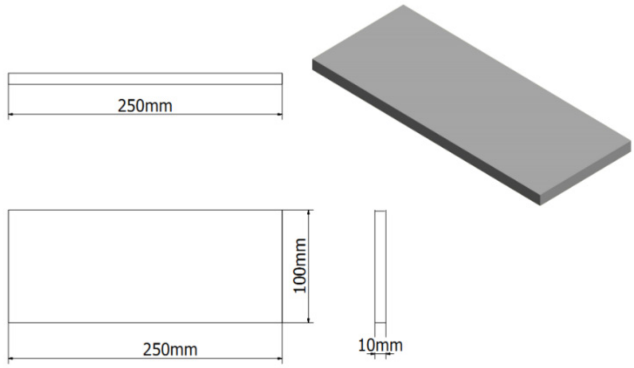

Fig. 3. Plate (all in mm)

Thickness of plate = 10 mm
Volume of plate = l wt, (2)

where:
l = length, w = width and t = thickness

$$\text{Density, } \rho_a = \frac{mass}{volume}$$
$$Mass = \rho_a \ x \ volume \qquad (3)$$

To determine the weight of the liquid alloy to be poured (includes the casting, gating and feeding elements), [9] suggested casting yield of 60%.
To determine pouring time, [9] suggested that pouring rate of 0.25 – 0.45 kg/s for Aluminum alloy should be used for casting of mass up to 10kg.

$$Pouring\ \text{rate} = \frac{\text{mass}}{\text{pouring time}}$$
$$Pouring\ \text{time} = \frac{\text{mass}}{\text{pouring rate}} \qquad (4)$$

To determine the choke area A of the gating system.

$$A = \frac{w}{dtc\sqrt{2gH}} \tag{5}$$

where:
w = weight of casting kg
d = mass density of the molten metal (kg/mm^3)
t = pouring time, s
H = effective metal head
= Sprue height (mm)
c = efficiency factor which is a function of the gating system used.

Parting Line Gating Design

$$H = h - \frac{p^2}{2c} \quad [9] \tag{6}$$

H = height of sprue
p = height of mould cavity in cope
c = total height of mould cavity
where, h = static head,

$$choke\ \text{area} = \frac{w}{dtc\sqrt{2gH}} \tag{7}$$

To determine the sprue exit diameter, sprue of the gating system is taken as a cone.

$A = (\pi D^2) / 4$
$D^2 = 4A / \pi$

The flow rate of the motel metal is defined by;

$$Q = A_1 V_1 = A_2 V_2 \tag{8}$$

The sprue entry area is described by;

$A_t = (\pi D^2) / 4$
$D^2 = (4A_t) / \pi$

Gating Ratio
Sprue exit area: Runner: Ingates
Risering Design
Assume an open cylindrical riser
Surface area of plate;

$$S_a = 2(lw + lt + wt) \tag{9}$$

Modulus of casting

$$M_c = \frac{V_c}{S_a} \tag{10}$$

Modulus of riser,

$$M_r = 1.2\, M_c \tag{11}$$

Diameter of Riser,

$$D = 6\, M_c \tag{12}$$

The gating parameters are presented in Table 3 [10]. Figure 4 presents the parameters in isometric view of the plate.

Table 3.
Plate Gating Parameters [10]

Parameters	**Plate**
Dimensions (mm)	250 x100 x10
Volume (mm^3)	250000
Mass of casting (Kg)	0.6675
Casting yield	60%
Weight of casting (Kg)	1.11
Pouring time (s)	9.0
Choke area (mm^2)	83.48
Sprue exit diameter (mm)	10
Sprue entry diameter (mm)	18
Sprue base well area (mm^2)	417
Sprue base cross-sectional area (mm^2)	52 x 8
Gating Ratio 1:2:4	
Runner (mm * mm)	22 x 8
Two Ingates (mm * mm)	22 x 8

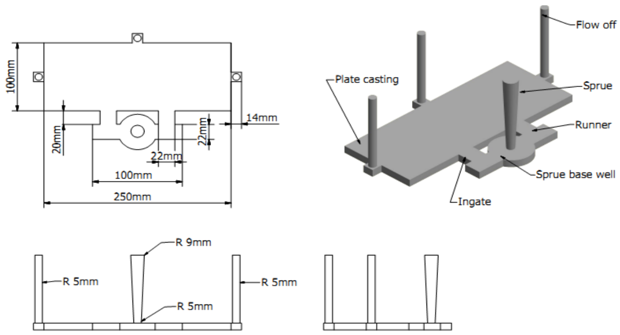

Fig. 4. Representation of the gating parameters

3. Results and Discussions

3.1. Surface Roughness Results of the Plate Castings

The surface roughness values of the plate castings are presented in Table 4. The coating mix with 90 % Silica-10 % Kaolin ratio and 650 ^{O}C pouring temperature had the lowest roughness value. From Table 4, it was observed that as the pouring temperature increases, the value of the surface roughness increases. It is generally taken that the lower the value of roughness the better the surface. It is also noted that as the content of the kaolin which acts as binder increases the roughness also increases. [5 and 7] observed that at low content of binder and temperature close to 650 ^{O}C of Al-alloys, best values of casting roughness are achieved. [12] advised that the content of the binder used in refractory coating should be as low as possible; about 10 % of the composition of the material.

Table 4.
Surface Roughness Values of Plate Castings

Mixture ratio	Pouring Temp	R_a (µm)
90% Silica-10% Kaolin	650^{0}C	5.07
90% Silica-10% Kaolin	700^{0}C	5.96
90% Silica-10% Kaolin	750^{0}C	7.99
85% Silica-15% Kaolin	650^{0}C	6.32
85% Silica-15% Kaolin	700^{0}C	7.27
85% Silica-15% Kaolin	750^{0}C	7.48
80% Silica-20% Kaolin	650^{0}C	10.84
80% Silica-20% Kaolin	700^{0}C	12.23
80% Silica-20% Kaolin	750^{0}C	12.43

3.2. Results of Characterisation of the Refractory Material

The results of the three DTA tests conducted are shown in Figures 5, 6 and 7. The Plots revealed that each of the mixtures had high refractoriness; the range of temperature being 20 °C - 1000 °C that the DTA could carry. The DTA shows the thermal degradation characteristics of the refractory samples. The heating rate employed was 20 °C/minute as degradation rate and temperature differences under air. DTA in Figure 5 showed that the peak existed at 563.9 °C - 20.61 mW/mg, which means that the material loss recorded in the test was 20.61 mW/mg. In Figure 6 the peak existed at 561.9 °C - 24.06 mW/mg and the material loss is 24.06mW/mg and in Figure 7 the peak was at 562.8 °C - 21.49 mW/mg, showing that the material loss is 21.49 mW/mg. The degradation of the mixtures followed the same pattern, starting at about 50 °C with the peaks at close range. The DTA in Figure 5 had the lowest material loss. This characteristic helps in metal casting when good surface finish of the casting is desired [11]. The reason is that the refractory material should not only provide good surface finish but also act as a barrier between the molten metal and the moulding sand, hence preventing metal penetration. The slow rate of material loss that happened in Figure 5 makes it the best refractory sample in this study as it provided the lowest value of surface roughness. The material losses in the other two samples are higher than the one experienced in Figure 5.

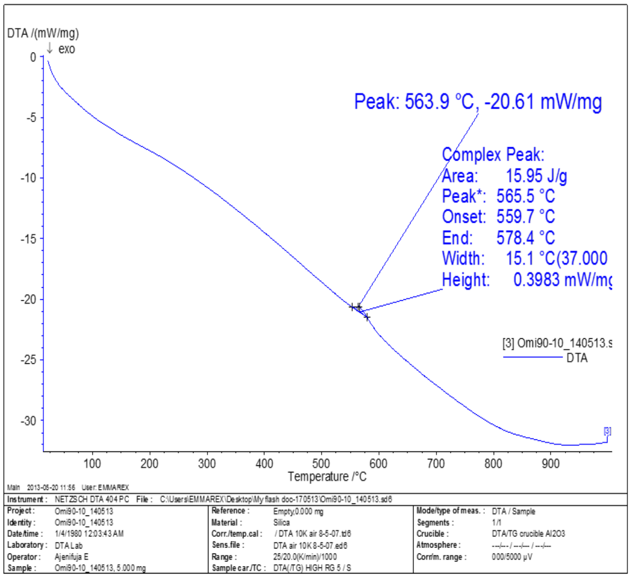

Fig. 5. DTA of 90% Silica-10% Kaolin Mixture

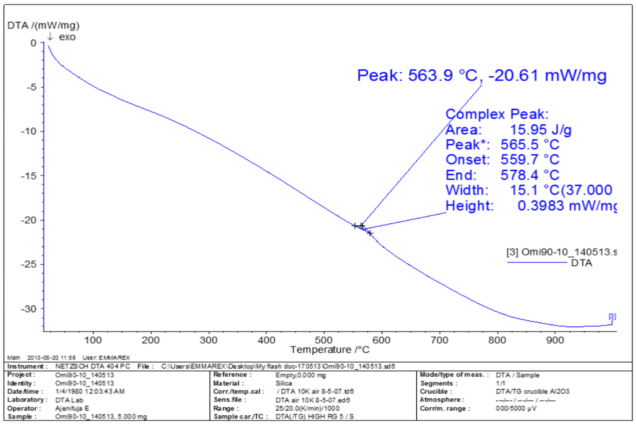

Fig. 6. DTA of 85% Silica-15% Kaolin Mixture

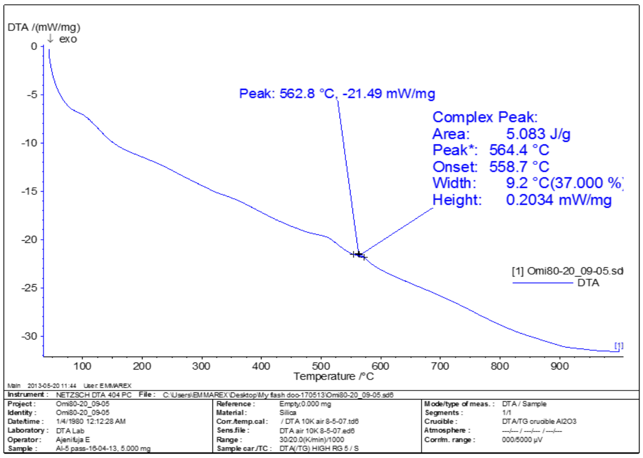

Fig. 7. DTA of 80% Silica-20% Kaolin Mixture

On analyzing the results of the XRD, the highest of the peaks showed silicon oxide and other peaks showed aluminum oxide and aluminum silicate were present in the silica sand sample. The XRD of the silica sand is shown in Figure 8 whose significance is to determine the composition of the silica sand. It is amorphous in nature.

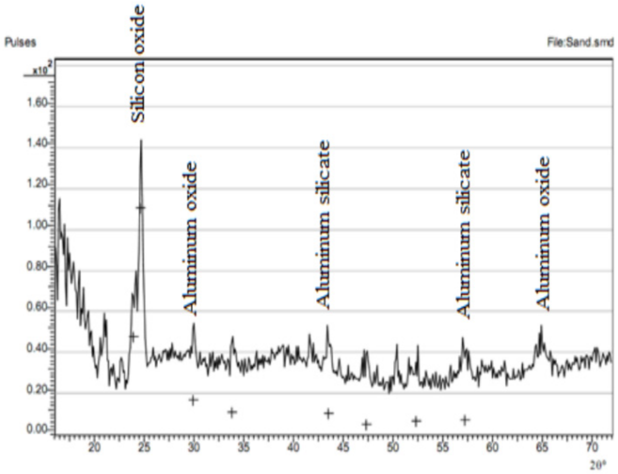

Fig. 8. X-ray diffraction of the Silica Sand

4. Conclusions

The silica flour with kaolin as binder provided good surface finish on the plate castings. Researchers have shown that between 10µm and 50µm surface roughness could be achieved in sand castings, it is herein shown that surface roughness of between 5 µm and 13 µm are achievable with the use of evaporated patterns coated with silica flour. The coating having the composition of 90% silica- 10% kaolin produced the lowest values of surface roughness.

References

[1] Lessiter, M.J. (1996). Expendable Pattern Casting: State of the Process'. *Modern Casting*. 84(1), 36-38.

[2] Houzeaux, G. & Codina, R. (2004). A finite element model for the simulation of lost foam casting. *International Journal of Numerical Methods in Fluids*. 46, 203-226.

[3] Chen, X., Penumadu, D. (2008). *Permeability measurement and numerical modeling for refractory porous materials*. AFS tractions, America Foundry Society, Schaumburg IL, USA.

[4] Lee, K-W., Cho, G-S., Choe, K-H., Jo, H-H., Ikenaga, A. & Koroyasu, S. (2006). Effects of Reduced Pressure and Coat Permeability on Casting Characteristics of Magnesium Alloy in Evaporative Pattern Casting Process. *Materials Transactions*. 47(11), 2798-2803.

[5] Kumar, S., Kumar, P., & Shan, H.S. (2009). Characterization of the refractory coating material used in vacuum assisted evaporative pattern casting process. *Journal of Material Processing Technology*. 209, 2699-2706.

[6] Nwaogu, U.C. & Tiedje, N.S. (2011). Foundry Coating Technology: A Review. *Material Sciences and Application*. 2, 1143-1160.

[7] Singh, B., Kumar, P., Mishra, B.K. (2011). Parametric Optimisation of Casting Surface Roughness Produced by Ceramic Shell Investment Casting Process. National Conference on Advancements and Futuristic Trends in Mechanical and Materials Engineering.

[8] Groover, M.P. (2010). *Fundamentals of Modern Manufacturing Materials, Processes and Systems*, John Willey and Sons Inc, New York.

[9] Rao, P.N. (2001) *Manufacturing Technology: Foundry, Forming and Welding*, Tata McGraw-Hill Publishing Company Limited, New Delhi.

[10] Omidiji, B.V., Owolabi, H.A. & Khan, R.H. (2015). Application of Taguchi's approach for obtaining mechanical properties and microstructures of evaporative pattern castings, *International Journal of Advanced Manufacturing Technology*. 79, 461-468.

[11] Kumar, S., Kumar, P., & Shan, H.S. (2008). Optimization of tensile properties of evaporative pattern casting process through Taguchi's method. *Journal of Material Processing Technology*. 204, 59-69.

[12] Kumar, S., Kumar, P. & Shan, H.S. (2006). Parametric optimization of surface roughness castings produced by Evaporative Pattern Casting Process. *Materials letters*. 60, 3048-3053.