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# SURFACE ROUGHNESS OF CAST ALUMINUM ALLOY BY EVAPORATIVE PATTERN CASTING (EPC) PROCESS USING POWDERED SILICA-KAOLIN MIX AS PATTERN COATING

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## 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. 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.

**Key words:** *Pattern coating, Evaporative patterns, surface roughness, carrier, binder and pouring 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 (Lessiter, 1996). Houzeaux and Codina (2004) posited that the coating determines the flow of the evacuation of evolved gases during casting. For a high permeable coating, it is observed that the gas front velocity increases linearly with the pouring temperature. Chen and Penumadu (2008) observed that mould filling times decreased with permeability of the coatings. The moulds are filled with liquid melt. 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, percent solid, 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 (Kyong-Whoan et al., 2006). In a recent development, additional binders and chemical agents have been applied to produce a reactive coating and reacts 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, (Kumar et al., 2009 and Nwaogu et al., 2011) 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, (Singh et al 2011) obtained 2 µm surface roughness value but with sand casting method between 10 µm and 50 µm was obtained (Nwaogu et al., 2011).

In this study, ratio method had been employed to produce refractory material samples which were characterized using differential thermal analysis (DTA) to determine the rate of material loss and X-ray diffraction of the Silica sand was done to determine the composition and Atomic Absorption Spectroscopy method had been 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 had been designed (parting line gating method) to introduce the molten metal into the prepared moulds. The chemical composition of the Al-alloy was done by sparkling method 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 sundried 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 (Figure 1) was employed for the sieving process. For coating of patterns, grains of between 75µm and 200µm of the refractory material are used (Nwaogu et al 2011 and Kumar et al 2009). 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.



Figure 1: Mechanical sieve shaker

### 2.2. 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 2. The mixture ratios (of the silica flour and kaolin) 90%-10%, 85%-15% and 80%-20% were employed. Kumar et al (2008) used a stepped block to test the effect of the zircon coating on the surface roughness of the castings obtained but a plate casting was employed in this experiment. The gating and feeding systems had been designed for the plate casting using gating ratio 1:2:4 and the thickness of the coating as between 0.15mm and 0.2mm. 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 3).

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 coatings from peeling off. Mould employed here was a sand mould. The moulding material was sourced from Osun River in Osogbo. The coated plate with the gating system was buried inside the mould with the moulding material; one flask was used.

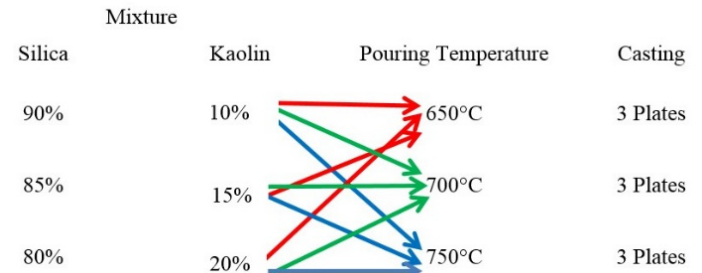


Figure 2: Mixture ratios/ Design of Experiment

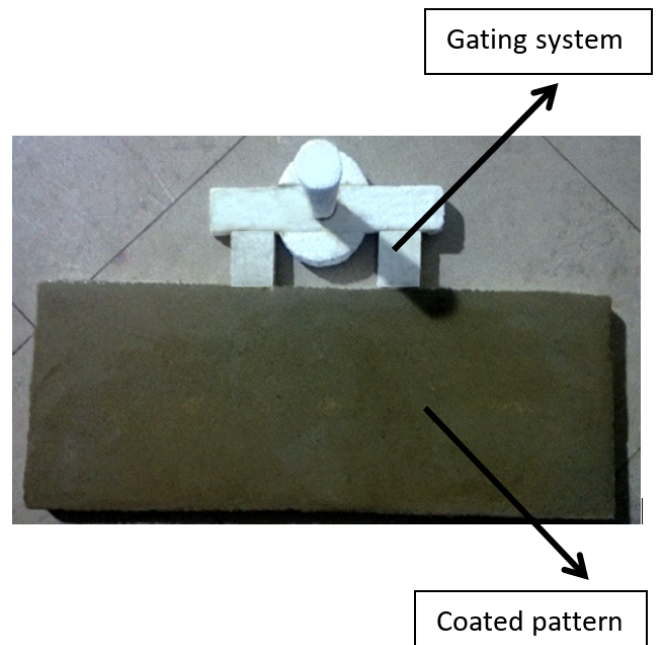


Figure 3: Coated Plate Pattern

### 2.3. Characterisation 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 CuKα 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 20mA. The scanning regions of the diffraction were 16-72° on the 2θ angle. Atomic Absorption Spectrophotometry (AAS) method was used to determine the chemical analysis of the clay sample (kaolin) used.

**2.4. Measurement of the Surface Roughness of the Castings**

The surface profiling of the nine plate castings that had been 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 placed under the stylus of the profilometer and stylus touches the surfaces of the samples. The stylus is 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 (Groover, 2010),

$$R_a = \int_0^{L_m} \frac{|y|}{L_m} dx \tag{1}$$

where,  $R_a$ =arithmetic mean value of roughness,  $\mu\text{m}$ ;  $y$  = the vertical deviation from nominal surface (converted to absolute value),  $\mu\text{m}$ ; and  $L_m$ =the specified distance over which the surface deviations are measured.

**Casting Material** The casting material taken as scrap is an aluminum alloy. The chemical composition of the alloy was determined by sparkling method.

**2.5. Gating System Design for Aluminum Alloy Plate**

A plate of dimension 250mmx100mmx10mm is presented in figure 4. Using the dimension, the volume is determined. By employing properties of the plate the mass, pouring rate of the melt, pouring time and choke area are determined.

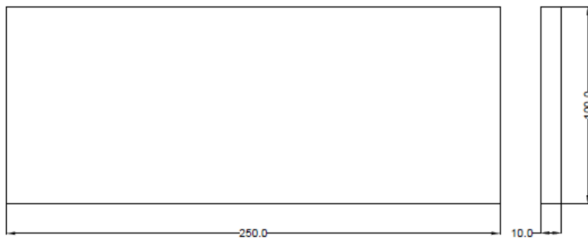


Figure 4: Plate

Thickness of plate = 10 mm  
 Volume of plate =  $lwt$ , (2)

where,  $l$ =length,  $w$ =width and  $t$ =thickness  
 Density= $\rho_a$

$$\therefore \rho_a = \frac{\text{mass}}{\text{volume}} \tag{3}$$

$$\text{mass} = \rho_a \times \text{volume}$$

To determine the weight of the liquid alloy to be poured (includes the casting, gating and feeding elements), Rao, 2001 suggested casting yield of 60%. To determine pouring time, Rao, (2001) suggested that pouring rate of 0.25 – 0.45 kg/s for Aluminum alloy should be used for casting of mass up to 10kg.

$$\text{Pouring rate} = \frac{\text{mass}}{\text{pouring time}} \tag{4}$$

$$\text{Pouring time} = \frac{\text{mass}}{\text{pouring rate}}$$

To determine the choke area  $A$  of the gating system

$$A = \frac{w}{d t c \sqrt{2gH}} \tag{5}$$

where,  $w$  = weight of casting kg  
 $d$  = mass density of the molten metal ( $\text{kg}/\text{mm}^3$ )  
 $t$  = 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

$$H = h - \frac{p^2}{2c} \quad (\text{Rao, 2001}) \tag{6}$$

$H$  = height of sprue

where,  $p$  = height of mould cavity in cope

$c$  = total height of mould cavity

$h$  = Static head

$$\text{choke area} = \frac{w}{d t c \sqrt{2gH}} \tag{7}$$

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

$$A = \frac{\pi D^2}{4}$$

$$D^2 = \frac{4A}{\pi}$$

The flow rate of the molten metal is defined by;

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

The sprue entry area is described by;

$$A_t = \frac{\pi D^2}{4}$$

$$D^2 = \frac{4A_t}{\pi}$$

Gating Ratio: Sprue exit area: Runner: Ingates

**2.6. Riser Design**

Assume an open cylindrical riser

$$\text{Surface area of plate } S_a = 2(lw + lt + wt) \tag{9}$$

$$\text{Modulus of casting } M_c = \frac{V_c}{S_a} \tag{10}$$

$$\text{Modulus of riser } M_r = 1.2M_c \tag{11}$$

$$\text{Diameter of riser } D = 6M_c \tag{12}$$

The gating parameters are presented in Table 1



Table 1: Plate Gating Parameters

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

Source: Omidiji et al (2015)

### 3. RESULTS AND DISCUSSIONS

#### 3.1. Chemical Composition of the Al-Alloy

The result of the chemical composition of the Al-alloy which was done by sparking method is presented in Table 2. It is an Al-Si alloy because all other alloying elements are negligible in % composition.

#### 3.2. Visual Examination of the Castings

Visual inspection was made to check for casting defects that might be on the surface of the plates. It was observed that there was no form of defects. Dimensional accuracy was also checked with the use of instrument; calibrated scale. It was observed during measuring that the dimensions were accurate. An isometric view of a plate is shown in Figure 5.

#### 3.3. Surface Roughness Results of the Plate Castings

The surface roughness values of the plate castings are presented in Table 3. The coating mix with 90% Silica-10% Kaolin ratio and 650 °C pouring temperature had the lowest roughness value. From Table 3, 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.

Kumar et al (2009) and Singh et al (2011) observed that at low content of binder and temperature close to 650 °C of Al-alloys, best values of casting roughness are achieved. Kumar et al (2006) 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.

#### 3.4. Results of Characterisation of the Refractory Material

The results of the three DTA tests conducted are shown in Figures 6, 7 and 8. The Plots revealed that each of the mixtures had high refractoriness; the range of temperature being 20 °C -1000 °C that the DTA can 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 6 showed that the peak existed at 563.9 °C-20.61mW/mg, which means that the material loss recorded in the test was 20.61mW/mg. In Figure 7 the peak existed at 561.9 °C-24.06mW/mg and the material loss is 24.06mW/mg and in Figure 8 the peak was at 562.8 °C-21.49mW/mg, showing that the material loss is 21.49mW/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 6 has the lowest material loss. This characteristic helps in metal casting when good surface finish of the casting is desired (Kumar et al 2008). 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 6 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 6

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 9 whose significance is to determine the composition of the silica sand. It is amorphous in nature. Table 4 shows the chemical composition of the kaolin which was done by AAS method whose significance is to determine the composition

Table 2: Chemical composition of the Al-alloy

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 3: Surface Roughness Values of Plate Castings

Mixture ratio	Pouring Temp	R <sub>a</sub> (µm)
90% Silica-10% Kaolin	650°C	5.07
90% Silica-10% Kaolin	700°C	5.96
90% Silica-10% Kaolin	750°C	7.99
85% Silica-15% Kaolin	650°C	6.32
85% Silica-15% Kaolin	700°C	7.27
85% Silica-15% Kaolin	750°C	7.48
80% Silica-20% Kaolin	650°C	10.84
80% Silica-20% Kaolin	700°C	12.23
80% Silica-20% Kaolin	750°C	12.43

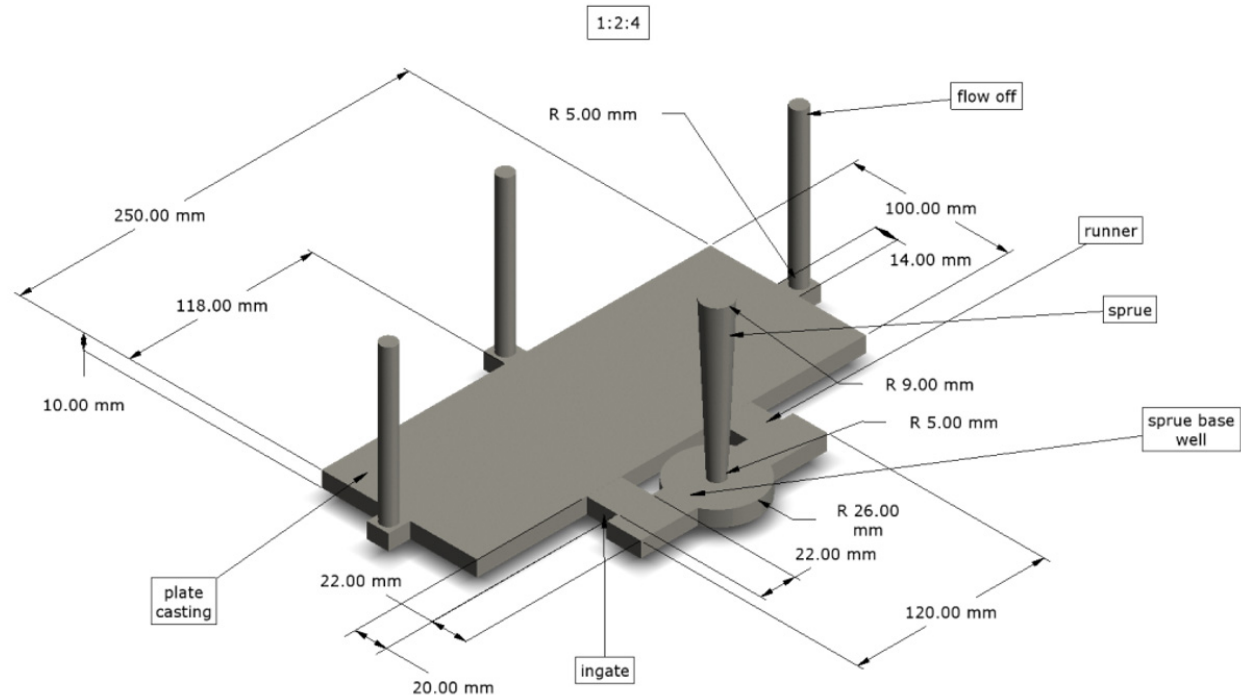


Figure 5: Isometric view of plate casting and feeding system

4. CONCLUSION

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

- Chen, X and Penumadu, D., "Permeability measurement and numerical modeling for refractory porous materials". AFS tractions, America Foundry Society, Schaumburg IL, USA. 2008.
- Groover, M.P., Fundamentals of Modern Manufacturing Materials, Processes and Systems, John Wiley and Sons Inc, New York, 2010.

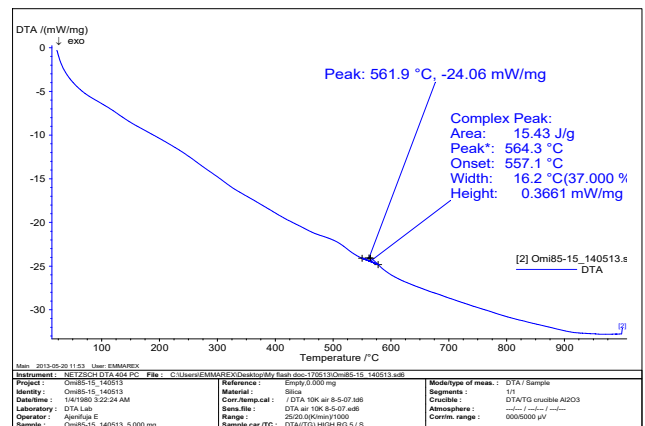


Figure 7: DTA of 85% Silica-15% Kaolin Mixture

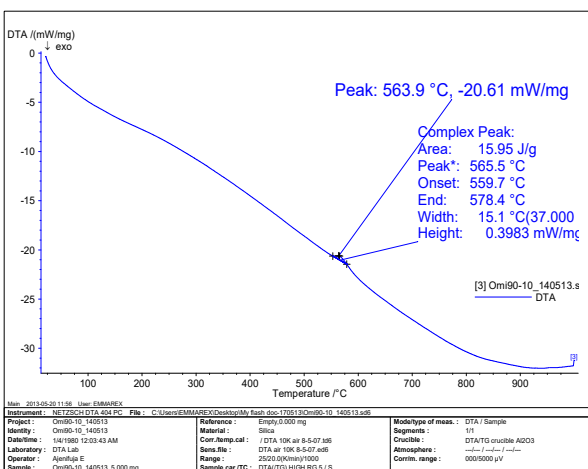


Figure 6: DTA of 90% Silica-10% Kaolin Mixture

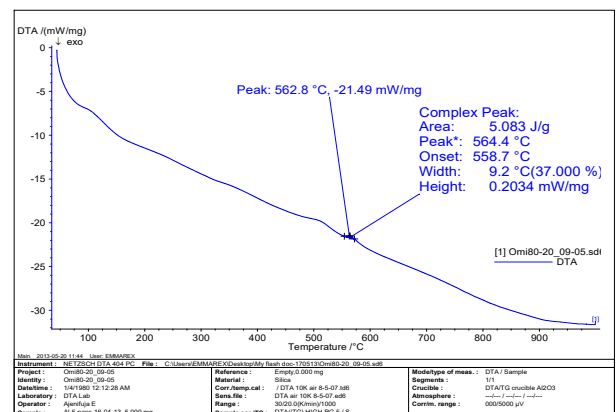


Figure 8: DTA of 80% Silica-20% Kaolin Mixture

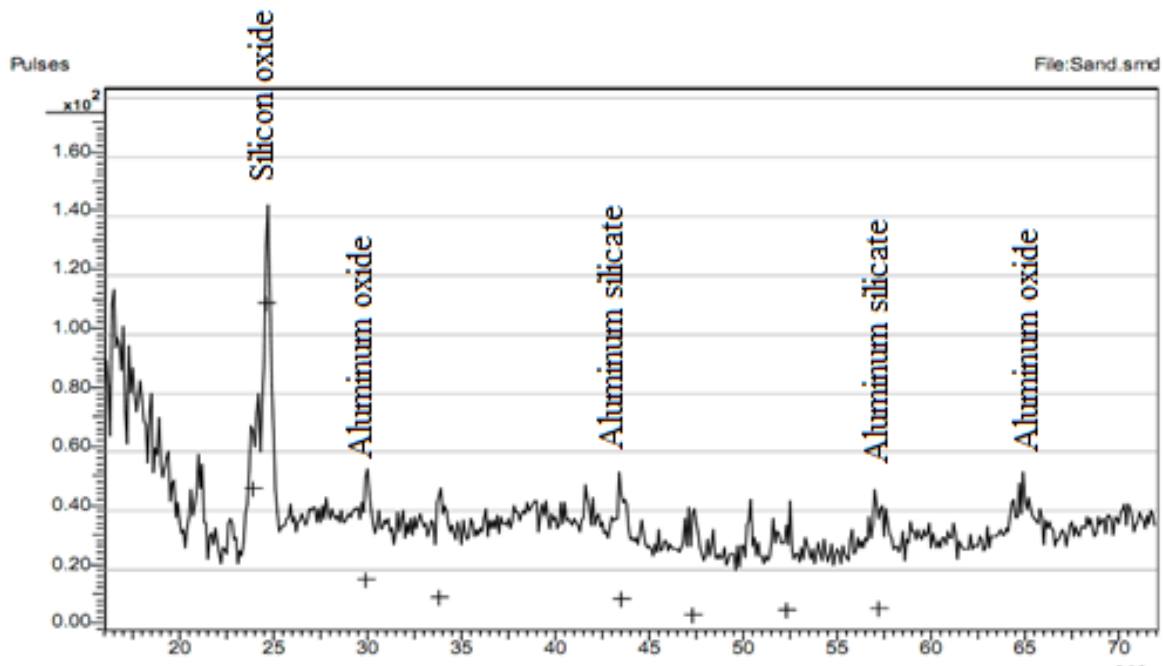


Figure 9: X-ray diffraction of the Silica Sand

Table 4: Chemical composition of clay

Chem. Comp.	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>
% Comp	55.91	29.91	1.91	0.2	0.4	1.9	0.2	0.9

Houzeaux, G. and Codina, R., "A finite element model for the simulation of lost foam casting". *International Journal of Numerical Methods in Fluids*, 46: 203-226, 2004.

Kumar, S., Kumar, P., and Shan, H.S., "Characterization of the refractory coating material used in vacuum assisted evaporative pattern casting process". *Journal of Material Processing Technology*, 209:2699-2706, 2009

Kumar, S., Kumar, P., and Shan, H.S., "Optimization of tensile properties of evaporative pattern casting process through Taguchi's method". *Journal of Material Processing Technology*, 204:59-69, 2008.

Kumar, S., Kumar, P., and Shan, H.S., "Parametric optimization of surface roughness castings produced by Evaporative Pattern Casting Process". *Materials letters*. 60, 3048-3053, 2006.

Kyong-Whoan Lee, Gue-Serb Cho, Kyeong-Hwan Choe, Hyung-Ho Jo, Akira Ikenaga and Sadatoshi Koroyasu, "Effects of Reduced Pressure and Coat Permeability on Casting Characteristics of Magnesium Alloy in Evaporative Pattern Casting Process". *Materials Transactions*, 47(11): 2798 -2803, 2006.

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

Nwaogu, U.C. and Tiedje, N.S., "Foundry Coating Technology: A Review". *Material Sciences and Application*. 2:1143-1160, 2011.

Omidiji, B.V., Owolabi, H.A. and Khan, R.H., "Application of Taguchi's approach for obtaining mechanical properties and microstructures of evaporative pattern castings", *International journal of Advanced Manufacturing Technology*. 79: 461-468, 2015.

Rao, P.N., "Manufacturing Technology: Foundry, Forming and Welding", Tata McGraw-Hill Publishing Company Limited, New Delhi, 2001.

Singh, B., Kumar, P. and Mishra, B.K., "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*, 2011.