Full Paper

A STUDY ON THE EFFECT OF MACHINING PARAMETERS ON THE SURFACE ROUGHNESS OF ALUMINUM ALLOY CASTINGS OBTAINED BY EVAPORATIVE PATTERN CASTING (EPC) PROCESS

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ABSTRACT

In this study, the effect of machining parameters on the integrity of aluminum alloy obtained by evaporative casting pattern (EPC) process was considered. The pattern, gating system and mould were designed for the casting process. Three process parameters used in generating the Taguchi's code for the analysis of the surface roughness are the pouring temperature, grain finest number of the moulding material and the gating ratio. The analysis revealed that the best surface finish of aluminium alloy was obtained at 650°C. At temperature higher than this, casting obtained have very rough surfaces with more defects. The Taguchi codes generated lead to nine numbers of runs, and the results of surface roughness gotten under the examination of computer numeric control (CNC) machine were analysed by statistical analysis software (Minitab). The effect of speed decreases with the increase in speed, the effect of feed rate gives a better finish at 90mm/min while the parameter depth of cut gives a reasonable result between 0.5 to 1.0 mm. In the analysis, it was discovered that machining parameters also have significant effect on the surface roughness of cast aluminium alloy.

Keywords: Machining, parameters, aluminum, casting and moulding.

1. INTRODUCTION

Metal cutting had been used for quite a very long time by our fore fathers without really having a good understanding of the cutting process or what occurs when the cutting tool come in contact with the metal (Konig, 1983). Metal cutting is defined by Black, 1979 as the removal of chips from a metal work piece so as to obtain a finished product of desired size, shape and surface roughness. The science of metal cutting is aimed at providing a solution to the problems of efficient and precise metal cutting operations (Ager, 2014). It has been discovered that reliable quantitative predictions preferably in equation form of various technological performance measures are essential in the development of optimized procedure for the selection of efficient cutting conditions (Astakhov, 1999). The surface roughness of a machined part affects the functionalities of the part in ways such as; fatigue resistance, light reflection, corrosion resistance, creep life, surface friction during contact, wear, light reflection and lubricant holding ability (ASME, 1996).

Evaporative pattern casting process (EPC) is the process of casting whereby the pattern used in the mould gets evaporated when it gets in contact with the molten metal (Maltais, 2004 and Omidiji, et al, 2015). The process came up in the year 1956 when H.F. Shroyer machined a block of polystyrene foam as a pattern and buried it in a moulding sand (Clegg, 1991). He poured molten metal into the prepared mould without removing the pattern unlike the traditional sand-casting process in which the patterns are removed before pouring. The invention is therefore credited to H.F. Shroyer and since then researches are on-going on the process, having presented advantages in its capacity to produce intricate shapes without cores (Clegg, 2000). A number of parameters identified through research have significant effects on the process by affecting the products whether ferrous or non-ferrous materials (Behm, 2003). These parameters are therefore controlled to ensure sound castings are produced (Omidiji, et al, 2016). Some of them include pouring temperature, gating ratio, grain fineness number of the moulding sand, refractory coatings and vibration to mention a few (Omidiji, 2014).

In 1964 M.C. Flemings applied loose sand instead of the green sand used by H.F. Shroyer to run the process and achieved good success (Clegg, 2000). Foundry men have since classified the use of the green sand and loose sand as evaporative pattern casting process and lost foam process respectively. The subtle difference lies in the use of the bounded and un-bounded sand samples (Omidiji, 2014).

Due to the sensitivity of the EPC Process to the parameters that are always observed in conducting experiments, sound gating system must be designed and implemented in the course of moulding. This reduces turbulence and therefore eliminates casting defects significantly. The gating ratio employed in gating system design for Aluminum as a non-ferrous material is non pressurized one.

This study looks at the effects machining parameters are having on evaporative pattern castings. The machining procedure was observed by taking speed, feed rate and depth of cut as machining parameters at three levels. These machining parameters were synchronized to determine experimental runs of machining for the nine pulleys that were produced. The Taguchi's method was also used. Minitab 15, free trial version was employed for the analysis and determination of the effects of the parameters on the surface roughness of the castings. The surface roughness was taken as the quality assessed in the castings to test for the integrity.

2. MATERIALS AND METHODS

2.1. Materials

The materials for this research and their uses are presented in Table 1.

Table1: Materials

S/N	Material	Source	Use
1	Polystyrene	Market	To construct the patterns
2	Silica sand	Rivers	To construct the moulds
3	Al alloy 6061	Market	To melt as casting material
4	Glue	Market	To join the pattern and gating elements
5	Hexachloromathane	Market	To de-gas the melt

Polystyrene was chosen as the pattern material to make the replica of the work piece to be produced. This is due to the ability of polystyrene to evaporate and vaporize when in contact with molten metal. River sand was selected as the molding material due to its adhesive property, easy workability, relative abundance, and low cost. Also due to years of washing away, it has been subjected to abrasion which makes the particle shape rounded and smooth because it has very low clay and slit content. Aluminum alloy 6061 used in this study is one of the most commonly used aluminum alloys. It is a precipitation hardenable aluminium alloy, containing magnesium and silicon as its major alloying elements. Its elemental composition as determined by sparkling method is shown in table 2. Glue was chosen as the joining material to hold the pattern to the mould and other materials together during the casting.

2.2. Methods

2.2.1. Gating system design for the casting

A non-pressurized gating system was used for this study in ratio:

A_s:A_r:A_g=1:2:4 (Non-pressurized gating ratio) (1)

Where A_s = Cross sectional area of the sprue exit, A_r= Cross sectional area of the Runner(s) and A_g = the cross-sectional area of the ingate(s).

The cross-sectional area of the sprue exit A_s, is of same size as the cross-sectional area of the choke A_c. The shrinkage allowance for aluminum (16 mm) was added to the actual dimension to make room for the shrinkage during solidification of the molten metal.

Actual diameter of work piece 40 mm, length is 75 mm.

Therefore, the Pattern diameter= 40+ (0.04×16) = 40+0.64 =40.64 mm

Pattern Length = 75+ (0.075 × 16) = 76.2 mm

Volume = πr^2L (2)

= 3.142 x 20 ^{2} x75

= 94,247.78 mm^3

Assuming aluminum alloy density (ρ) to be 0.00272 g/mm^3

Density=mass/volume (3)

Mass = density × volume

= 0.00272 ×94,247.78

= 256.35 ≈ 0.256 kg

2.2.2. Pouring rate and pouring time

Pouring Rate Formula for Non-ferrous gating:

R=$b\sqrt{W}$ (4)

Where, R= pouring rate, b= constant, depends on wall thickness W= weight of the casting

b= 0.47 for wall thickness above 12mm

Therefore; R = 0.47 ×$\sqrt{0.256}$ =0.238 kg/s

R_a=$\frac{R}{K.C}$ (5)

Where, R_a= Adjusted pouring rate, K= Metal fluidity, C= Effect of friction with values of 0.85-0.90 for tapered sprues in gating system.

t= $\frac{W}{R_a}$ (6)

Where, t= pouring time

R_a= $\frac{0.238}{1\times 0.85}$ = 0.280 kg/s

t=$\frac{0.256}{0.280}$= 0.914 second

2.2.3. Effective sprue height

To calculate effective sprue height

Sprue Height H = 100 mm

Height of casting in the cope h1=20 mm

Total height of casting h2=40 mm

Then,

H_p= H-0.5$\frac{h1^2}{h2}$ (Rao, 2000) (7)

Where, H_p= effective sprue height.

H_p = 100 - 0.5$\frac{20^2}{40}$ = 95 mm

2.2.4. Choking area

Choke Area, A_c= $\frac{W}{\rho\times t\times c\sqrt{2gH_p}}$ (Rao,2000) (8)

Where, W = casting weight (kg), ρ= density of molten metal (kg/m^3), c= discharge coefficient (0.8), g=9.81m/s^2, t= pouring time(s), H_p= Effective sprue height (mm)

Hence,

Choke area = $\frac{0.256}{2720\times 0.914\times 0.8\times\sqrt{2\times 9.81\times 95\times 0.001}}$ = 94.28 mm^2

Table 2: Elemental Composition

Element	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Ni	Zn
%	96.33	0.22	0.30	0.5	1.07	0.08	0.52	0.69	0.07	0.21

2.2.5. Sprue inlet area

From equation 1, As =Ac

Continuity equation:

$A_{sprue-inlet}$=$\frac{A_{sprue-exit}\sqrt{H_{sprue-exit}}}{\sqrt{H_{sprue-inlet}}}$ (Rao, 2000) (9)

Where $A_{sprue-inlet}$= sprue inlet cross-sectional area

$A_{sprue-exit}$ = sprue exit cross-sectional area

$H_{sprue-inlet}$= Distance between the ladle and sprue top and

$H_{sprue-exit}$ = Distance between ladle and sprue exit.

$A_{sprue-exit}$= 94.28mm^2, $H_{sprue-inlet}$= 50mm, $H_{sprue-exit}$= 50 + 100 = 150 mm

$A_{sprue-inlet} = 94.28\times\frac{\sqrt{150}}{\sqrt{50}}$ = 163.30 mm^2

Radius of the sprue inlet:

$R_{inlet} = \sqrt{\frac{A_{sprue-inlet}}{\Pi}} = \sqrt{\frac{163.30}{3.1416}} = 7.21$ mm

Radius of the sprue exit:

$R_{exit} = \sqrt{\frac{A_{sprue-exit}}{\Pi}} = \sqrt{\frac{94.28}{3.1416}} = 5.48$ mm

Ingates, Runner and sprue well cross-sectional areas using a gating ratio of 1:2:4

Runner cross sectional area= 2 × 94.28 mm^2 = 188.56 mm^2

Area of a square = L × B

Length of runner cross section=Breadth of runner cross section; Area=2L

Length of Runner = $\sqrt{377.12}$ = 19.42 mm

Breadth of Runner = 19.42 mm

Ingates cross sectional area:

Assume 2 ingates will be made;

Each gate area = 0.5 × 188.56 mm^2= 94.28 mm^2

Assume sprue well is 5 times bigger than the sprue exit;

Therefore, Sprue well cross-sectional area = 5 × $A_{sprue-exit}$ = 5 × 94.28 = 471.4 mm^2

The depth is also assumed to be 2 times the Runner depth= 2 × 19.42 = 38.84 mm.

The values of the various elements are presented in Table 3 and Figure 1 shows the graphics of the gating system.

Table 3: Design Dimensions of Gating System

Gating part	Length (mm)	Breadth/Width (mm)	Height/Thickness (mm)
Pouring Basin	50.00	50.00	50.00
Sprue	100.00	Inlet radius=7.21	Exit radius=5.48
Runner	26	19.42	19.42
Ingate	75	Radius=7.46	Radius=7.46

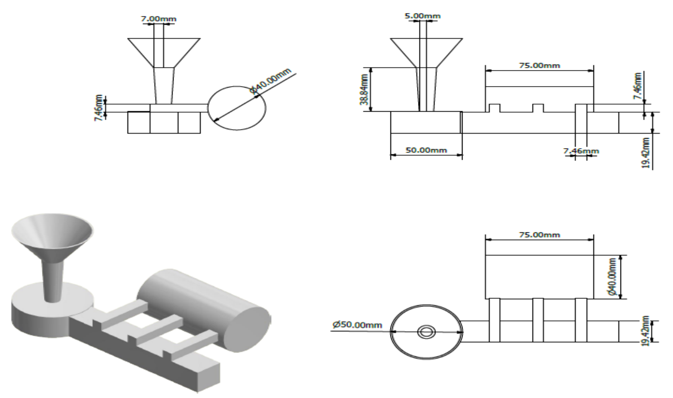

Figure 1: Pictorial View of the Gating System with Detail

2.2.6. Pattern Preparation and Mould Construction

Preheated wire was used to cut the patterns from a block of polystyrene. This was to ensure good surface finish. The patterns were coated with refractory coating prepared from a mixture of silica flour and kaolin and 99% methyl alcohol used as the carrier to transfer the refractory particles to the body of the patterns.

One flask mould was used to construct the moulds. The moulding material was silica sand of varying grain fineness numbers. Assembled patterns and gating systems were buried in the moulds made ready for pouring.

2.2.7. Taguchi's Experimental Design of the EPC Process

Process parameters taken into consideration were gating ratio (1:2:4, 1:3:3, and 1:4:4 for aluminium alloy), pouring temperature (650°C, 700°C,750°C) and moulding materials of grain finene number (40, 60 and 80). The moulding sand was taken from Isasa River at Ipetumodu, Osun River and Eti-osa River. Table 4 shows the process parameters with level of treatment that was investigated. Table 5 depicts the runs of experiment in line with the Taguchi's approach.

Table 4: Process Parameters with Level of Treatment

S/N	Process parameters	Levels 1	2	3
1	Pouring temperature	650°C	7000°C	7500°C
2	Moulding material	40	60	80
3	Gating ratios	1:2:4	1:3:3	1:4:4

Table 5: Taguchi's approach to design of experiments applied to EPC process

S/N	Pouring Temp°C	GFN	Gating Ratio	Component
1	650	40	1:2:4	Pulley
2	650	60	1:3:3	Pulley
3	650	80	1:4:4	Pulley
4	700	60	1:4:4	Pulley
5	700	80	1:2:4	Pulley
6	700	40	1:3:3	Pulley
7	750	80	1:3:3	Pulley
8	750	40	1:4:4	Pulley
9	750	60	1:2:4	Pulley

3. RESULTS AND DISCUSSION

3.1. Machining Parameters and Surface roughness values of Aluminum Alloy

The aluminum alloy castings obtained by evaporative pattern casting process were machined on the CNC milling machine and the machining parameters (spindle speed, feed rate and depth of cut) were considered as factors. The factors are in three levels. Altogether, nine pulleys were machined and the surface roughness values were measured with surface roughness tester, TR100 with piezoelectric pick up type. Table 6 shows the machining parameters with levels and Table 7 gives the Taguchi's approach with the surface roughness values that were determined.

Table 6: Machining Parameters

S/N	Machining parameters	Levels 1	2	3
1	Spindle speed (rpm)	500	1000	1500
2	Feed rate (mm/min)	30	60	90
3	Depth od cut (mm)	0.5	1.0	1.5

Table 7: Taguchi's Design and the Result of their Roughness Values

Runs	Speed (rpm)	Feed rate (mm/mim)	Depth of cut (mm)	Surface roughness Ra (μm)
1	500	30	0.5	170
2	500	30	1.0	205
3	500	30	1.5	160
4	1000	60	1.0	125
5	1000	60	1.5	130
6	1000	60	0.5	235
7	1500	90	1.5	215
8	1500	90	0.5	185
9	1500	90	1.0	85

3.2. Analysis of results

The analysis was carried out by the use of Minitab software 17.0, trial version. The signal to noise ratio employed gives the condition of 'smaller is better' to determine the effects of the machining parameters on the surface roughness values, Ra. Figure 2 shows the main plot effects of the parameters on the Ra. The figure 2 depicts that the values of speed, feed rate and depth of cut at

1500rpm, 90 and 1.0mm respectively produced the best of the roughness value, Ra. Figure 3 shows the interaction plot, bringing together the interaction effects of the parameters. From figure 3, the interaction of the speed and depth of cut reveals a value of 1500rpm for speed as depicted in figure 2. The interaction of feed rate and depth of cut reveals a value of 90 mm/mm for the feed rate. This is also depicted in figure 2. Contor plots describing the interaction of the parameters and further confirming results obtained in figures 2 and 3 are shown in figures 4, 5 and 6. The darkest blue portions of the contors showed where the optimal results are obtained. In figure 4, optimal values of speed vs feed rate are 1500 rpm vs 90 mm/mm. Figure 5 gave 1500rpm vs 1.0 mm for the interaction of speed vs depth of cut and figure 6 gave the value of 90 mm vs 1.0 mm for the interaction of feed rate vs depth of cut.

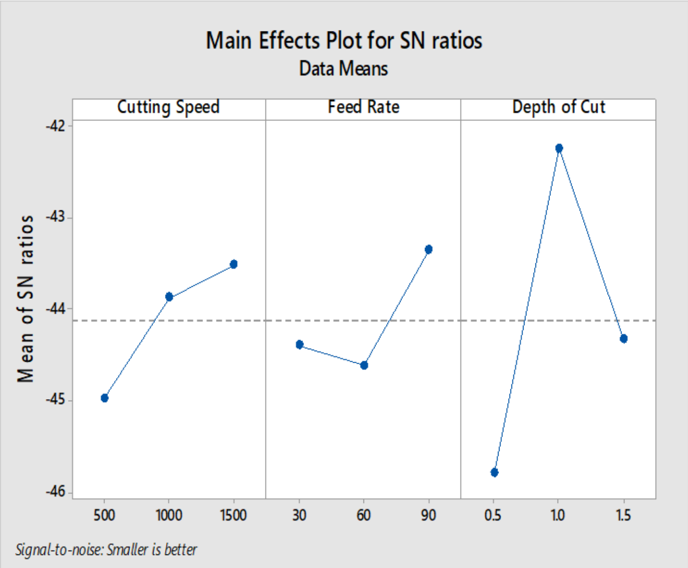

Figure 2: Main plots effects for SN ratios

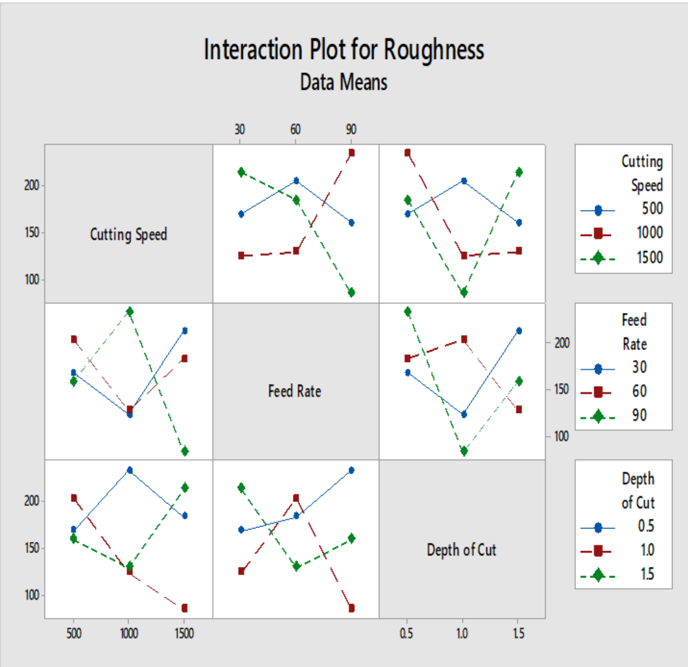

Figure 3: Interaction effects plot

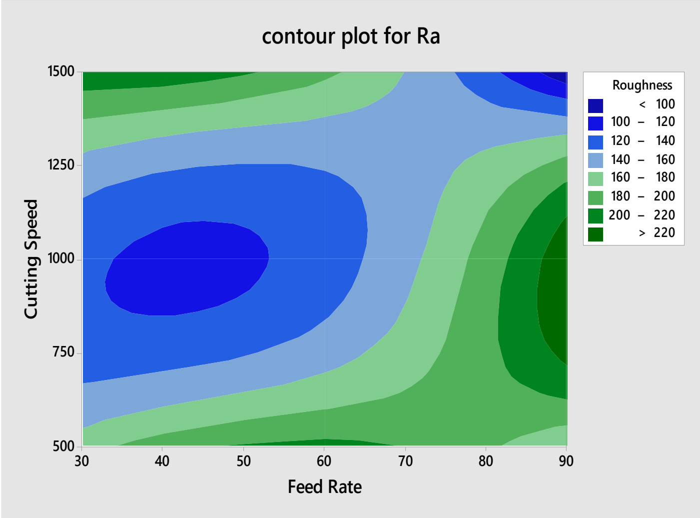

Figure 4: Interaction plot of speed and feed rate

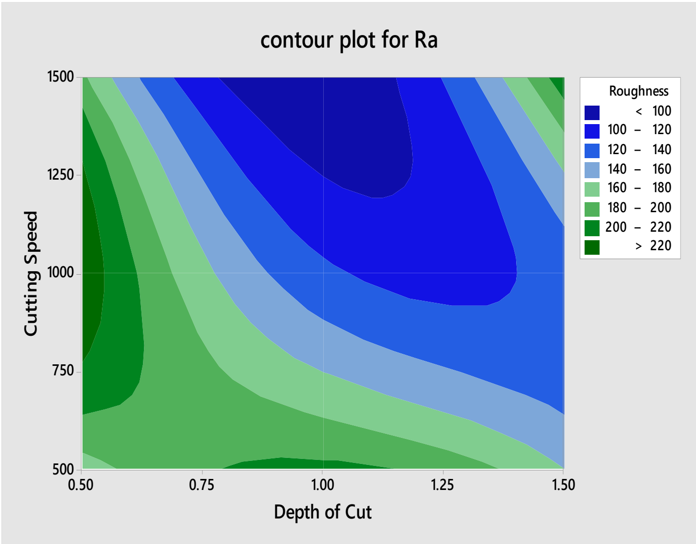

Figure 5: Interaction plot of speed and depth of cut

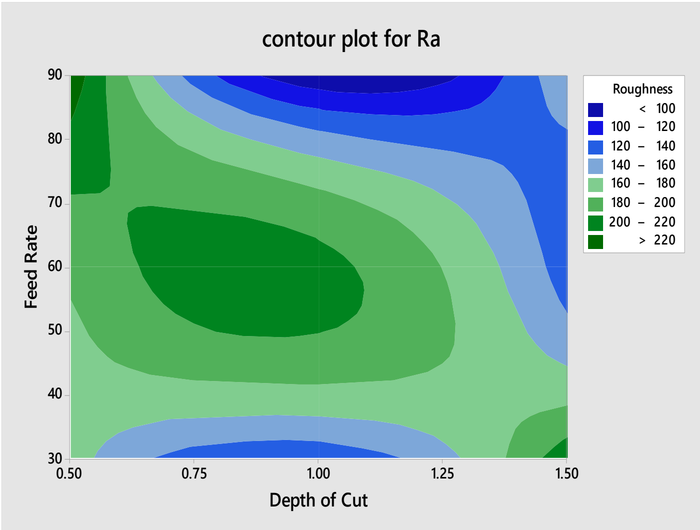

Figure 6: Interaction plot of feed rate and depth of cut

4. Conclusion

The study considered the production of Aluminum alloy pulleys with the method of evaporative pattern casting process. Three process parameters at three levels were used in the production of the pulleys, making nine runs of experiments. Thereafter three maching parameters at three levels were adopted in Taguchi's approach to design of experiments for machining purpose. Main and interaction effects of the machining parameters were determined and confirmed by the contor plots which showed clearly that to obtain the lowest value of the surface roughness, a combination of spindle speed, feed rate and depth of cut of 1500 rpm, 90 mm/mm and 1.0 mm respectively would give an optimal value of 85 µm which is less than 100 mm given by the statistical software, Minitab 17, trial version.

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