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Optimisation of Machining Responses for Drilling of Al-Si Alloy on CNC Vertical Machining Centre Under Dry Drilling Conditions

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Abstract

This paper deals with analysis of machining parameters and optimisation of machining responses such as the thrust force and surface roughness in the drilling of aluminium silicon alloy on CNC vertical machining centre using HSS and carbide tool. All experiments were performed under dry drilling condition which is applied for machining performances for drilling of aluminium silicon alloy on CNC vertical machining centre. Machining parameters such as spindle speed, feed rate and Drill diameter are chosen as the numerical factors, the drill material is considered as the categorical factor. An experimental plan of four-factors with mixed level is tabulated using MINITAB 16® platform. Taguchi design based on L_{18} orthogonal array is employed to carry out the experiments.

The utilisation of aluminium-silicon alloys within the last few years are rapidly increased, particularly in the automobile industries and aircrafts applications, due to their high strength to weight ratio, high wear resistance, low density and low coefficient of thermal expansion.

1. Introduction

Aluminium-silicon (Al-Si) alloy contains silicon as the main alloying element for ease of casting. Al-Si alloys comprise 85% to 90% of the total aluminum-cast parts produced. These alloys are the most important commercial casting alloys mainly due to their superior casting characteristics as compared with other alloys. Aluminium alloys have excellent castability, machinability and corrosion resistance. Aluminium casting alloys can be classified into three groups based on their silicon content: Hypoeutectic alloys, in which the silicon content is between 5-10% ,Eutectic alloys ,in which silicon content is between 11-13%,and Hypereutectic alloys, in which the silicon content is between 14-20% [1-2]. Hypereutectic alloy machinability is improved as the silicon particles become finer and more evenly distributed. Strengthening of these alloys is achieved by small additions of elements such as magnesium, copper, and nickel, which also bring about changes in other properties. For example, in hypoeutectic alloys, silicon provides good casting properties, and copper improves tensile strength, machinability, and thermal conductivity at the expense of a reduction in ductility and corrosion resistance [1].

Aluminium silicon can be cast using various processes including high pressure die casting, permanent mold casting, sand casting, lost foam casting etc., aluminium and silicon form a simple eutectic system with limited solid solutions.

Al-Si is an important alloy for many commercial automotive applications (pistons, cylinder liners, cylinder blocks, cylinder heads, pistons, and valve lifters etc.) Al-Si casting alloy are the most versatile of all common foundry cast alloys in the production of pistons for automotive engines [1-2], [8].

1.1 Taguchi Method

Taguchi method is a technique which is used to find the best combination of factor effects with few experiments. Taguchi method incorporates two important tools which are orthogonal array and Signal to noise ratio(S/N ratio) Taguchi defined a performance measure known as the signal to noise ratio and aims to optimise it by properly selecting the factor levels.

Taguchi methods have been widely utilised in engineering analysis and experimental plan. The main advantage of this method is the saving of effort by conducting experiments, saving experiment time, reducing the cost and finding significant factors quickly than factorial experiment [3-7].

The steps applied for Taguchi optimisation in this work are as follows:

- Select Control factors
- Select Taguchi Orthogonal array
- Conduct Experiments
- Thrust Force measurement
- Surface Roughness measurement
- Analyse Results
- Optimum Performance

2. Experimental Work

2.1 Work piece

Aluminium silicon cast alloy plate of 150x150x15mm is used as a work piece in drilling operation. The optical emission spectrometry was used to test the chemical composition of aluminium silicon cast alloy. The chemical composition of aluminium silicon alloy is shown in below Table 1

Table 1. The chemical composition of aluminium silicon alloy

S.No	Elements	Contents (%)
1	Silicon, Si	12.20
2	Magnesium, Mg	1.0
3	Copper , Cu	0.90
4	Nickel, Ni	0.9
5	Aluminium, Al	Bal

2.2 Design of Machining Parameters and Levels

The machining parameters such as drill bit, spindle speed, feed rate and drill diameter are selected for drilling of aluminium silicon plate on CNC vertical machining centre. The design of machining parameters and their levels are shown in Table 2.

Table 2. Design of machining parameters and levels

Parameters	Levels		
	1	2	3
Drill Bit	Hss	Carbide	-
Spindle Speed (r.p.m)	1000	1500	2000
Feed Rate (mm/min)	50	75	100
Drill Dia (mm)	8	10	12

2.3 Selection of an Orthogonal Array

The degrees of freedom of 2-level factor have one degree of freedom and a 3-level factor has two degrees of freedom. One 2-level and three 3-level factors require 7 degrees of freedom.

The smallest orthogonal array with atleast 7 degrees of freedom is the L_8 (2^7) orthogonal array. However this orthogonal array can accommodate seven 2-level factors, it cannot accommodate any 3-level factors. Therefore L_8 orthogonal array cannot use for this experiment. The next possibility is the L_{18} (2^1 x 3^7) orthogonal array. This array can accommodate one 2-level and seven 3-level factors. Therefore, it is possible to assign one 2-level factor to 2-level column and three 3-level factors to the three of seven 3-level columns by leaving four 3-level columns un assigned. Also, it is possible to select an L_{36} orthogonal array. However it results inefficient experimentation since 36 experiments have to be conducted. So, an L_{18} orthogonal array is better choice for this experiment [3-7]. Design layout of L18 orthogonal array is shown in Table 3.

Degrees of freedom of an orthogonal array,

$$V_{OA} = \text{Number of experiments} - 1 = 18-1 = 17$$

Where,

V_f is degrees of freedom of number of factor levels,

V_{OA} is degrees of freedom of an orthogonal array.

$V_f < V_{OA}$, Degrees of freedom calculated by number of factor levels is less than the degrees of freedom calculated for the orthogonal array. This is because L_{18} (2^1 x 3^7) has special property where two degrees of freedom are taken up between a 2-level factor and 3-level factor [3].

Table 3. Design layout of L18 orthogonal array

Exp.No	Drill Bit	Spindle Speed (r.p.m)	Feed Rate (mm/min)	Drill Dia(mm)
1	Hss	1000	50	8
2	Hss	1000	75	10
3	Hss	1000	100	12
4	Hss	1500	50	8
5	Hss	1500	75	10
6	Hss	1500	100	12
7	Hss	2000	50	10
8	Hss	2000	75	12
9	Hss	2000	100	8
10	Carbide	1000	50	12
11	Carbide	1000	75	8
12	Carbide	1000	100	10
13	Carbide	1500	50	10
14	Carbide	1500	75	12
15	Carbide	1500	100	8
16	Carbide	2000	50	12
17	Carbide	2000	75	8
18	Carbide	2000	100	10

3. Experiment Procedure

The drilling experiments were carried out in a computer numerical control (CNC) vertical machining center (ARIX VMC 100) as shown in Fig.1 .The machining sample is prepared in the form of 150×150×15-mm plate.The experiments were conducted as per the L_{18} orthogonal array on a CNC Vertical machining centre using HSS, Carbide drills of diameter 8,10 and 12mm, a helix angle of 30 degrees and point angle of 118 degrees.The machining parameters considered for this experiments are spindle speed, feed rate, drill diameter and type of drills. The experimental design under dry drilling condition which is applied for machining performances in drilling of aluminium silicon alloy on CNC vertical machining centre

Computer controlled data acquisition system - used to collect and record the data during experiments.

Kistler dynamometer - used to record the thrust forces (Fz) during experiments.

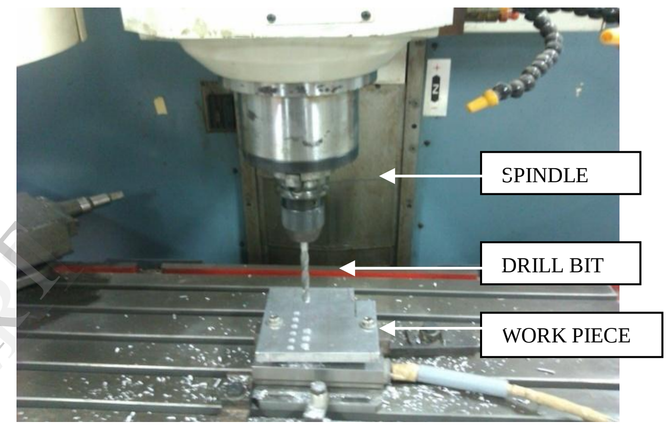

Figure 1. Photographic view of drilling of aluminium silicon plate on VMC

4. Experimental Results and Discussions

4.1 Thrust Force Measurement

Kistler Dynamometer is used to record the thrust forces during experiments. Time is fixed to 40 sec for recording the thrust forces for each experiment. DYNOWARE 7.511.328 software is used to calculate mean value of thrust force for each experiment. Thrust force values for each experiment are shown in Table 4.

4.2 Surface Roughness Measurement

Surface roughness of machines work piece can be carried out by means of different measurement techniques .These techniques can be classified in to following:

1. Direct measurement techniques
2. Comparison based techniques
3. Non contact methods
4. On-process measurement techniques

Stylus type profilometer (Surtronic Taylor 3+) is an direct measurement instrument which is used to measure surface roughness of hole [4], [11-12]. Roughness measurements in the transverse direction, on the work piece have been reapeted four times and average of surface roughness, Ra values has been recorded. Surface roughness, Ra values are show in Table 4.

Table 4. Machining responses

Exp.No	Thrust Force, Fz in (N)	Surface Roughness, Ra in (µm)
1	92.11	1.78
2	127.80	4.32
3	216.50	6.68
4	57.69	2.78
5	104.20	3.22
6	122.40	2.48
7	65.22	0.79
8	84.78	3.64
9	81.58	5.58
10	74.90	2.46
11	81.00	1.57
12	110.00	1.79
13	36.65	0.54
14	62.93	2.62
15	68.03	3.74
16	44.51	1.54
17	31.74	2.34
18	63.25	5.96

4.3 Analysis of Experiment

The Thrust force, Fz and Surface roughness, Ra values was collected according to the L_{18} orthogonal array design layout

MINITAB 16® software is used to create the design layout and analyse the Taguchi design of L_{18} orthogonal array.

Signal to noise ratio (S/N ratio) measures how the response varies relative to the nominal or target value under different conditions [3], [13-16]. They are:

- Smaller the better
- Larger the better
- Nominal the best

For calculating the Signal to noise ratio of Thrust force, 'Fz' and Surface roughness, 'Ra' a smaller the better condition has been selected. The Main effects plots for thrust force and Main effects plot for surface roughness are shown in Fig. 2 and Fig. 3.

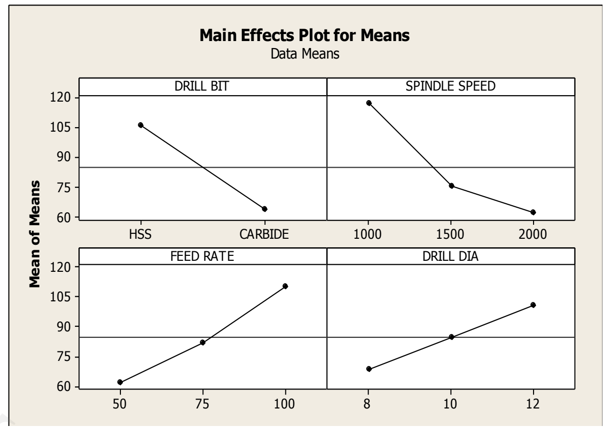

Figure 2 Shows main effect plot for mean thrust force

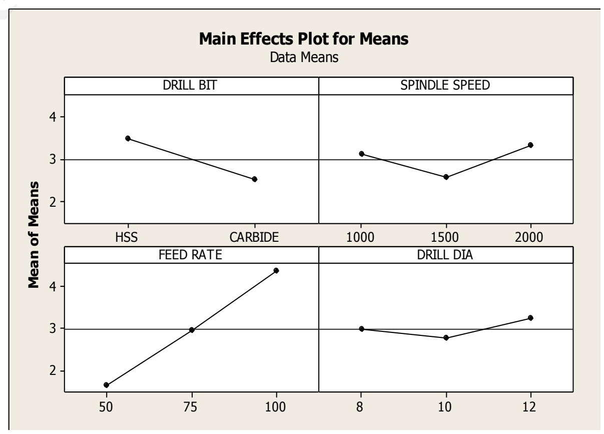

Figure 3 Shows main effect plot for mean surface roughness

The above Fig. 2 and Fig. 3 shows that among the tools considered, the carbide drill bit performs better than the HSS drill bit for reducing thrust force and better surface roughness in the drilling of Al-Si alloy plate.

Thrust force generally increases as the speed increases but further decreases in the case of carbide drill bit. Thrust force recorded for HSS drill bit was high when compared to Carbide. Since the hardness of HSS drill bit is less than the Carbide drill bit.

Thrust force is high as feed rate increases due to change in shear area.

Surface roughnesses is better with decrease in feed rate and also when the type of drill bit have been used to carbide.

5. Conclusion

The following conclusions have been drawn from the Figure2 and Figure 3:

- Carbide drill bit with increasing a spindle speed of 2000 rpm and reducing feed rate of 50 mm/min and drill dia of 8mm, gives optimum thrust force because hardness of HSS drill bit is less than the carbide drill bit.
- Thrust force decreases with increase in spindle speed and vice versa.
- Carbide drill bit at a spindle speed of 1500 r.p.m , feed rate of 50 mm/min and drill dia of 10mm gives optimum surface roughness.
- Surface roughness increases with decrease in feed rate and vice versa.

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