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EFFECT OF PROCESS PARAMETERS ON SURFACE ROUGHNESS IN HIGH-SPEED END MILLING OF Al - ALLOY

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This paper presents a study of the Taguchi design application to surface quality in a CNC end milling operation. In the present investigation, the straight flute end-milling cutter was used for machining of Al-Si-Mg-Fe alloy work pieces. The surface roughness depends upon the cutting speed, feed rate and depth of cuts. The influence of high-speed end milling on surface roughness in Al-Si-Mg-Fe alloy work pieces, which were cast by the sand, investment and die casting method, was investigated. The results concluded that the surface roughness decreases with increase in the cutting speed, increases with increase in feed rate and depth of cut.

1. Introduction

Under periodically varying milling forces, the cutting tool experiences both static and dynamic deformations, which are passed as dimensional, and surface finish errors to the product. The conditions that affect the surface finish are feed, speed, material, and tool geometry. The residual stresses may be induced during machining due to milling forces and heat generation.

In the present work, the influence of high-speed end milling on surface roughness and residual stresses in Al-Si-Mg-Fe alloy work pieces, which were cast by the sand, investment and die casting method, was investigated. The end mills have cutting teeth on the end as well as on the periphery of the cutter. In the present investigation, the straight flute end-milling cutter was used for machining of Al-Si-Mg-Fe alloy work pieces.

The effects of high speed milling of cast Al-Si-Mg-Fe alloys were investigated in terms of surface morphology and residual stresses of work piece. The surface morphology was investigated through the measurement of surface roughness [1] and scanning electron microscopy (SEM).

2. Design of Experiments

The Al-Si-Mg-Fe alloy was prepared and chemical analysis of their ingredients was done. The chemical composition of alloy is given in Table 1. The sand mould, investment shell, and cast iron mould were employed to prepare the samples for high-speed end milling.

Table-1: Chemical composition of alloys

Alloy	Composition determined spectrographically, %						
Element	Al	Si	Mg	Fe	Cu	Mn	Cr
%	85.22	9.0	2.0	3.5	0.01	0.25	0.02

2.1 Selection of the quality characteristics

The selection of quality characteristics to measure as experimental outputs greatly influences the number of tests that will have to be done statistically meaningful. The quality characteristics, which were selected to influence the high-speed end milling of Al-Si-Mg-Fe alloy, are the surface roughness and residual stresses.

2.2 *Selection of machining parameters*

This is the most important phase of investigation. If important parameters are unknowingly left out of the experiment, then the information gained from the experiment will not be in a positive sense. The parameters, which influence the performance of the high-speed end milling, are:

- Microstructure of Al-Si-Mg-Fe alloy
- Cutting speed
- Feed rate
- Depth of cut
- Coolant

Since the high-speed milling involves high cost of machining, the process parameters were optimized using Taguchi's method [2]. Taguchi techniques offer potential savings in test time and money by more efficient testing strategies. Not only are savings in test time and cost available but also a more fully developed product or process will emerge with the use of better experimental strategies.

Table-2 Control parameters and levels

Parameter	Symbol	Level – 1	Level – 2	Level-3
Casting	c	Sand casting	Investment casting	Die casting
Cutting speed, m/min	n	600	1200	1800
Feed rate, mm/min	f	1000	3000	5000
Depth of cut, mm	d	0.2	0.4	0.6

Control parameters are those parameters that a manufacturer can control the design of high-speed end milling. The levels chosen for the control parameters were in the operational range of the high-speed end milling. Trial runs were conducted by choosing one of the machining parameters and keeping the rest of them at constant values. The selected levels for the chosen control parameters are summarized in Table – 2. Each of the four control parameters was studied at three levels.

2.4 Assignment of control parameters

The orthogonal array, L_9 was selected for the high-speed end milling. The parameters were assigned to the various columns of orthogonal array (OA). The assignment of parameters along with the OA matrix is given in Table–3.

Table-3 Orthogonal Array (L_9) and control parameters

Treat No.	n	f	d	c
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3. Results and Discussion

The experiments were conducted randomly and repeated twice. The surface roughness (R_a) values under various combinations of machining variables are given in Table 3. The roughness profiles for some machining conditions are shown in Figures 1-3. The summary of ANOVA (analysis of variance) for surface roughness is shown in Table 4. According to the analysis of variance, all the process variables have significant influence on the variation of surface roughness. The percent contribution indicates that the variable d (depth of cut) all by itself contributes the most toward the variation observed in the surface roughness (Ra values): almost 73.45%. The variable f (feed rate) contributes over 13.42% of the total variation observed. The variables n (cutting speed) and c (type of casting) contribute 7.02% and 6.09% respectively to the total variation in surface roughness.

Table-3: Experimental results of surface roughness

Treat No.	Surface roughness (Ra), microns	
	Trial-1	Trial-2
1	3.76	3.72
2	4.48	4.34
3	5.52	5.56
4	3.69	3.75
5	5.19	5.24
6	3.82	3.91
7	4.56	4.67
8	3.04	2.89
9	4.68	4.61

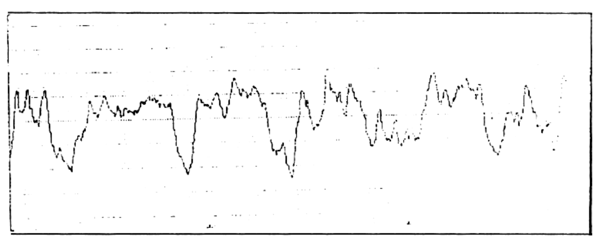

Figure 1: Treatment No:1; Ra = 3.76 microns

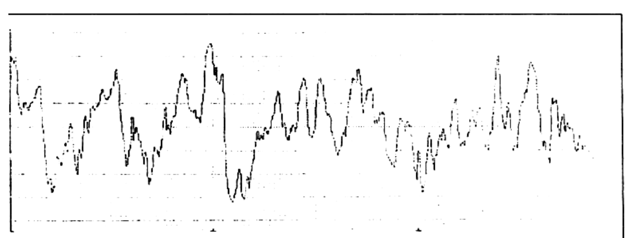

Figure 2: Treatment No:3; Ra = 5.52 microns

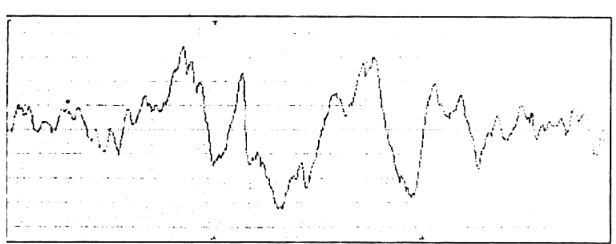

Figure 3: Treatment No:5; Ra = 5.19 microns

Table-4: ANOVA summary of surface roughness

Column No	Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
1	n	124.944	109.227	99.634	0.726433	2	0.36322	85.4628	7.02
2	f	97.204	105.672	131.602	1.399433	2	0.69972	164.639	13.42
3	d	74.483	108.800	157.491	7.6969	2	3.8485	905.518	73.45
4	c	123.307	110.768	99.634	0.630433	2	0.31522	74.1686	6.09
5	e	----	----	---	0.03825	9	0.00425	---------	---------

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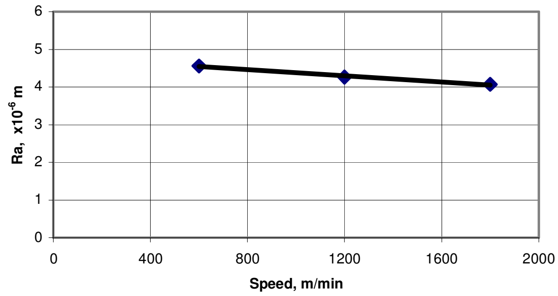

Figure 4: Effect of cutting speed on the surface roughness

The effect of cutting speed on the surface roughness is shown in Figure 4. The surface roughness decreases with increase in the cutting speed. Indeed, low speeds are used for rough cutting and high speeds are employed for fine finishing in the machine shop.

The effect of feed rate on the surface roughness is illustrated in Figure 5. It can be understood that the surface roughness increases with increase in feed rate. The cutting with a tool having a certain wear generates surface roughness than a fresh tool, because the tool wear is proportional to the cutting feed rate and roughness is a reproduction of the tool nose profile on the workpiece surface.

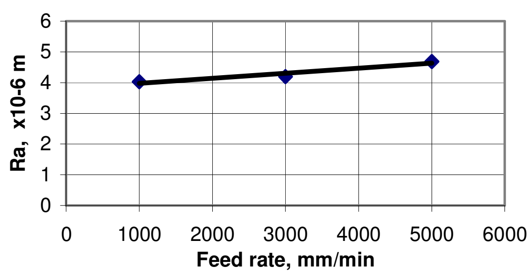

Figure 5: Effect of feed rate on the surface roughness.

The variation of surface roughness of the workpiece on account of depth of cut is shown in Figure 6. It is clearly seen that the roughness increases with increase in depth of cut. Depth of cut plays major role on the roughness of the workpiece surface. The rigidity of the cutting and machine is largely depending upon the depth of cut. The rigidity decreases with increase in depth of cut [3]. The amount of heat generation increases with increase in depth of cut, because the cutting tool has to remove large volume of material from the workpiece. The plastic deformation of the workpiece is proportional to the amount of heat generation in the workpiece. Large amount of plastic deformation in the workpiece promotes roughness on the workpiece surface.

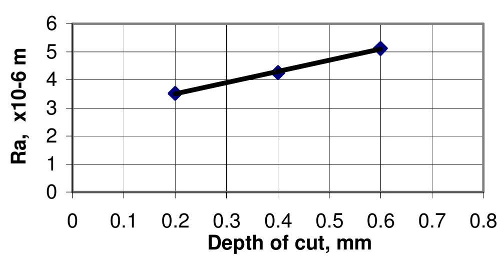

Figure 6: Effect of depth of cut on the surface roughness.

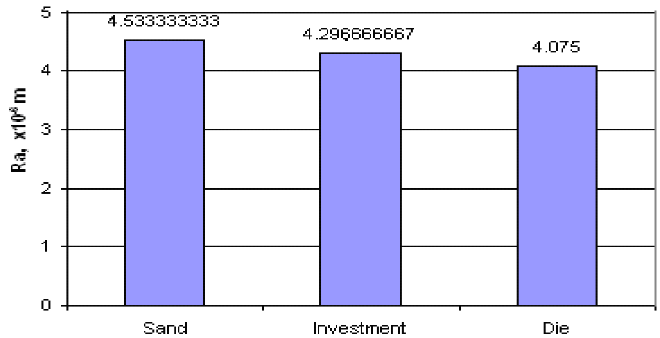

Figure 7: Effect of casting condition on the surface roughness

The variation of surface roughness with casting condition is shown in Figure 7. The sand cast specimens promote greater roughness than die cast specimens. This is due to fact that the sand specimens have coarse grain structure, whereas the die cast specimens have fine grain structure. The surface roughness of investment cast specimens is intermediate to the sand and die cast specimens.

In the SEM micrography (Figure 8(a), the white lines parallel to the milling direction are caused by the tearing of material. The tearing of material is observed with deeper depth of cuts. In Figure 8(b) the white lines caused by tearing are less evident and the spreading of material is observed. The spreading of material is resulted with lower depth of cuts.

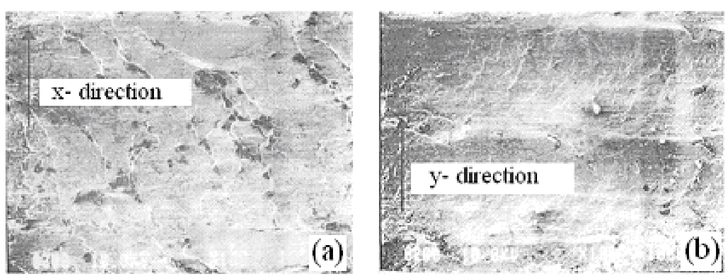

Figure 8: Surface morphology after high-speed milling (SEM)

4. Conclusions

The surface roughness depends upon the cutting speed, depth of cuts and feed rates. The surface roughness decreases with an increase in the cutting speed and, increases with increase in feed rate and depth of cut. The rigidity of the cutting and machine is largely depending upon the depth of cut.

5. References

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