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EFFECT OF VARIOUS MACHINING PARAMETERS ON CHIP THICKNESS RATIO OF HIGH SPEED MACHINED AL- SI ALLOY

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Abstract— *Aluminum Silicon alloys are finding increasing applications in automobile industry, aerospace structural application and military application because of there excellent cast ability, good weld ability, good thermal conductivity, high strength at elevated temperature and excellent corrosion resistance. It is well known that the quality of machined surface*

Determines characteristics of a product such as its longevity and reliability. The ability of a material to withstand severe conditions of stress, temperature and corrosion depends on quality of the surface generated during machining. In this paper we have studied the surface integrity of Al-Si alloy. Cutting speed, feed, depth of cut and silicon percentage are used as variable parameters for machining. Two levels of every parameter were chosen to see the effect on cutting forces and surface roughness. ANOVA software is used for the analysis of cutting forces as well as surface roughness. It is found that increase in silicon percentage has its direct effect on hardness to increase, along with the cutting forces resulting in higher surface finish. Similar observations were seen for speed variation. So it is important to select speed and silicon percentage for high speed machining of Al-Si alloy.

Keywords—*Al-Si alloy, CNC lathes, Cutting forces, surface roughness.*

Introduction

Aluminium Silicon alloy are finding increasing applications in automobile industry, aerospace structural

application and military application because of there excellent cast ability, good weld ability, good thermal conductivity, high strength at elevated temperature and excellent corrosion resistance. When alloys are to be used as a product, the characterisation of surface generated involving surface topography and surface integrity play an important role in the performance of the product. When Al-Si alloys are used in a product, characteristics of the surface generated significantly influence the product performance. It is well known that the quality of machined surface determines characteristics of a product such as its longevity and reliability. The ability of a material to withstand severe conditions of stress, temperature and corrosion depends on quality of the surface generated during machining. Machined surface quality can be defined by two measures-surface topography and sub-surface integrity. The surface topography can be measured using standard surface roughness measurement equipment; whereas the measurement of sub-surface integrity is a complex task. In order to understand the effect of process parameters on the chip thickness ratio large number of machining experiments has to be performed and analysed. Hence empirical /statistical approaches are widely used over the conventional mathematical models. In this experimental work, an approach based on the full factorial is used.

Selection of work material and tooling

Experiments were planned using two specimens having different silicon percentage. The chemical composition of both the alloys is given in Table 1a and Table 2a.All the ingredients with silicon and aluminum are placed at the bottom of the crucible. The melting operation was carried out in a natural gas fired crucible furnace, where the materials were placed in a graphite cruible. The melt was superheated at a temperature of 750°c and then held at this temperature for about 5 min. The melt was stirred and poured at 700-720° first into a cast iron keel block mould followed immediately by pouring into a green sand mould, The specimen of material Al-Si alloy with varying silicon percentage such as 8.5 and 11.2 were prepared using casting process. Initially the scrap pistons are melted up to 750˚C.Then by holding this at about 5 minute, stirring and

Pouring action is carried out at about 700-720˚C. Then the silicon percentage is measured by laboratory testing.

(a) Work piece material

Work piece Al-Si alloy (11.2%Si)

11.2 Si – 2.3 Ni – 0.77Mg – 0.82 Cu

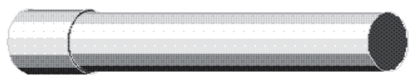
Size: Diameter: 40 mm

Length: 240 mm

Commercial name: A384.0

Table 1 (a) Composition of work piece Al-Si alloy (11.2%Si)

Si	**Cu**	**Pb**	**Fe**	**Mn**
11.2	0.82	0.12	0.76	0.14
Mg	**Ni**	**Zn**	**Sn**	**Al**
0.77	2.30	0.11	0.10	Remain



Automotive and diesel pistons, pulleys, sheaves and other applications where high temperature strength, low coefficient of thermal expansion and good resistance to wear are required.

Table 1 (b) Mechanical and physical characteristics of Al-Si alloy (11.2%Si)

Sr. No	Name	Value
1	Tensile Strength	330MPa
2	Yield Strength	165Mpa
3	Die Casting Temp.	615-700^{0}C
4	Thermal Conductivity	96 W/m.k

Work piece Al-Si alloy (8.0%Si)

8.0 Si – 2.4 Ni – 0.77Mg – 0.84 Cu

Size: Diameter: 40 mm

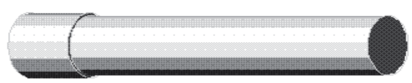
Length: 240 mm

Commercial name: A380

Table 2 (a) Composition of work piece

Al-Si alloy (8.0%Si)

Si	**Cu**	**Pb**	**Fe**	**Mn**
8.0	0.84	0.11	0.78	0.12
Mg	**Ni**	**Zn**	**Sn**	**Al**
0.77	2.40	0.10	0.10	Remain



Typical uses are applications where good high temperature strength, low coefficient of thermal expansion and good resistance to wear are required (for example automotive and diesel pistons, pulleys, sheaves etc.)

Table 2 (b) Mechanical and physical characteristics of

Al-Si alloy (8.0%Si)

Sr.No.	Name	Value
1	Tensile Strength	330MPa
2	Yield Strength	165Mpa
3	Die Casting Temp.	635-705^{0}C
4	Thermal Conductivity	96.2 W/m.k

b) Cutting Tool

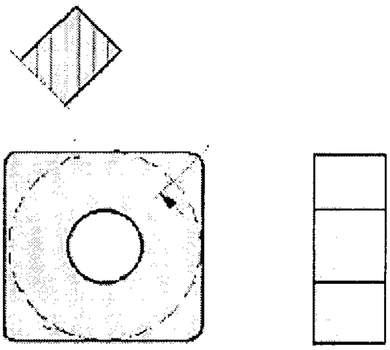
Poly crystalline diamond (PCD) inserts were selected as a cutting tool. The extremely high hardness of diamond makes it a suitable for cutting tools. PCD tools are used especially for machining hypereutectic Al-Si alloy (piston alloy) due to extremely abrasive nature of coarse silicon content and thus very difficult to machine, compared to carbide tipped tools. These tools have longer operating lives, higher precision and better operating stability. Currently PCD tools are widely used since these passes much better isotropic mechanical properties than mono-crystalline (natural) diamonds. PCD tools are less sensitive to impact loading and can be used where interrupted cutting actions occur.

Depending upon the cutting conditions, PCD tools are about 40 to 100 times more efficient than carbide tools. This means that in individual cases the operating life of the PCD tools can be up to 100 times longer than that of carbide tools, thus more than compensating for this higher price.

Specification of insert:

ISO designation: CNGA 12 04 08 S 0 1025 and CNGA 12 08 08 S 0 1025

Grade : KD 100



Make : Kennametal

A polycrystalline diamond tip (PCD) is brazed onto a carbide substrate. In this type, grade KD 100 is recommended for general-purpose turning operation. The cutting tool material contains a binder in addition to diamond particles. This makes the grade suitable for roughing to finishing of all types of highly abrasive work pieces, including non-ferrous metals and non-metallic materials. These inserts are the first choice on high content silicon aluminium alloys (hypereutectic). It has the best mechanical shock resistance and suitable to operate at very high speeds.

Specification of cutting tool holder

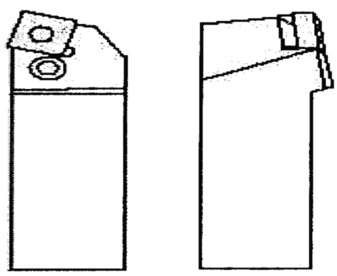
ISO designation: PCLNL 2525 M 12

Tool Geometry:

Principal cutting edge angle: 95°

Orthogonal rake angle : -6°

Clearance angle : 0



Machine Tool

The high speed CNC lathe supplied by ACE Designers with jobber XL model was selected for conducting the experiments. The speed ranges are also co-coordinated by silicon percentage, feed, and depth of cut.

Fig. 1 CNC Machine used for experimental work

Nikon Measuring Microscope

The chip cross sections (chip width and chip thickness) were measured using Nikon Measuring Microscope (Model No MM-40/L3U) having magnifications 12X to 3000X. The Eyepiece used was CFWN10XCM (Field No. 20). This device was connected with digital counter to display, which measures a distance of accuracy 0.0001 mm.

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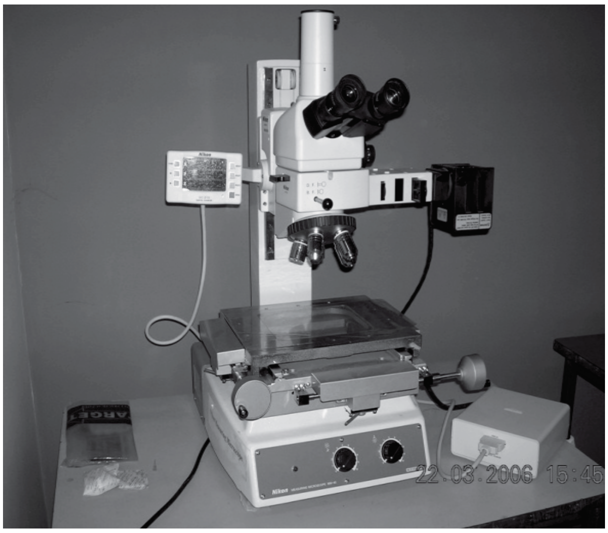

Fig. 2 Nikon Measuring Microscope

Selection of Input Parameters

Selection of Input factors and Their Levels:

It is known that the various factors directly or indirectly influence the performance of machined surface quality in terms of surface finish, cutting force magnitude and chip characteristics in machining of Al-Si alloy with PCD insert. These are discussed in the following paragraph.

Input or Controllable Factors

From the past work, it is observed that the parameters such as cutting speed, feed rate, depth of cut and silicon percentage are the primary parameters having most significant effect on machining performance In this experimental study, four parameters as cutting speed, feed rate, and depth of cut and silicon percentage were selected.

Cutting Speed (V)

It is known that the cutting speed has greater effect on cutting force and surface finish. Cutting speed influence the temperature produced in the Deformation zone and thus governs the mechanism of chip formation and thus resultant magnitude of cutting forces and surface finish.

Feed Rate (f)

A variation in the feed has greater influence on surface finish than the depth of cut. It is known that the height of the surface generated while machining is directly proportional to the feed rate [f]. It is possible to obtain better surface finish by increasing the feed rate and cutting speed.

Depth of Cut (d)

It has great influence on cutting force than feed rate .As depth of cut increase, the cutting force also increases. Depth of cut influences the volume of material involved in machining deformation. Thus higher the depth of cut, larger the material deformation. Thus by controlling the depth of cut cutting forces and hence surface finish can be controlled.

Silicon Percentage (%Si)

It has moderate effect on cutting force and surface finish. Silicon is added in the aluminium during melting to improve the fluidity.

Noise Factors (X)

These are the parameters that cannot be controlled by the designer or operator. They are inherent in the system. These factors cause the response 'y' to deviate from the target specified by the signal factor 'W' and lead to quality loss. The noise factors in this work are machine vibrations, rigidity and tool wear, operator skill, temperature in the shop.

Signal Factors (W)

These are the factors set by user or operator for the product to express the intended value for the response of the product. Design engineer based on the engineering knowledge of the product/process being developed, selects the signal factors. Two or more signal factors (a) variable and (b) fixed were used. In the present study, the cutting speed, feed rate, depth of cut, as tool related factor whereas silicon percentage as a material related factor were selected.

Selection of Response Variables

It is seen from the past work that the performance of turning process is evaluated in terms of surface finish, cutting forces and surface integrity. However in the present investigation, the focus is on the evaluation of surface finish and cutting forces. Therefore, there two output variable were chosen as the response variable.

Table 3 Input factors and their levels

Factors	Machining parameter	Unit	Level	
			1	2
Variable	Silicon Percentage, %Si		8.0	11.2
	Cutting Speed, *V*	m/min	450	500
	Feed Rate, f	mm/rev	0.1	0.5
	Depth of Cut, *d*	mm	0.1	0.05
Fixed	Tool geometry (clearance angle= 0°, 80° rhombus shape, nose radius = 0.8 mm, back rake angle = -6°, approach angle=95°, side cutting edge=5°)			
	Tool material (PCD)			

Many parameters affect the performance of diamond machining, so the first task is to select a reasonable set of input parameters. On one hand a smaller number of parameters might not serve the purpose, but on the other hand a large number of parameters

will make the prediction more difficult. Thus, the choice of input parameters is, to some extent, a compromise. Based on the survey of literature, experience of the operators and some preliminary screening experiments, input parameters were chosen. These control parameters were varied in a range during the experiments to study their effect on the performance measure. The control parameter and its range are given in tables.

Control parameters

Factor/ parameter	Level 1	Level 2
Cutting speed (m/min)	450	500
Feed (mm / rev)	0.05	0.2
Depth of cut (mm)	0.1	0.5
Silicon (%)	8.0	11.2

Arithmetic surface roughness of 2^3 factorial design matrixes with replicates is shown in Table 5.

Fixed parameters

There are other factors, which can be expected to have an effect on the measures of performance. In order to minimize their effects, other factors were held constant. The other fixed parameters are

Work piece material: Aluminium-Silicon alloy

Tool nose radius : 0.2 mm
Tool rake angle : 0^0
Clearance angle : 10^0
Work piece dia. : 40 mm
Work piece length : 240 mm

Experimental Procedure

The cylindrical work piece of Al-Si alloy having diameter 40 mm and length 240 mm was mounted on rigid CNC turret lathe machine with tail stock support. A PCD insert with MT KD 100 grade was clamped on tool holder PCLN L 2525 M12 that was mounted on the top plate of the Kistler dynamometer. The force plate with cutting tool was mounted on a CNC machine turret with supporting fixture plate. The forces were measured online and recorded on computer with DYNOWARE software.

The experiments were performed randomly as per the full factorial method. Before starting first experiment the work piece was prepared for experiment and the turning length was selected as 25 mm. Then the machining parameters were selected according to the first experiment data on CNC machine. For every new experiment, the next 25 mm of the work piece was used. Thus on a work piece of 240 mm eight experiments were conducted. After each set of eight experiments new workspace of same dimensions was used. According to cutting speed and diameter of work piece the rpm of spindle was adjusted. In this manner total 16 experiments were performed one by one in random order. For sixteen experiments one PCD insert is used and chips were collected. While performing experiment the forces were measured and after completing the experiment the roughness value was measured by Tomlinson surface Tester and chip Nikon measuring microscope measured cross section and thickness.

Analysis of variance (ANOVA)

Analysis of variance is used to estimate the statistically significant machining parameters and to determine percent contribution of machining parameters on cutting forces, chip thickness ratio and surface roughness during machining of Al-Si alloy. As stated earlier each experiment is repeated ones. Average value of each response is tabulated in Table 5. The η values of machining performance for each full factorial experiment can be calculated from S/N ratio of cutting forces, chip thickness ratio and surface roughness, for this purpose a statistical software MINITAB, version 15 was used. In this experiment each effect having P-value less than 0.05 is considered as significant for 95%confidence interval. ANOVA for cutting forces, chip thickness ratio and surface roughness are also discussed systematically one by one in next section. However, there may be possibility that another factor or factors also affect the process performance. Similar calculations are performed to evaluate cutting forces, chip thickness ratio and surface roughness. The results of the experiments performed for average arithmetic surface roughness of 2^3 factorial design matrix with replicates is shown in Table

Table 5. Designed matrix 2^k and the observed response values

Silicon amount (%)	Depth of cut (mm)	Feed rate (mm/rev)	Cutting speed (m/min)	Chip thickness ratio
1	1	1	1	0.42
1	1	1	2	0.44
1	1	2	1	0.25

1	1	2	2	0.20
1	2	1	1	0.23
1	2	1	2	0.51
1	2	2	1	0.56
1	2	2	2	0.51
2	1	1	1	0.52
2	1	1	2	0.51
2	1	2	1	0.25
2	1	2	2	0.25
2	2	1	1	0.53
2	2	1	2	0.42
2	2	2	1	0.31
2	2	2	2	0.56

Analysis of chip thickness ratio (k)

Chip thickness during machining of Al-Si alloy were measured using Nikon measuring microscope and process for the statistically analysis.

Considering chip thickness ratio as response variable ANOVA is carried out to see the effect of process parameters on chip thickness ratio in machining of Al-Si alloy. Figure 3 and Table 6 show the corresponding main effects plot and ANOVA

Table 6. ANOVA for Chip thickness ratio, k

Source	Degrees of Freedom	Sum of Square	Mean Square	F-ratio	P-ratio$_{2-}$

Speed	1	0.526	0.526	0.35	0.567
Depth of cut	1	15.563	15.563	10.31	0.008
Feed	1	63.282	63.282	41.91	0.000
Silicon percentage	1	8.910	8.910	5.90	0.033
Error	11	16.610	16.610	--	--
Total	15	104.891	--	--	--
S = 1.22881 R-Sq = 84.16% R-Sq (adj) = 78.41					

It is observed that the feed, speed, depth of cut and silicon percentage is most significant factor governing K for ANOVA that at 500 m/min, feed 0.20, depth of cut 0.5 mm and silicon percentage 8.0 with polycrystalline diamond tool was maximum observed. It is observed that feed and depth of cut has significant effect on surface roughness at 95% confidence interval

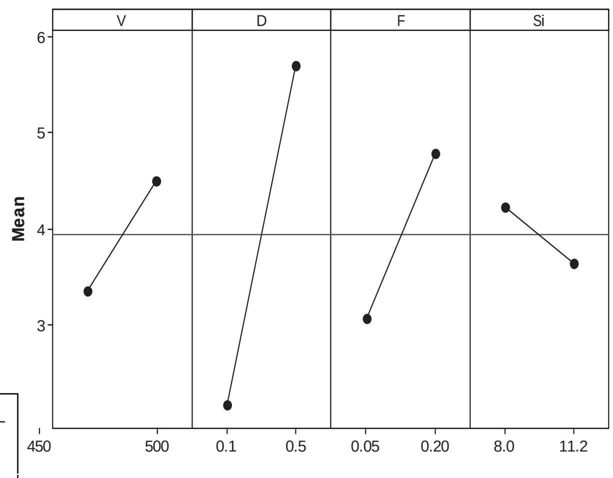

Fig. 3 Means plot for Chip thickness ratio

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The effect of cutting speed on Chip thickness ratio

It is observed from main effects plots Figure 3 that, as cutting speed increases from 450 m/min to 500 m/min, Chip thickness ratio increases. A prominent observation found from the experiments that at higher cutting speed the chips becomes more ductile and continuous in nature because of increased temperature of the shear zone

The effect of feed rate on Chip thickness ratio

The effects plots show that there is increase in surface chip thickness ratio when feed rate increases from 0.05 mm/rev to 0.20 mm/rev.

The effect of depth of cut on Chip thickness ratio

As depth of cut increases from 0.1 mm to 0.5 mm, there is increase in chip thickness ratio. However as the depth of cut increases, the chip becomes more continuous in nature. The chip thickness ratio is calculated from the chip measurement for each experiment. This ratio is related to the tool rake angle and shear plane angle and it will always be less than unity and often in the range 0.2 to 0.5.

The effect of Silicon Percentage on Chip thickness ratio

It is observed from main effects plots Figure 3 that as silicon percentage increases from 8 to 11.2 the chip thickness ratio decreases. Due to addition of silicon particles material become brittle and chip thickness decreases.

Influence of Machining Parameters on Chip thickness ratio (k)

In order to obtain the effect of the cutting parameters on the machining performance for each different level, the average response of each fixed parameter and level for each machining performance are summed up. Table 6. Shows the total average response at the levels of four parameters on Chip thickness ratio (k). The result shows that the optimum machining performance for the Chip thickness ratio (k) is obtained at 450 m/min, feed 0.5 depth of cut 0.20 mm and silicon percentage 8.0 with polycrystalline diamond tool.

This is the optimum setting obtained under the conditions i.e. under which the experiments were performed. In this report, the Chip thickness ratio (k) 0.56 has been achieved

The results of ANOVA for the Chip thickness ratio (k) are presented in Table 6. The ANOVA for Chip thickness ratio (k) shows that the effect of factor depth of cut and feed is significant. From Figure 3, it was found that, the arithmetic Chip thickness ratio (k) increases with increase in depth of cut and increase with increase in feed. Hence, generally higher depth of cut and higher feed are selected for achieving the better chip thickness ratio. In this experiment, speed and silicon percentage are not most significant factors that affect the chip thickness ratio (k).

The form of the chip produced is one of the major parameter influencing productivity in metal cutting industry. According to Kaldor et.al there are two types of chip forms 1) acceptable chips and 2) unacceptable chips, based on the convenience of handling. Acceptable chips do not interface with work or tool and do not cause problems of disposal. Unacceptable chips interrupt regular manufacturing operation, as they tend to tangle around the tool and work piece and pose safety problems to operators. These chips can lead to unexpected surface finish and tool wear. Sometimes the chips clogs between the cutting edge and the machined surface which reduces cutting action, increases friction and results increase in higher forces and breaks the cutting tool by catastrophic failure.

Conclusion

This work has carried out to study the viability of high speed machining of Al-Si alloy. In this work, experimental design matrix as shown in table 6. was used to investigate the effect of combination of various control factors on the high speed machining performance of Al-Si alloy. The measures of performance are chip thickness ratio. An optimum parameter combination for the minimum surface finish within the range of selected control parameter was obtained using the analysis of variance (ANOVA). The experiments were carried out to express the effect of process parameters on machining of Al-Si alloy. From the experimental investigations based on full factorial method and considering the limits of the variables employed, the following conclusions can be drawn

1. The optimum parameter for the chip thickness ratio is the 500m/min, feed 0.20, depth of cut 0.5mm and silicon percentage 8.0 with polycrystalline diamond tool.

2. The feed, speed and silicon percentage are seen to make the largest contribution to the Chip thickness ratio.

3. The speed and silicon percentage seems to be the most critical parameters and should be selected carefully in order to reduce all kinds of damages.

It is observed that, depth of cut is the factor, which influences most on the chip thickness ratio. After depth of cut, speed and silicon percentage are the other two factors that affect the chip thickness ratio.

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