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Full Length Research Paper

Determination and optimization of the machining parameters of the welded areas in moulds

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In this study, the parameters of surface roughness, cutting temperature and cutting forces in the milling of the repaired welding regions of DIN 1.2344 hot work tool steel, which was used in mould manufacturing, with end mills coated multilayer TiAlN were examined experimentally. The effects of the feed rate, cutting speed and depth of cut on surface roughness, cutting temperature and cutting force were searched. In order to optimize the cutting conditions, Taguchi optimization method was applied. The effect of each parameter on the obtained results was determined by the use of analysis of variance (ANOVA). The relationship of the dependent parameters and independent parameters was modelled with regression analysis. It was seen that this experiment study made many a contribution to the machinability of DIN 1.2344 hot work tool steel, which was repaired by welding, with carbide end mills coated with multilayer TiAlN and accelerated the improvement in the performance of the cutting tool.

Key words: The welded areas, machining parameters, Taguchi optimization method, anova, regression analysis.

INTRODUCTION

Mould manufacturing is one of the important manufacturing methods of industry. Moulds are used in many production areas like shaping, drilling, cutting or volumetric casting. Moulds being widely used, their cost bears great significance in manufacturing processes. Moulds are exposed to a great deal of stress in every usage. These stresses result in damages such as wear and cracking on the surfaces of the moulds and the product tolerances change because of wear or damages. Remanufacturing a worn out mould calls for a high cost and most importantly, it causes time loss. To lower the cost and time loss and for the mould used to be long lived, the repair and the maintenance of these moulds are essential. The repair and maintenance of the moulds which have been damaged but have a chance to be saved especially help the firm derive a profit. At this point, mould repair welding plays a very important role (Preciado and Bohorquez, 2006).

DIN 1.2344 hot work tool steel is used widely in mould manufacturing because of the heat stability, thermal conductivity, toughness and wear resistance it has. It can also raise the hardness via heat treatment. While those materials have a hardness that is 20 to 25 HRC before the heat treatment is performed, the material hardness after the heat treatment changes between 30 to 60 HRC. As such kinds of materials are used widely in mould manufacturing, it is necessary to determine the machining parameters accurately. In the literature, the machining parameters of this material which is also called as AISI H13 have been tried to be determined (Kang et al., 2008. Nurul et al., 2008; Branda et al., 2008; Koshy et al., 2002; Arsecularatne et al., 2006; Ghani et al., 2004; Abou-El- Hossein et al., 2007; Coldwell et al., 2003; Orhan et al., 2007).

In this experimental study, artificial errors were created on DIN 1.2334 hot work tool steel. Those errors were repaired by welding. Chip removal over the repaired areas of the experiment samples was carried out using multilayer TiAlN carbide end mills which were used widely in previous studies and have been fruitful. Thereby, the machining parameters of repair welding areas were tried to be determined. In order to determine the optimum cutting conditions, Taguchi method was used. Plus, the effect of each parameter on the obtained results was determined by the use of analysis of variance (ANOVA). Finally, the relationship of the dependent

Table 1. Chemical composition of DIN 1.2344.

DIN 1.2344	C	Mn	Si	Cr	Mo	V
Base	0.35	0.40	0.8	4.8	1.2	0.85

Table 2. Mechanical properties of DIN 1.2344.

Tensile strength (N/mm^2)	Yield Strength (N/mm^2)	Elongation (%)	Hardness (HRC)
460	530 to 650	24	36 to 40

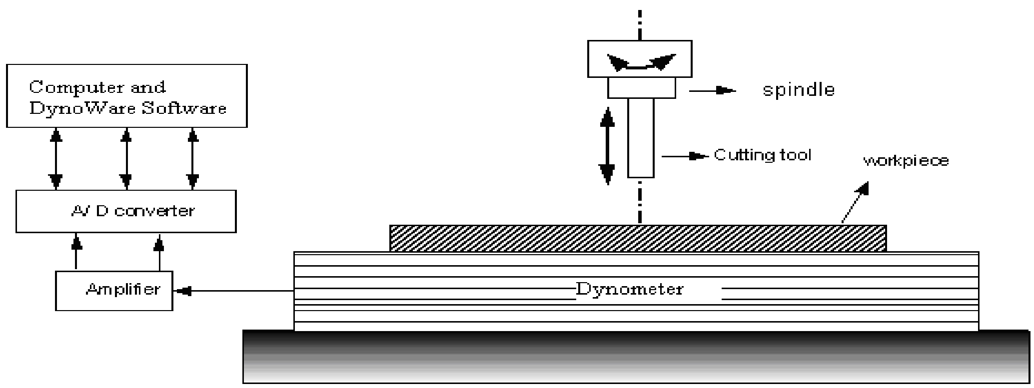

Figure 1. Experimental set up.

parameters and independent parameters was modelled with regression analysis.

MATERIALS AND METHODS

In this study, experiment conditions were set, taking the available technical literature researches and the firms in the sector into consideration. Firstly, cutting force and the heat generation during the cutting process were measured. In the machined sample, having examined the surface quality, a relationship between the change in cutting parameters and the surface quality was tried to be obtained. Secondly, the obtained experimental results (surface roughness, cutting force and cutting temperature) and the determined parameters were optimized with Taguchi method, being one of the widely used optimization methods in technical literature.

The parameters effective in shaping the results and the effect of them on those results were determined with analysis of variance. Using regression model, researches were carried out calculating an equation between dependent parameters and independent parameters.

Experimental method

The samples used in the experimental study were made from DIN 1.2344 hot work tool steel and artificial errors were formed on this material. Welding was used to repair those artificial errors. The samples were in the shape of a square. Their length is 135x135 mm and thickness is 50 mm. DIN 1.2344 hot work tool steel, whose chemical compositions were given in Table 1 and mechanical properties were shown in Table 2, was a material which did not lose its high temperature resistance, thermal conductivity, toughness and wear resistance. In the experiments, a JOHNFORD VMC-850/550+APC CNC triaxial (x-y-z) milling machine was used. The two flutes helical end mills used in this experimental study were 4XSGEO L9322 carbide end mills and coated with multilayer TiAIN. The surface roughness value on the workpiece obtained after the machining process was measured by MAHR- Perth meter. For the force measurements, KISTLER 9265B type dynamometer, KISTLER 5019b type charge amplifier and DynoWare analysis program were used (Figure 1). Temperature measurements were taken with OMEGA OS532 infrared device.

Experimental design

Experimental design was done using Taguchi method. Hence, it has been possible to reach more comprehensive results with doing less experiment. In this sense, time and money have been used more efficiently (Chung-Chen and Honk, 2002). In the determination of the characteristics of the quality as the rates of surface roughness to be measured, temperature and cutting force were required to be minimum, “less is more” principle has been applied among the quality values expected to be reached at the end of the experiments.

$$S/N(\eta) = -10x\log\left(\frac{1}{n}\sum_{i=1}^{n} y_{i^2}\right) \quad (1)$$

Where n is the number of experiments done under experiment conditions and y represents the calculated characteristics

Table 3. Experiment factors and their levels.

Parameters	(A) Feed (mm/min)	(B) Speed (rpm)	(C) Cutting depth (mm)
Level I	150	2000	0.25
Level II	200	2500	0.50
Level III	250	3000	0.75

Table 4. Taguchi L_9 experiment design.

Experiment no.	Variables	(A) f (mm/min)	(B) S (rpm)	(C) d (mm)
1	$A_1B_1C_1$	1	1	1
2	$A_1B_2C_2$	1	2	2
3	$A_1B_3C_3$	1	3	3
4	$A_2B_1C_2$	2	1	2
5	$A_2B_2C_3$	2	2	3
6	$A_2B_3C_1$	2	3	1
7	$A_3B_1C_3$	3	1	3
8	$A_3B_2C_1$	3	2	1
9	$A_3B_3C_2$	3	3	2

Table 5. Measured values in the experiments, Surface roughness (Ra µm), Cutting temperature (°C), Cutting force (N) values.

Experiment no.	Variables	Ra (µm)	Temperature (°C)	Cutting force (N)
1	$A_1B_1C_1$	0.63	27	54.29
2	$A_1B_2C_2$	0.64	26	66.01
3	$A_1B_3C_3$	0.77	24	86.52
4	$A_2B_1C_2$	0.76	29	63.08
5	$A_2B_2C_3$	0.87	26	60.15
6	$A_2B_3C_1$	0.71	25	33.60
7	$A_3B_1C_3$	0.89	34	86.52
8	$A_3B_2C_1$	0.73	27	13.28
9	$A_3B_3C_2$	0.84	33	80.66

(dependent variable).

In this experimental study, feed rate (f), spindle speed (S) and depth of cut (d) were the main parameters. In all the experiments, carbide end mills coated with multilayer TiAIN were used and the experiments were carried out in the form of finishing machining. Experiment factors and their levels were presented in Table 3 and L9 experiment design in Table 4.

RESULTS

Chip removal over the repair welding regions of the experiment samples was carried out. The finishing machining parameters of the repair welding regions were aimed at being determined. In Table 5, the values of surface roughness (Ra µm), cutting temperature and cutting force (N), obtained for the finishing machining, were presented.

The surface roughness

The obtained roughness values were between 0.63 to 0.89 µm. In the average of the nine experiments the optimum surface quality could be obtained when feed was 200 mm/min, cutting speed was 3000 rpm and depth of cut was 0.25 mm according to S/N rate for finishing.

The cutting force

The minimum cutting force was obtained when the feed was 250 mm, cutting speed was 2500 rpm and depth of cut was 0.25 mm according to S/N rate for finishing.

The temperature

The ideal temperature value was kept when feed was

Table 6. S/N ratios of surface roughness values.

Level	A (Feed mm/min)	B (Speed rpm)	C (Cutting Depth mm)
1	3.387	2.470	3.241
2	2.189	2.607	2.592
3	1.753	2.253	1.497
$\Delta_{max-min}$	1.633	0.353	1.743
Rank	2	3	1

Table 7. S/N ratios of cutting force values.

Level	A (Feed mm/min)	B (Speed rpm)	C (Cutting Depth mm)
1	-36.61	-36.48	-29.23
2	-34.04	-31.48	-36.84
3	-33.11	-35.80	-37.69
$\Delta_{max-min}$	3.50	5.00	8.46
Rank	3	2	1

Table 8. S/N ratios of cutting temperature values.

Level	A (Feed mm/min rpm)	B (Speed)	C (Cutting Depth mm)
1	-28.18	-29.50	-28.40
2	-28.50	-28.41	-29.31
3	-29.88	-28.64	-28.84
$\Delta_{max-min}$	1.70	1.09	0.90
Rank	1	2	3

Table 9. ANOVA versus Ra.

Notations	Degree of freedom	Sum of squares	Variables	F ratio	Percentage ratio (%)
A	2	0.031200	0.015600	16.71	45.65
B	2	0.001067	0.000533	0.57	1.55
C	2	0.036067	0.018033	19.32	52.78
Error (e)	2	0.001867	0.000933		0.02
Total	8	0.070200			100

150 mm/min, rotation was 2500 rpm and depth of cut was 0.75 mm according to S/N ratios for finishing.

The analysis of variance (ANOVA)

The ANOVA results of the average values of surface roughness were presented in Table 9.

The Ra predictive equation by regression model

To formulate a predictive equation between the control factors used during chip removal (feed, cutting speed and depth of cut) and the result (average surface roughness) and to define this relationship, linear regression analysis was used. The Ra equation formulated for this experimental study was represented below:

$$Ra = 0.453 + 0.0700\,A + 0.0067\,B + 0.0767\,C \quad R^2 = 0.925 \tag{3}$$

DISCUSSION

Evaluation of the surface roughness

Another subject examined in the experimental study is

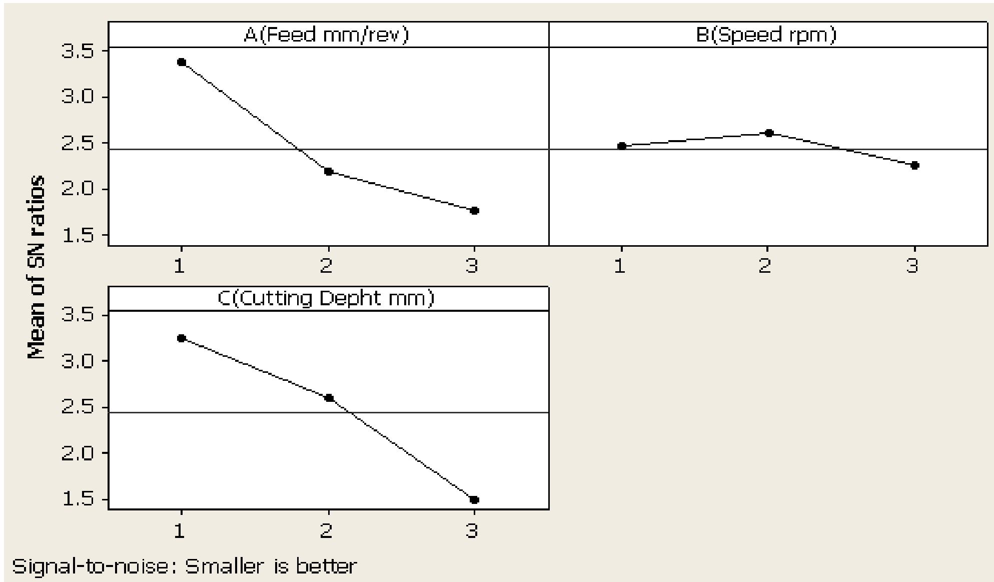

Figure 2. Control factors versus S/N ratios.

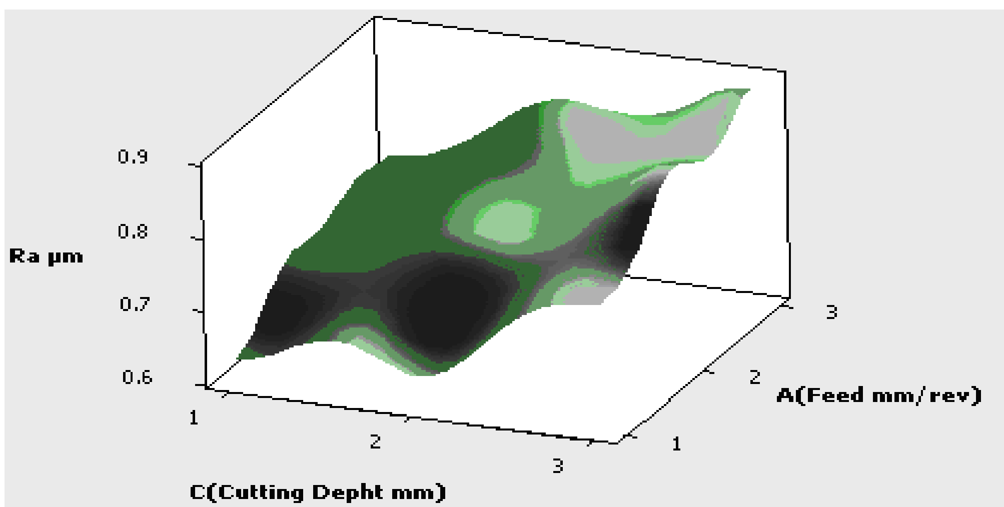

Figure 3. Effects of cutting depth and feed on surface roughness.

the roughness values of the machined surfaces. The effective parameters in the formation of surface roughness can be shown in Equation 4.

$$R_a = \frac{f.r^2.1000}{4D} \quad (4)$$

Here (Equation 4), Ra: surface roughness, f: feed, r: nose radius and D: diameter of the cutting tool. As it can be seen in Equation 4, Ra surface roughness value is in a direct proportion with feed rate and inverse proportion with nose radius of the cutting tool. Still, this is a too general equation. The results obtained in our study are compatible to the equation. The surface roughness values were shown in Figures 2 and 3. In general, the obtained roughness value has been between 0.63 to 0.89 µm.

Evaluation of the cutting force

The results obtained by the cutting force measurement which have been taken by Kistler dynamometer have been determining as to the effect of the cutting parameters on cutting forces. The assignment of the

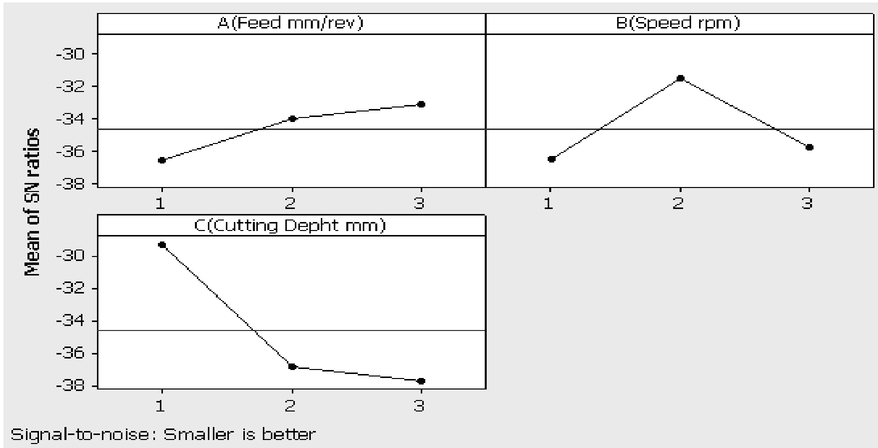

Figure 4. Control factors versus S/N ratios.

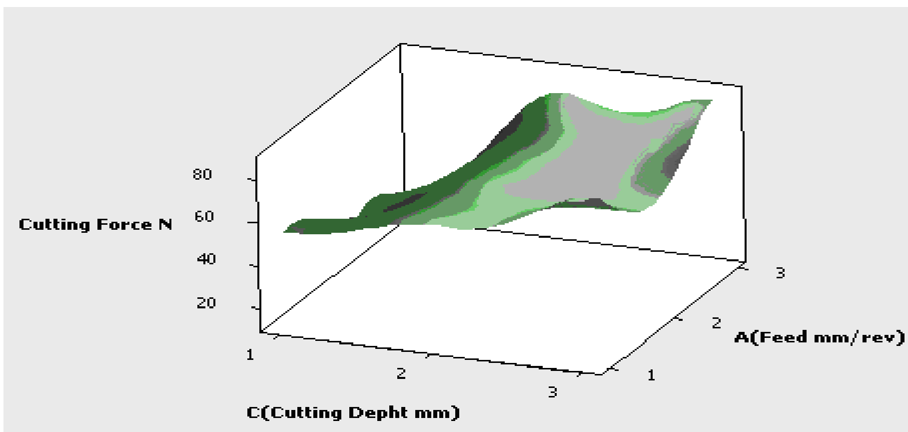

Figure 5. Effects of depth of cut and feed on cutting force.

cutting forces is important for the workpiece and cutting tool for it affects both of them. In that sense, the determination of the optimum cutting forces necessary during the chip removal which has been carried out over that material is a sine qua non for the assignment of the machinability of a material (Aboul-El-Hossein et al., 2007; Bakır, 2005).

As it has been mentioned afore, the change in the cutting force is highly affected by the increase of the feed and depth of cut. Plus, the latter engenders an increase in cutting force as it also increases the flow rate of the depth of cut. It was shown in Figures 4 and 5.

Evaluation of the temperature

Of the energy spent during the chip removal process, the friction between tool-work piece and tool- interface causes heat formation on the cutting tool. This heat formation wears the tool. The power applied in the chip removal substantially turns out to be heat in an area near to the nose of the cutting tool. A high proportion of the heat is removed via chips. The left diffuses into the workpiece and cutting tool. This heat is the cause of the problems occurring during the cutting processes. Thus, the cutting temperature's exceeding certain values affects both the workpiece and cutting tool negatively. The heat generated during the cutting process's staying at the minimum level prevents the tool wear and other problems considerably (Branda et al., 2008).

Considering the figures, the cutting temperature is directly proportional with feed and depth of cut as the previous parameter also increases the flow rate of the amount of the chips. It was shown in Figures 6 and 7.

Evaluation of the parameters using ANOVA

In milling of DIN 1.2344 hot work tool steel with cutting tools coated with TiAlN, nine experiments were carried

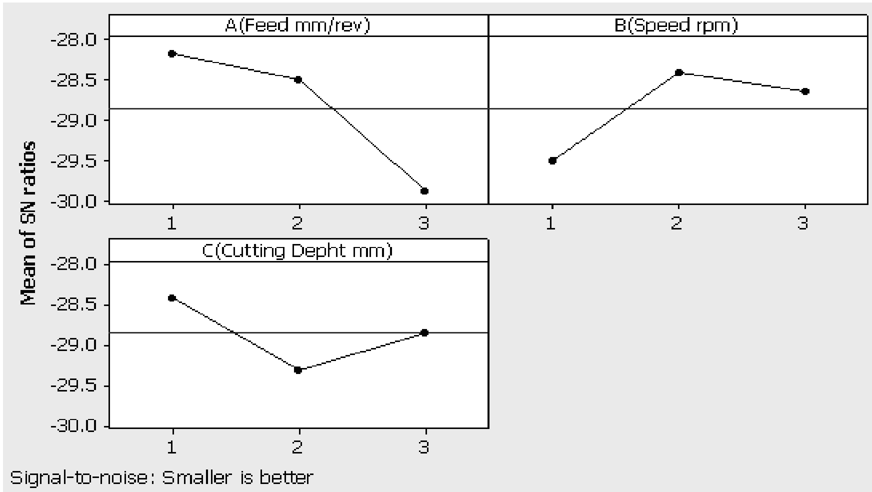

Figure 6. Control factors versus S/N ratios.

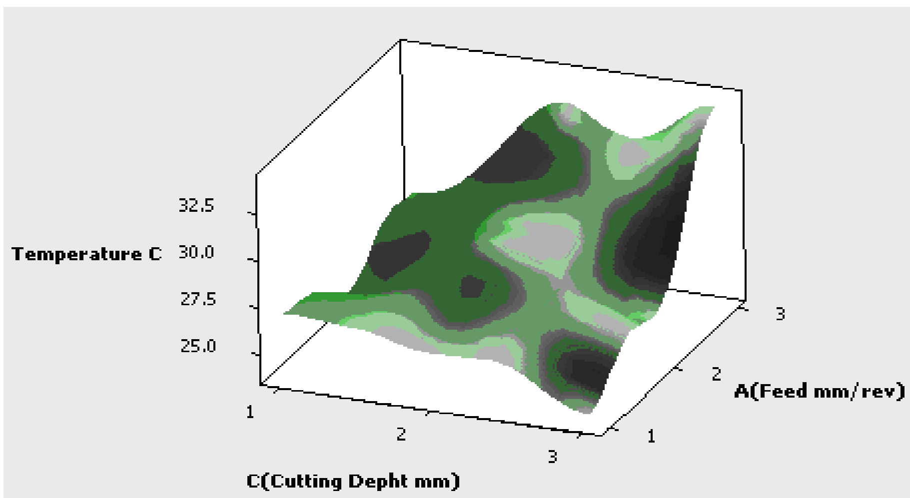

Figure 7. Effects of depth of cut and feed on cutting temperature.

out using three different factors at three different levels and different Ra values were obtained from each experiment. Whether these differences are only a coincidence or results from the factors and the influence of each factor in this answer will be determined by the analysis of variance. The ANOVA results of the average values of surface roughness were presented in Table 9. The depth of cut with a proportion of 52.78% was the most effective factor in the formation of the roughness on the machined surfaces.

Conclusions

This study of the machinability of the experimental material, which was DIN 1.2344 hot work tool steel repaired by welding, with the carbide end mills coated with TiAIN produced some useful results. The criteria for the machinability were surface roughness, cutting force and heat generation. Three control factors which were considered as effective in creating the most suitable conditions for those criteria (feed, cutting speed and depth of cut) were chosen at three different levels and the methods of the finishing machining were applied in the experimental study. Below was the summary of the results:

i) The most effective control factor on the finishing machining of the regions which were repaired by welding of DIN 1.2344 hot work tool steel with cutting tools coated with TiAIN and on the value of surface roughness formed on this machined surface was depth of cut.

ii) In the formation of the cutting force, each of the control factors (cutting speed, depth of cut and feed) was effective.

iii) It became obvious that depth of cut and feed were two effective factors for finishing process.

iv) Taguchi optimization method was beneficial for the experimental design of the machinability of DIN 1.2344 hot work tool steel material, which was repaired by welding.

v) The effect of each parameter on the obtained results was determined by the use of analysis of variance (ANOVA).

vi) The relationship of the dependent parameters and independent parameters was modelled with regression analysis.

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