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The optimal selection of machining parameters by TOPSIS method during machining of Inconel 718 (superalloy)

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Abstract - The Inconel 718 (superalloy) was machined by using the Tungalloy made tool insert (SNMG 120408 rake =6º, φ=75º). The dry turning was performed in a lathe. The experiments were arranged according to the (Taguchi's) L9 orthogonal array. The speed, feed and depth of cut (doc) were the input process parameters. The surface roughness (R_a) and chip reduction coefficient (CRC) were the objectives. The collected chips were examined under the scanning electron microscope. The optimal combination of process parameters was identified by using the TOPSIS (technique for order preference by similarity to ideal solution) method. All steps of the TOPSIS method were incorporated for the analysis. The optimum condition (rank1) was attained at the speed of 70 m/min., the feed of 0.06 mm/rev., and the depth of cut (doc) of 1 mm. The ANOVA for surface roughness indicated the higher percentage contribution (50.34%) by the feed. The ANOVA for CRC showed the higher percentage contribution (49.23%) by the speed. The optimal result obtained by using the TOPSIS method was validated by the macroscopic study with the type of chips. The validation study was further explored with reference to the SEM examination of chip surfaces.

Keywords – Inconel 718;. Dry turning;. TOPSIS

INTRODUCTION

The Inconel 718 is a nickel-based superalloy. This material is used in gas turbine and aviation industry. The machinability of this material is very poor due to poor thermal conductivity of the material. Better machinability can be achieved by optimal selection of machining parameters. The dry turning was done considering Inconel 718 as the work piece material. The carbide cutting tool was used for the machining. Six objective functions were considered as the attributes. The cutting speed, feed and depth of cut were the input process parameters. The higher rank solution was preferred [1]. The methodology for assessing the sustainability of the machining processes has been explored. The developed model enabled decision makers to utilize the responses to predict the suitable process. The weight of every indicator was determined by the entropy weight method. The rank of the process parameters was assigned by the MCDM (TOPSIS) method. The case studies were referred to validate the methodology. The MATLAB code was created to enable the industry to identify the sustainability of the machining processes [2]. The diamond like carbon coating was deposited on the tungsten carbide tool insert by using the CVD technique. The TOPSIS method was used to identify the optimal input parameters during the turning on 6061 aluminium alloy. The speed, feed and depth of cut were the input parameters and the responses were the tool flank wear, PDZ temperature and surface roughness. The processed tool insert was the better tool for the machining process [3]. The machining of hard materials (Ti-6Al-4V, Inconel 718 and Tool Steel) will be possible through the proper selection of the machining parameters only [4]. The superalloys (INCONEL 718 etc) are considered as difficult to machine materials. The quality of the FE model depends on the input parameters. The main aspect is to employ the correct material model for the FE simulation. The decoupled material model was developed by extensive experimental studies on INCONEL 718 superalloy. Subsequently FE simulation was performed using the developed material model. Based on this experimental work, a new coupled empirical model is proposed to describe the particular behaviour of nickel-based alloys at elevated temperatures and high strain rates. This material behaviour model introduces the softening phenomena as well as the coupling between the temperature and the strain rate. This material model is used for the machining simulations (FEM) with the Inconel 718 as superalloy [5]. The Inconel 718 super alloy was machined considering speed, feed and doc as input parameters. Experimentation was performed according to the (Taguchi's) L9 orthogonal array. The machining condition was according to the MQL machining. The machining responses were the surface roughness, the surface subsurface hardness, the tool wear and the chip morphology. The PVD Titanium carbide, cubic boron nitride and ceramic tools were used for the study. The optimal parametric condition was obtained for the machining of Inconel 718 super alloy [6]. The aim of the present study is to optimize the process parameters by the TOPSIS method and to examine the validity of the finding.

EXPERIMENTAL PROCEDURE

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TABLE 1
INPUT PARAMETERS AND LEVELS

Parameters	Levels		
	1	2	3
Speed m/min	40	70	110
Feed mm/rev.	0.06	0.10	0.16
DOC mm	0.5	1	1.5

The Inconel 718 round bar was procured and the dry tuning was done according to the designed levels and parameters (Table 1). The chip thicknesses were measured. The surface roughness values (µm) at different experimental conditions were measured by using the 3D optical surface roughness profilometer. The surfaces of the collected chips at various experimental conditions were examined under the scanning electron microscope.

RESULTS AND DISCUSSION

The measured surface roughness and the CRC values are shown in Table 2. Subsequently normalised values of the Ra and the CRC were obtained (Table 3). Thereafter the weighted normalised matrix was formed (Table3). Subsequently the separation measures were obtained and the closeness coefficients were listed (Table 4 and Table 5). The obtained closeness coefficients at different experimental conditions are shown in Fig 1. Finally, the optimal condition was obtained at (212) (Experiment number 4, speed: 70 m/min., feed: 0.06 mm/rev., doc: 1mm). The ANOVA for R_a (Table 6) indicated the feed as the most influential parameter (50.34%). The ANOVA for CRC (Table 7) showed the most influential parameter as speed (49.23%).

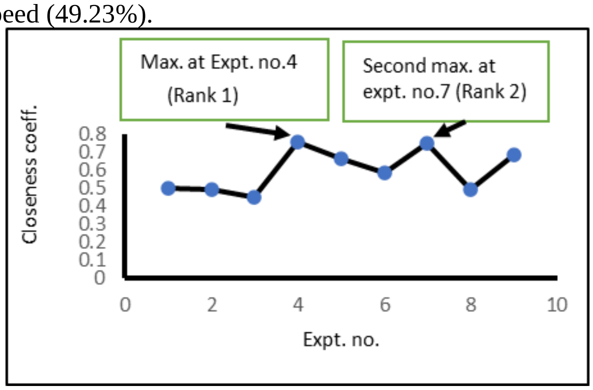

Fig. 1 Distributed closeness coefficients

TABLE 2
EXPERIMENTAL SEQUENCE AND RESPONSES

Expt. No.	Speed level	Feed level	DOC level	Surface roughness	CRC
1	1	1	1	0.777	9.3677
2	1	2	2	1.737	6.9186
3	1	3	3	2.531	5.5121
4	2	1	2	1.339	3.6580
5	2	2	3	2.128	2.9418
6	2	3	1	1.333	6.2174
7	3	1	3	1.423	3.5419
8	3	2	1	3.837	1.2635
9	3	3	2	1.319	4.7005

TABLE 3
NORMALISED AND WEIGHTED NORMALISED MATRIX

Expt. No.	Normalised matrix		Weighted normalised matrix	
1	0.1284	0.5777	0.0642	0.2889
2	0.2871	0.4267	0.1435	0.2133
3	0.4183	0.3399	0.2091	0.1700
4	0.2213	0.2256	0.1106	0.1128
5	0.3517	0.1814	0.1758	0.0907
6	0.2203	0.3834	0.1102	0.1917
7	0.2352	0.2184	0.1176	0.1092
8	0.6341	0.0779	0.3171	0.0390
9	0.2180	0.2899	0.1090	0.1449

TABLE 4
SEPARATION MEASURES

Expt. No.	Separation of positive ideal solution	Separation of positive ideal solution
1	0.2499	0.2529
2	0.1916	0.1893
3	0.1954	0.1606
4	0.0872	0.2713
5	0.1230	0.2433
6	0.1595	0.2286
7	0.0882	0.2684
8	0.2529	0.2499
9	0.1151	0.2530

TABLE 5
CLOSENESS COEFFICIENTS AND RANK

Expt. No.	Closeness coeff.	Rank
1	0.5029	6
2	0.4970	8
3	0.4511	9
4	0.7567	1
5	0.6641	4
6	0.5890	5
7	0.7526	2
8	0.4971	7
9	0.6874	3

TABLE 6
ANOVA for Ra

Source	SS	DOF	Variance	F-ratio	% Cont.
Speed	8.1983	2	4.0947	0.1863	6.42
Feed	64.2182	2	32.1091	1.4612	50.34
DOC	11.2048	2	5.6024	0.2549	8.78
Total	127.5626	8			
Error	43.9503	2	21.9751		34.45

TABLE 7
ANOVA for CRC

Source	SS	DOF	Variance	F-ratio	% Cont.
Speed	101.9873	2	50.9937	2.0728	49.23

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Feed	49.0779	2	24.5389	0.9974	23.69
DOC	6.8938	2	3.4469	0.1401	3.33
Total	207.1625	8			
Error	49.2035	2	24.6017		23.75

The chip appearance (continuous) at Fig 2d (212) and at Fig 2g (313) are preferable amongst all the chip macrographs. These are in agreement with the optimal results (rank 1, rank 2).

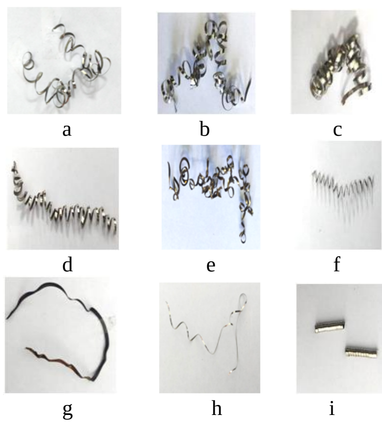

Fig. 2 Chip macrographs (a)1, 111, (b) 2, 122 (c)3, 133(d)4, 212 (e)5, 223, (f) 6, 231, (g)7, 313, (h) 8, 321,(i) 9, 332

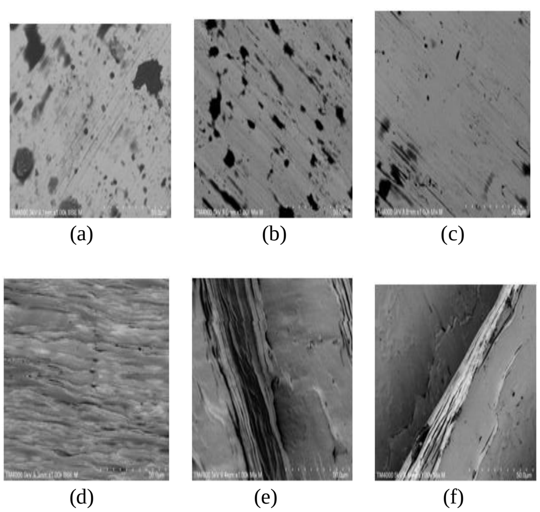

Fig. 3 SEM image of under surfaces (a) (111) (b) (223) (c) (332) and top surfaces d (111) (e) (223) (f) (332) X1000

Fig 3a shows the (under) surface of the chip at low speed (40 m/min). Massive secondary phases are present at the (under) surface. This shows the improper machining response. Fig 3b and Fig 3c show the (under) surfaces of the chips at moderate speed (70m/min) and high speed (110 m/min.). Dispersed secondary phases are seen at the (under) surface. This indicates the improved machining at the moderate and the high-speed. This shows that speed levels (2,3) are acceptable in the present machining process. This is in agreement with the TOPSIS result.

Fig 3d shows the SEM image of the (top) surface of the chip at the low feed (0.06 mm/rev.). The chip formation occurs by the successive lamellar sliding mechanism. This indicates the better chip formation mode at the low feed (0.06 mm/rev.). Fig. 3e and Fig. 3f show the SEM image of the (top) surface of the chips at the medium (0.1 mm/rev.) and the high (0.16 mm/rev.) feed. Interlamellar spacing increases with the increase of the feed. This indicates improper machining. Thus, the low feed (0.06 mm/rev.) machining can be preferred. This is also in agreement with the optimization result by the TOPSIS method.

It was realised that the machining with the higher doc was preferable to reduce the vibration in the machining. Thus, machining with the moderate (1 mm) and the higher doc (1.5 mm) may be preferable in the present machining process. Thus, the optimization result by the TOPSIS method i.e., machining with (212) or (313) can be considered as the machining with the better selection of the parameters.

CONCLUSIONS

The superalloy (Inconel 718) can be considered as difficult to machine material because of the poor thermal conductivity of the material. The adiabatic shear instability condition is raised at the flow zone during the machining. This causes improper surface features in the machined component.

The problem with the machining of this superalloy can be reduced by the judicial selection of machining parameters. The TOPSIS method can be applied effectively for the optimal selection of the machining parameters.

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