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SIMULTANEOUSLY OPTIMUM MACHINING PARAMETERS SELECTION FOR FACING PROCESS OF INCONEL 718

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ABSTRACT
An assemblage of the components requires close tolerance it can be achieved by the finish facing operations of mating the surfaces. In this study the low-cost coated carbide inserts are used to perform the finish facing operations on the work material made of Inconel 718. The response surface methodology (RSM) is the best statistical tool predominantly used for simultaneously optimizing the independent variables against minimization of both responses of flank wear and surface roughness. When the parameters are simultaneously optimized in facing process depth of cut and feed rates are altered whilst cutting speed kept in higher level. Experimental validation has been conducted for the selected machining parameters and the effectiveness of the optimization processes. Finally, the contour plots are developed for visually selection of machining parameters in the feasible boundary regions. The machining parameters and its influences on the responses are investigated which are having good agreement with experimental results.

Keywords: *Facing process, Flank wear, Inconel 718, Response optimizer, Simultaneous optimization, Taguchi's optimization*

1. INTRODUCTION
The heat resistant super alloys (HRSA) like Inconel materials are most widely used in gas turbine, aerospace, automotive, heat energy conversion machinery and components of oil and gas industries. The essential and highly desired physio-chemical properties of high resistance to corrosion, high weight to strength proportion and withstand the hot hardness which are motivates the Inconel 718 for high temperatures applications [1-3]. This Inconel 718 material is the most important and frequently used alloy for the manufacture of a wide variety of heat resistive parts such as discs, casings, rings, blades, shafts, engine mounts etc., because of its competence to maintain the strength in the temperature range of –250°C to 705°C and also exhibits high corrosion resistance. The metallurgical characteristics, mechanical and physical properties are accountable for maintaining the resistance of creep at high temperature along with good strength [4,5]. At the same context these properties are very hard to machine due its work hardening severity and heat resistivity of chip material's heat dissipation [6,7]. Inevitability of machining process to make a required shape and size highly challenging the process planner. The lack of understanding and availability of limited researches about the cutting tool performance in facing operations, they are often machined in lower productivity and inferior quality.

The available literatures in machining of Inconel 718 are investigating turning and milling processes but very rare to find the facing process even though it requires crucial in engineering assembly of parts and components. More number of components are used in the aerospace industries which inevitably requires facing as the major operations with desired surface finish [9]. The facing operations are completely different from the turning operations whereas machining parameters are not being separately derived by the cutting tools handbook. The process planners are forced to select the machining parameters for facing process which are used as turning processes. If the same machining parameters are used which yields poor quality of surface and increase the cost of machining by consumption of cutting tool inserts [10-12]. Few researchers have been found significant differences in the performance of cutting tools in turning and facing operations when identical cutting tools are employed [9,13,14]. The cutting tool inserts are made of different materials and shapes that are generally used for machining of Inconel 718 are discussed in many literatures. Many researchers conducted the research on specific purpose and they were addressed advantages of tools, limitations of environmental issues and longevity of tools usage. Many machining industries for machining of Inconel 718 are used as coated or uncoated carbide cutting tools in the past several years. For intermittent machining like shaping, planning, slotting, tapping and broaching the HSS tools are usually employed. Whilst the various grades of carbides are used for continuous machining operations like turning, boring and facing operations. In many occasions the carbide tools are having poor thermo-chemical stability which self-diffusion of materials at the chip-tool interface during that machining speed exceeds 30 m/min [11,15]. Nalbant et al [6] revealed that the wear mechanisms of ceramic tools are majorly categorized as flank wear, crater, notching and plastic deformation with irrespective of cutting conditions. Flank wear predominantly acted as a factor of catastrophe during the machining process of Inconel 718 using carbide cutting tools. Different coated cutting tools were used by Sharman et al [7,12] for machining of Inconel 718, they found that CrN and TiAlN coated tools produces better performance than uncoated tools. And also observed that due to the built-up edge formation and excessive heat generation on the chip tool interface the CrN coatings are disappeared even in primary region of tool wear period. TiAlN coated carbide tools are produced better machining performance in all conditions of machining with Inconel 718. The response surface methodology (RSM) [10] is an elegant statistical based mathematical modelling technique, which are used to develop the predictive mathematical relationship used to analyzing such machining problems in which response of interest is influenced by the independent variables correlated with dependent objectives. Response surface methodology (RSM) based mathematical regression models are developed for cutting force, surface roughness, metal removal rate, tool wear and tool life by varying the machining parameters of cutting speed, feed and depth of cut for finish turning of Inconel 718 [13-15]. Choudhury and El-Baradie [1] also analyzed similar kind of research using coated and uncoated carbide tools for machining of Inconel 718 and found that RSM models are capable to predict the optimum parameters. The recent researchers conducting experimental researches on work materials, tool geometries and surface texturing with tools are provided an exposure on significant effect of machining parameters and its selection in the various machining processes [16-18].

This paper describes the performance of coated carbide insets as (SNMG) geometry of double-sided square for finish facing process of Inconel 718. Few trail experiments were conducted initially for selection of the cutting parameters for the finish facing process because of unavailability of selection guidelines from tool manufacturers. The SNMG inserts are used for low machining cost, stronger geometries and other conversant tool features. Among the types of tool wear, the flank wear and its mode of failure during desired surface roughness as expectation need high-level attention to the process planner, hence it has been critically analyzed.

2. EXPERIMENTAL METHODS

The finish facing operations were conducted in CNC lathe (Made of ACE Designer) under dry cutting conditions. The solution annealed Inconel 718 material in cylindrical bar stock of 60mm diameter rigidly hold by the hydraulic chuck. Every trail of experiment the work piece has constant cutting length and all the machining parameters are fixed by the design of experiments. To investigate the performance of coated carbide inserts as cutting tool and in the experiment trails a new cutting edge has been used.

2.1 Cutting Tools and work piece materials

TiAlN coated carbide inserts are used and it has eight cutting edges which designated as SNMG 120408-QM H13 based on ISO specification. New cutting edge was selected and clamped to cutting tool's holder of DSKL 2020K 12 IMP. The performance analysis and wear mechanism study has been carried out for finish facing of Inconel 718 based on the ASTM standards are used for machining performance measurement. The work material was received from the industry in the form of 60 mm diameter of cylindrical bar stock. The work piece materials are prepared from the cylindrical bar of Inconel 718 each specimen prepared for equal length could be hold and withdraw easily from the check. The chemical components and mechanical properties of Inconel 718 by percentage of weight basis are given in Tables 1 and 2.

Table 1 Inconel 718 weight basis of chemical compositions.

Ni	Cr	Nb+Ta	Mo	Ti	Al	Mn	Si	Cu	Co	C	Fe
50.80	17.40	5.30	2.98	0.98	0.48	0.09	0.07	0.04	0.04	0.034	Bal

Table 2 Inconel 718 mechanical properties.

Young modulus (MPa)	Tensile strength (MPa)	Yield strength (MPa)	Density (kg/m3)	Melting point(℃)	Hardness (HRC)	Thermal conductivity (W/mK)
208	1280	1090	819	1285	20	12.43

2.2 Selection of cutting parameters range and levels

The parameter levels are selected based on the literature, tools manufacture's recommendations and pre-trails of experiment. The center composite design (CCD) of experiments were used to conduct the machining experiments for three cutting parameters in 3 levels which are in the Table 3. Based on the central composite design of experiments 15 trails of experiments for finish facing operations were conducted. Each trail of experiment starts with peripheral surface and ends with center point of the work piece specimen as completed the cutting length of 30 mm.

Table 3 Levels of experimental parameters.

Machining parameters	Level 1	Level 2	Level 3
Cutting Speed 'V' (m/min)	45	60	75
Feed 'f' (mm/rev)	0.10	0.15	0.20
Depth of cut 'a_p' (mm)	0.50	0.75	1.00

2.3 Design of Experiments and Responses

Experiment trails were conducted on the parametric levels given in the Table 3. Based on the central composite design(CCD) of experiment recommends 15 trails of experiments were conducted. Each trails of experiments have been conducted as per the CCD procedure and simultaneously checking also performed for every combination machining parameter which leading to all the 15 tests with one set of replications it requires analysis of variance of the responses. In each trail of experiment has been conducted with a new edges of the tools were employed. The surface roughness values were measured by the surface tester Mitutoyo-SJ210. Surf tester stylus should be positioning to the feed marks on the machined surface towards the center of machined surface. The surface roughness has been taken at four different locations (90°apart) and recurrent at every face of the machined surface and therefore the average values are recorded. Flank wear was measured at the tool face at the end of every trail of the experiments using computerized image processing microscope.

3. RESULTS AND DISCUSSION

The experimental responses such as surface roughness and flank wear were individually treated for smaller the better signal to noise ratio based optimization using Taguchi technique. These responses were simultaneously optimized by using response surface methodology which are developing regression models for optimizing the responses by varying the machining parameters. Both methods are capable to predicts the optimum machining parameters however response surface methodology dynamically working and intelligently simulated the optimum of machining parameters.

3.1 Taguchi optimization for minimum surface roughness

In statistical analysis the signal to noise ratio relationships were established at every level of the responses are changed. The means of response results varied in the different levels are analyzed for smaller the better optimization. Feed rate is the parameter which has highly influenced than other two parameters of cutting speed and depth of cut. The graphical analytics shows that the cutting parameters for minimum surface roughness were shown in the figure1. Variation is the indicator of the graphical analysis a steeper slope indicates a larger impact on the parameters with respect to the dependent response. Figure 1 depicts feed rate was a high magnitude parameter on surface roughness (Ra) than the other 2 parameters. Regardless of cutting conditions, feed has high influence by increasing the value up to 0.15 mm/rev. Through the Taguchi's optimization smaller the better technique for minimizing the surface roughness, the optimum performance of facing parameters are obtained at cutting speed (60 m/ min), feed (0.1 mm/rev) and depth of cut (0.5 mm).

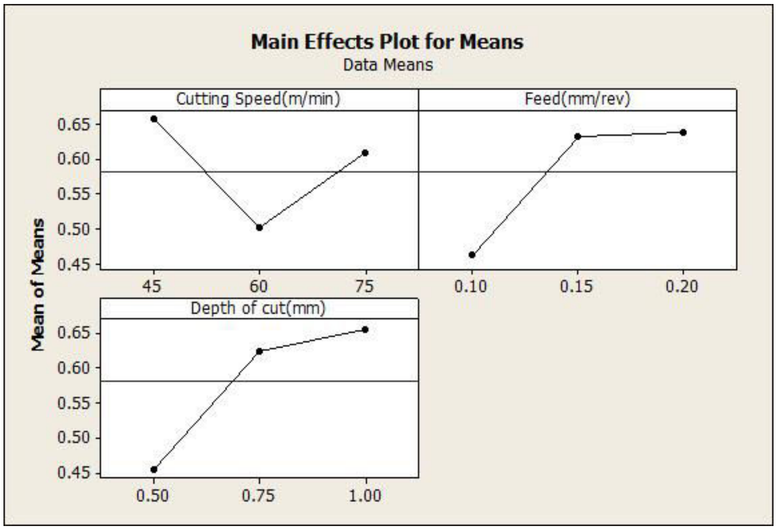


Figure 1 Surface roughness effects on the machining parameters.

3.2 Taguchi's optimization for flank wear minimization

The flank wear is the most crucial kind to affects tool life in turn to decide the cost effectiveness of the machining process. Irrespective of the machining operations on the Inconel 718 material the flank wear has the leading tool failure which induces other failures of tool. In this optimization process aimed to minimize the flank wear by optimizing the machining parameters, during this process smaller the better technique found that depth of cut and feed rate parameters are having higher influence than the cutting speed. The facing operation couldn't be chosen as higher cutting speed like 100 m/min, if so the higher cutting speed accelerates the wear in primary tool wear region and promotes rapid tool failure. It can be observed that the flank wear also increased with increase of cutting speed and additional adverse effects also happened due to the combination feed and depth of cut parameters are increased. Based on the inferences obtained in the graph shown in figure 2 the feed rate and depth of cut possess high influence on the flank wear. Figure 2, shows that the optimum performance for minimum flank wear in facing process was obtained at cutting speed (45m/min), feed (0.15 mm/rev) and depth of cut (1 mm).

3.3 Simultaneous optimization of surface roughness and flank wear

Response surface methodology (RSM) is the modelling and multi objectives optimization technique by generating the regression relationship between the independent parameters and dependent responses. A second order polynomial model has been developed to predict the dependent responses such as surface roughness and flank wear by exploitation of independent machining parameters. These developed mathematical models are used to analyses the impact of machining parameters on the responses for minimum surface roughness and minimum flank wear. Analysis of variance has been created to checkout the importance of cutting parameters on the responses. MINITAB software package contains various statistical tools, the response optimizer also a kind of tool has been used to optimizes the multiobjective responses based on the desirability functions of the experimetal data analysis. Central composite design (CCD) is the best method of design of experiment for simultaneous optimization hence many researchers and industrial process planners are using now. An individual desirability functions (di) have been derived for surface roughness and flank wear are 1 and 0.76 respectively. This desirability operates as an indicator of the given responses which closeness to the goal. The machining parameters are chosen to minimize the desirability supported the composite desirability (D) it reached as 0.97. The regeression equations are developed by the optimizer for minimum surface roughness and minimum flank wear. During that optimization process for an individual response diserability value, the machining parameters are fitting in the regression model the composite desirability value acted as constraints then the global optimum parameters are obtained. This composite desirability values automatically fitting the machining parametrs for the individual response and their desirability values in the simultaneous optimization process. The results of the optimization plot were shown in the figure 3. The minimum surface roughness and minimum flank wear has been obtained by selected from allowable range of the machining parameters and feed to the response optimizer has simultanously optimized values are shown in the Table 4.

Table 4 Optimization results using response surface methodology

Cutting Speed 'V' (m/min)	Feed 'f' (mm/rev)	Depth of cut 'a_p' (mm)	Flank wear 'VB' (mm)	Surface roughness 'Ra' (μm)
60	0.15	0.50	0.14	0.50

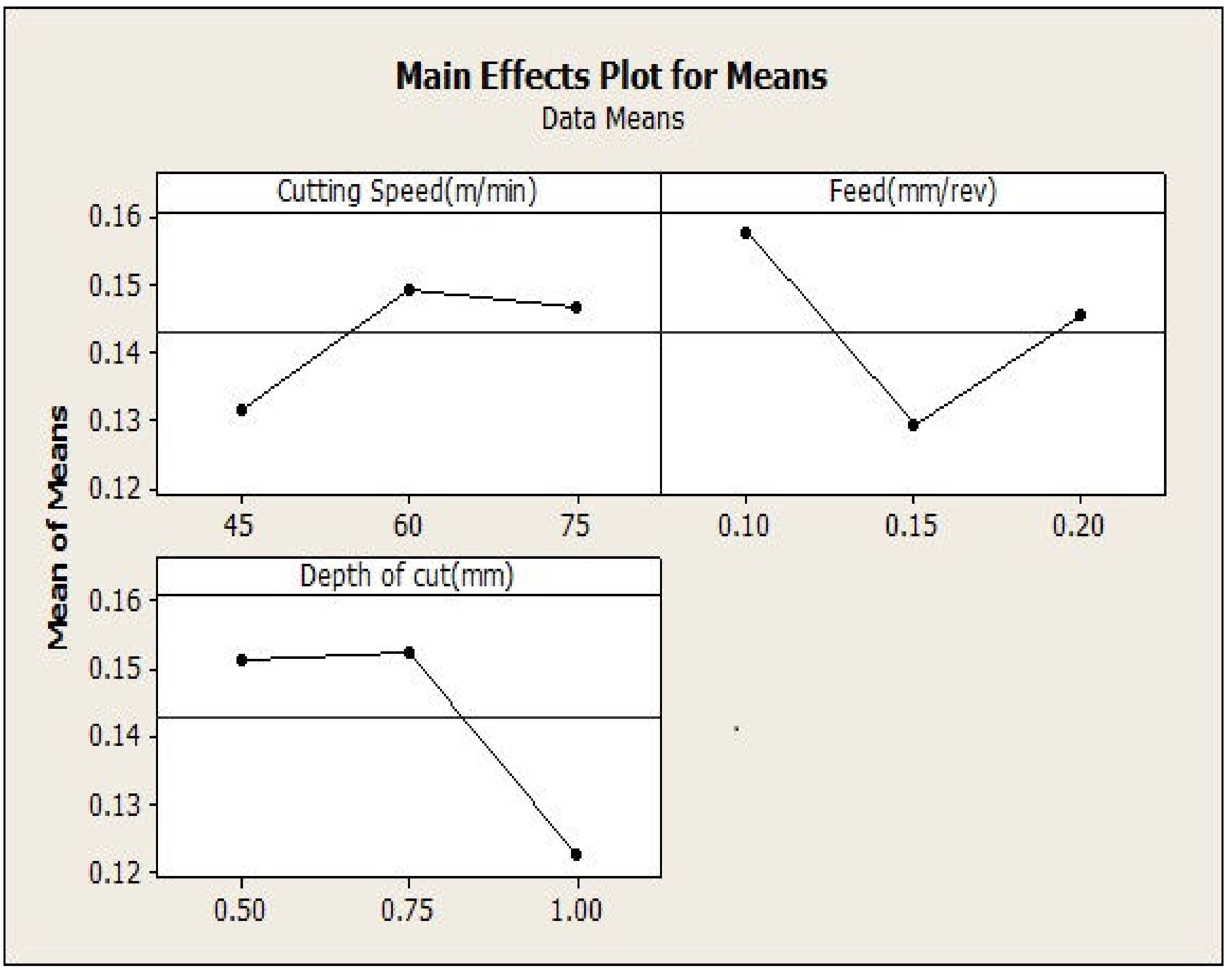


Figure 2 Effect of cutting parameters on flank wear.

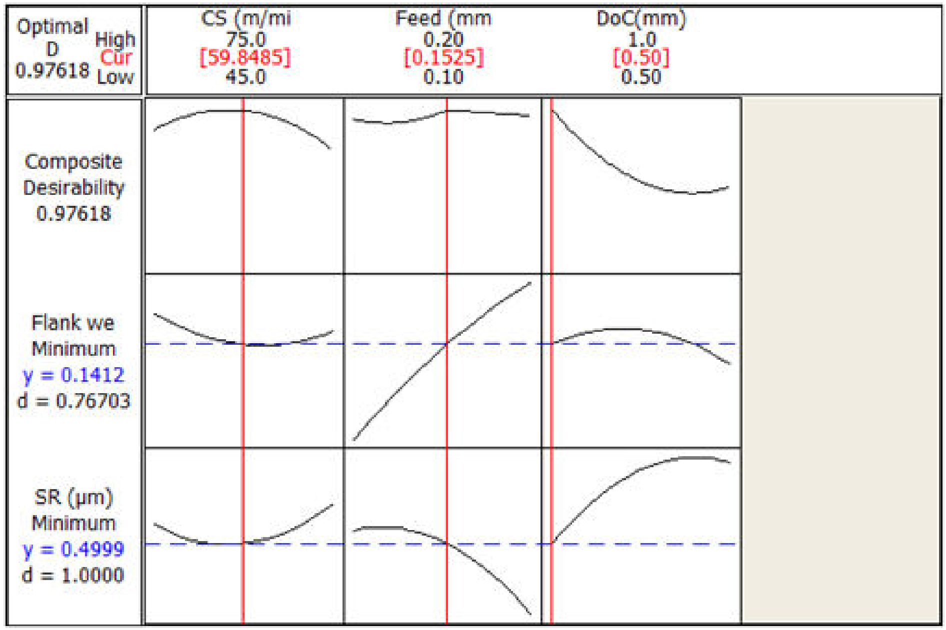


Figure 3 Response optimizer for simultaneous optimization plot.

3.4 Effect of surface roughness on variation of the machining parameters

The machining parameters are varying their impact on the surface roughness are displayed in the figure 4 with spectrum of coloured contour plots. From that contour plot the surface roughness improves with the raise of cutting speed till that minimum value. And also the cutting speed conjointly discovered that feed and depth of cut adversely affects the surface roughness. The contour plots of surface roughness are drawn by holding the optimum machining parameters of cutting speed 60 m/min, feed 0.15 mm/rev and depth of cut 0.75 mm, the raise in feed with cutting speed will increase the surface roughness. Whereas the interaction of feed and depth of cut doesn't influence much on the response, particularly lower feed and depth of cut yields useable surface roughness.

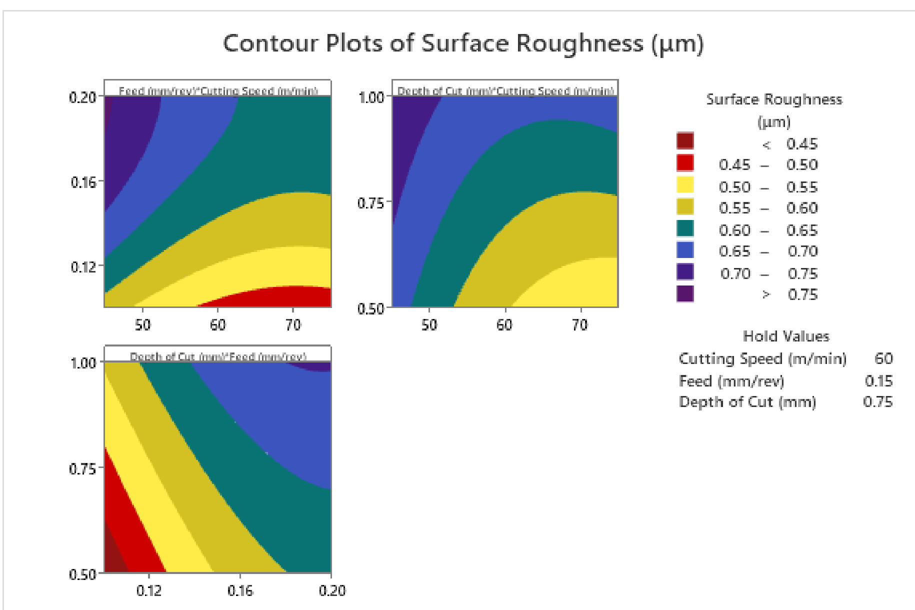


Figure 4 Contour plot for Surface roughness.

3.5 Effect of the flank wear on variation of the machining parameters

The increase of the cutting speed has highly required for production and quality aspects but it drastically affects the tool performance due to flank wear. The associated tool wear mechanism indicates that flank wear is a kind of abrasive wear due to the hard particles of the chip formation the work material jump over the tool face and it removes tool material by the mechanical action. When increasing the cutting speed from 50m/min, the cutting tools are worn-out due to thermal softening of the cobalt binder and consequently plastic deformation occurred on the cutting edges [12]. The figure 5, ascertained that, the higher cutting speed will increase the flank wear whereas depth of cut and feed rate interaction has less effective on promoting the wear land on the tool face. Higher depth of cut with any range of cutting speed doesn't influence the flank wear growth but increasing the machining time extremely affects the flank wear. The main reason for the wear progression due to breakage of the heat barrier on the coating layer with chip tool interface. These can be proved by the experimental results and shown in the figure 6. Based on the contour plot the cutting speed has selected as 50 m/min , depth of cut was 1.00 mm and feed rate was 0.15 mm/rev, the minimum flank wear has been recorded on the other hand high cutting speed 70 m/min, low feed 0.1mm/rev and medium depth of cut 0.75 mm the flank wear has increased higher which illustrates in figure 6.a and 6.b., the optimum cutting parameters (v = 60, f = 0.15, a_p = 0.5)are obtained by the response optimizer and cross validated with contour plot the flank wear was small in similar machining conditions and show in figure 6.c.

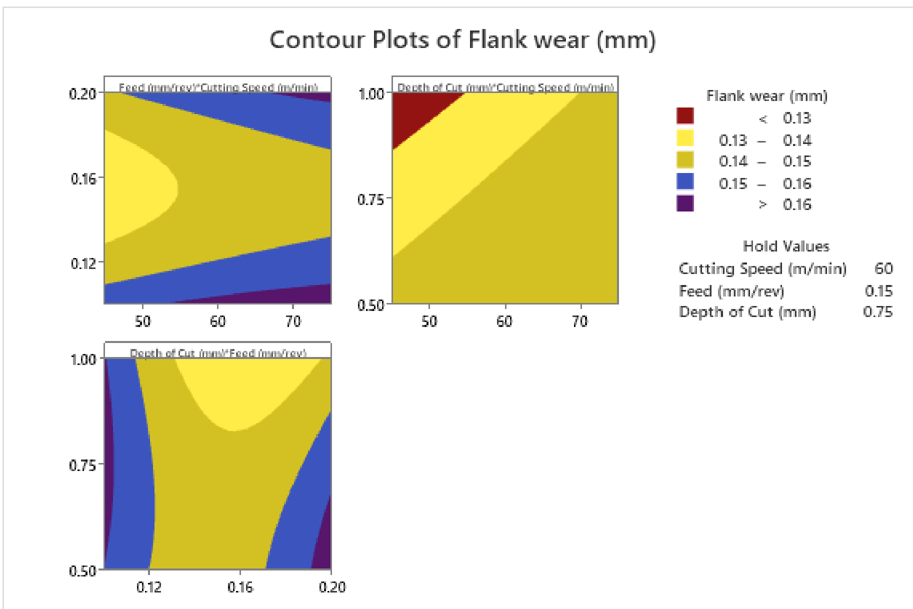
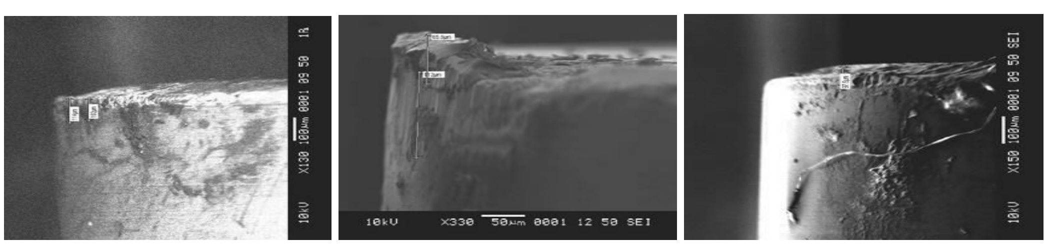


Figure 5 Contour plot for Flank wear.



6.a) V=50, f = 0.15, ap = 1.0. 6.b) V=70, f = 0.1, ap = 0.75 6.c) V=60, f = 0.15, ap = 0.50

Figure 6 Flank wear images at different machining parameters.

4. CONCLUSION

The following conclusions arrived based on the performance of coated low-cost carbide tools for finish facing operations of Inconel 718. The central composite design of experiments with three level of machining parameters are considered with 15 trails of experiment were conducted which required minimum amount of cutting tool inserts, experimental time and resources. The finish facing parameters were optimized by the Taguchi's method for minimum surface roughness. The optimum parameters are cutting speed 60 m/ min, feed rate 0.1 mm/rev and depth of cut 0.5 mm. Based on the optimal parameters the predicted surface roughness was 0.285µm whereas actual was 0.36µm. Similarly, the finish facing parameters were optimized by the Taguchi's method for minimum flank wear. The optimum parameters are cutting speed 45 m/ min, feed rate 0.15 mm/rev and depth of cut 1 mm. Based on the optimal parameters the predicted flank wear is 0.123 mm whereas actual was 0.134 mm. The finish facing parameters were simultaneous optimized by using response surface methodology. The optimum cutting parameters are predicted for minimum surface roughness and minimum flank wear, which are cutting speed 60 m/ min, feed rate 0.15 mm/rev and depth of cut 0.5 mm. For the optimum parameters the predicted surface roughness was 0.5µm and flank wear were 0.1412 mm whereas actual surface roughness was 0.52 µm and flank wear were 0.145 mm. The parameters feed rate and depth of cut have higher effect on the surface roughness and flank wear whilst the cutting speed has moderate effect, this might be numerous and different phenomena for the facing operations. It indicates that feed rate and depth of cut alone required elaborate investigation on further analysis of the finish facing operations. Using the contour plots the process planner can easily select the best range of cutting parameters in the feasible region.

Taguchi's optimization always predicts individual response only whereas surface response methodology (RSM) optimizes up to 24 responses can simultaneously optimize in the single run. Finally, the predictive optimum machining parameters are evaluated with experimental results and proved the effectiveness of optimization process.

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