Optimization of Process parameters in Heat Assisted Turning of Inconel 718 by WASPAS Method and Simulation using ABAQUS Software

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Abstract – In this paper, series of machining experiments on Inconel 718 has been carried out as per taguchi L18 orthogonal array using coated and uncoated carbides to establish the influence of surface temperature, spindle speed, feed and depth of cut on forces (feed, radial and thrust forces), surface roughness, MRR, power consumption and hardness in hot-turning of Inconel 718 alloy. Carbide tools are in the form of 80° rhomboid shaped inserts without any chip breaker have been used at different cutting conditions. Experiments were conducted on both heat assisted turning and conventional turning to determine the relative advantage offered by hot turning. For heat assisted turning, an LPG set-up was designed and attached to lathe machine. Inconel 718 specimen heated with LPG Gas flame and machined on a lathe under different cutting surface temperatures of 150°C and 300°C. In this paper, the applicability of weighted aggregated sum product assessment (WASPAS) method is explored for optimization of cutting parameters. Cutting parameters are optimized by maximizing material removal rate and minimizing surface roughness, forces and power consumption. The simulation has been done with optimized parameters by using ABAQUS software and the results (forces, MRR and power consumption) were compared with the actual experimental results.

Keywords— Heat assisted machining, Inconel 718, carbide and coated carbide inserts, MRR, Surface roughness, forces, power consumption, Hardness, WASPAS and ABAQUS software.

1. INTRODUCTION

Inconel 718 is one of the most difficult-to-cut materials because of its low thermal diffusive property, high hardness, high dynamic shear strength, high work hardening, high reaction with tool materials and high strength at high temperature. Machining of such materials with conventional method of machining was proved to be very costly as these materials greatly affect the tool life. So to decrease the tool wear, power consumption and better surface finish hot machining is preferred. The work piece is heated below its recrystallization temperature, so as to reduce the shear strength of the material.

Inconel 718 super alloy is one such material with excellent wear resistance, corrosive resistance and good strength and hence, has wide applications such as in aerospace, gas turbine, cryogenic storage tanks, nuclear fuel element spacers, pump body components, down hole shafts, wellhead parts [5]. These alloys are difficult to machine, which cause steep temperature gradient at the tool edge and the shift the location of the maximum temperature towards the tool tip.

As a result, excessive tool wear, premature cracking and built-up edge formation are observed. Other factors that contribute to the poor machinability of IN718 include the strong tendency to strain hardening during machining, the adhesion to the tool material, and the presence of hard abrasive carbides and intermetallic phases in its microstructure [6]. The high operating temperature in hot turning process imparts softness on the material under investigation, which eases the machining process and further reduces the high cost of changing and sharpening cutting tools.

Softening of the workpiece in hot machining is a more effective method than strengthening the cutting tool in conventional machining. Due to these advantages of hot machining, extremely hard and brittle materials like ceramics can also be machined using this technique [4].

2. LITERATURE REVIEW

R.K Suresh et. al. [1], have evaluated that the vegetable oil based cutting fluids like castor oil, palm oil and ground nut oil is made to drop at tool-work interface using over-head system and the experimental investigation carried out for machinability study of hardened AISI D3 steel in combination with CVD coated cemented carbide inserts of different styles and to obtain optimum process parameters using WASPAS method. An orthogonal array, overall performance index and analysis of variance (ANOVA) are applied to study the performance of process parameters such as insert style, cutting fluid cutting speed, feed and depth of cut with consideration of quality characteristics i.e., surface roughness, material removal rate, interface temperature, specific energy consumption and flank wear. Finally a clear presentation is made for WASPAS method. Ilhan Asilturk and Harun Akkus [2], study focuses on optimizing turning parameters based on the Taguchi method to minimize surface roughness (Ra and Rz). Experiments have been conducted using the L9 orthogonal array in a CNC turning machine. Dry turning tests are carried out on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. The statistical methods of signal to noise ratio (SNR) and the analysis of variance (ANOVA) are applied to investigate effects of cutting speed, feed rate and depth of cut on surface roughness. Results of this study indicate that the feed rate has the most significant effect on Ra and Rz. A. Kiran Kumar and P. Venkataramaiah [4], investigated the effect of hot machining on surface roughness. In hot Machining the temperature of the work piece is raised to several hundred Celsius above ambient, which causes reduction in the shear strength of the material. We used flame heating method for heating the work piece and experiments were carried out to establish the influence of surface temperature, spindle speed, and feed rate on surface roughness. Using Grey Relational Analysis the optimum parameters are determined. H. Attia et. al. [6], studied the high-speed machinability of this material under laser-assisted machining (LAM) and dry conditions. Finish turning tests were performed for cutting speeds upto 500 m/min and feeds up to 0.5 mm/rev, using focused laser beam and ceramic tool. At optimum machining conditions, nearly eight-fold increase in material removal rate and significant improvement in the tool life and surface finish were achieved, compared to conventional machining. The mechanisms of tool failure were identified. SEM analysis and microstructure examination of machined surfaces revealed the improvement in the surface integrity under LAM conditions. Sumit verma and Hari Singh[8], have optimized the parameters to minimize radial force in turning of EN-8 steel using carbide inserts as cutting tool. The experiments are conducted using L18 orthogonal array as an experimental design. The cutting parameters are optimized using signal to noise ratio and the analysis of variance. The effects of nose radius, spindle speed, feed rate and depth of cut are analyzed. The confirmation tests are carried out at optimum cutting conditions. Optimal values of process parameters for desired performance characteristic are obtained by Taguchi's approach. M.Fahad et. al.[14], employed hybrid methodology in which finite element modelling (FEM) and experimental tests were used to evaluate the performance of multilayer functionally graded coated tools on the basis of heat partition into the tool and growth of flank wear. Cutting tests were conducted on AISI/SAE 4140 low carbon steel using multilayer coated tungsten carbide tools with TiCN/Al2O3 coatings on the rake face and TiCN/Al2O3/TiN coatings on the flank face.

3. EXPERIMENTAL DETAILS

For conducting experiments, a liquefied petroleum gas (LPG) heating setup was used to heat the work piece material as shown in Figure 1. LPG heating is one of the best choices for hot machining it requires low cost equipment. The flame was generated through the nozzle of the torch. The torch movement can either be automated or manually moved, a special attachment was used to move the torch mounted on carriage to provide a flexible movement of heat source while machining, here we placed flame torch in the place of coolant nozzle. The gas pressure was adjusted by a pressure regulator and it is varied with respect to requirement throughout the experiment. Metallurgical damage to the workpiece will be low. During all the experiments, the distance between the torch and work piece is maintained at 25 mm. The turning experiments on the work piece were conducted on TURNMASTER-350 Lathe machine which have maximum spindle speed of 1800rpm and maximum power of 16KW. Work piece is preheated up to required temperature and then machining has been done.

Figure 1: Experimental setup.

3.1. Workpiece and tool materials

An Inconel 718 rod of 30 mm diameter and 200 mm length is used in the experiments. The chemical composition of Inconel 718 with hardness ≤363 BHN is shown in Table 1. Carbide insert with CNMG 120408 NC6210 and multilayer coated (TiCN/Al2O3/TiN) carbide insert with CNMG 120408 MT TT5100 specification are used as a cutting tool. The input parameters range was decided on the basis of machine capability and pilot experiments.

Element	C	Ti	Cr	Fe	Ni	Nb	Mo
% by mass	8.24	0.59	14.81	15.46	54.39	4.10	2.41

Table 1**:** Chemical composition of Inconel 718 [9]

3.2. Measurements

3.2.1. Measurement of forces

Piezo-electric tool dynamometer (Figure 2) has been used to measure the cutting force, radial force, and feed force. Cutting force (Fc) acts against the work piece turning motion and forces the cutting tool downwards perpendicular to the work piece axis. Feed force (Ft) acts parallel to the work piece axis and is in the reverse direction of the feed. Radial force (Fr) acts perpendicular in direction to the machined surface, radial force that tends to push the tool away from the work piece being machined and forces the cutting tool backwards.

Figure 2: Lathe tool dynamometer

3.2.2. Measurement of power consumption

Power consumption was measured after every experimental trial by using watt meter (Figure 3).

Figure 3: Wattmeter

3.2.3. Measurement of surface roughness

Surface roughness was measured after every experimental trial by using Talysurf (Figure 4).

Figure 4: Talysurf [Surface Measuring Device]

3.2.4. Measurement of surface temperature

The surface temperatures were measured by using infrared pyrometer (Figure 5)

Figure 5: Pyrometer

3.2.5. Measurement of material removal rate (mrr)

MRR is calculated using the difference of weight of workpiece before and after the machining operation and time of machining of each experiment, measured using stopwatch.

3.2.6. Hardness test

The hardness values are taken at three different places and average hardness values are calculated by using specified diameter indenter and load on the Brinell hardness machine. The Brinell hardness number (BHN) values are calculated using equation.

$$BHN = \frac{P}{\frac{\pi}{2} D[D - \sqrt{D^2 - d^2}]}$$

Where:

BHN = Brinell Hardness Number

P = applied load in kilogram-force (kgf)

D = diameter of indenter (mm)

d = diameter of indentation (mm)

4. DESIGN OF EXPERIMENT

The experiments were planned using Taguchi's orthogonal array in the design of experiments which help in reducing the number of experiments. The investigation carried out by varying four control factors Insert type, Cutting Speed, Feed rate and Temperature on Heat assisted machining. In Taguchi method L18 Orthogonal array provides a set of well-balanced experiments. The selected range of input parameters is shown in Table 2.

Symbol	process parameter	Units	Levels		
			I	II	III
A	Insert type		carbide	coated carbide	
B	surface temperature	°C	room temperature	150	300
C	spindle speed	rpm	180	450	710
D	Feed	mm/rev	0.05	0.1	0.16

Table 2: Levels of input parameters

Exp. no.	A	B	C	D
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

Table 3: L_{18} Orthogonal array

5. METHODOLOGY

The entire proposed modelling and architecture of the current research paper should be presented in this section. This section gives the original contribution of the authors. This section should be written in Times New Roman font with size 10. Accepted manuscripts should be written by following this template. Once the manuscript is accepted authors should transfer the copyright form to the journal editorial office. Authors should write their manuscripts without any mistakes especially spelling and grammar.

5.1 Entropy approach for weight determination

Entropy method is one of the well-known and widely used methods to calculate the criteria of decision weights. Decision weights increases the importance of criteria and is usually categorized into two types. One is subjective weight which is determined by the knowledge and experience of experts or individuals, and the other is objective weight which is determined mathematically by analyzing the collected data. Here, it is an objective weighting method. W_{MRR}, W_{Power}, $W_{Roughness}$, $W_{Thrust\ force}$, $W_{Feed\ force}$, $W_{Cutting\ force}$ are the weights assigned to the MRR, Power, Roughness, Thrust force, Feed force, Cutting force, W_{MRR}=0.31275, W_{Power}=0.047134, $W_{Roughness}$= 0.17481461, $W_{Thrust\ force}$= 0.132965254, $W_{Feed\ force}$= 0.209485666, $W_{Cutting\ force}$= 0.122851403.

5.2 WASPAS METHOD

Weighted aggregated sum product assessment (WASPAS) method for solving MCDM. The procedural steps being involved in solving multi objective optimization problems is presented below

Step 1. Set the initial decision matrix

Step 2. Normalization of the decision matrix by using the following equations:

$$\bar{X}_{ij} = \frac{x_{ij}}{max_i x_{ij}} \quad (1)$$

$$\bar{X}_{ij} = \frac{min_i x_{ij}}{x_{ij}} \quad (2)$$

Where x_{ij} is the assessment value of the i^{th} alternative with respect to the j^{th} criterion, and equations 1 and 2 are used for maximization and minimization criteria, respectively.

Step 3. The total relative importance of the i^{th} alternative, based on weighted sum method (WSM), is calculated as follows:

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{X}_{ij} . W_j \quad (3)$$

Step 4. The total relative importance of the i^{th} alternative, based on weighted product method (WPM), is calculated as follows:

$$Q_i^{(2)} = \prod_{j=1}^{n} \overline{X_{ij}}^{W_j} \quad (4)$$

Step 5. In order to have increased ranking accuracy and effectiveness of the decision making process, in the WASPAS method, a more generalized equation for determining the total relative importance of alternatives is developed as below:

$$Q_i = \lambda . Q_i^{(1)} + (1 - \lambda) . Q_i^{(2)} \quad (5)$$

Where λ= 0, 0.1, 0.2…….

6. RESULTS AND DISCUSSIONS

A series of turning tests were conducted to assess the effect of turning parameters on power consumption, forces, surface roughness, material removal rate and hardness.

Exp. No.	A	B	C	D	MRR (gm/min)	Power (Watts)	Roughness (µm)	Thrust Force (N)	Feed Force (N)	Cutting Force (N)	Hardness (BHN)
1	1	1	1	1	1.915	500	0.45	117.72	58.86	88.29	462
2	1	1	2	2	10.169	800	0.33	147.15	98.1	137.34	494
3	1	1	3	3	16.667	950	0.9	176.58	117.72	196.2	477
4	1	2	1	1	1.978	400	0.21	68.67	29.43	58.86	462
5	1	2	2	2	10.588	600	0.31	78.48	58.86	98.1	432
6	1	2	3	3	18.576	700	0.73	107.91	98.1	147.15	477
7	1	3	1	2	3.072	400	0.22	78.48	29.43	68.67	511
8	1	3	2	3	11.25	400	0.25	68.67	39.24	68.67	548
9	1	3	3	1	5.455	500	0.65	39.24	19.62	49.05	529
10	2	1	1	3	4.615	500	0.41	215.82	78.48	98.1	511
11	2	1	2	1	3.39	600	0.44	98.1	49.05	127.53	529
12	2	1	3	2	10.843	700	1	156.96	68.67	156.96	529
13	2	2	1	2	3.871	400	0.29	68.67	49.05	78.48	548
14	2	2	2	3	15	500	0.35	117.72	68.67	98.1	529
15	2	2	3	1	8	600	0.94	78.48	29.43	117.72	548
16	2	3	1	3	9.474	400	0.3	127.53	58.86	49.05	548
17	**2**	**3**	**2**	**1**	**7.5**	**400**	**0.23**	**58.86**	**19.62**	**49.05**	529
18	2	3	3	2	22.785	600	0.87	78.48	39.24	68.67	548

Table 4: Experimental responses

xp. No.	A	B	C	D	Normalised values X_{ij}					
					MRR	Power	Roughness	Thrust Force	Feed Force	Radial Force
1	1	1	1	1	0.08404	0.8	0.46667	0.33333	0.33333	0.55556
2	1	1	2	2	0.44633	0.5	0.63636	0.26667	0.2	0.35714
3	1	1	3	3	0.73148	0.42	0.23333	0.22222	0.16667	0.25
4	1	2	1	1	0.08681	1	1	0.57143	0.66667	0.83333
5	1	2	2	2	0.46471	0.67	0.67021	0.5	0.33333	0.5
6	1	2	3	3	0.81527	0.57	0.28767	0.36364	0.2	0.33333
7	1	3	1	2	0.13481	1	0.95455	0.5	0.66667	0.71429
8	1	3	2	3	0.49375	1	0.84	0.57143	0.5	0.71429
9	1	3	3	1	0.23939	0.8	0.32308	1	1	1

10	2	1	1	3	0.20256	0.8	0.51639	0.18182	0.25	0.5
11	2	1	2	1	0.14878	0.67	0.47727	0.4	0.4	0.38462
12	2	1	3	2	0.4759	0.57	0.21	0.25	0.28571	0.3125
13	2	2	1	2	0.16989	1	0.72414	0.57143	0.4	0.625
14	2	2	2	3	0.65833	0.8	0.6	0.33333	0.28571	0.5
15	2	2	3	1	0.35111	0.67	0.2234	0.5	0.66667	0.41667
16	2	3	1	3	0.41579	1	0.7	0.30769	0.33333	1
17	2	3	2	1	0.32917	1	0.91304	0.66667	1	1
18	2	3	3	2	1	0.67	0.24138	0.5	0.5	0.71429

Table 5: Normalized decision matrix

The results of experimentation are shown in table 4. The normalization of decision matrix is calculated by using equations (1) and (2), which is shown in table 5.

SL.NO	A	B	C	D	WSM Values $Q_i^{(1)}$	WPM Values $Q_i^{(2)}$	Q	Rank
1	1	1	1	1	0.327972	0.254951	0.291462	18
2	1	1	2	2	0.395631	0.366641	0.381136	13
3	1	1	3	3	0.384581	0.320263	0.352422	14
4	1	2	1	1	0.567112	0.388250	0.477681	9
5	1	2	2	2	0.491659	0.478929	0.485294	8
6	1	2	3	3	0.463398	0.400642	0.43202	10
7	1	3	1	2	0.550055	0.426014	0.488035	7
8	1	3	2	3	0.616872	0.599209	0.60804	3
9	1	3	3	1	0.634358	0.519361	0.57686	4
10	2	1	1	3	0.329304	0.292980	0.311142	17
11	2	1	2	1	0.345617	0.308673	0.327145	16
12	2	1	3	2	0.343969	0.325925	0.334947	15
13	2	2	1	2	0.463414	0.392624	0.428019	11
14	2	2	2	3	0.514090	0.484699	0.499394	6
15	2	2	3	1	0.437614	0.409379	0.423497	12
16	2	3	1	3	0.533134	0.484966	0.50905	5
17	2	3	2	1	0.730674	0.658797	0.694735	1
18	2	3	3	2	0.645345	0.579091	0.612218	2

Table 6: The total relative importance and ranking of alternatives using WASPAS method

The total relative importance of the i^{th} alternative, based on weighted sum method (WSM) and weighted product method (WPM) are calculated using equation (3) and (4), which was shown in table 6.

Process Parameter	Avarage Waspas Index (Spm)				
	Level1	Level 2	Level 3	Max-Min	Rank
Temperature	0.333042	0.457651	**0.58149**	0.2484475	1
Speed	0.417565	**0.499291**	0.455327	0.0817261	2
Feed	**0.46523**	0.454941	0.452011	0.0132185	3
Insert	0.454772	**0.460016**		0.0052441	4

Total mean value of the overall performance index = 0.45739

Table 7: Response table for WASPAS method

The optimal parameters setting lies at temperature L3, speed L2, feed L1 and insert type L2 from the table 7.

7. MAIN EFFECT PLOTS

7.1 Conventional turning vs heat assisted turning

The relative advantage offered by hot turning over the conventional turning in terms of responses can be seen from the Figures 6 to 9.

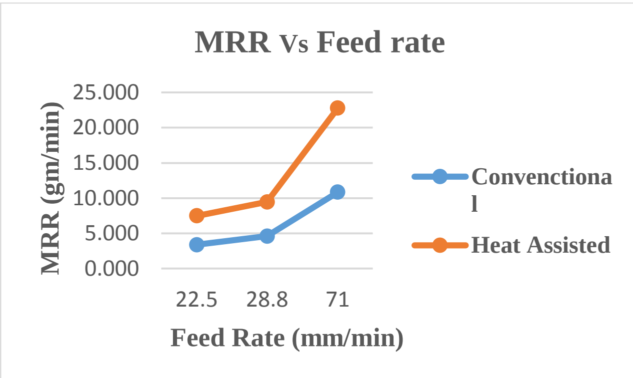

Figure 6: MRR Vs Feedrate

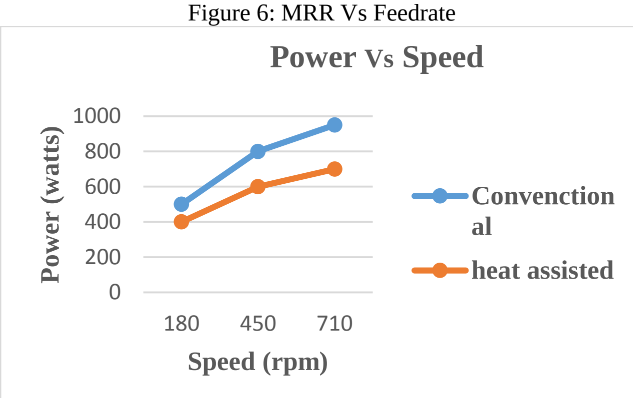

Figure 7: Power Vs Speed

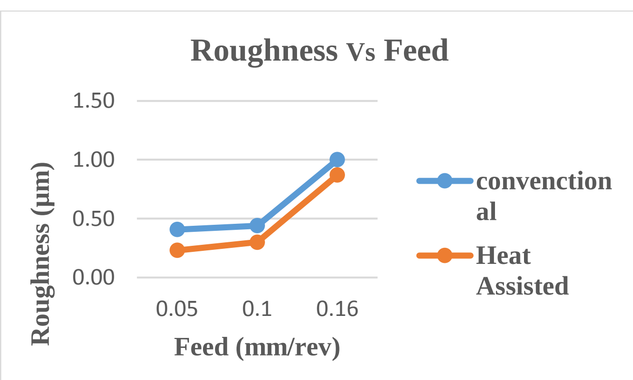

Figure 8: Roughness Vs Feed

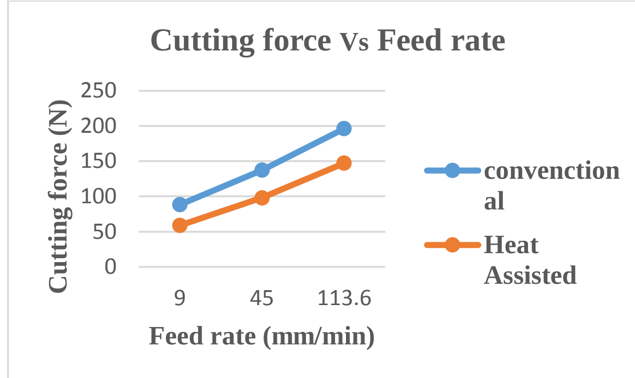

Figure 9: Cutting Force Vs Speed

7.2. Carbide tool vs coated carbide tool

The plots are drawn on the effect of cutting speed and feed on the performance of uncoated and multilayer coated carbide tools when turning Inconel 718 alloy in figure 10 to 13.

Comparison of uncoated and coated carbide tools shows that force, MRR and power consumption in coated carbide tool is lower than uncoated carbide tool. And the surface roughness obtained when machined with coated carbide is higher than the uncoated carbide.

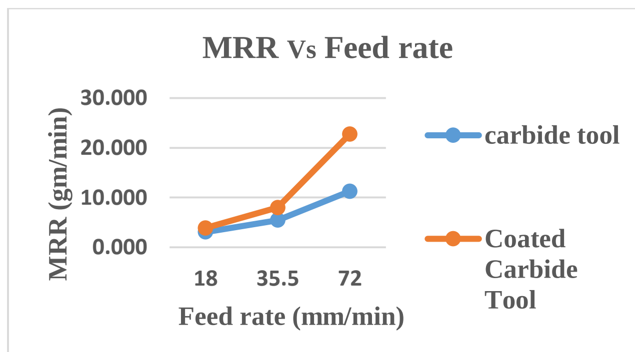

Figure 10: MRR Vs Feedrate

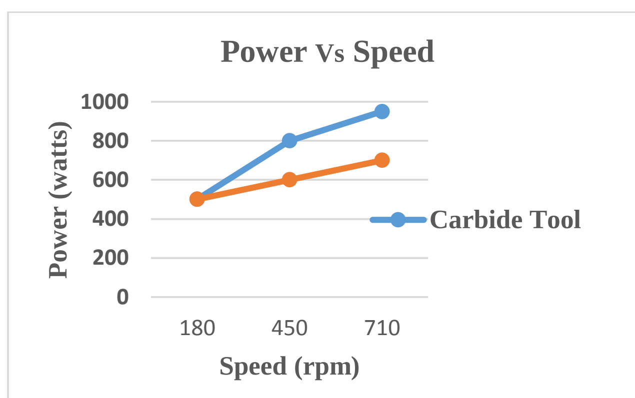

Figure 11: Power Vs Speed

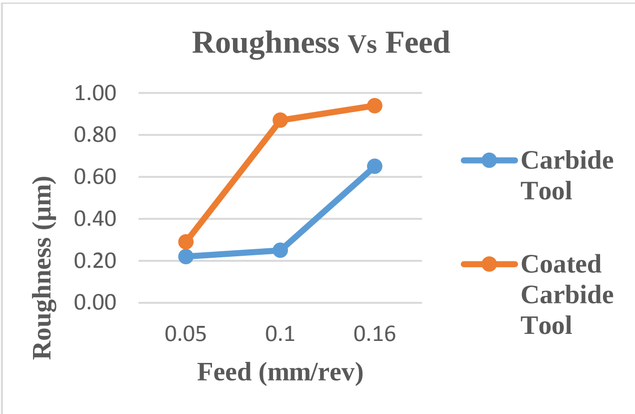

Figure 12: Roughness Vs Feed

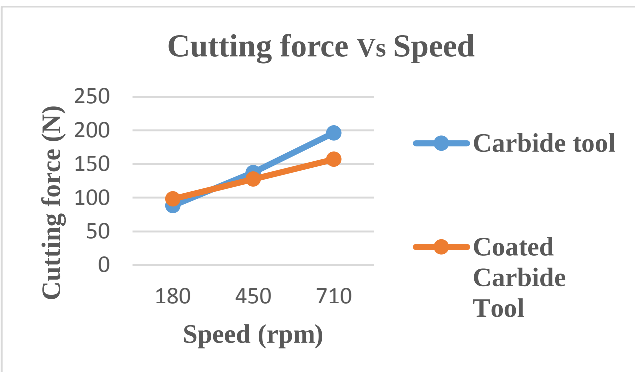

Figure 13: Cutting Force Vs Speed

7.3 Plot for hardness vs temperature

The graph is drawn between surface temperature of workpiece and hardness. The workpiece is heated and the turning operation is done then cooled in air.

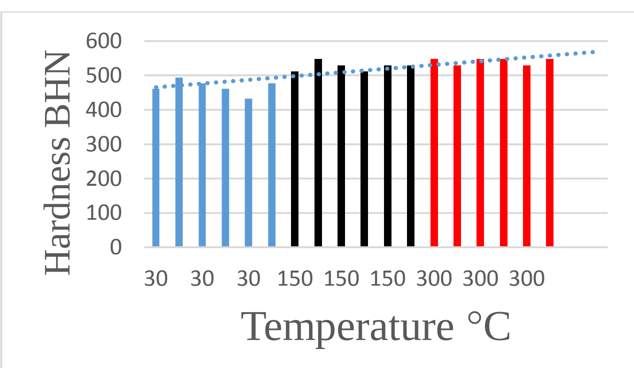

Figure 14: Surface temperature Vs Hardness

From Figure 14, it is observed that as the temperature increases the hardness is increasing.

8. FORCES AND MRR ANALYSIS USING FEM

The selection of finite element software for modelling machining is an important factor in determining the quality and scope of analysis that can be performed. Most commonly used softwares for FEM analysis in machining are Deform™, Abaqus™ and AdvantEdge™. Given the complexity of the finite element method, the choice of package is very important for the analysis that can be performed and quality of the results as well. This is because different packages have different capabilities and it is critical to select the package with the appropriate feature set. Furthermore, the assumptions and solver techniques used in the package have far reaching consequences in the results obtained from the simulations.

The present work uses the software Abaqus™ for machining simulation. The workpiece material was modelled as the geomentry and properties of inconel 718 workpiece and meshes are created. The cutting tool was considered as a stiff elastic material, for which the mechanical properties were obtained from Fahad [14]. The simulation is done at optimised level input parameters as shown in Figure 15. The forces and MRR of simulated and measured values are comparied in the plots shown in Figures 16 and 17.

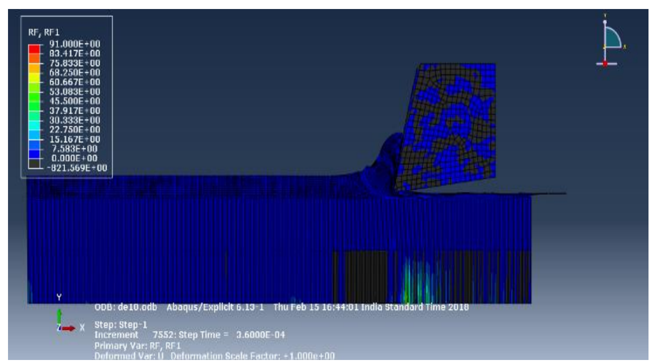

Figure 15: Cutting Force at optimum level parameters

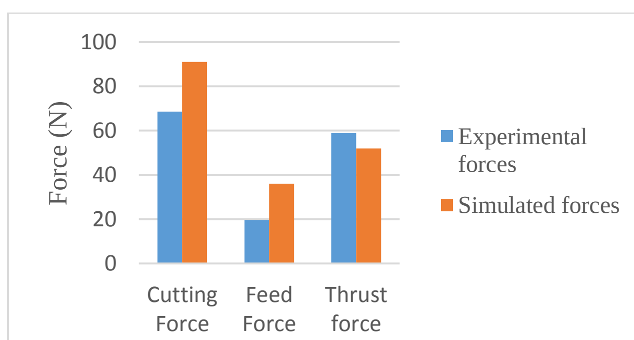

Figure 16: Comparison of Cutting Force between Experimental and Simulated

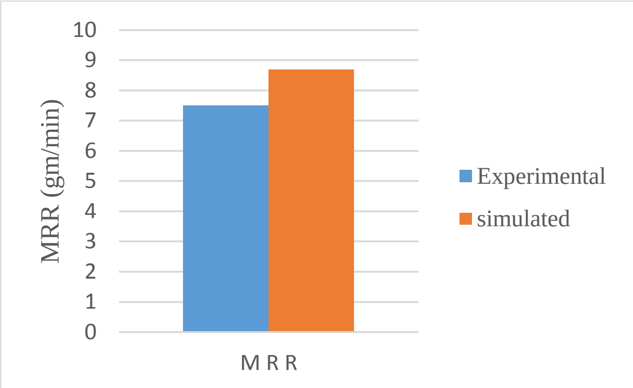

Figure 17: Comparison of MRR between Experimental and Simulated

9. CONCLUSIONS

From the research of present work, the followingconclusions are drawn.

- The optimal process parameter setting lies at coated carbide insert type, surface temperature 300°C, spindle speed 450 rpm and feed 0.05 mm/rev, their corresponding optimum responses are surface roughness 0.23 µm, power consumed 400 W, feed force 2 kg, cutting force 5 kg, thrust force 6 kg and MRR is 7.5 gm/min.
- Surface finish was improved remarkably in hot machining compare to machining at room temperature. But when compare to coated tool, uncoated carbide tool gives good surface finish.
- The cutting forces, material removal rate and power consumption got reduced with coated carbide tools.
- Cutting Forces are predominantly low with hot turning over conventional turning was observed.
- Increased in MRR was observed in hot turning compared to conventional turning.
- The experimental responses and ABAQUS simulated responses are compared, it is satisfactory.

9.1 Scope for future work

- The effect of temperature can be studied by carrying out experiments at different temperatures.
- Isolated pre-heating of the workpiece can be implemented to reduce heat transfer to the surroundings.
- The technique of hot machining can be applied in cutting composites.
- Metallurgical aspects of the Workpiece after heat assisted machining can be studied.

REFERENCES

[1] R.K Suresh, G.Krishnaiah, P.Venkataramaiah "An Experimental Investigation towards Multi Objective Optimization during Hard Turning of Tool Steel Using a Novel MCDM Technique" International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 9 (2017).

[2] Ilhan Asilturk, Harun Akkus "Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method" doi:10.1016/j.measurement.2011 .07.003

[3] Jeffrey D. Thiele, Shreyes N. Melkote "Effect of cutting edge geometry and workpiece hardness on surface generation in the ®nish hard turning of AISI 52100 steel" Journal of Materials Processing Technology 94 (1999).

[4] A Kiran Kumar, P Venkataramaiah "Experimental Studies in Heat Assisted Machining of Inconel Alloy" IJRMET Vol. 7, Issue 1, Nov 2016 - Apri l 2017

[5] Venkatesh G, Sivaiah P, Chakradhar D "Optimization of Hot Turning Parameters by using Taguchi based Grey Relation Analysis" International Journal of Engineering Research Volume No.5 Issue: Special 2

[6] H. Attia, S. Tavakoli, R. Vargas, V. Thomson "Laser-assisted high-speed finish turning of superalloy Inconel 718 under dry conditions" CIRP Annals - Manufacturing Technology doi:10.1016/j.cirp.2010.03.093

[7] E. *0.* Ezugwu, Z. M. Wang And C. I. Okeke "Tool Life and Surface Integrity When Machining Inconel718 With PVD- and CVD-Coated Tools" Tribology Transitions, vol. 42 (1999), 2, 353-360

[8] Sumit Verma, Hari Singh "Optimization of Radial Force in Turning Process Using Taguchi's Approach" 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India.

[9] G.M.Sayeed Ahmed, S.Sibghatullah Hussaini Quadri, Md Sadiq Mohiuddin "Optimization of Feed and Radial Force in Turning Process byusing Taguchi Design Approach" 4th International Conference on Materials Processing and Characterisation (ICMPC 2015), Materials Today: Proceedings 2 (2015) 3277 – 3285

[10] D.I. Lalwani, N.K. Mehta, P.K. Jain "Experimental investigations of cutting parameters influence on cutting forces and surface roughness in finish hard turning of MDN250 steel" journal of materials processing technology 2 0 6 (2 0 0 8) 167–179

[11] I A Choudhury and M A El-Baradie "Machining nickel base superalloys: Inconel 718" Proc Instn Mech Engrs Vol 212 Part B

[12] [36] S. Amini, M. H. Fatemi, R. Atefi "High Speed Turning of Inconel 718 Using Ceramic and Carbide Cutting Tools" Arab J Sci Eng (2014) 39:2323–2330, DOI 10.1007/s13369-013-0776-x

[13] Moaz H. Ali, Basim A. Khidhir, M.N.M. Ansari, Bashir Mohamed "FEM to predict the effect of feed rate on surface roughness with cutting force during face milling of titanium alloy" HBRC Journal (2013) 9, 263–269

[14] M Fahad, P T Mativenga, and M A Sheikh "An investigation of multilayer coated (TiCN/Al2O3-TiN) tungsten carbide tools in high speed cutting using a hybrid finite element and experimental technique" DOI: 10.1177/0954405411404504