Machinability Evaluation of Inconel 718 on Machining Induced Microstructure using 3-D Finite Element based Simulation

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Abstract— Inconel 718 super alloy is one of the difficult to machining material employed widely in aerospace industries. The main objective of this study its implements a reliable finite element model for orthogonal machining of Inconel 718 alloy and prediction of the microstructure changes during the process. The experimental results of surface roughness and material removal rate were taken in to account to identify the most suitable cutting parameter among the number of trials. The finite element numerical model was calibrated using an iterative procedures Newton Rapshon method. The results shows that a very good agreement has been found between the machinability analysis both in experimental and simulation. The FEM analysis has predicted some useful response using Deform 3-D.

Key words: Inconel, Rapshon Methode, Machinability, Age-hardenable, Super Jobber

I. Introduction

Machining is the most important of the manufacturing processes. Machining can be defined as the process of removing material from a work piece in the form of chips. The term metal cutting is used when the material is metallic. Most machining has very low set-up cost compared to forming, molding, and casting processes. Machining is necessary where tight tolerances on dimensions and finishes are required. Turning is another of the basic machining processes. Turning produces solids of revolution which can be tightly tolerance because of the specialized nature of the operation. Turning is performed on a machine called a lathe in which the tool is stationary and the part is rotated. Lathes are designed solely for turning operations, so that precise control of the cutting results in tight tolerances. The work piece is mounted on the chuck, which rotates relative to the stationary tool.

A. Machinability of Nickel

Machinability of nickel based super - alloys is extremely poor, mainly due to their low thermal conductivity, build up edge and self-hardening, which leads to high dynamic cutting forces. Due to these factors the tool wear is extremely high and increasing the tool life by minutes is an enormous success. The greatest problem in machining these materials is the heat stress. An extreme heat load is applied to the tools and the plastic deformation of the cutting edge may be observed. When the cutting speed is about 30 m/min the cutting temperature can exceed1100°C. This can lead to diffusion of carbide particles and to the weakening of the bonding strength between carbides and binder. Materials such as Inconel 718 have also high strength and hardness which leads to high flow stress of about 1-3 GPa on the tool when these materials are machined.

B. FEM

The success of FEM is based largely on the basic finite element procedures used: the formulation of the problem in variation form, the finite element discretization of this formulation and the effective solution of the resulting finite element equations. These basic steps are the same whichever problem is considered and together with the use of the digital computer present a quite natural approach to engineering analysis. The objective of this course is to present briefly each of the above aspects of the finite element analysis and thus to provide a basis for the understanding of the complete solution process. According to three basic areas in which knowledge is required, the course is divided into three parts. The first part of the course comprises the formulation of FEM and the numerical procedures used to evaluate the element matrices and the matrices of the complete element assemblage. In the second part, methods for the efficient solution of the finite element equilibrium equations in static and dynamic analyses will be discussed. In the third part of the course, some modeling aspects and general features of some Finite Element Programs (ANSYS, NISA, LS-DYNA) will be briefly examined.

II. Problem Identification

The nickel based super alloy like Inconel, ivory, monel, nicrofer, nimonic are investigated in the past years, but even there is some gap in the research are identified, and put forth to investigate. The Inconel alloy are difficult to machine due to the hardness, hence because of the strength ratio is less reach area. The microstructure analysis of nickel alloys shows that the strong adhesive nature with Iron-Carbon region, hence the study of optical diffraction is very less in microstructural analysis. These information about the materials are not accurate, description in the function of strain rate, temperature and other parameters. There is no proper iterative convergent procedures was employed to improve Finite Element (FE) prediction.

III. Objective

To evaluate the machinability index for the hard material like Inconel and to increase the hardness of the material through the heat treatment and evaluate the machinability of the material. The adhesive of the Inconel material is to increase by the heating process and it is analyzed by microstructure. To determine the accurate value of stress & strain rate, temperature, displacement and velocity of the nickel alloy Inconel 718 and evaluate a proper iterative convergent procedures to improve the Finite Element (FE) prediction.

IV. EXPERIMENTAL DETAILS

A. CNC Machine Super Jobber500

The Super Jobber is a precision, cost effective, full fledge CNC machine designed and built to take advantage of CNC features like high rapid rates, cutting parameters, constant surface speed etc., The machine elements like Ball screws, Bearings, CNC systems and Drives have been chosen appropriately. The machine is put together by a dedicated team of skilled craftsmen, under expert technical guidance. The schematic representation of CNC machine and tool insert and workpiece contact are shown in fig 1.

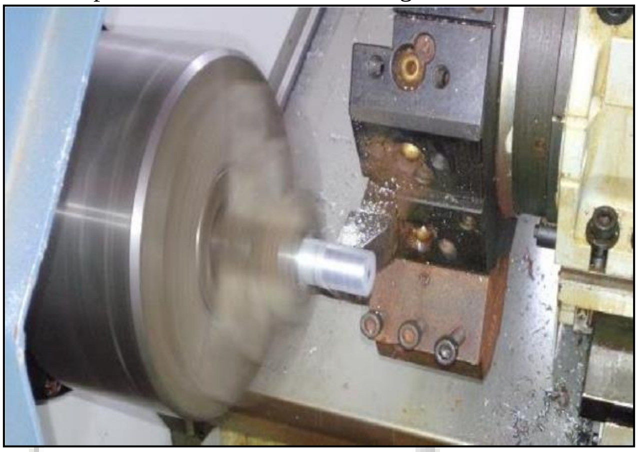

Fig. 1: CNC Machine

B. Material

INCONEL® alloy 718 (UNS N07718/W.Nr. 2.4668) is a high-strength, corrosion-resistant nickel chromium material used at -423° to 1300°F. The age-hardenable alloy can be readily fabricated, even into complex parts. Its welding characteristics, especially its resistance to postweld cracking, are outstanding. The ease and economy with which INCONEL alloy 718can be fabricated, combined with good tensile, fatigue, creep, and rupture strength, have resulted in its use in awide range of applications. Examples of these are components for liquid fueled rockets, rings, casings andvarious formed sheet metal parts for aircraft and land-based gas turbine engines, and cryogenic tank age. It is also usedfor fasteners and instrumentation parts. Fig 2 represents the raw material and machined material of Inconel 718.

Fig. 2: Raw Materials

C. Muffle Furnace

A muffle furnace is the furnace with an externally heating chamber and wall of which radiantly heard the contents of the chamber. Fig.3 represent the muffle furnace.

Fig. 3: Muffle Furnace

V. EXPERIMENTAL DESIGN AND EVALUATION

The Taguchi's L_9 orthogonal array was used to design the experiment with three factors and three levels. Experiments were conducted based on the Taguchi's method which a powerful tool is used in design of experiments. The machining parameters and levels are shown in Table 1. Design of experiment and calculation for untreated material is shown in table 2, and treated material are shown in table 3.

Parameter	Level 1	Level 2	Level 3
Speed (rpm)	700	800	900
Feed (mm/rev)	0.20	0.25	0.30
Depth of cut (mm)	0.50	0.75	1.00

Table 1: Machining Parameters and Levels

S.NO	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	R_a (μm)	MRR (mm^3/sec)
1.	700	0.20	0.50	1.76	36.17
2.	700	0.25	0.75	1.89	67.40
3.	700	0.30	1.00	2.35	107.77
4.	800	0.20	0.75	2.97	61.62
5.	800	0.25	1.00	3.26	102.07
6.	800	0.30	0.50	2.07	62.003
7.	900	0.20	1.00	1.83	91.866
8.	900	0.25	0.50	2.85	58.136
9.	900	0.30	0.75	3.16	103.999

Table 2: Design of Experiment and Calculation for Untreated Material

S.NO	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	R_a (μm)	MRR (mm^3/sec)
1.	700	0.20	0.50	2.72	45.92
2.	700	0.25	0.75	3.56	86.95
3.	700	0.30	1.00	3.98	100.92
4.	800	0.20	0.75	3.15	75.95
5.	800	0.25	1.00	3.96	98.26
6.	800	0.30	0.50	4.53	90.85
7.	900	0.20	1.00	2.95	101.82
8.	900	0.25	0.50	3.62	62.35
9.	900	0.30	0.75	4.82	112.567

Table 3: Design of Experiment and Calculation for Treated Material

VI. RESULTS AND DISCUSSION

A. Machinability

For the machining of workpiece Inconel 718 and tool insert are chosen and an appropriate machining parameters with their levels are identified. The main effects plots for mean surface roughness value indicate that cutting speed 700 rpm feed 0.20 mm/rev and depth of cut 0.50 mm is the optimum parametric level among the nine experimental trials is shown in the Fig 4.

The comparison of surface roughness and metal removal rate for treated and untreated material shown in table 4.

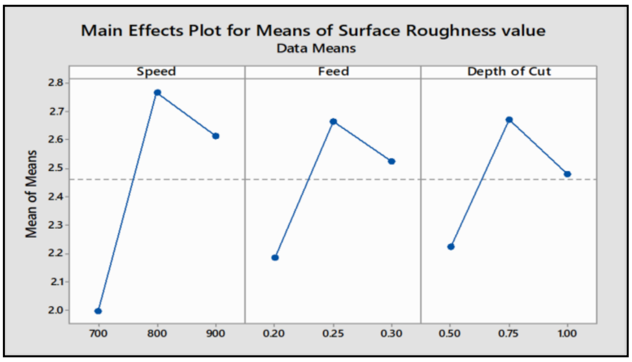

Fig. 4: Surface Roughness

S.NO	Surface Roughness (R_a)	Metal removal rate (MRR)	Surface Roughness (R_a)	Metal Removal rate (MRR)
1.	1.76	36.17	2.72	45.92
2.	1.89	67.40	3.56	86.95
3.	2.35	107.77	3.98	100.92
4.	2.97	61.62	3.15	75.95
5.	3.26	102.07	3.96	98.26
6.	2.07	62.002	4.53	90.85
7.	1.83	91.866	2.95	101.82
8.	2.85	58.136	3.62	62.35
9.	3.16	103.999	4.82	112.567

Table 4: Surface Roughness and Metal Removal Rate for Treated and Untreated Material

The comparison of Surface roughness (R_a) and Metal Removal Rate (MRR) between treated and untreated material is shown in Chart- 1.

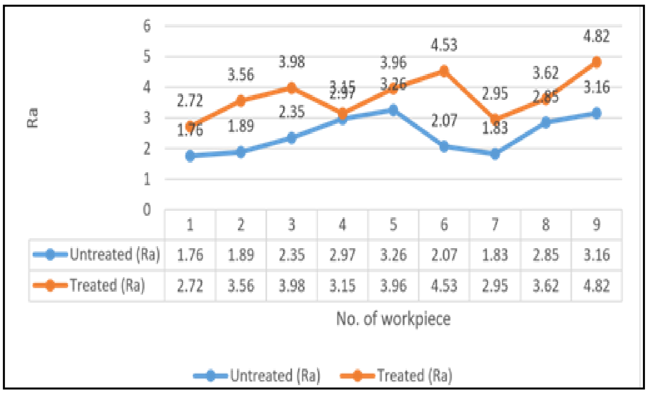

Chart 1: The Comparison of (R_a) and (MRR)

B. Result of FEM

The commercial FEA software Deform 3-D, Alagragian implicit code was used to simulate the orthogonal cutting process of aluminium 6061. An FEM model of the orthogonal cutting process was developed and composed of the work piece and tool. The work piece was initially merges with 1000 isoperimetric quadrilateral elements, while the tool has rigid, was merged and sub divided and 1500 is shown in fig.5.

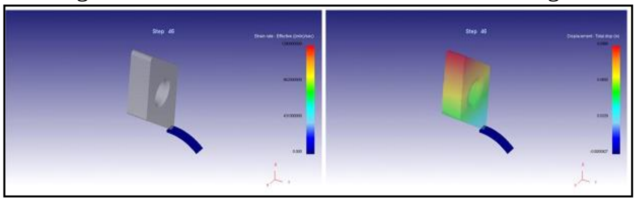

Fig. 5: FEM Modal

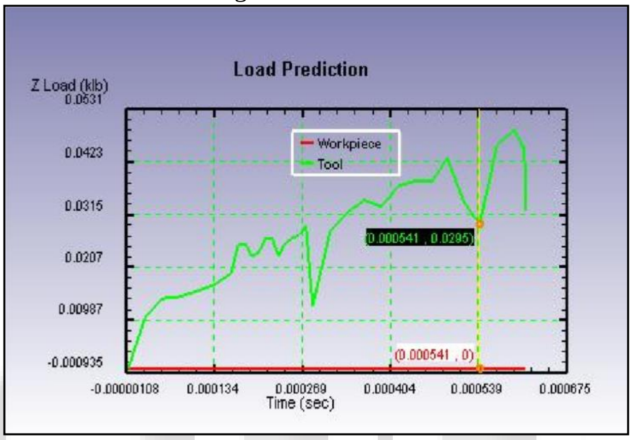

Chart 2: Z Load (klb) vs Time (sec)

Change in load in machining of aluminium 6061at spindle speed 700 rpm, depth of cut 0.50 mm, feed rate 0.20 mm/rev is shown in chart- 2.

VII. CONCLUSION

FE model was proposed to improve some of the limitations for the orthogonal cutting simulation of the Inconel 718 alloy. A set of experimental data were taken in to account to identify and determine the most important simulation parameters.

The following conclusions can be drawn:

A 3D model has been developed using the commercial code DEFORM 3D reproducing accurately geometry and cutting condition involved in experimental dates. The elasto plastic work piece and rigid tool insert with various cutting parameters results the FEM modeling approach. The strain, strain rate effective, stress effective, velocity, displacement, normal pressure and temperature are observed and compared with the experimental values collected from the various research article is found to be very close to the target point with minimal error values.

A set of L_9 reading were performed with treated and untreated work piece with carbide insert, the responses collected are surface roughness and MRR. The results shows a good correlation between experimental and predicted results.

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