FINITE ELEMENT SIMULATION OF MACHINING OF INCONEL 825, A NICKEL BASED SUPERALLOY

A thesis submitted in partial fulfilment of the

Requirements for the degree of

Bachelor of Technology

In

Mechanical Engineering

By

Prabir Kumar Patra

(111ME0333)

Department of Mechanical Engineering

National Institute of Technology, Rourkela

Rourkela, Odisha – 769008

Declaration

I hereby declare that this thesis is my own work and effort. Throughout this documentation wherever contributions of others are involved, every effort was made to acknowledge this clearly with due reference to literature. This work is being submitted for meeting the partial fulfilment for the degree of Bachelor of Technology in Mechanical Engineering at National Institute of Technology, Rourkela for the Academic Session 2011 – 2015.

Prabir Kumar Patra (111ME0333)

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA 769008, INDIA

Certificate of Approval

This is to certify that the thesis entitled "**FINITE ELEMENT SIMULATION OF MACHINING OF INCONEL 825, A NICKEL BASED SUPERALLOY**" submitted to the National Institute of Technology, Rourkela by **PRABIR KUMAR PATRA**, **Roll Number 111ME0333,** for the award of the Degree of Bachelor of Technology in Mechanical Engineering is a record of bona fide research work carried out by him under my supervision and guidance. The results presented in this thesis has not been, to the best of my knowledge, submitted to any other University or Institute for the award of any degree or diploma. The thesis, in my opinion, has reached the standards fulfilling the requirement for the award of the degree of Bachelor of Technology in accordance with regulations of the Institute.

Dr. Soumya Gangopadhyay

Assistant Professor

Department of Mechanical Engineering

National Institute of Technology, Rourkela

Date: 29/05/2015

Acknowledgement

This project would not have been possible, in spite of my best efforts, without the kind support and help of many individuals and the department. I would like to extend my sincere thanks to all of them.

I would like to express our gratitude and special thanks to my project guide Dr Soumya Gangopadhyay, Assistant Professor, Department of Mechanical Engineering, National Institute of Technology, Rourkela, for all the cooperation and time. I would also like to thank Mrs. Aruna Thakur, a PhD. student in the Department of Mechanical Engineering, National Institute of Technology, Rourkela for taking the time to help me solve the various problems that I faced during the course of my work.

My special thanks to Dr. Siba Sankar Mahapatra, Head of Department, Department of Mechanical Engineering, National Institute of Technology, Rourkela for his support and enthusiasm.

Prabir Kumar Patra (111ME0333)

Abstract

Machining of nickel based super-alloys has gained a lot of importance in the last decade or so owing to their applications in areas like power generation (gas turbine), military aircrafts, marine propulsion and nuclear reactors. However, during high speed machining it faces a lot of problems in regard to thermal stress, and strain hardening, leading to premature tool failure. Use of cooling lubricants has declined in popularity because they pose a lot of problem with regards to their disposal, reuse and environmental safety. As a result coated tools have come into picture which improve the tool life in case of dry machining and increase productivity owing to their high thermal stability and integrity.

Inconel 825 is a relatively newer grade of nickel bases super-alloys, on which a few tests have only been done. An attempt has been made to study the temperature and stress behaviour of tool insert, which in this case is taken as SNMG 120408 with respect to turning operation performed on Inconel 825 superalloy. The tool tip temperatures were found out and the temperature profiles were plotted for various feed and cutting speeds. Initial principal stress induced on the tool is also calculated. The variation of tool tip temperature and effective stress with respect to different cutting conditions were analysed and justified with respect to known knowledge. Comparative study has also been made between the uncoated tool and a CVD coated tool for the same cutting conditions.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

In modern industrial scenario, productivity and quality are main challenges for manufacturing industry. With the development of harder alloys and materials, stronger tools are required for their efficient machining. In machining of hard-to-machine materials using uncoated carbide tools, consumption of cooling lubricant is very essential. The associated costs of acquiring coolants and lubricants, their use, disposal and cleaning of machine parts after operation are significant. The may be as high as almost 4 times the cost of tools used. The use of cooling lubricants not only make the process cumbersome and costly, they also make it environmentally unsafe due to the required disposal of used coolants which are not reusable in many cases. Thus, to cut the manufacturing costs and to make the process environmental friendly, the attention of manufacturers has moved towards dry machining with eliminating or minimal use of cooling lubricants. Proper selection of surface coating on carbide tools can mitigate this problem at high cutting speeds.

In order to obtain high productivity, higher cutting speeds need to be implemented, which poses safety concerns in case of dry machining in particular. At high cutting speeds, the tool is subjected to very high cutting forces as well as temperature domains. While the slight reduction in cutting forces can be attributed to the apparent softening of work piece metal at elevated temperatures, the same can be considered for the tool material as well. At very high temperatures, the metallic structure of the tool is subject to change, which coupled with longer running times and high cutting forces can be responsible for premature failure of tools under harsh operating conditions.

With the unavailability of coolant, the heat dissipation from the cutting zone solely depends upon the thermal properties of the tool. Controlling the cutting zone or tool tip temperature is important in achieving better finish, tool life and productivity. This depends upon the properties, thickness and size of coatings used as well as their combinations. Coatings such as TiN, TiC, TiCN, TiAlN, Al_20_3 etc. are mainly provided with the use of physical vapour deposition techniques, which uses adhesion between coating and the substrate material, which in this study is the carbide tool. A brief overview of PVD coating techniques is given in the next sub-section.

1.1 Overview of surface coating

Surface coatings are used on raw tools so as to improve their performance characteristics. Surface coating can have a variety of applications in mechanical, electrical, optical, magnetic, thermal or chemical property manipulation of substrate. In case of mechanical utility, machining is one of the most important issue addressed by surface coating in recent times. During metal cutting, the tool's surface coating faces the most adverse of the conditions- a combination of intense heat, pressure and vibration.

Surface coatings need to possess certain qualities which will make them suitable for use in metal cutting operations. They need to have high surface hardness, low friction coefficient, high heat insulation, chemical inertness, and wear resistance. Although all these characteristics are not possible to find in a single substrate-coating combination, a good combination of these qualities will give a more practicable coating formulation.

Physical vapour deposition or PVD coating uses physical affinity between coating material and substrate for adhesion, unlike chemical vapour deposition or CVD, which uses chemical reaction at the interface to adhere the coating to the tool. In PVD technique, we first prepare the surface properly and then coat it using vapour produced from material used for coating.

1.2 Heat Generation in metal machining

Almost all work done during metal machining is converted in to heat energy due to the presence of friction in many forms. The total work input in metal machining can be broadly categorised into 3 parts – a) Work done for shearing to produce chips and fresh surface, b) Work to slide the chip over the tool rake surface, c) Work to slide the tool flank surface over the newly machined surface. While the work done due to shearing is due to the internal friction between the layers of the material being cut, the others are required to overcome the friction between tool and chip or new surface. [5]

The temperature achieved on the rake surface of the tool at the cutting edge is called cutting temperature. The chips carry away some part of heat energy generated, while a very small part is conducted back to the work piece. The remaining heat is transferred to the tool via conduction. The heat generation is affected by tool wear, work piece material, cutting conditions, friction between tool and work piece and chip formation mechanism etc.

Generally, there are 3 different zones of heat generation.

a. Primary shear zone – In this zone, shearing occurs in the work piece material, which produces the chip and the freshly cut surface. Here heat generation is dependent upon the cutting parameters and the work piece material.
b. Secondary deformation zone – This region occurs at the tool-chip interface. Here friction heat is generated due to shearing which occurs due to the sliding of the chip on the rake face of the tool and the friction between them. It depends upon sliding velocity of chip and the contact length between the chip and the tool.
c. Tertiary zone – This is the zone of rubbing between the flank surface of the tool and the freshly cut surface. Although, effect of tertiary zone can be reduced by providing clearance angle, this becomes more prominent at higher cutting speeds. Increase in flank wear also contributes to this mode of heat generation.

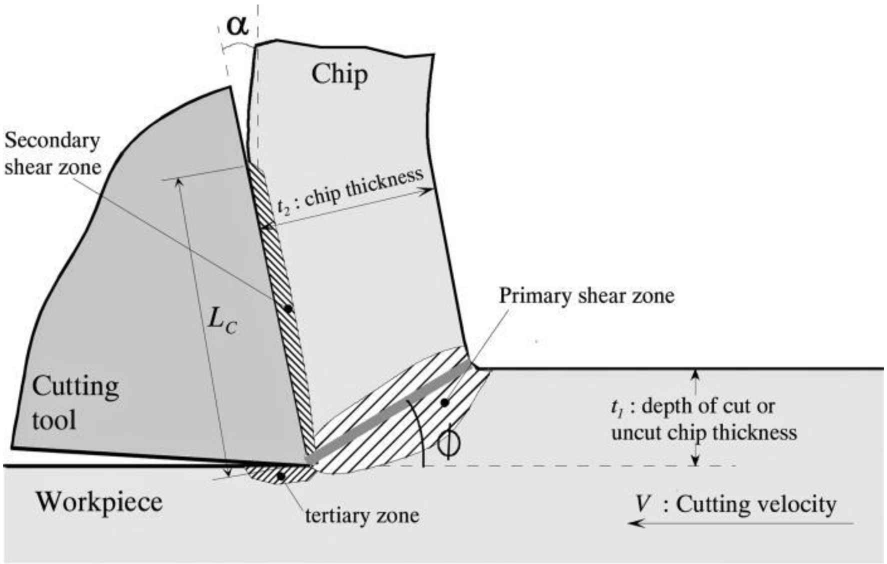


Figure 1: Heat generation zones in metal cutting

Primary heat generation and secondary heat generation are greatly influenced by cutting parameters, whereas tertiary heat generation is mainly dependent upon flank wear. Temperature rise in cutting tool is primarily due to heat generation in secondary heat generation, but primary source also affects temperature distribution in the rake surface.

1.3 Temperature measurement in cutting tools

Many practical methods have been employed to measure the tool temperature during machining. Although it is very difficult to accurately pinpoint the temperature at the cutting tip, practical methods coupled with analytical methods are employed to estimate the tool tip temperature.

One of the most commonly used temperature measurement techniques is the tool-work thermocouple. Here, emf is generated between tool and work piece. The cutting zone forms the hot junction whereas the electrical connection to the cold parts of tool and work piece forms the cold junction. The difficulty of this method is in its calibration. Due to the presence of temperature gradient along rake surfaced, it is likely to give inaccurate results. [4]

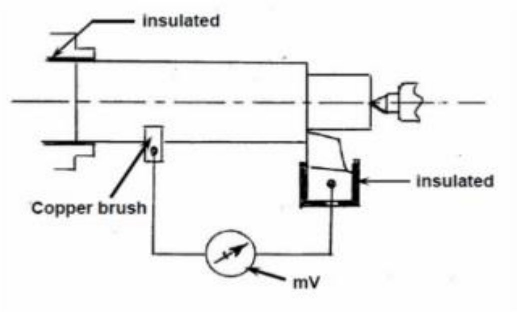


Figure 2: Tool-Work thermocouple

Another method is the use of inserted thermocouples [3]. A number of thermocouples of small diameter are inserted into the holes made in the tool. The difficulty of this method is that it is not possible to put the thermocouples extremely close to the cutting zone, where there are very high gradients in temperature.

Another method was developed to measure the flank surface temperature using a wire of different material than the work piece [24]. The wire is insulated and inserted to the work piece. When the tool touches the wire during machining the wire is cut and forms a thermocouple with the tool.

Kato et al. developed a method for finding the temperature distribution of tool by using fine powders whose melting points are constant. The tool was divided into two symmetrical parts along chip sliding direction and on one side the powders were scattered. The melted areas were observed for different powders used and temperature distribution was gauged.

Radiation methods are also implemented in measuring tool surface temperatures. It gives more accurately the temperature distribution of exposed regions of the tool. These are very complicated and require proper handling of equipment. Radiation pyrometer used in this method need to be carefully handled/ now a days infrared sensors are available with quick response times and devoid of any minimum temperature requirements. [4]

Thermo-sensitive paints can also be used to measure the tool temperature. However this method is considered inaccurate due to the uncertainty in the results generated.

2. LITERATURE REVIEW

2.1 Temperature modelling at tool tip

It has been shown through extensive study that the heat generation during machining is intensively concentrated in three regions, i.e., the primary shear zone parallel to the shear plane, the secondary shear zone along tool-chip interface and the tertiary zone where flank surface of the tool slides against the freshly cut surface. Approximately all the work is converted to heat energy. [1, 2]. Majumdar et al. modelled the process based upon multi-dimensional heat diffusion equations considering heat loss due to convective heat transfer at surfaces. They neglected the heat generated at the secondary shear zone and assumed a uniform heat source at tool-chip interface. [1]. Dogu et al. followed a similar approach, but considered the secondary heat zone distributed over a definite area with negligible frictional heating. They considered the primary heat zone as a rectangular area around the shear plane and the secondary heat zone as a triangular region parallel to tool-chip interface. The triangular region has maximum width at the start and reduces to zero thickness at tool-chip separation region. [2]

Chou and Song used machining forces and cutting characteristics to approximate intensity of heat generated and shear plane geometry and the heat sources at rake face. They considered 3 dimensional heat sources and discretized them into smaller heat sources to study temperature rise. Temperature rise due to these small elements are superimposed to find final distribution. They observed that maximum temperatures were affected adversely by increase of feed rate and cutting velocity but affected favourably by increase of depth of cut, especially at high feed rates. [5].

Komanduri and Hou considered the heat source at shear plane to estimate tool-chip interface temperature. Considering upper part of chip as adiabatic, they estimated the heat source as an induced stationary rectangular heat source caused by shear plane heat generation. [6]

Zhang et al. prepared a one-dimensional model for transient temperature distribution in single layered coated tools using Laplace transform. They observed that all coatings showed similar trends in interfacial temperature, however, aluminium oxide coating provided lower substrate temperature over time. [7] Zhang et al. also considered the theory of diffusion layer that causes thermal resistance between coating and substrate. They calculated the effective thermal resistance of the diffusion layer and used this to estimate rake face temperature and observed that this value came closer to the experimental values. [8]

Abukhshim et al. measured the tool tip temperature experimentally using pyrometer placed on tool rake surface. They observed the trend of cutting forces and heat partitioning into the tool. Heat partitioning into the tool decreased with increase in cutting speed till a certain value and increased after that. Finite element analysis showed maximum temperature at tool-chip interface, slightly away from cutting edge, which increases with increase of cutting speed, but not linearly due to varying heat partitioning. [9]

Grzesik et al. used a Lagrangian finite element code AdvantEdge to model a thermo-mechanical model of plane strain orthogonal metal cutting. Different coatings were considered and their effect on temperature rise in tool tip were studied. [10] Grzesik in his paper determined temperature distribution in cutting zone by integrating thermal analytical and simulation models of orthogonal cutting process with coated and uncoated tools. He solved the model using two models – In one he implemented properties of each individual layers and in second approach he replaced the multi-layer with a composite single layer. Although analytical model and experimental data showed similar trends, analytical model showed lower temperatures. The second approach gave higher temperatures than the first one. Better results were expected to be obtained by fine tuning friction factor and implementing measured coating thickness. [11]

Prediction of tool tip temperature using thermocouple witnesses severe drawbacks due to gap between tool tip and thermocouple positioning and high temperature gradient around tool tip. Lazard and Corvisier tried to solve this problem by formulating a quadrupole to accurately determine tool tip temperature independent of positioning of thermocouples. They used two thermocouples placed at two different positions to formulate the quadrupole and observed that it gave very good results agreeing with experimental data. [12]

Onyechi et al. modelled the heat intensity at shear zone as being non-uniform and found out different parameters such as cutting forces, stress distribution and temperature distribution. Analytical results were compared with ANSYS simulations to match results. [13]

Fang Du et al. developed two general boundary layer techniques to determine temperatures in materials containing thin films. The first method utilises a 2D approach which is applicable over a wide range of coating thickness whereas the second is based on single layer approximation which is applicable for thin coatings. Both the approach were found to give accurate results for thin coatings, however at higher coating thickness, the single layer approximation gave larger errors. [14]

Abhang et al. in their study reviewed temperature generated on cutting tool and experimental methods for measurement of tool temperatures. They gave special attention to tool-work thermocouple and its experimental setup. With this method, the average temperature at tool-chip interface was measured. [15] Carvalho et al. obtained a numerical solution of the 3D transient heat diffusion equation by considering both tool and tool holder assembly. Temperature varying thermal properties and convective heat losses were regarded. He performed several cutting tests using cemented carbide tool to validate the solution. [16]

Ramesh et al. carried out steady state 2D and 3D analysis for heat transfer in machining of isotropic materials. They highlighted the effect of convective heat transfer coefficient in machining. The authors developed a 3D finite element approach using Galerkin weighted approach. They used the same cutting conditions and geometry used by Tay et al. [18] to check developed software. They observed that the effect of depth of cut is marginal and effect of feed and cutting speed is significant on tool temperature. [17]

2.2 Friction modelling in machining

Filice et al. did a rigorous investigation on the impact of applied friction model in modelling of orthogonal metal cutting. A 2D simulation of orthogonal cutting was carried out. Five different friction models were analysed and simulation was done using DEFORM-2D. They observed that mechanical results such as cutting forces, contact length etc. were not sensitive to friction models, whereas thermal modelling was highly sensitive to it. [19]

Grzesik in his paper bought out the knowledge on tribological response of substrate/coating-chip system. He did experimental analysis of tribological properties against cutting speed, feed and contact factor. He concluded that use of multilayer coatings improve tribological properties of surfaces. When thermal shielding occurs, coating significantly reduces range of contact temperatures and distinctly helps in improving the heat transfer at higher cutting speeds. [20]

Abdelali et al. developed a new tribometer system to estimate the contact conditions as those encountered in cutting. In addition to measurement of friction factor, it provided information about heat flux transmitted to the pin, thus helping in estimating heat partitioning. It was observed that sliding speed of the chip is the most influential parameter whereas contact pressure has very less influence. They found three friction regimes. In first regime at low sliding velocity, friction factor nearly remains constant and heat flux transmitted to pin remains proportional to sliding velocity. At intermediate sliding velocity, friction factor decreases considerably and heat flux remained constant. At higher velocities, friction factor remains constant again, whereas heat flux transmitted to the pin increases again. [21] Bonnet et al. used the modified pin-on-disc system used previously to determine a friction model that has to be used based upon sliding velocity. They considered AISI316L austenitic steel as work piece and TiN coated carbide tools. A new key parameter was revealed, i.e. average sliding velocity at contact. [22]

Sebhi et al. studied the tribological behaviour of coated carbide tools during turning of steel and concluded that friction coefficient decreases significantly by increasing cutting speed. The most distinguished wear phenomena observed was abrasive in nature. Flank wear and crater wear became more important at high cutting velocities and surface quality is better for low flank wear. [23]

3. METHODOLOGY

Turning operation was considered for temperature modelling of the tool as is one the most common machining operations. The simulation was done using DEFORM-3D V6.1. Various combination of feed rates (f) and cutting speeds (V) were taken as shown. Depth of cut (d) was taken as 1 mm for all the cases.

Cutting speed (m/min)	84			124		
Feed rate (mm/rev)	0.08	0.14	0.2	0.08	0.14	0.2

Table 1: Various Cutting parameters considered

3.1 Geometry

The tool insert considered was SNMG 120408. The insert has a MR4 type chip breaker which is also modelled. The insert is a square shaped zero clearance type and has an edge length of 12 mm, height of 4 mm and nose radius of 0.8 mm. The geometry of the insert is shows in Figure-3. The tool geometry was prepared using SOLIDWORKS software and imported.

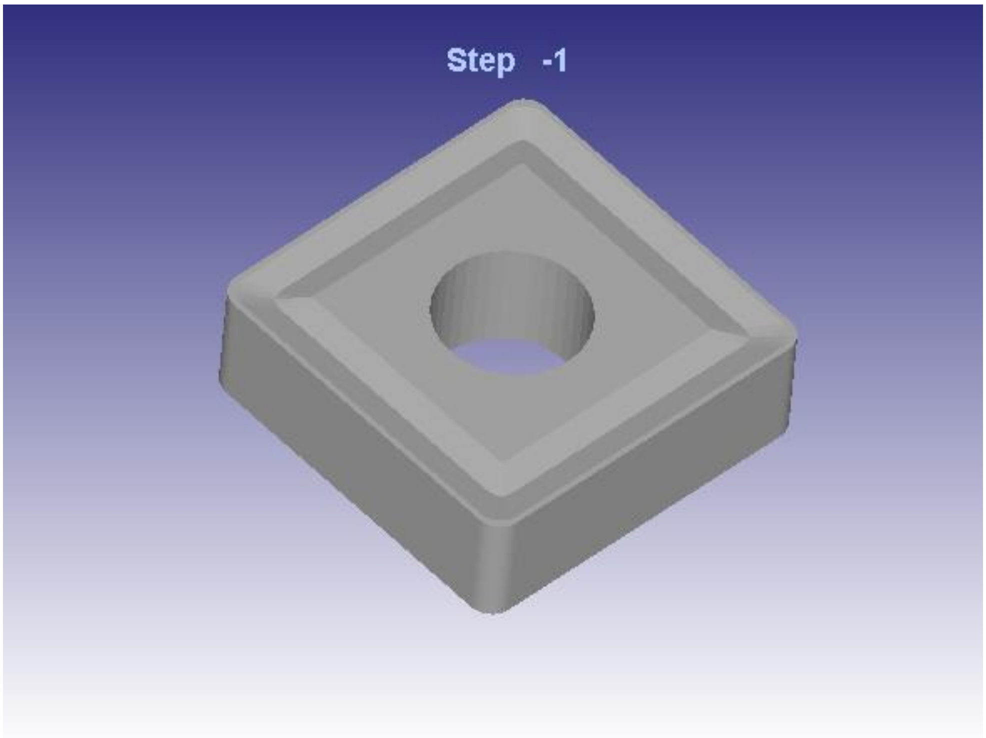


Figure 3: Tool insert geometry

The work piece was transformed into a simplified linear type for easy visualisation as shown in Figure-4.

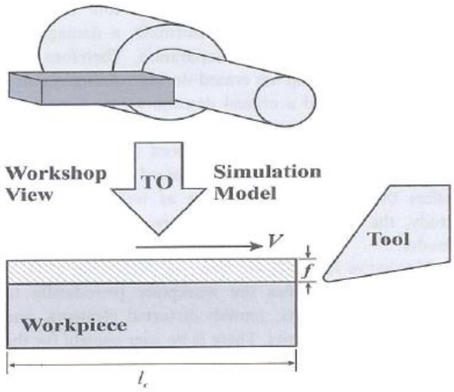


Figure 4: Workshop to Simulation model transformation [10]

3.2 Meshing

Both the wok piece and the tool were meshed using DEFORM 3D. The meshing was biased to give finer element size close to the cutting zone and coarser mesh away from the cutting zone. This resulted in some de-featuring away from the cutting zone which would have negligible impact on the temperature and stress calculations. The tool was meshed using relative meshing with size ratio 4 and work piece was meshed using absolute meshing and size ratio 7. The insert and the work piece mesh are shown in Figure-5 and Figure-6 respectively.

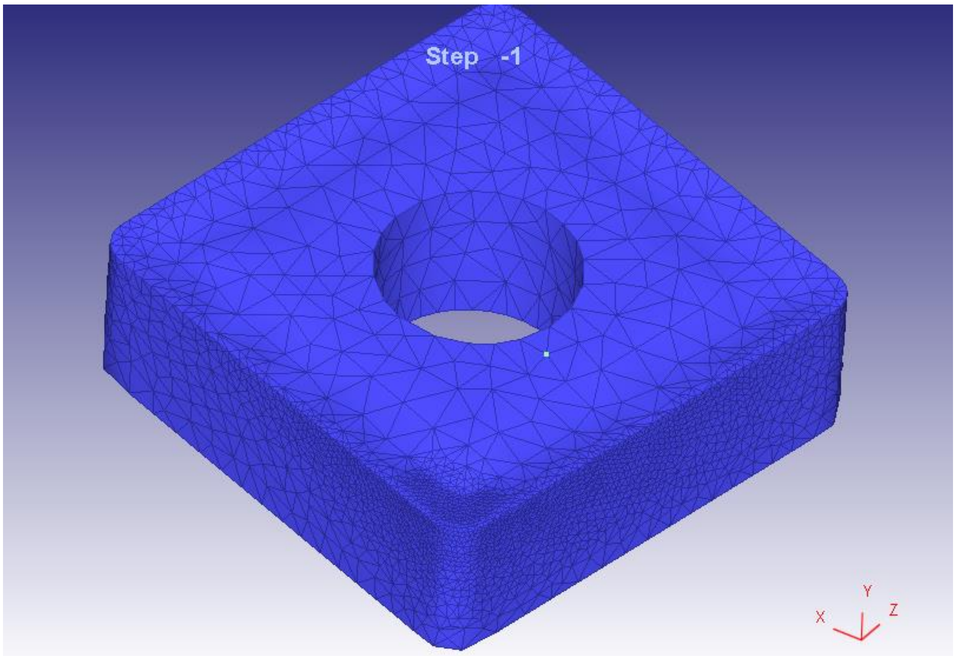


Figure 5: Tool insert meshing

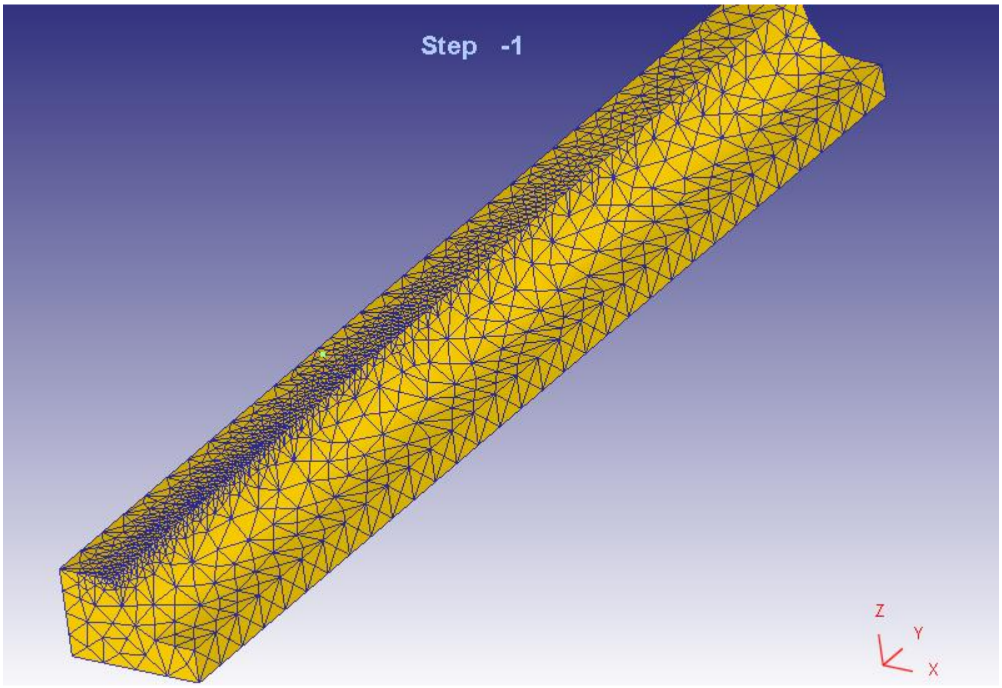


Figure 6: Work piece meshing

The meshing details of tool and work piece are given in following table.

	Tool	Work piece
Number of nodes	5230	1518
Number of elements	22087	6127

Table 2: Tool and work piece mesh details

3.3 Setup

The cutting conditions such as depth of cut, feed rate and cutting speeds were specified in different combinations as shown in table. The length of cut was specified as 5 mm. Two kinds of tools were taken. One is the uncoated Tungsten carbide tool and another is a CVD coated tungsten carbide tool. Both are of SNMG 120408 type with MR4 type chip breaker. The coated tool has an inner coating of Ti(C, N) of 5 mm thickness and the outer coating is of Al_2O_3 of 3 mm thickness. The coatings were provided using the tool setup options.

The ambient temperature was taken as 22°C. The tool and the work piece temperature were also taken as 22°C. As no coolant were used, the surrounding air was taken as coolant and its convective heat transfer coefficient was taken as 20 W/m^2-K. For CVD coated tool, the tool-chip friction coefficient was taken as 0.8 and for uncoated tool it was taken as 0.7.

The tool holder considered is SSBCR2020K12. It has as side cutting angle of 15 degrees and side rake and end rake angle of minus 7 degrees each. The displacement of the work piece was restricted in X, Y and Z directions.

The tool was modelled as rigid and the base material was taken as Tungsten Carbide (WC). The work piece was modelled as plastic. The work piece material was taken as Inconel 825. The thermal and elastic properties of the work piece and tool material were predefined in the software considering their variation with respect to temperature. In case of coated tool, the coatings were specified as earlier.

The work piece and the tool setup is shown in Figure-7.

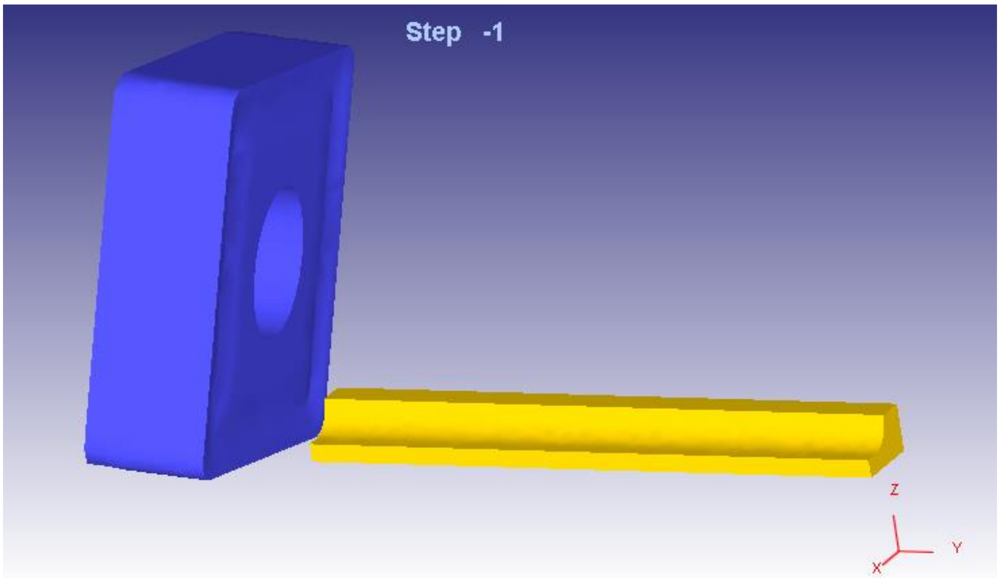


Figure 7: Tool-Work piece setup

3.4 Solution method

The problem was modelled as Lagrangian Incremental type with calculations done both for deformation in the work piece and the temperature of tool and work piece. The geometry error was taken as 0.0001% in tangential direction and 0.01% in normal direction. The velocity error was taken as 0.005% and force error as 0.05%. The simulation was run using SPARSE solver and direct iteration method was used.

The chip formation was simulated by constantly re-meshing the work piece. Only local re-meshing was done around the cutting zone and it was chosen to skip elements with good shape. The results were saved after every 10 steps.

3.5 Die Stress Analysis

The initial stress which is produced in the tool insert was estimated using die stress analysis. After the temperature and deformation calculations are over, stress analysis was done using die stress analysis operations. The tool meshing was kept similar as before. The force on the cutting tool was interpolated from the work piece to the tool. Then by restricting the displacement of the tool in X, Y and Z directions stress analysis was done. Although this analysis will give higher stress values than the steady state machining operation, it will give the initial stress reflected in the tool insert at the starting of the machining operation.

4. RESULTS AND DISCUSSION

4.1 Chip Formation

The chip formation process is shown for a particular case that is cutting speed of 124 m/min, feed rate of 0.2 mm/rev and depth of cut of 1 mm. The chip formation is shown at 6 different positions of the tool.

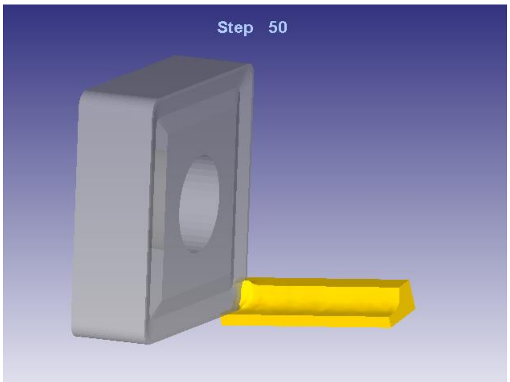


Figure 8

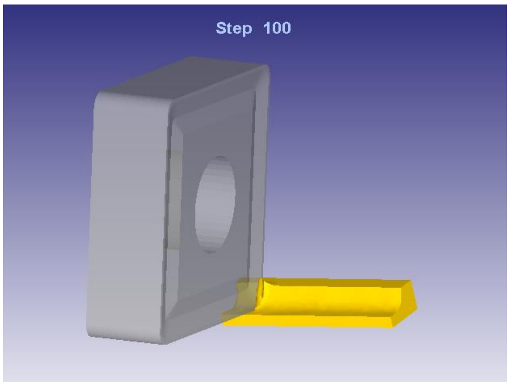


Figure 9

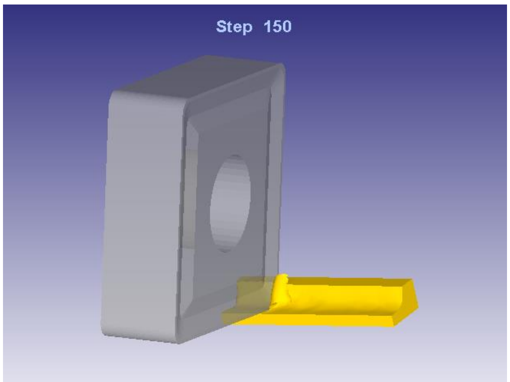


Figure 10

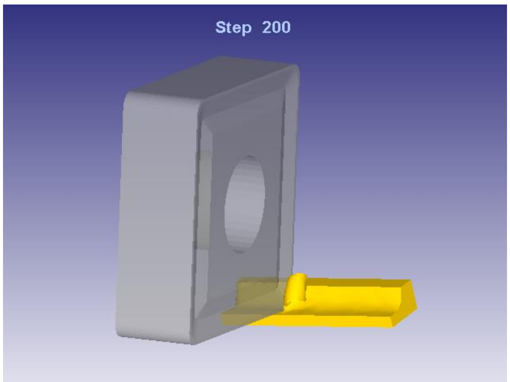


Figure 11

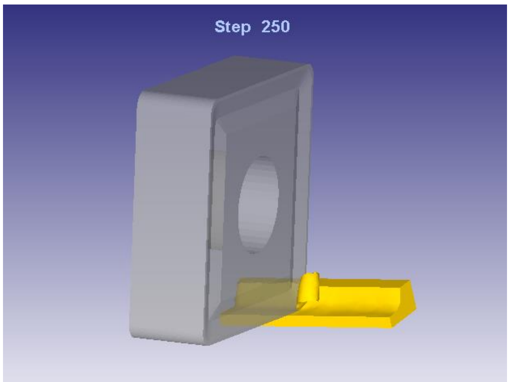


Figure 12

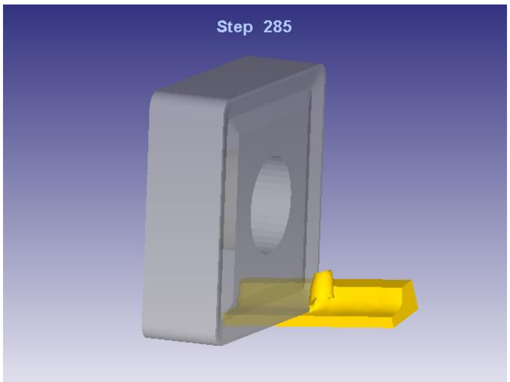


Figure 13

4.2 Tool tip temperature

The temperature profile for the tool tip for cutting speed of 84 m/ min and feed rate of 0.08 mm/rev is shown in Figure-14. As the machining is simulated for a fixed length of cut and the machining time is very less, there is very less dispersion of heat energy and the total temperature variation is concentrated only in the tool tip and the regions around it.

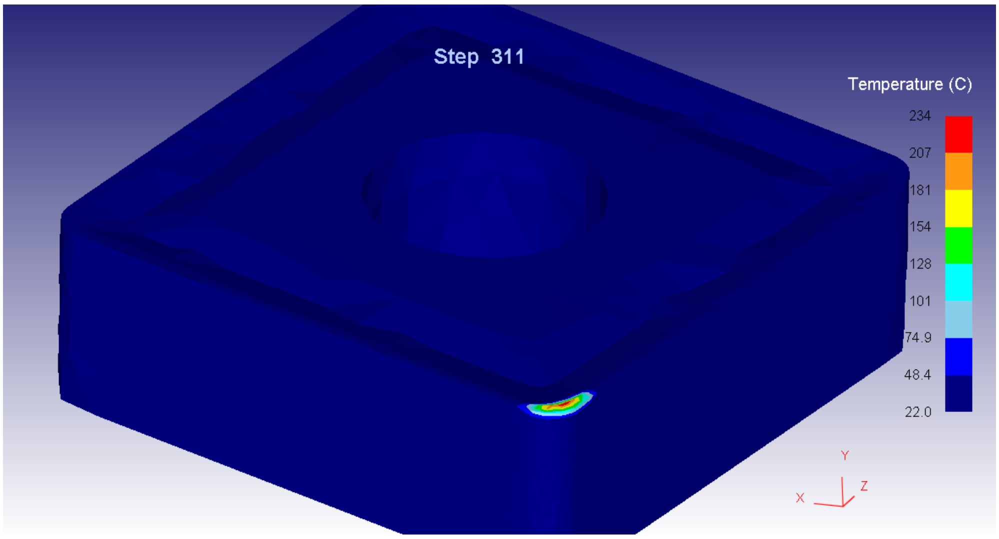


Figure 14: Tool tip temperature profile

The temperature variation in the chip in this condition is shown in Figure-15.

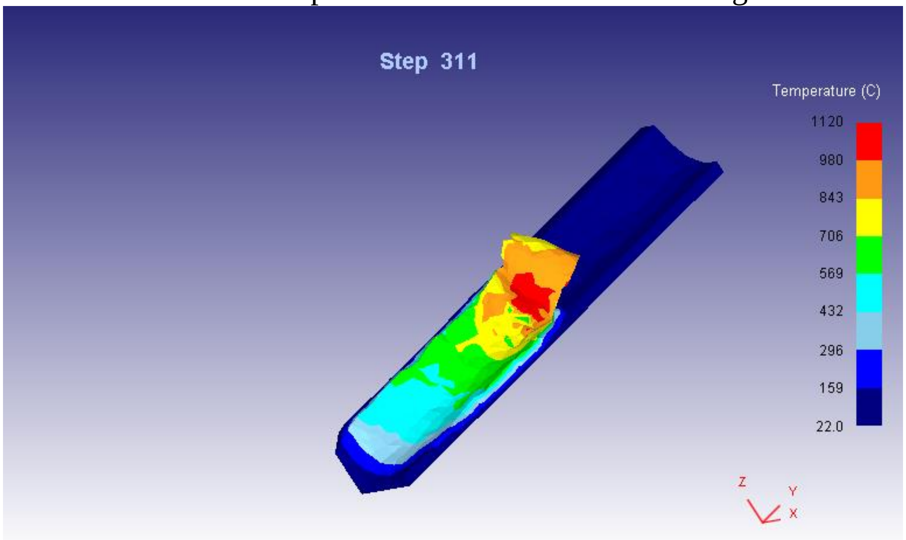


Figure 15: Chip temperature profile

The maximum temperature in the chip is erratic and no relation could be established with respect to cutting parameters. However, the maximum temperature fluctuated and lied in the range of 1100°C -1300°C for all the cases.

The variation of tool tip temperature for uncoated tool insert for different cutting conditions is shown in following tables.

Table 3: Temperature profile for uncoated tool and V=84 m/min

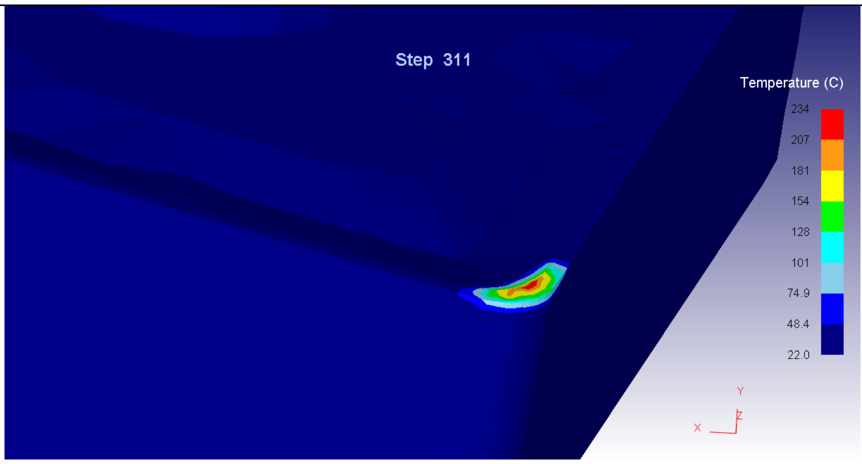
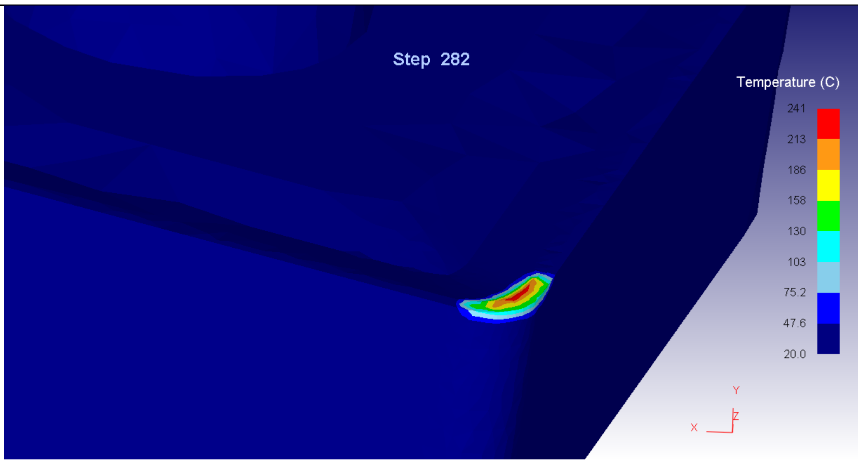
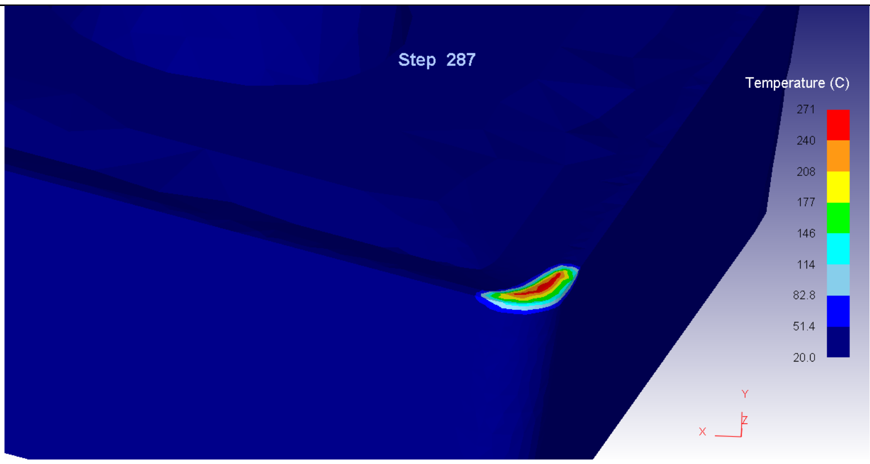
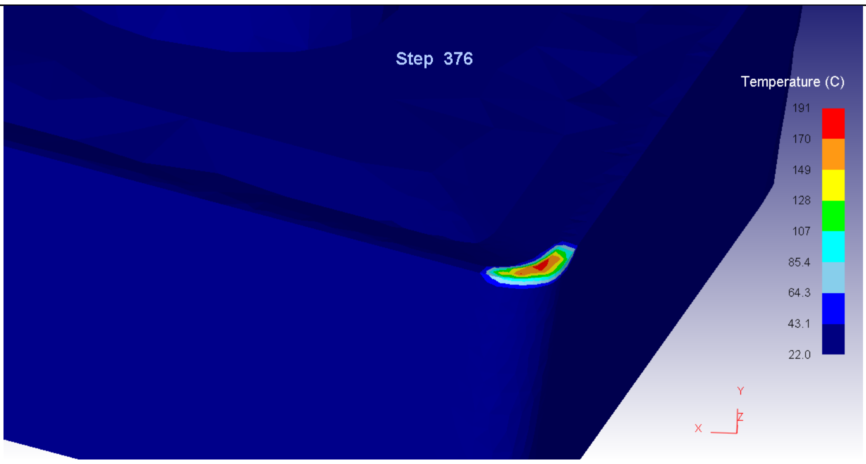
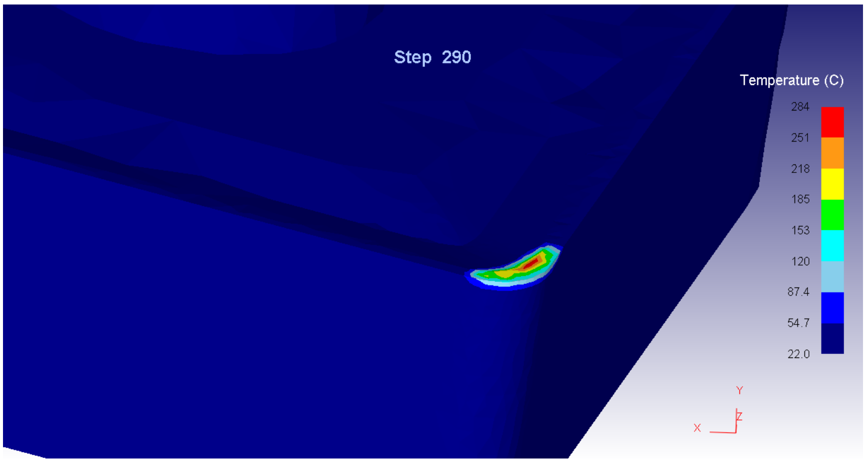
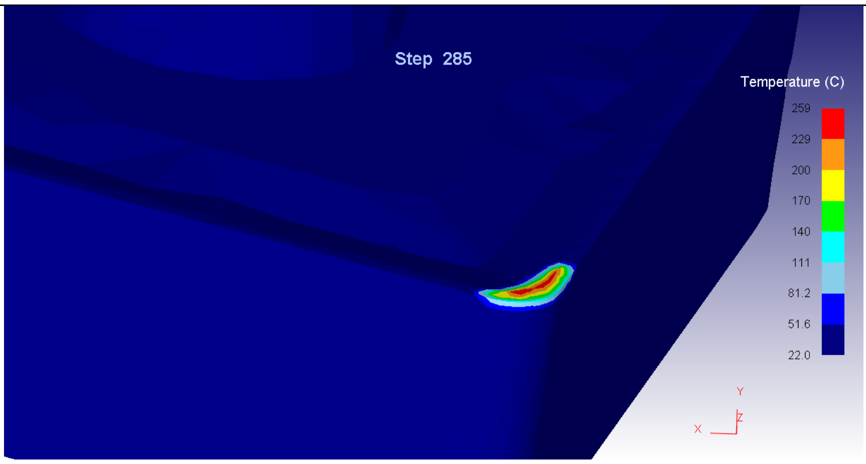
	V=84
f= 0.08 mm/rev	
f=0.14 mm/rev	
f=0.2 mm/rev	

Table 4: Temperature profile for uncoated tool and V=124 m/min

	V=124
f= 0.08 mm/rev	
f=0.14 mm/rev	
f=0.2 mm/rev	

For the cutting speed of 84 m/min in case of uncoated tool, the maximum temperature at the tool tip increases with an increase in feed rate. However, in case of cutting speed of 124 m/min, the maximum temperature at the tool tip slightly decreases as we move from feed of 0.14 mm/rev to 0.2 mm/rev. This can be caused due to the increase in contact area between the tool and the chip. As we increase the feed rate, the amount of heat energy generated also increases. However due to increase in contact region, the heat energy is dissipated into the work piece over an increased area, which decreases the value of the maximum temperature. As contact region increases, the region of maximum temperature for a particular case should be spread over a larger area than a case of lower feed rate. By comparing the temperature profiles for different feed rates corresponding to a particular cutting speed, we see that this is indeed the case.

Another aspect highlighted from the temperature profiles is that in case of uncoated tool, as we increase the cutting speed, keeping the feed rate constant, the temperatures obtained in case of lower cutting speeds is higher than that of higher cutting speeds. This is because as we increase the cutting speed, keeping the length of cut constant, higher cutting speeds provide less time for heat transfer between the chip and the tool. As a result, there is less time for temperature to increase in case of higher cutting speeds even though higher stress and heat generation values are obtained for higher cutting speeds.

In case of CVD coated tools, the outer layer is of aluminium oxide. This has a higher coefficient of friction as a result for CVD coated tools we get a higher peak temperature value for the same cutting conditions as uncoated tools. However, the coating of aluminium oxide and Ti (C, N) is known for its high durability and capability to endure higher temperatures. Also the layer of Al_2O_3 has a very low thermal conductivity which enables it to act as an insulator and shield the substrate material from heating up to higher temperatures. Also as most of the heat energy is concentrated on the surface of the tool, it increases the irradiative and convective cooling of the tool.

The same trend is followed in the temperature variation in the coated tool as in the uncoated tool. This can be seen from following tables. In case of uncoated tools the maximum temperature decreased as we increased cutting speed for a particular length of cut whereas for coated tool it increased. This can be justified by the fact that the coating considered has a very low thermal conductivity than the substrate. So as we increase the cutting speed, there is less time for the heat generated to be dissipated into the coating and onto the substrate. So most of the heat energy gets concentrated on the surface, hence giving higher temperature values.

Table 5: Temperature profile for coated tool and V=84 m/min

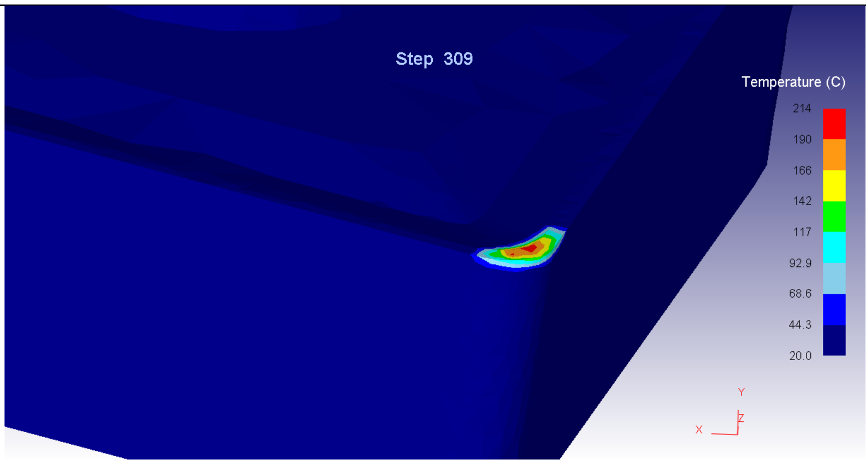
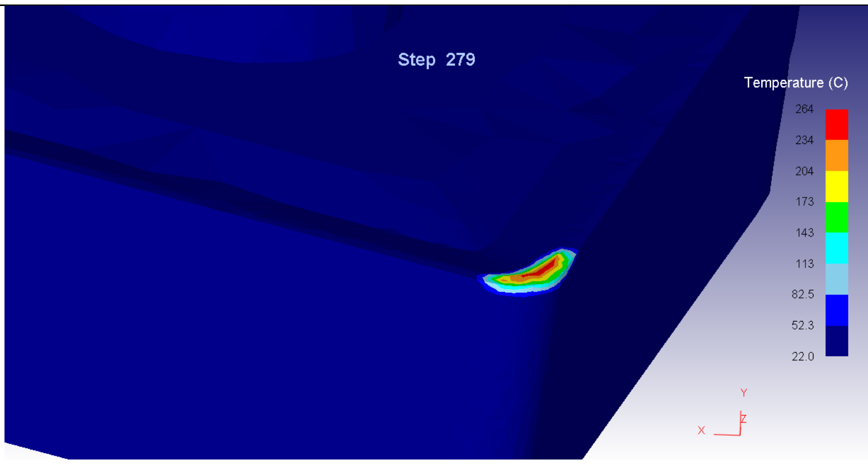
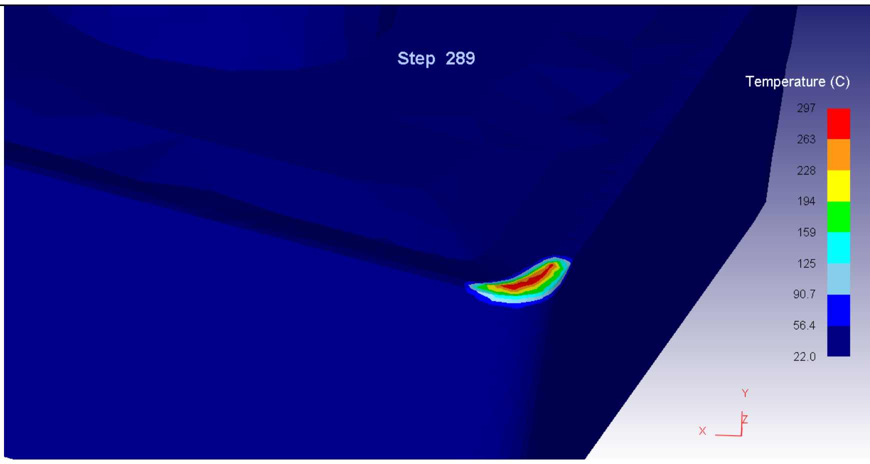
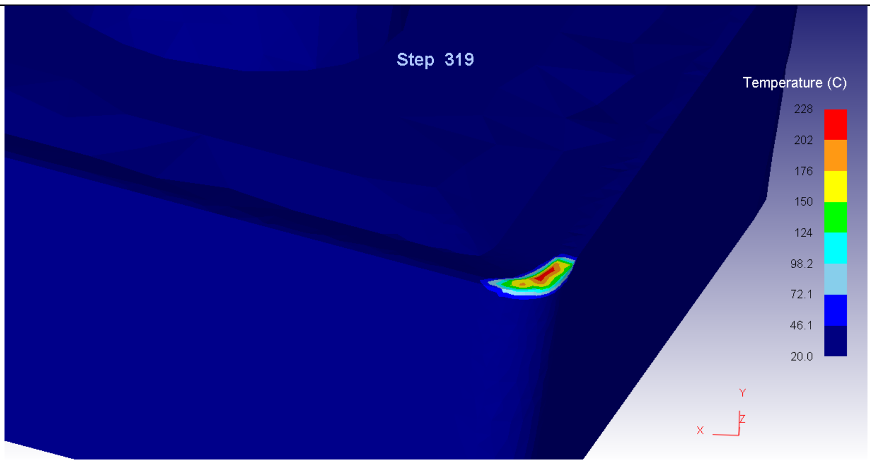
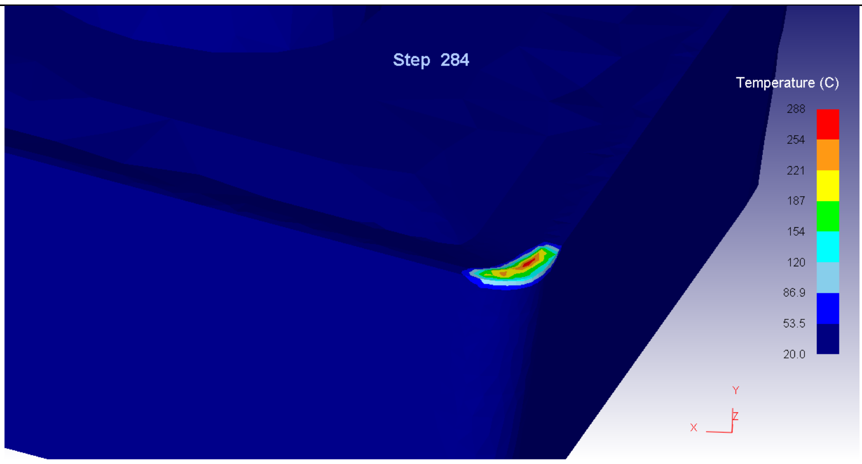
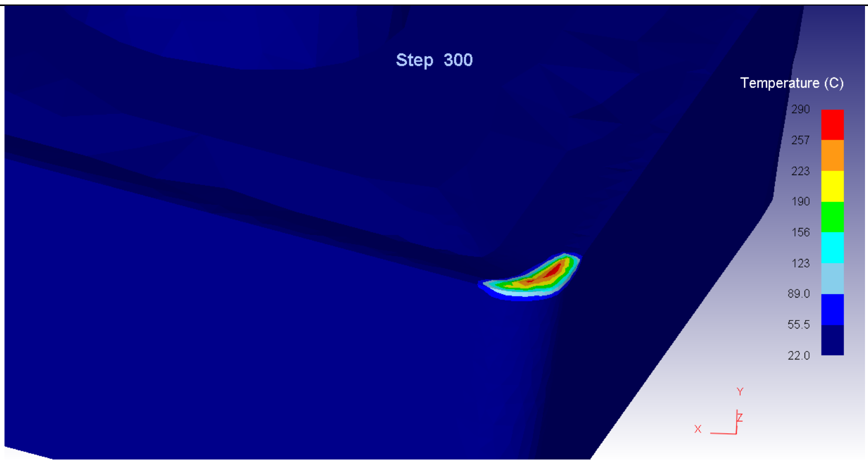
	V=84
f= 0.08 mm/rev	
f=0.14 mm/rev	
f=0.2 mm/rev	

Table 6: Temperature profile for coated tool and V=124m/min

	V=124
f= 0.08 mm/rev	
f=0.14 mm/rev	
f=0.2 mm/rev	

4.3 Tool tip stress

The variation of effective stress as per the cutting conditions is shown in table.

Table 7: Tool tip stress profile for Uncoated tool and V=84 m/min

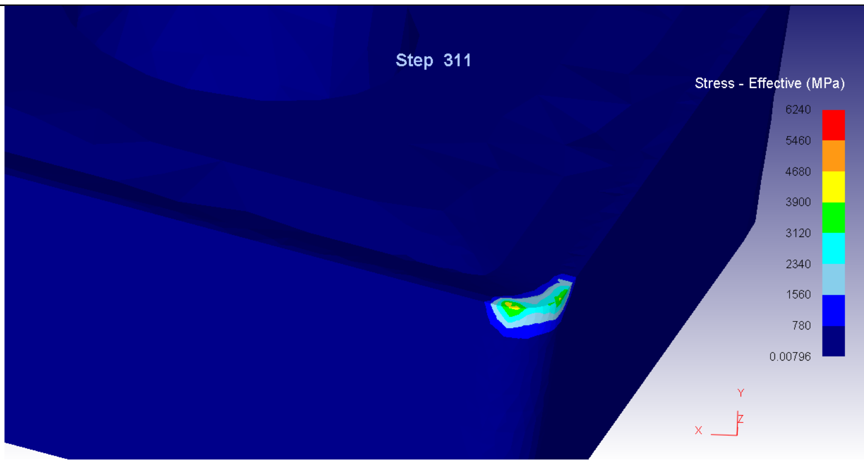
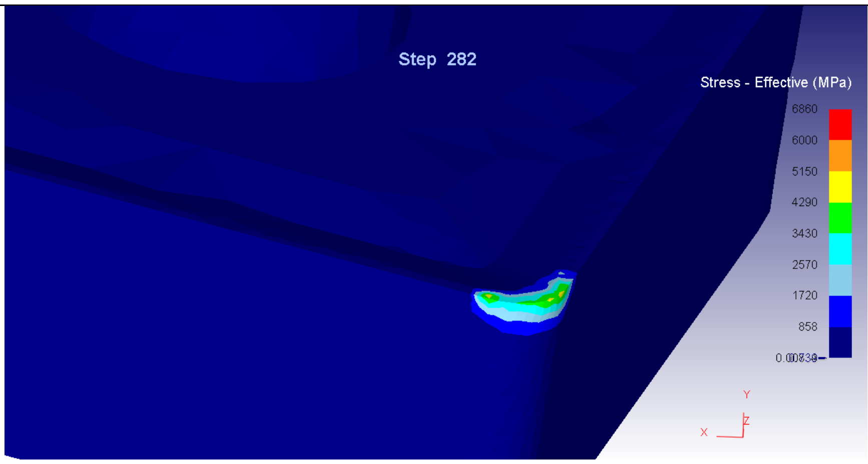
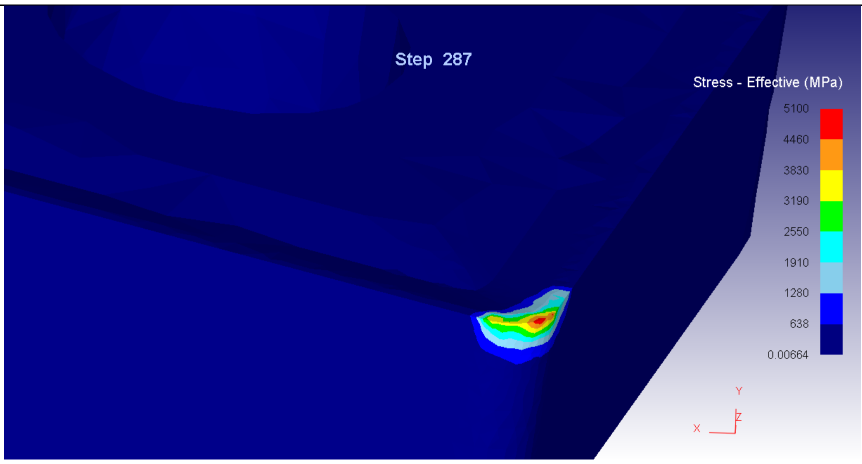
	V=84
f= 0.08 mm/rev	
f=0.14 mm/rev	
f=0.2 mm/rev	

Table 8: Tool tip stress profile for Uncoated tool and V= 124 m/min

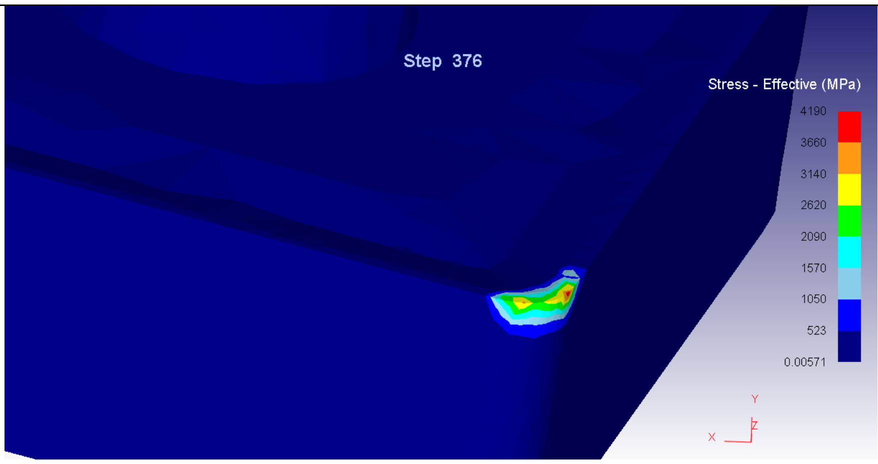
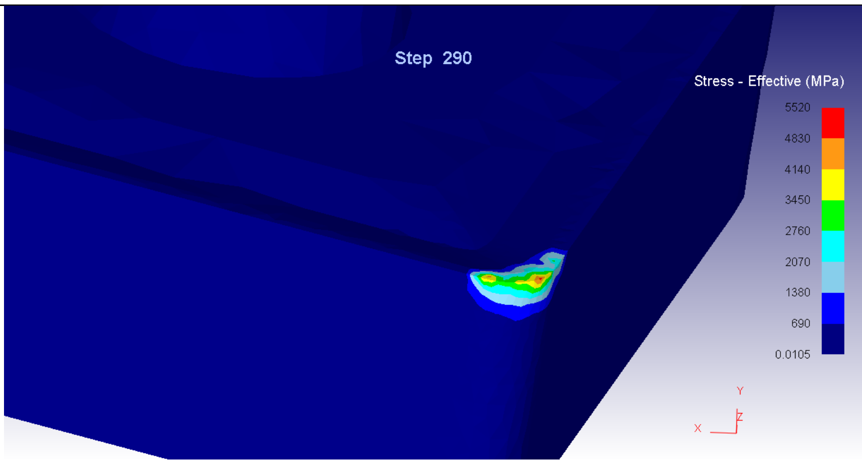
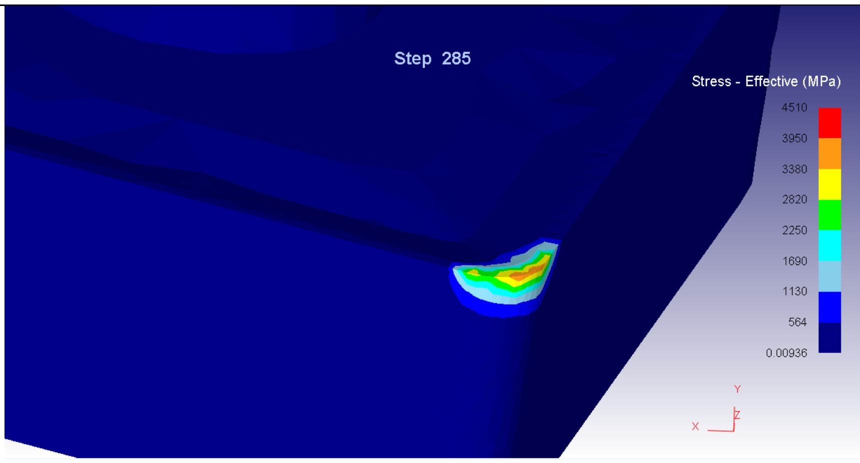
	V=124
f= 0.08 mm/rev	
f=0.14 mm/rev	
f=0.2 mm/rev	

Table 9: Tool tip stress profile for coated tool and V=84 m/min

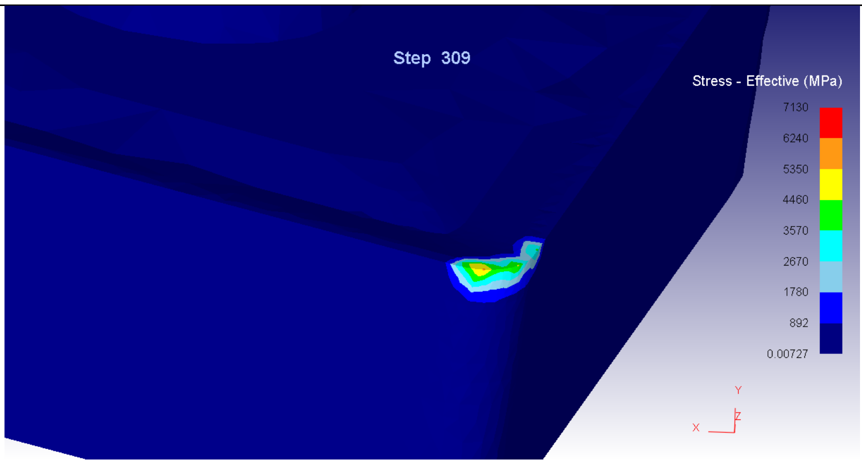
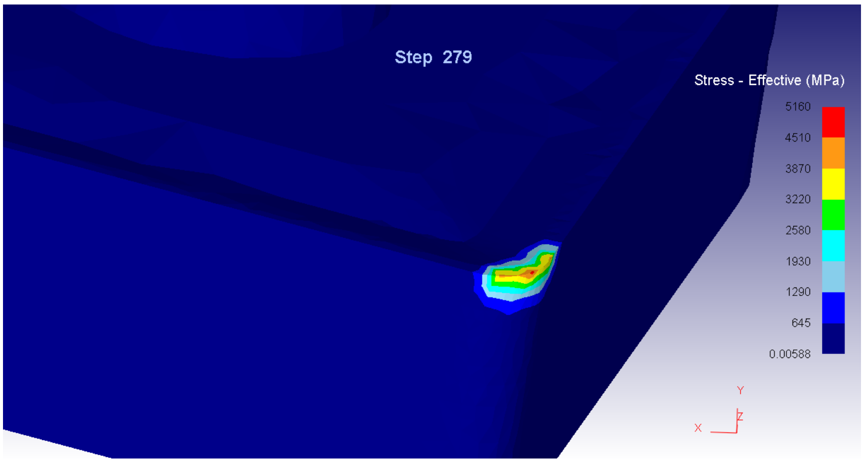
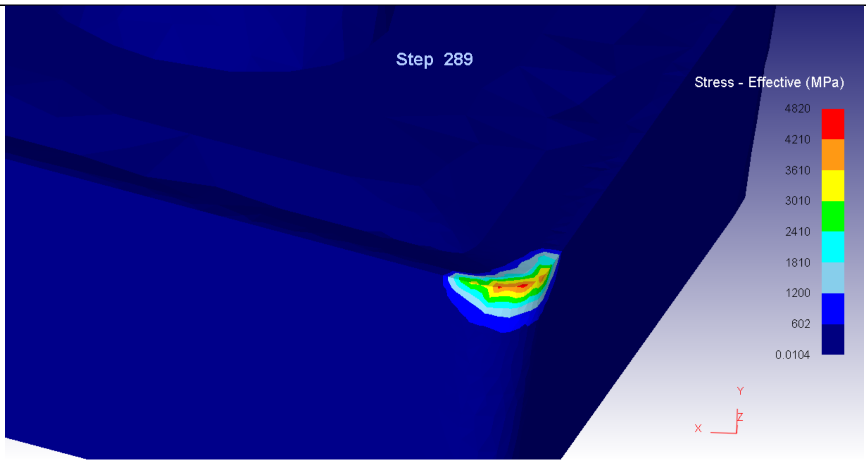
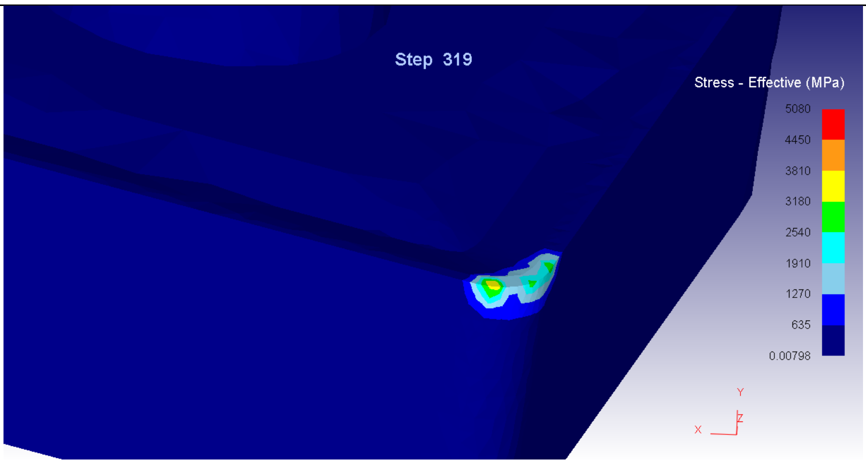
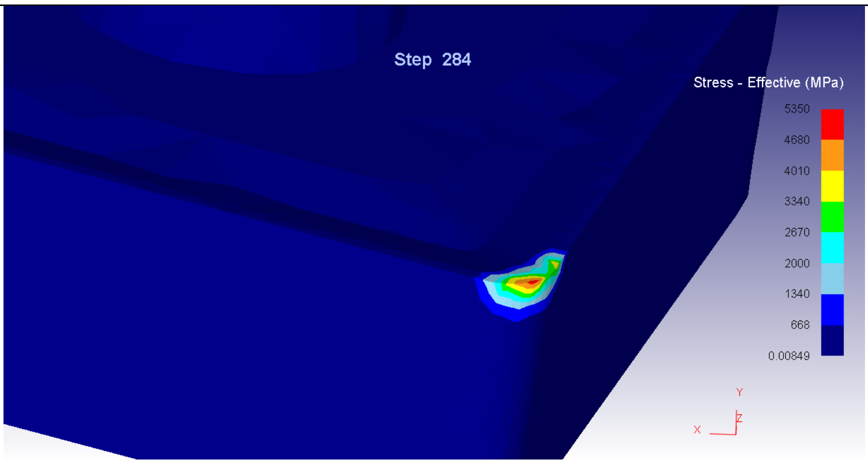
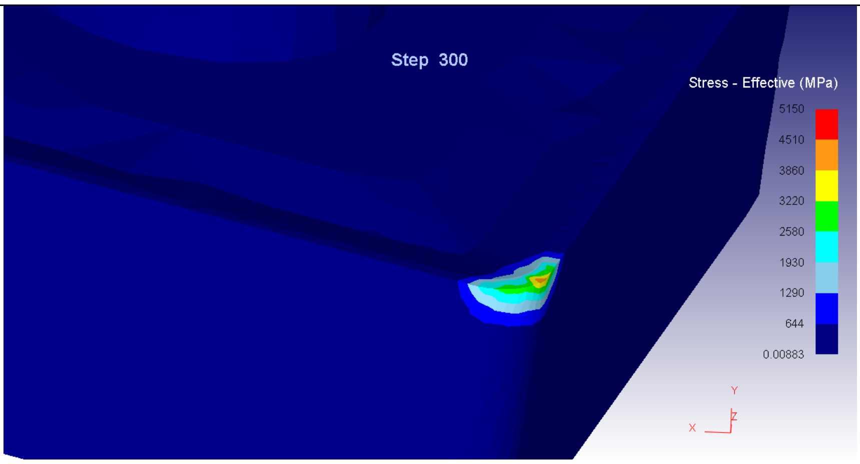
	V=84
f= 0.08 mm/rev	
f=0.14 mm/rev	
f=0.2 mm/rev	

Table 10: Tool tip stress profile for coated tool and V=124 m/min

	V=124
f= 0.08 mm/rev	
f=0.14 mm/rev	
f=0.2 mm/rev	

The stress obtained is the effective stress. As shown in the table 7 through table 10, we can observe that the average value of effective stress increases with an increase in cutting velocity as well an increase in feed rate. For coated tools the stress were greater than the uncoated tools because the friction factor considered for coated tools were higher which resulted in more cutting forces for coated tools. However the general trend is followed for coated and uncoated tools irrespective of the cutting conditions taken.

5. CONCLUSION

It can be concluded from this work that the work done by various researchers over the past decades on tool tip temperature modelling and stress analysis are justifiable. The simulation work has been extended to Inconel 825: a nickel bases superalloy, which is a relatively newer material. The material showed similar trends in cutting temperatures and stress produced as pointed out by various researchers. The temperature showed an increasing trend with respect to cutting velocity as well as feed rate. The coated tool showed larger values of peak temperature owing to the lower thermal conductivity of the coating used. Stress profiles found were similar to trends found earlier and showed an increasing trend with increasing feed and cutting speed.

6. REFERENCE

1. Majumdar, Pradip, R. Jayaramachandran, and S. Ganesan. "Finite element analysis of temperature rise in metal cutting processes." *Applied Thermal Engineering* 25.14 (2005): 2152-2168.
2. Dogu, Yahya, Ersan Aslan, and Necip Camuscu. "A numerical model to determine temperature distribution in orthogonal metal cutting." *Journal of Materials Processing Technology* 171.1 (2006): 1-9.
3. Qureshi, Ahmad Hussain, and F. Koenigsberger. "An investigation into the problem of measuring the temperature distribution on the rake face of a cutting tool." *CIRP ANN* 14.2 (1966): 189-199.
4. da Silva, Marcio Bacci, and James Wallbank. "Cutting temperature: prediction and measurement methods—a review." *Journal of materials processing technology* 88.1 (1999): 195-202.
5. Chou, Y. Kevin, and Hui Song. "Thermal modeling for finish hard turning using a new tool." *ASME 2003 International Mechanical Engineering Congress and Exposition*. American Society of Mechanical Engineers, 2003.
6. Komanduri, Ranga, and Zhen Bing Hou. "Thermal modeling of the metal cutting process—Part III: temperature rise distribution due to the combined effects of shear plane heat source and the tool–chip interface frictional heat source."*International Journal of Mechanical Sciences* 43.1 (2001): 89-107.
7. Zhang, Shijun, and Zhanqiang Liu. "An analytical model for transient temperature distributions in coated carbide cutting tools." *International Communications in Heat and Mass Transfer* 35.10 (2008): 1311-1315.
8. Zhang, Shijun, and Zhanqiang Liu. "A new approach to cutting temperature prediction considering the diffusion layer in coated tools." *International Journal of Machine Tools and Manufacture* 49.7 (2009): 619-624.
9. Abukhshim, N. A., P. T. Mativenga, and M. A. Sheikh. "Investigation of heat partition in high speed turning of high strength alloy steel." *International Journal of Machine Tools and Manufacture* 45.15 (2005): 1687-1695.
10. Grzesik, W., M. Bartoszuk, and P. Nieslony. "Finite element modelling of temperature distribution in the cutting zone in turning processes with differently coated tools." *Journal of Materials Processing Technology* 164 (2005): 1204-1211.

11. Grzesik, W. "Determination of temperature distribution in the cutting zone using hybrid analytical-FEM technique." *International Journal of Machine Tools and Manufacture* 46.6 (2006): 651-658.
12. Lazard, M., and P. Corvisier. "Modelling of a tool during turning: Analytical prediction of the temperature and of the heat flux at the tool's tip." *Applied thermal engineering* 24.5 (2004): 839-849.
13. Pius, Onyechi, Benjamin S. Oluwadare, and Obuka Nnaemeka. "Analytical Modelling of Temperature Distribution in Metal Cutting: Finite element approach." *International Journal of Engineering Science Invention* (2013): 17-33.
14. Du, Fang, Michael R. Lovell, and Tim W. Wu. "Boundary element method analysis of temperature fields in coated cutting tools." *International Journal of Solids and Structures* 38.26 (2001): 4557-4570.
15. Abhang, L. B., and M. Hameedullah. "Chip-tool interface temperature prediction model for turning process." *International Journal of Engineering Science and Technology* 2.4 (2010): 382-393.
16. Carvalho, S. R., et al. "Temperature determination at the chip–tool interface using an inverse thermal model considering the tool and tool holder." *Journal of Materials Processing Technology* 179.1 (2006): 97-104.
17. Ramesh, M. V., et al. "Finite element modelling of heat transfer analysis in machining of isotropic materials." *International journal of heat and mass transfer* 42.9 (1999): 1569-1583.
18. Tay, A. O., M. G. Stevenson, and G. De Vahl Davis. "Using the finite element method to determine temperature distributions in orthogonal machining."*Proceedings of the institution of mechanical engineers* 188.1 (1974): 627-638.
19. Filice, L., et al. "A critical analysis on the friction modelling in orthogonal machining." *International Journal of Machine Tools and Manufacture* 47.3 (2007): 709-714.
20. Grzesik, W. "The influence of thin hard coatings on frictional behaviour in the orthogonal cutting process." *Tribology international* 33.2 (2000): 131-140.
21. Abdelali, H. Ben, et al. "Experimental characterization of friction coefficient at the tool–chip–workpiece interface during dry cutting of AISI 1045." *Wear* 286 (2012): 108-115.
22. Bonnet, C., et al. "Identification of a friction model—application to the context of dry cutting of an AISI 316L austenitic stainless steel with a TiN coated carbide tool." *International Journal of Machine Tools and Manufacture* 48.11 (2008): 1211-1223.

23. Sebhi, Amar, Hocine Osmani, and Joel Rech. "Tribological Behaviour of Coated Carbide Tools during Turning of Steels with Improved Machinability." *Strojniški vestnik-Journal of Mechanical Engineering* 58.12 (2012): 744-749.

24. Hirao, M. "Determining temperature distribution on flank face of cutting tool."*Journal of Materials Shaping Technology* 6.3 (1989): 143-148.