MECHANICAL MICRO-DRILLING OF INCONEL 625 SUPERALLOY USING TUNGSTEN CARBIDE MICRO-DRILL BIT IN DEFORM 3D SOFTWARE

Presentation

By

Kalyan Kumar Adepu

(ME20M06)

M.Tech 2nd Year

Manufacturing Engineering

Under the Supervision of

Dr. Aruna Thakur

DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

NATIONAL INSTITUTE OF ADVANCED MANUFACTURING TECHNOLOGY, RANCHI

Contents

- Introduction
- Literature Review
- Objective
- Methodology
- Simulation
- Results
- Conclusion
- Future work

Introduction

- Micro Machining
- Micro Drilling
- Inconel 625 Superalloy

ELEMENT	Ni	Cr	Mo	Fe	Nb+Ta	Co	Mn	Al
Wt%	58-71	21-23	8-10	5	3.2-3.8	1	0.5	0.4

- MACHINING CHALLENGES:
- Temperature resistant
- High strength
- High hardness
- High corrosive resistant

APPLICATIONS:

1) marine (propeller blades for motors and fixtures)
2) Aerospace (exhaust equipment, fuel lines , etc..)
3) Nuclear technology(used in control rods,reactorcore)

LITERATURE REVIEW

AUTHOR	PAPER	INPUT	OUTPUT
1) Rahamathullah and MS Shunmugam	Thrust and torque analyses for different strategies adapted in microdrilling of glass-fibre-reinforced plastic	STRATEGIES: direct drilling of blind holes, peck drilling of blind holes and peck drilling through holes. INPUT: Spindle speed : 5000-10000 rpm Tool: WC uncoated Dia of drill bit:0.32mm Point angle: 118 deg	Thrust forces are less in peck drilling. Tool life is increased by peck drilling.
2) Jung Soo Nam, Pil-Ho Lee , Sang Won Lee	Experimental characterization of micro-drilling process using nanofluid minimum quantity lubrication	INPUT: Dia : 0.2mm Tool :WC Work piece: AL6061 Lubrication: Compressed air, nanofluid (nano diamond particles)	Reduction of thrust forces and torque. Nanofluid lubrication is more effective than compressed air lubrication. Increase in diamond particles leads to increase thrust force

AUTHOR	PAPER	INPUT	OUTPUT
3) M Imran, P T Mativenga, S Kannan, and D Novovic.	An experimental investigation of deep-hole micro drilling capability for a nickel-based superalloy	Diameter: 0.5 mm of WC with cobalt. Workpiece: nickel Spindle speed : 3000-5000 rpm Helix angle : 30 deg Point angle: 150 deg Web thickness: 30% of dia Feed: 0.005 mm/rev	Sharpness plays an important role. Standard parameters like conventional parameters are of no use for micro drilling. Pilot hole is necessary with 118 deg point angle Leads to gradual load action. tool life is increased. If feed is less than 0.005 mm/rev tool life decreases.
4) Hongyan Shi, Hui Li and Shengzhi Chen	Temperature simulation and its application in on-line temperature measurement of a micro drill bit	Dia: 0.3mm Helix angle :40deg Point angle:130 deg Web thickness: 0.14 mm Workpiece: AL6061 with dia = 0.6mm, t=0.1mm	Comparison of temperature measurement (simulation vs experimental) Only 20 deg centigrade deviation b/w experimental and simulation

AUTHOR	PAPER	INPUT	OUTPUT
5) M. Hokka, D.Gomon, A.Shrot, T. Leemet, M. Baker	Dynamic behaviour and high spped machining of Ti-6246 and Inconel 625 superalloys: Experimental and Modelling Aprroches.	The material behaviour was characterized in compression at temperature upto 730°C at strain rates ranging from 0.001 s^{-1} to 4600 s^{-1}	J C Model did not predict the plastic flow accurately. Modified J C model, the simulated cutting stresses were higher than experimental values and overestimates the strength of the material at large deformations.

RESEARCH GAP:

- There are only few papers on micro drilling operation
- There is no paper available on micro drilling operation on Inconel 625 superalloy
- There are very few papers available micro drilling simulation.

OBJECTIVE

- The objective of the present work is

- Performing simulation work using Deform 3D software

METHODOLOGY

↓

SIMULATION

↓

DEFORM 3D

↓

MATERIAL PARAMETERS

↓

DESIGN AND MESHING

↓

SIMULATION WORK

↓

RESULT

Simulation:

- Deform 3D ver13.0

a. Pre-processor
b. Simulation
c. Post-processor

Pre-processor

General

a. Material type
b. Initial temperature
c. Assigning material

2. Geometry specifications

- CATIA GEOMETRY

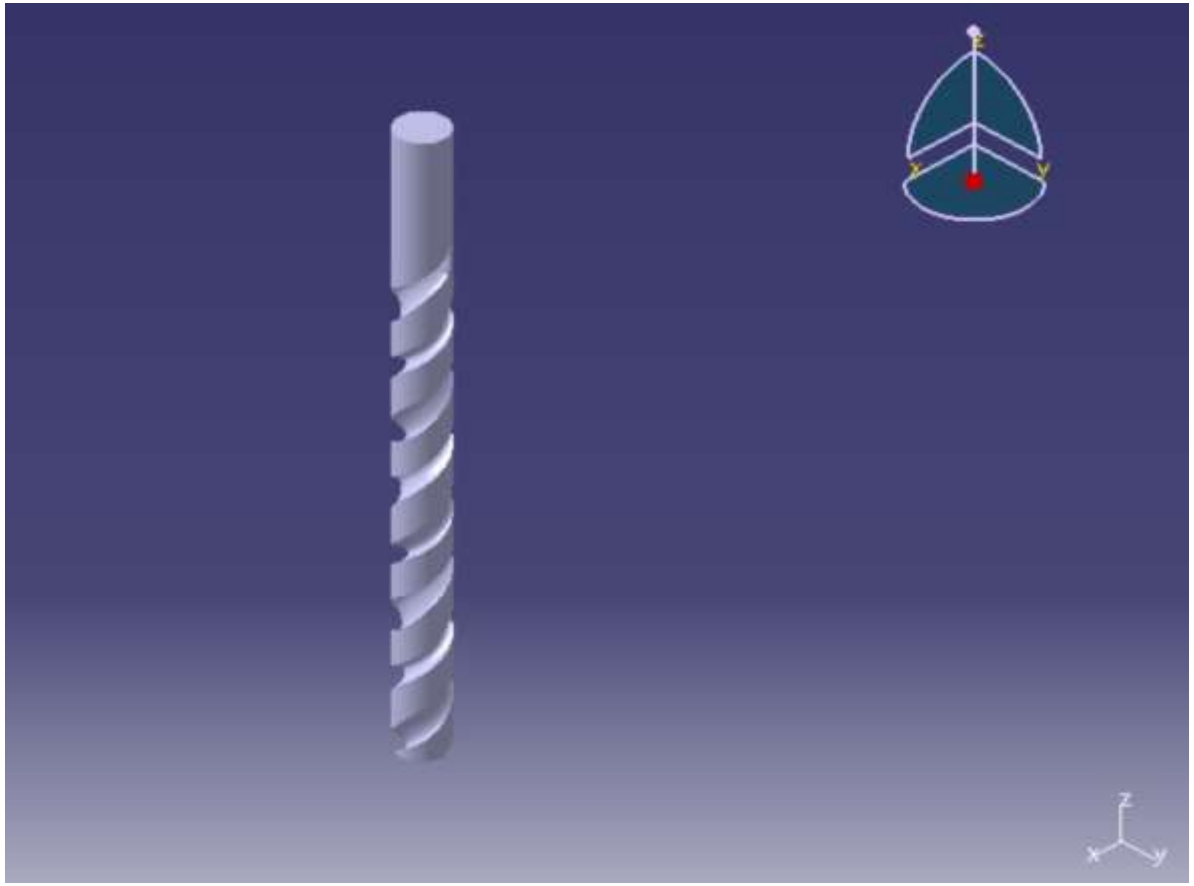


Table: Micro drill bit geometry specifications:

Length	**4mm**
Flute length	3.2mm
diameter	0.3mm
Helix angle	40°
Point angle	130°
Web thickness	0.14mm
Flute and Land ratio	1:2

Workpiece:

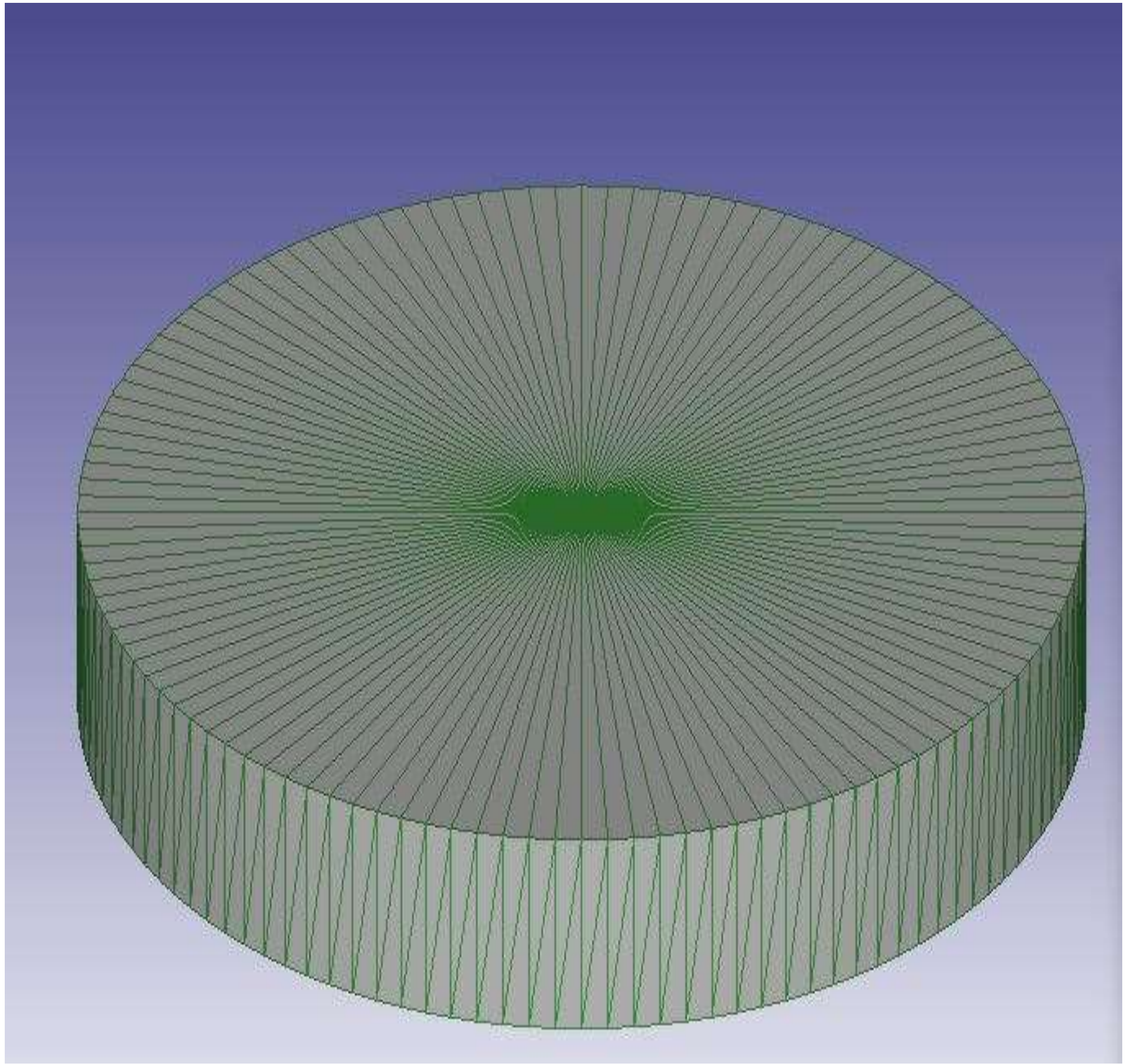


Fig 3.1: Work piece of diameter = 0.6mm and thickness = 0.1mm built in Deform 3D

MATERIAL PROPERTIES

Mechanical properties	Inconel 625	Tungsten carbide
Young's modulus (GPa)	207	640
Density (kg/m^3)	8440	14700
Poisson's ratio	0.308	0.21
Melting point temperature (°c)	1350	2870
Thermalconductivity at room temperature (W/mk)	9.8	110

Object Positioning:

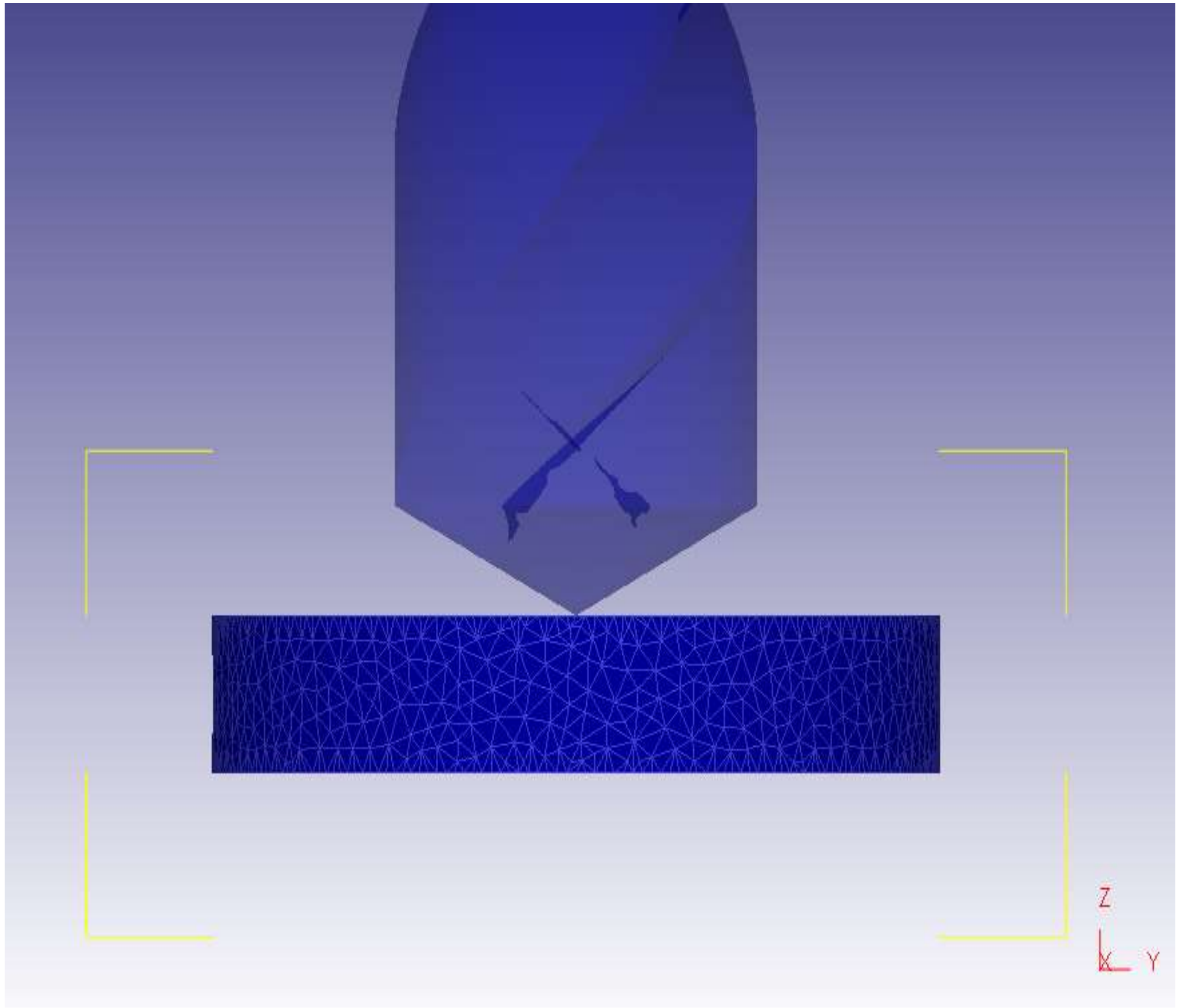


Fig 3.9: Micro-drill bit along Z direction

Flow stress model for Inconel 625:

Simulation results obtained through the Johnson-cook model for Inconel 625 were not acceptable because it overestimates the strength of the material at high strains.

$$\boldsymbol{\sigma} \quad = \quad (\boldsymbol{A} + \boldsymbol{B}\boldsymbol{\varepsilon}^{\boldsymbol{n}})(\mathbf{1} + \boldsymbol{C}\ \boldsymbol{ln}\frac{\boldsymbol{X}}{\boldsymbol{X_{ref}}})(\mathbf{1} - [\frac{\boldsymbol{T} - \boldsymbol{T_{ref}}}{\boldsymbol{T_m} - \boldsymbol{T_{ref}}}]^{\boldsymbol{m}})$$

where $(A + B\varepsilon^{n})$ = f(strain),

$(1 + C\ \ln\frac{X}{X_{ref}})$ = f(strain rate),

$(1 - [\frac{T-T_{ref}}{T_m-T_{ref}}]^{m})$= f(temp)

σ = Flow stress, A = Yield strength, B = Hardening modulus,

Ɛ= strain, X= strain rate, X_{ref}= Reference strain rate,

T= temperature, T_{ref}= reference temperature (20°C), C= strain rate sensitivity, T_m= melting point temperature of Inconel 625, n= Strain-hardening exponent, m= thermal softening exponent. [5]

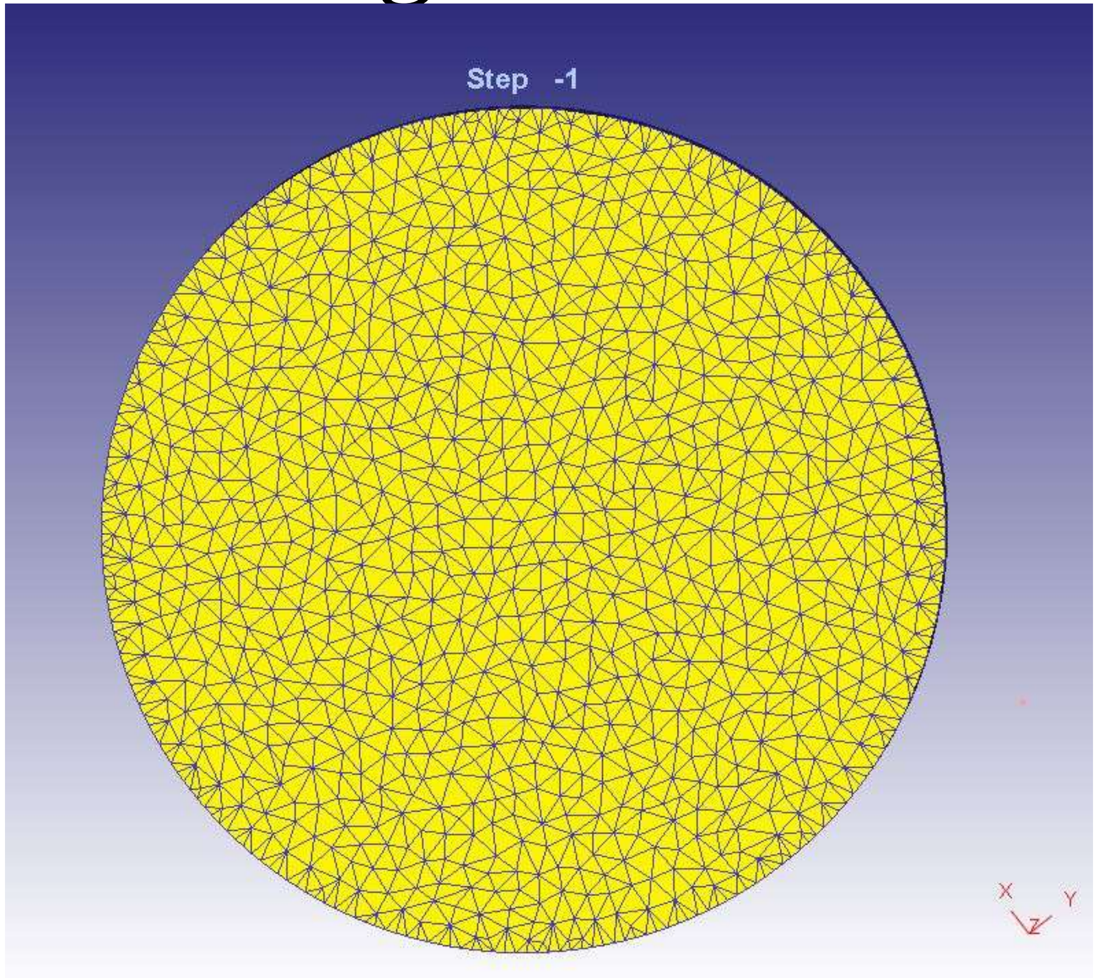
Modified JC Model

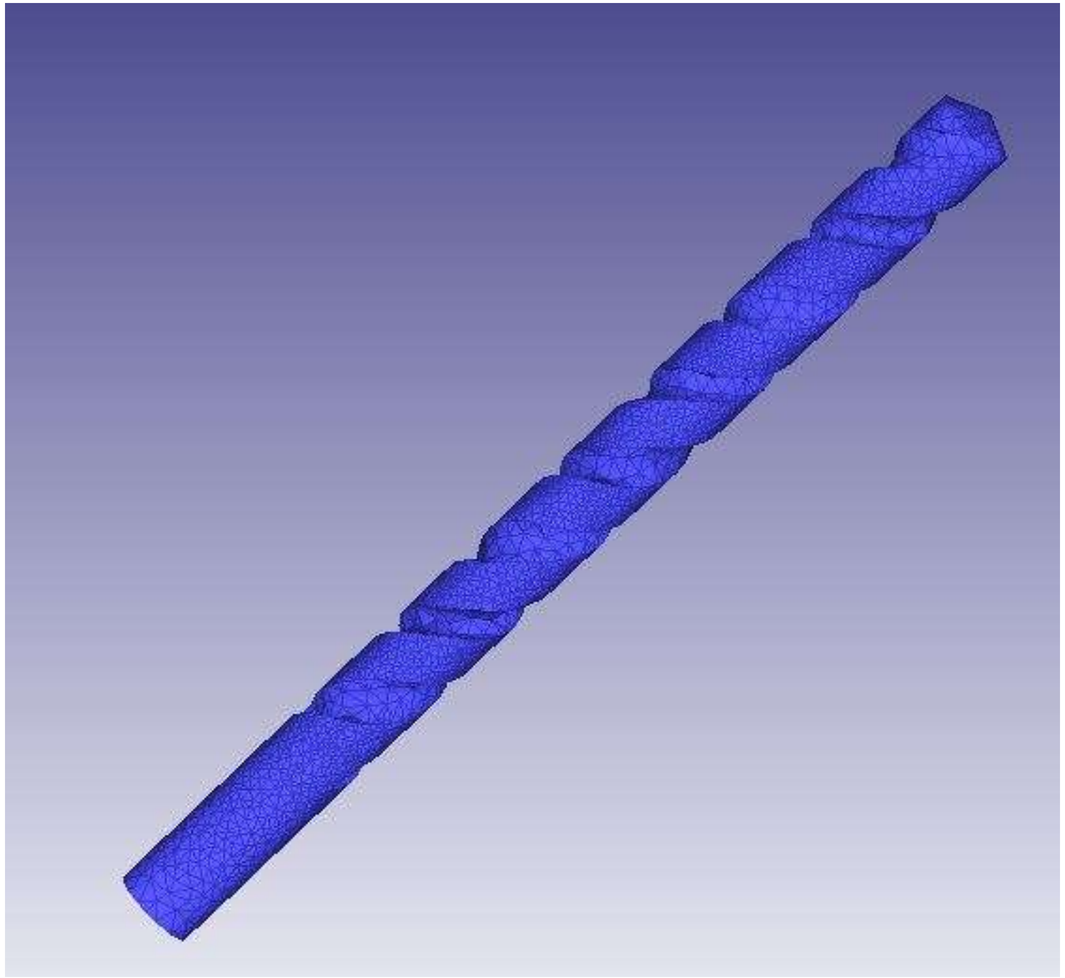
- $(A + B\varepsilon^n)(\tanh(\frac{1}{\varepsilon^k}))(1 + C\ \ln\frac{X}{X_{ref}})(1 - [\frac{T - T_{ref}}{T_m - T_{ref}}]^m)$

Parameter	A [MPa]	B [MPa]	n	C	m	X_{ref} [s^{-1}]	T_{ref}	T_m	C_p [J/Kg]	ρ [kg/m^3]
Values	558.8	2201.3	0.80	0.000209	1.146	1670	20	1350	480	8440

(Strain softening exponent) K =3 [5]

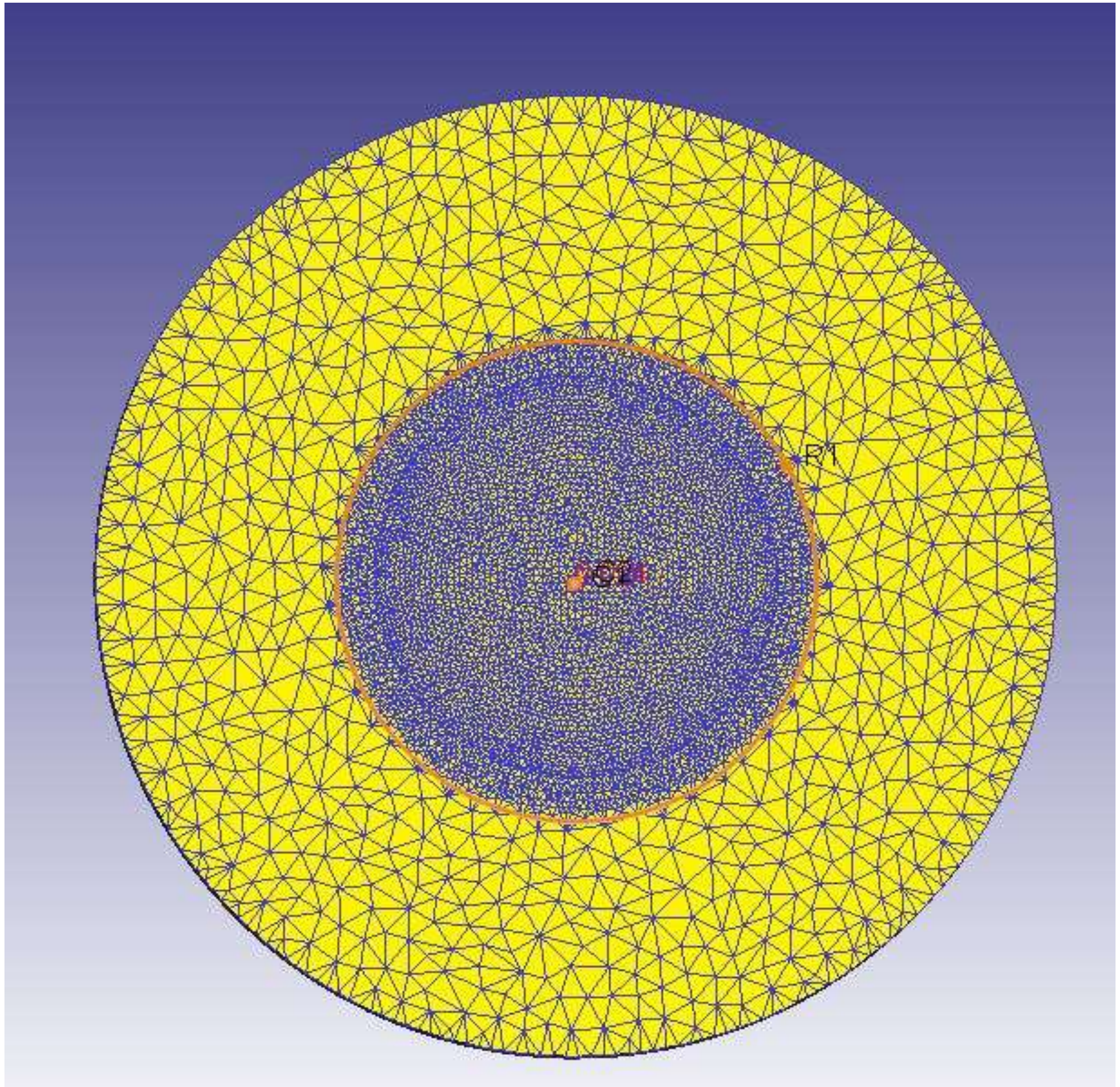
Meshing:





Here, element shape is tetrahedral and initial element size is 0.006mm for work piece, 0.02mm for micro-drill bit by choosing absolute mesh mode with size ratio 4.

Adaptive Meshing:

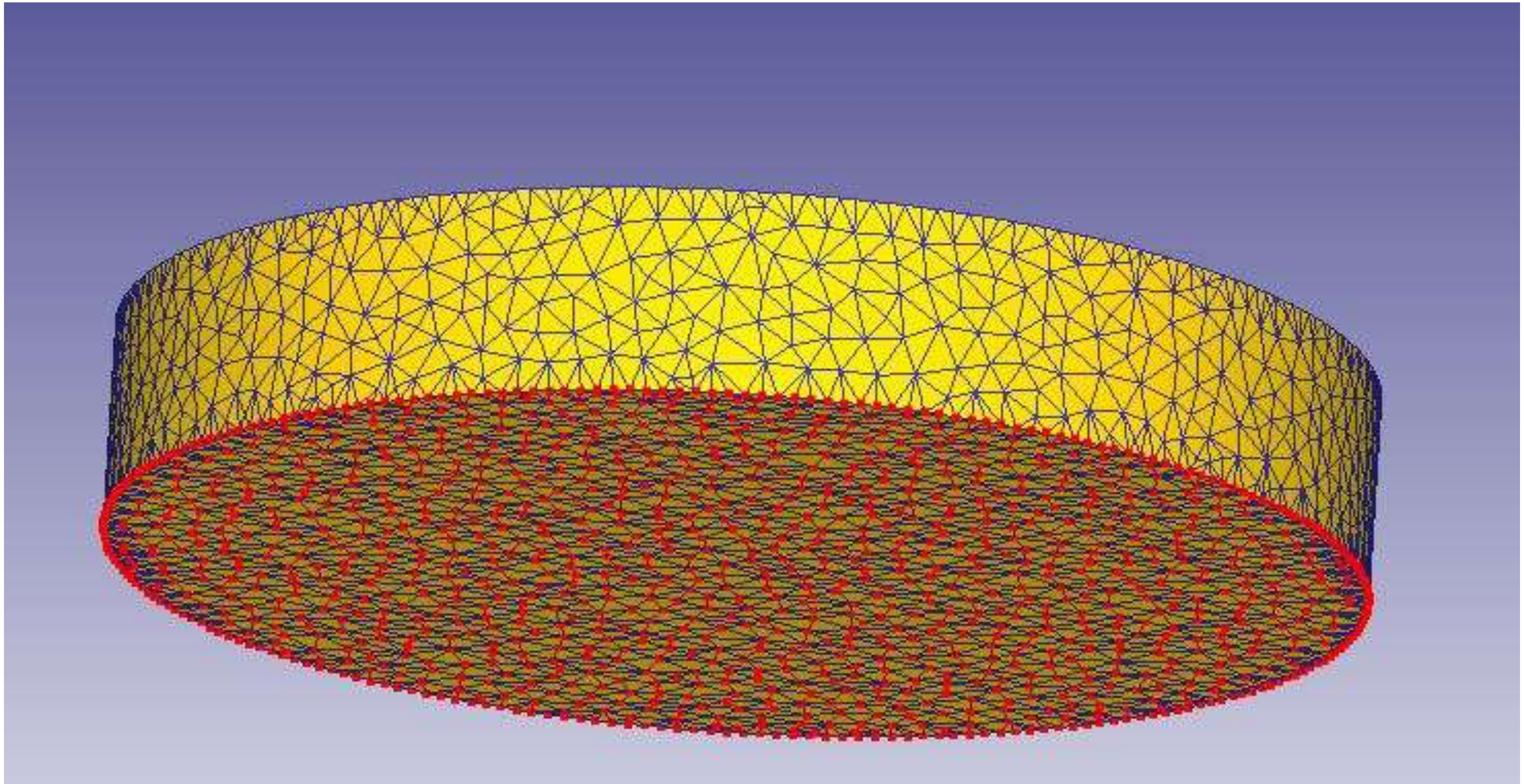


We can increase the element size of the surrounding according to the requirement. Modified mesh element size for work piece is 0.003mm

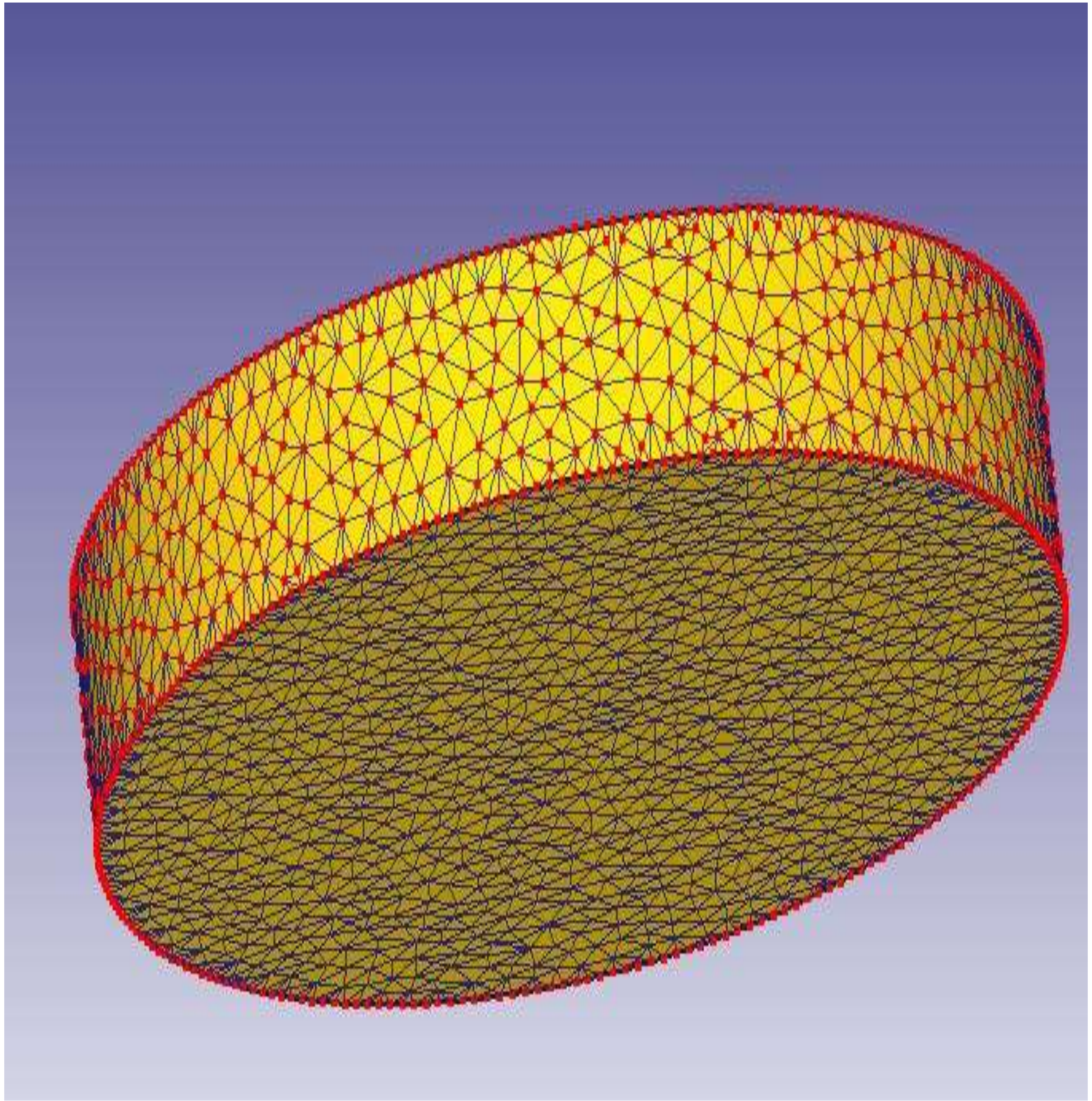
INPUT PARAMETERS REQUIRED FOR SIMULATION:

- RPM- 50krpm, 80krpm, 140krpm
- Displacement (mm) – 0.1mm (-Z direction)
- Heat transfer coefficient (N/mm/sec/°c)- 45
- No. of steps- 10000
- Shear friction factor- 0.6
- Feed rate - 3m/min, 4.8 m/min (-Z direction)
- Initial Temperature- 20 °C
- Time increment- 0.000001sec
- Convection coefficient-0.02 N/s/mm/°c

Boundary conditions (velocity deformation):



Fixing the base along Z direction for velocity deformation

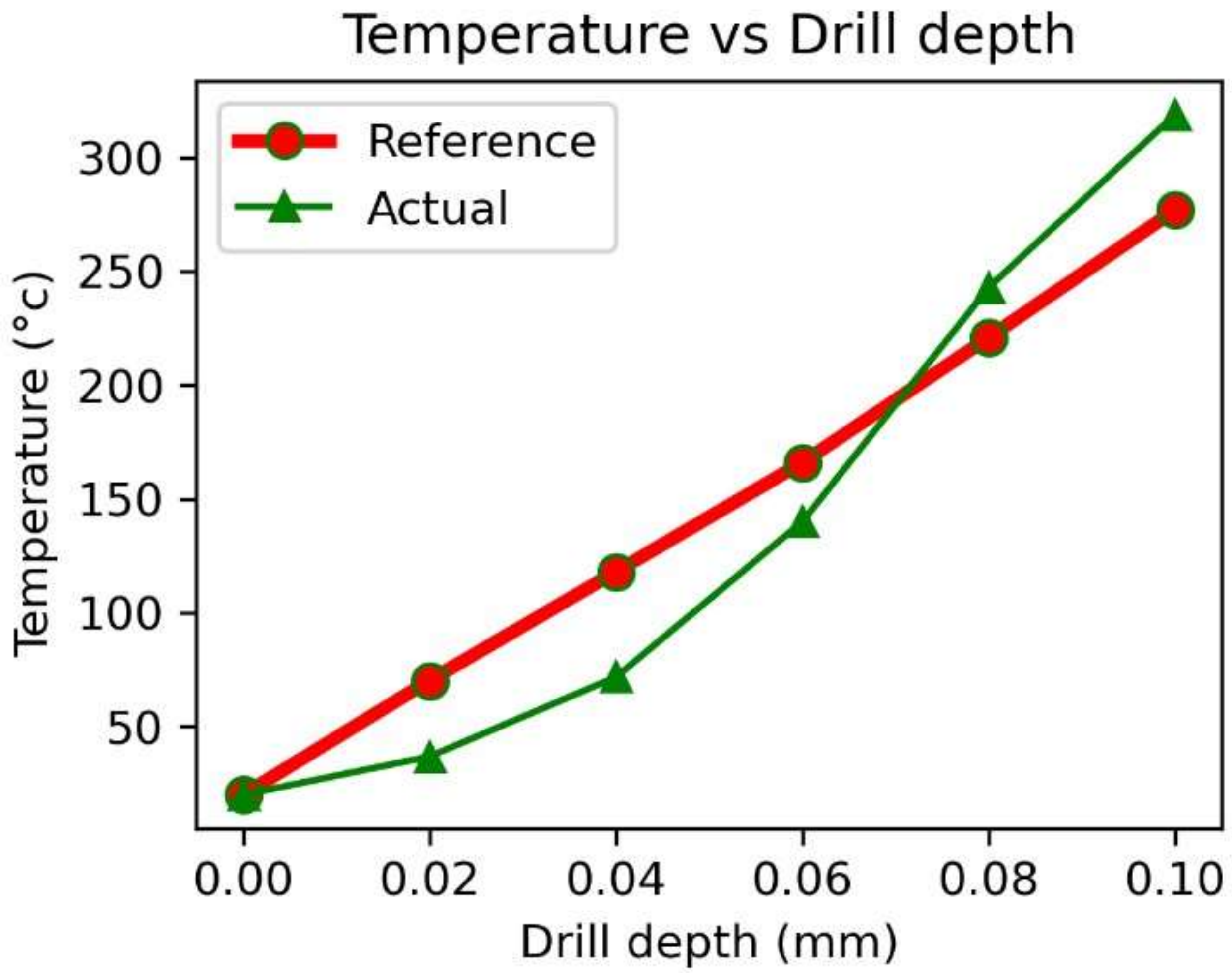


Fixing the outer surface along X, Y direction for velocity deformation

Heat transfer parameters:

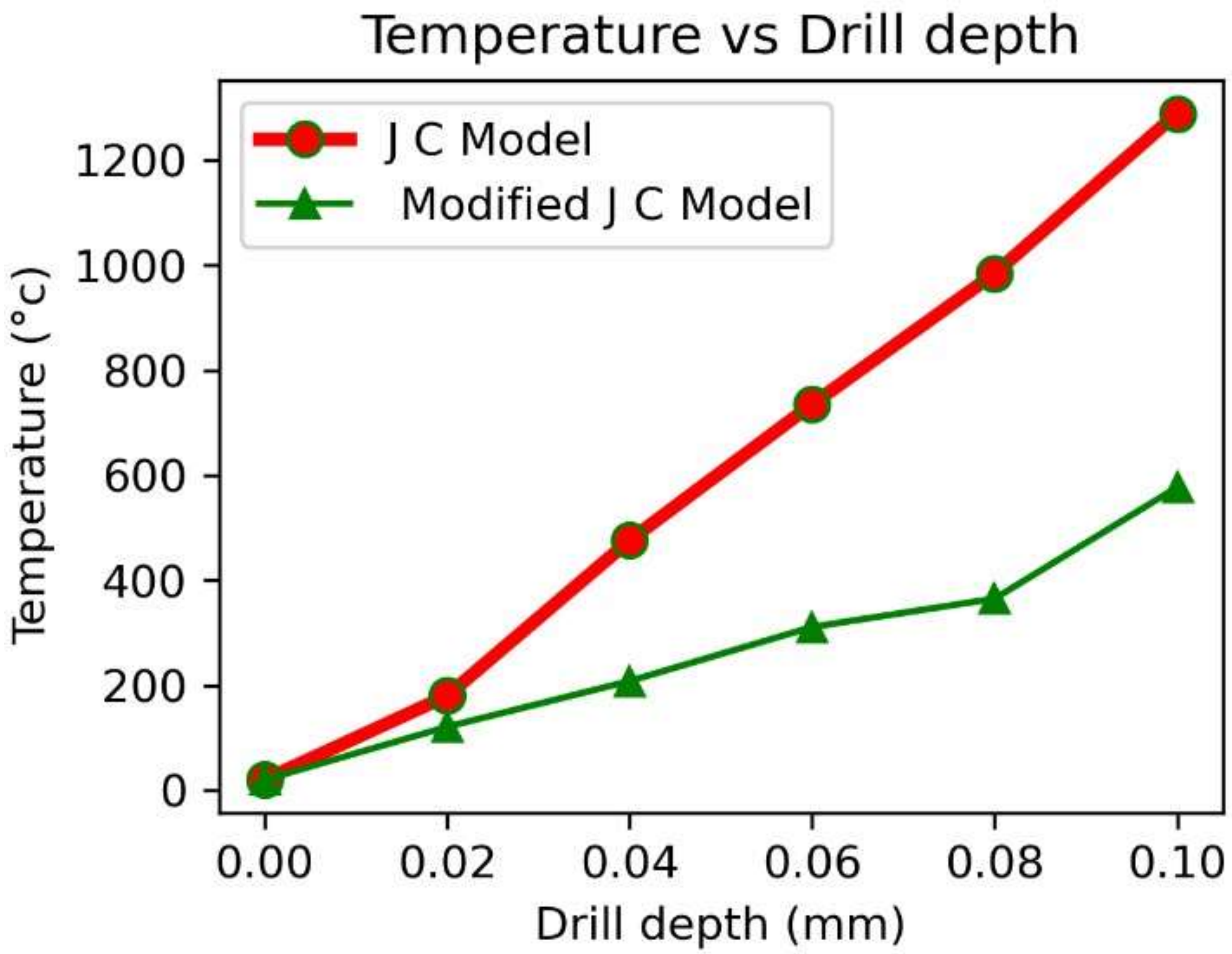
Environment:	Temperature	20 °C
	Convection coefficient	0.02 N/s/mm/°c
Tool – work piece interface:	Shear friction factor	0.5 (reference)
	Heat Transfer Coefficient	45 N/s/mm/°c

Results and discussion:



- Comparison with reference paper in Deform 3D
- The spindle speed = 150krpm, feed speed = 80 mm/sec . The work piece is a stationary one [4].

Flow stress model:



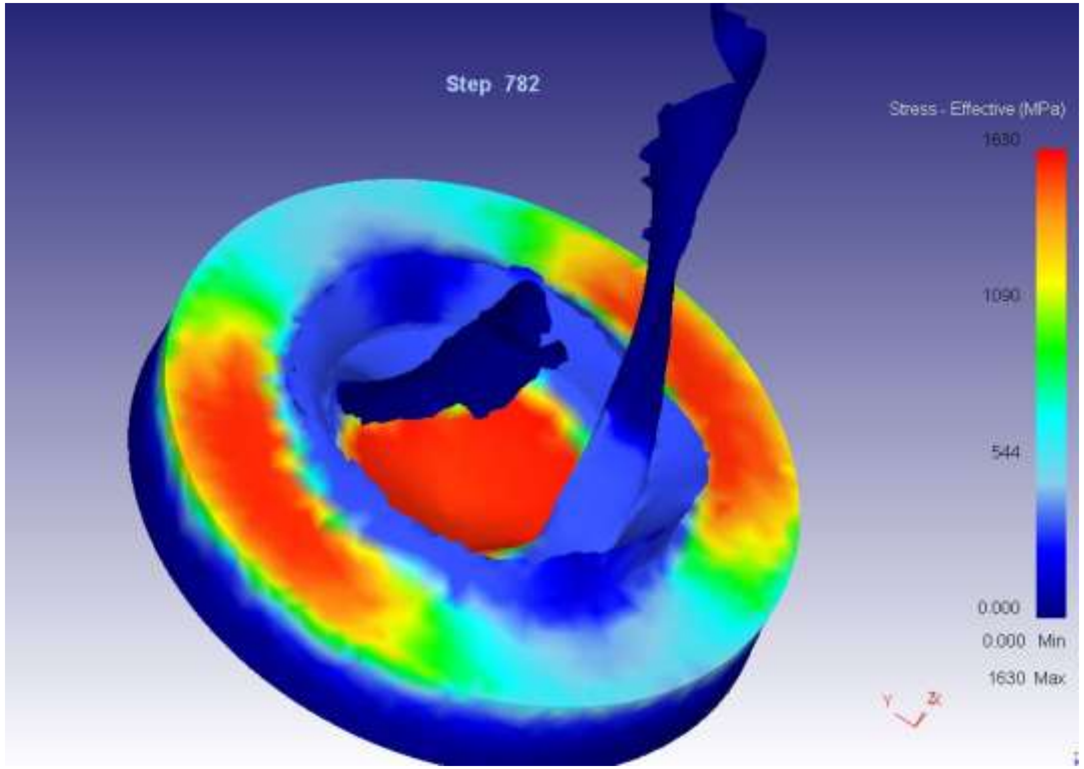
- Comparison between J C model and modified J C model of Inconel 625.
- For a spindle speed =50krpm and feed speed =3m/min.
- Work piece diameter = 0.6mm and thickness = 0.1 mm and WC drill bit of 0.3 mm diameter.

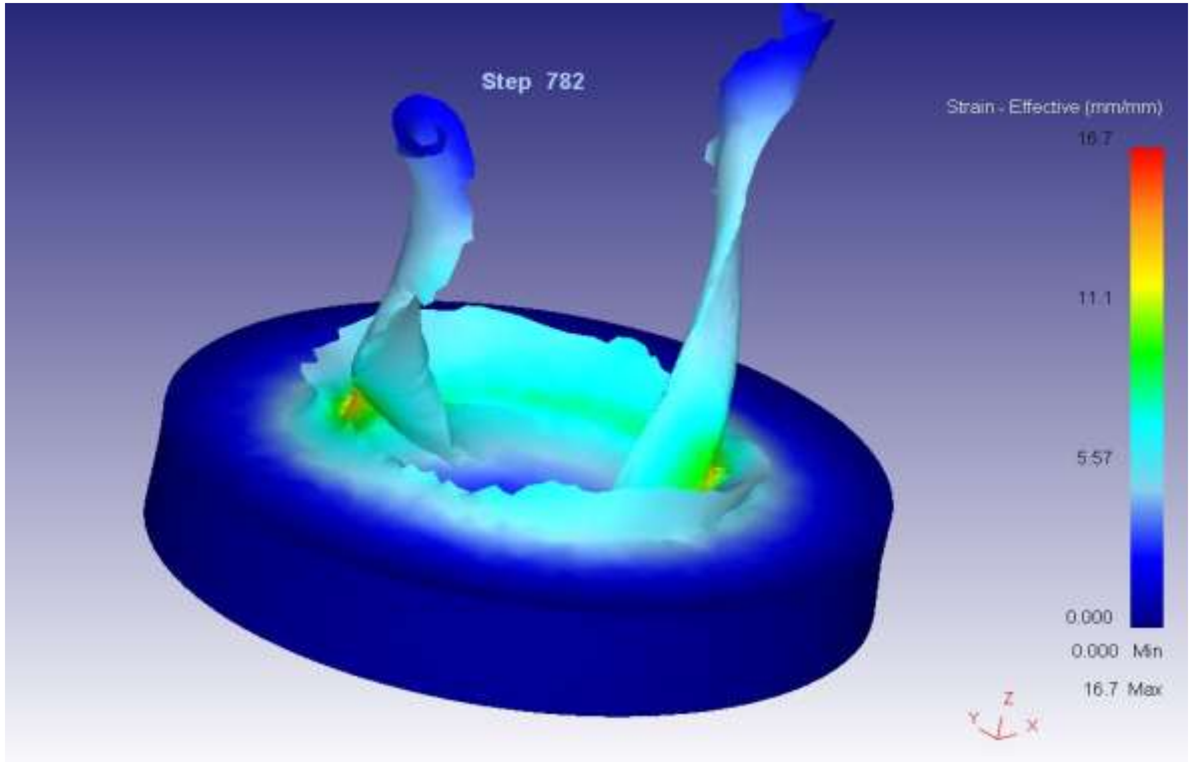
All results are considered under maximum condition. Spindle speed= 50krpm, feed speed= 3m/min

	Output	Drill depth in (mm)					
		0.00	0.02	0.04	0.06	0.08	0.10
workpiece	Stress (MPa)	0	1660	1700	1700	1640	1630
	Strain(mm/mm)	0	2.72	3.46	6.07	11.0	16.7
	Strain rate (mm/mm/sec)	0	28400	134000	334000	167000	410000
	Temperature (˚C)	20	121	208	311	365	577
Tool	Interface temperature (˚C)	0	85.4	165	239	297	421
	Sliding velocity (mm/sec)	0	297	547	798	858	975
	Interface pressure (MPa)	0	6140	16400	31800	8820	9780
	Tool wear rate (mm/sec)	0	0	0	0.00000288	0.00000273	0.00000612
	Fz (N)	0	30.3	111	212	173	221

Simulation results at drill depth of 0.1mm

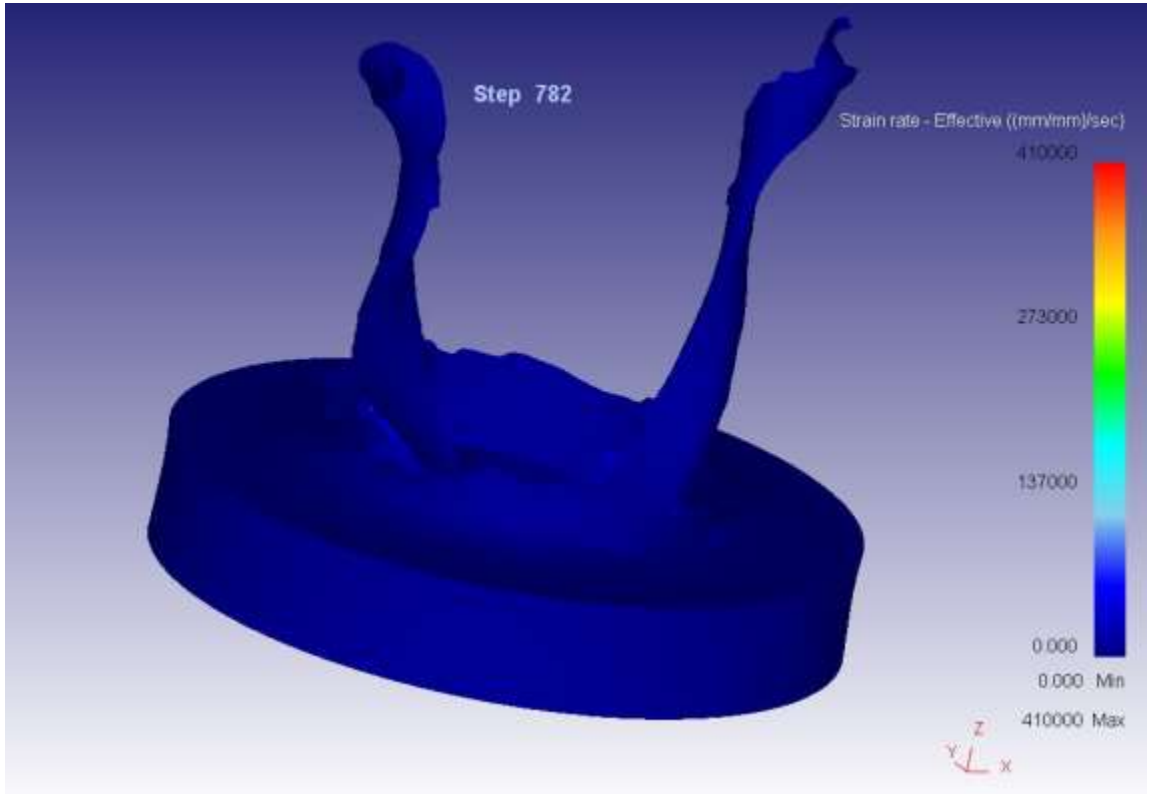
- Work piece



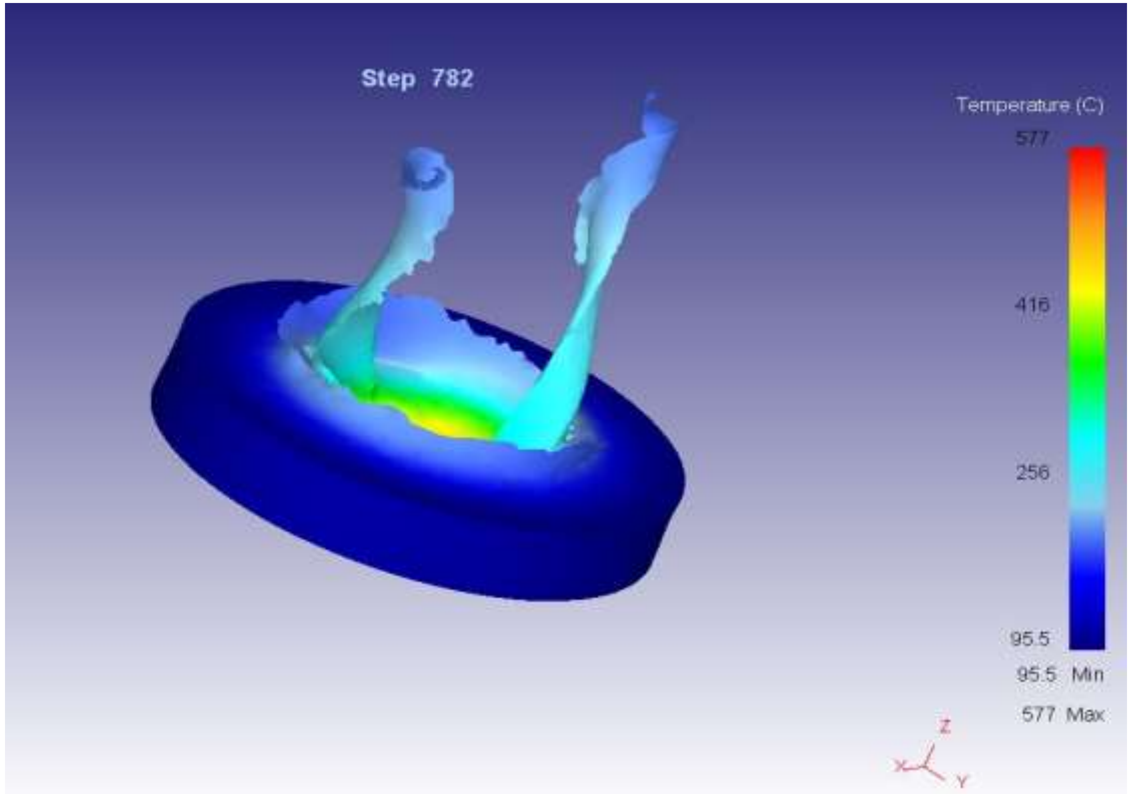


Stress (MPa)

Strain

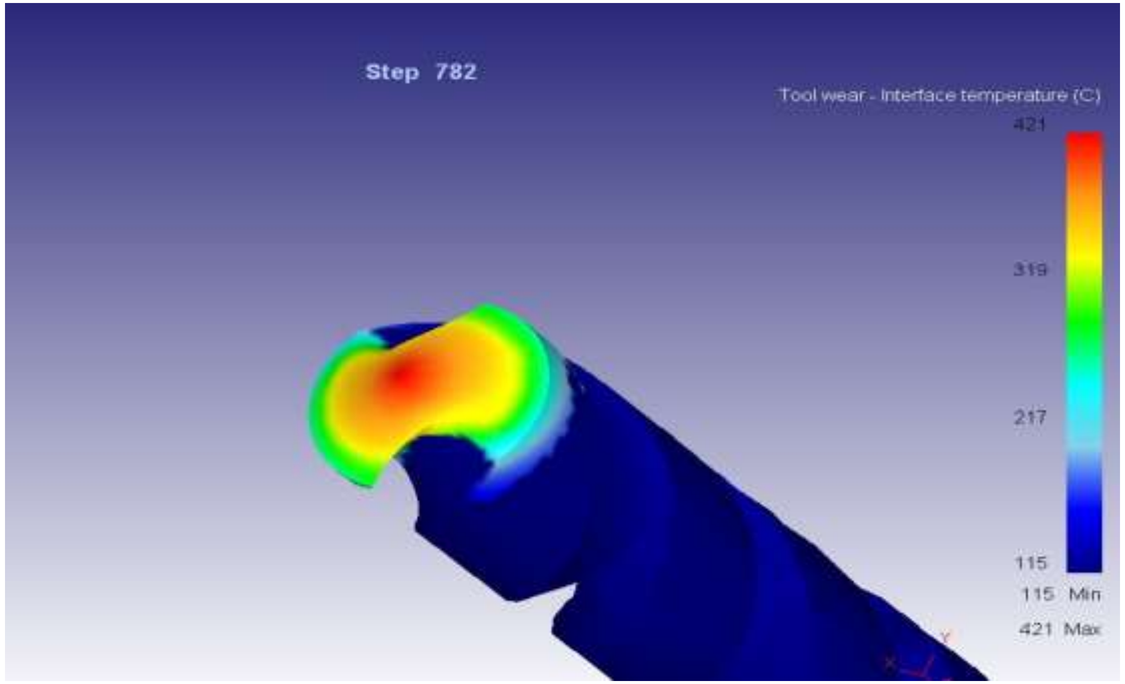


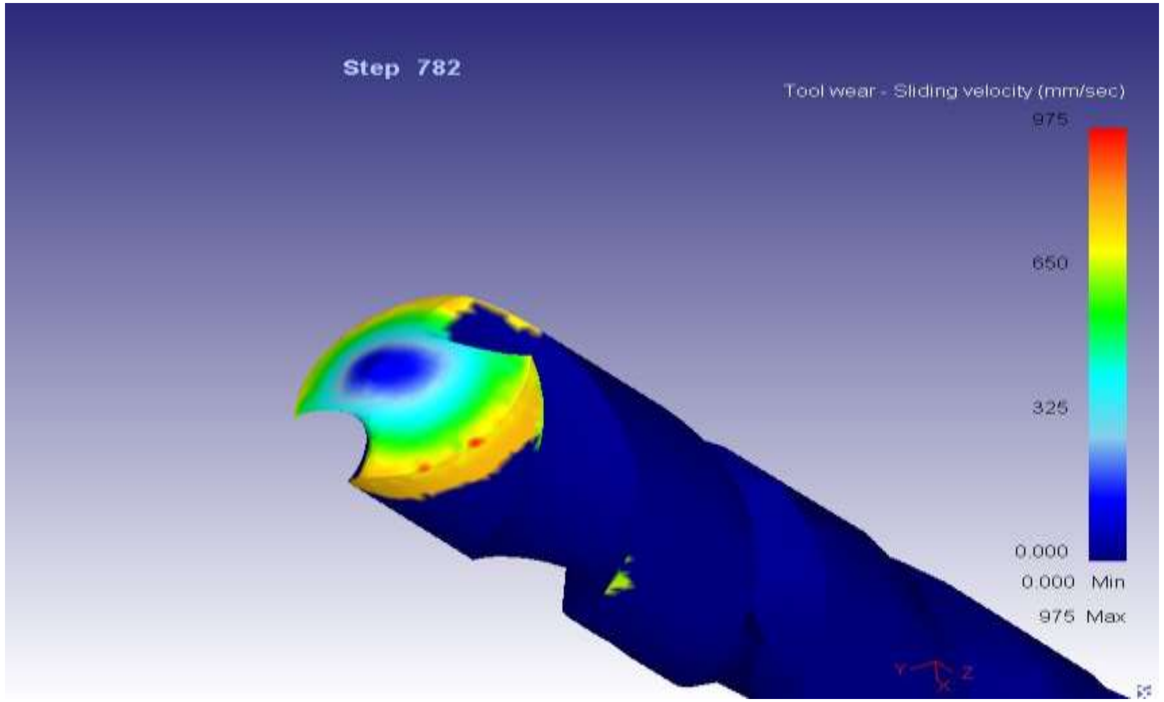
Strain rate



Temperature (°C)

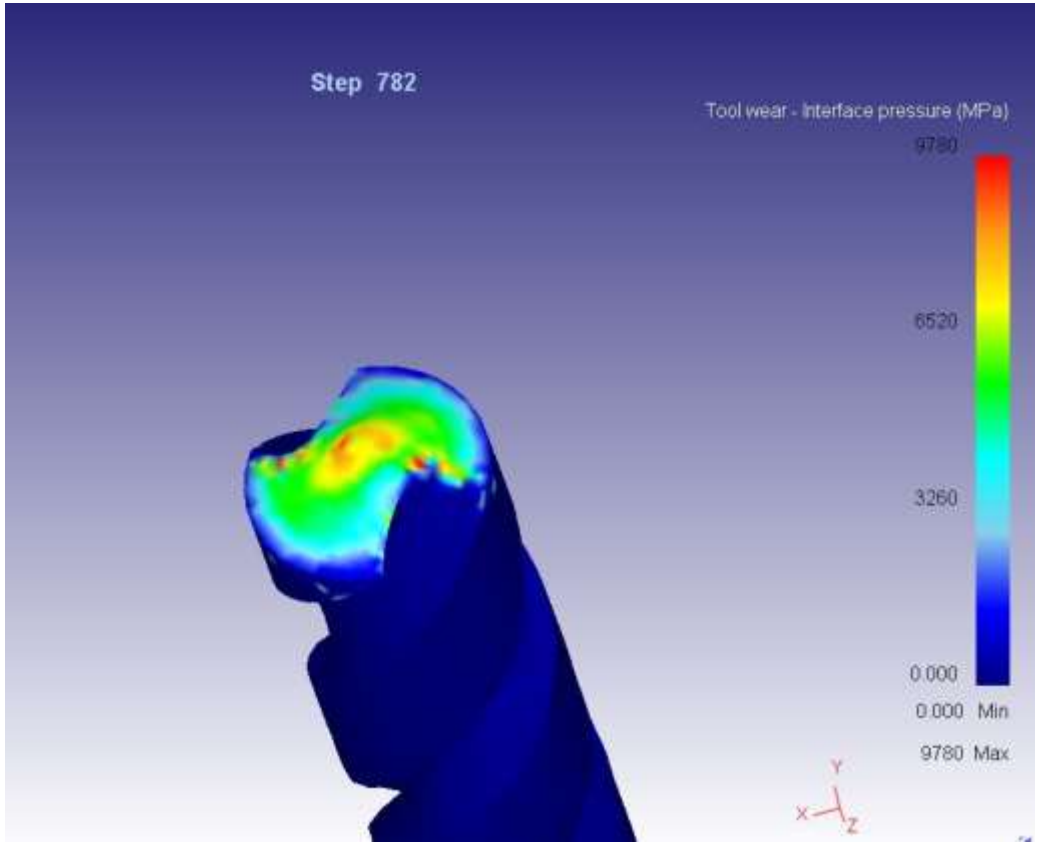
- Tool



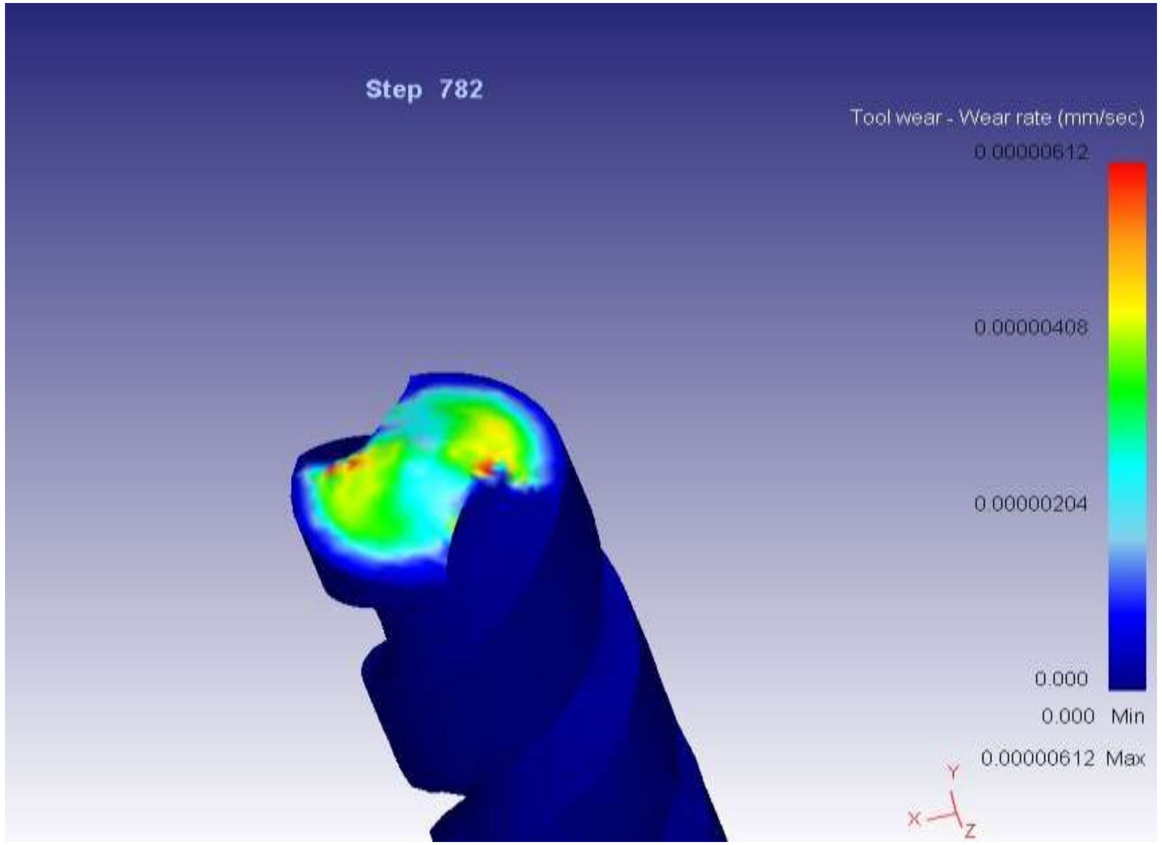


Interface temperature (°C)

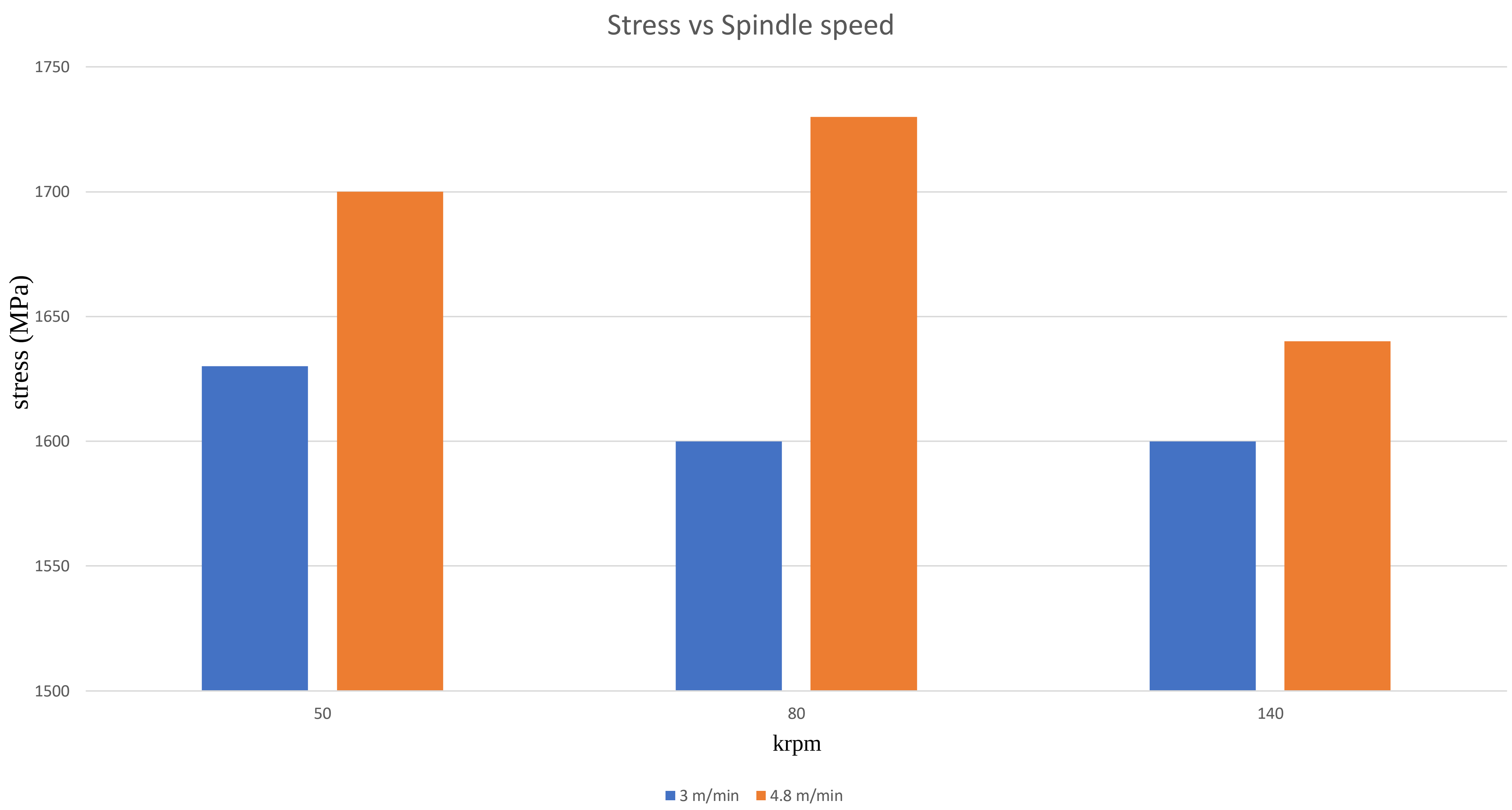
Sliding velocity (mm/s)



Interface pressure (MPa)

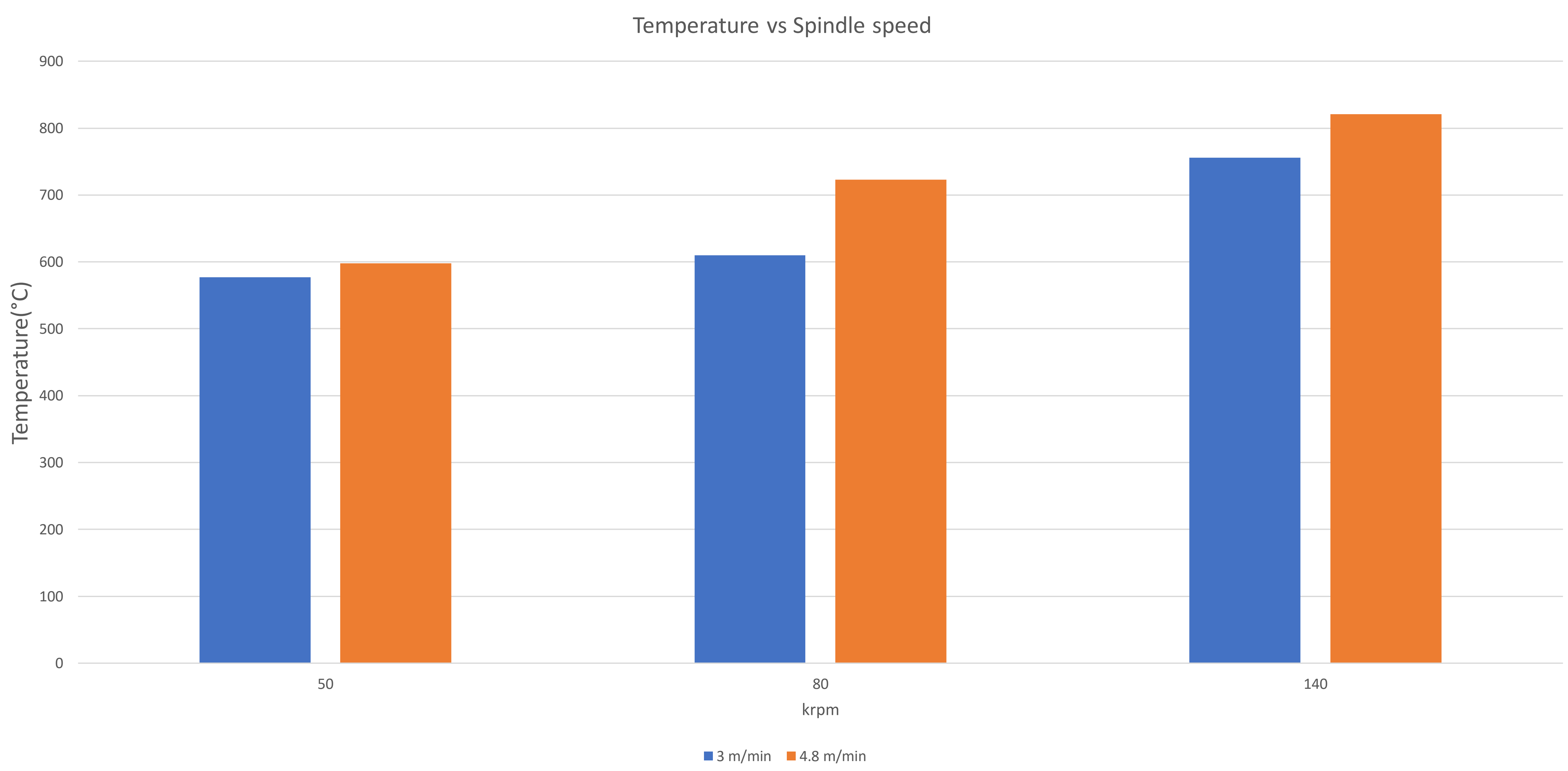


Wear rate (mm/sec)

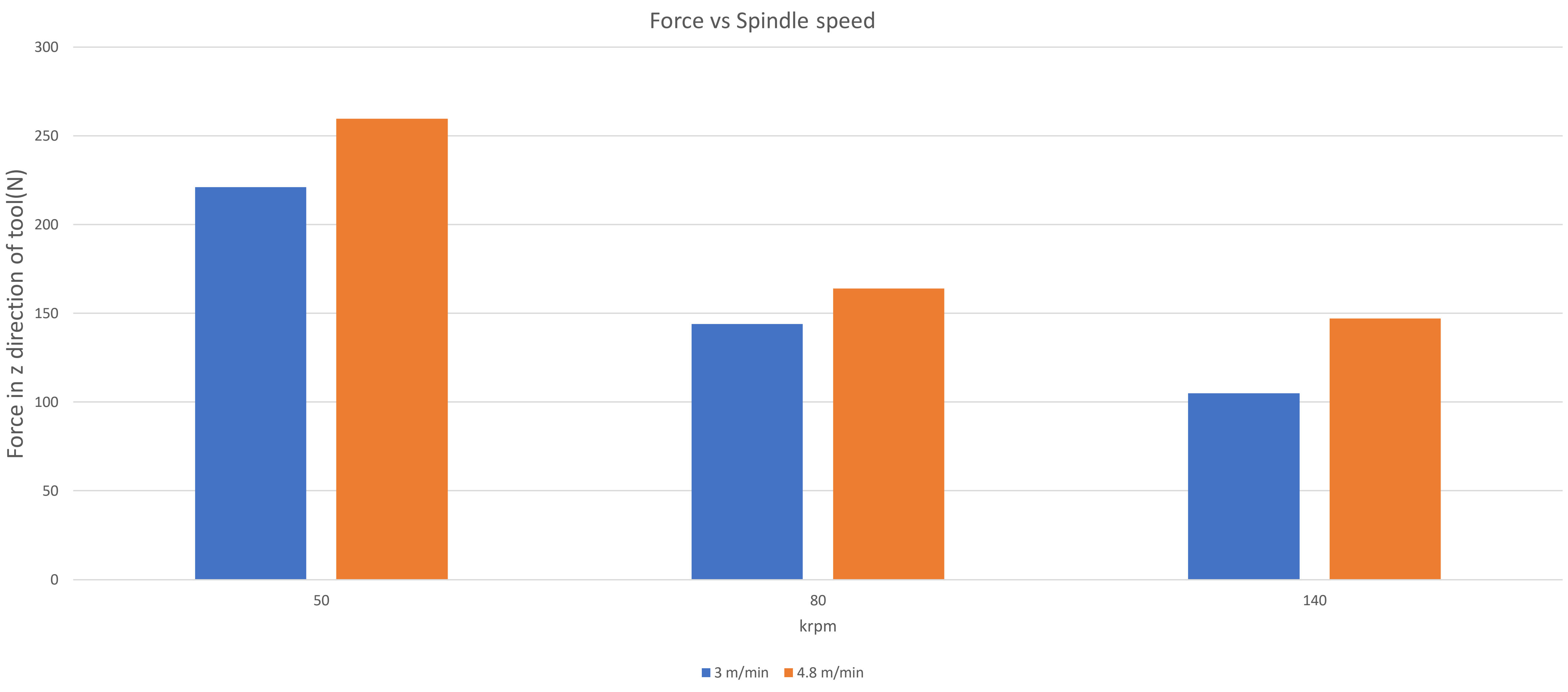


Comparison between Stress and Spindle speed with different feed rates

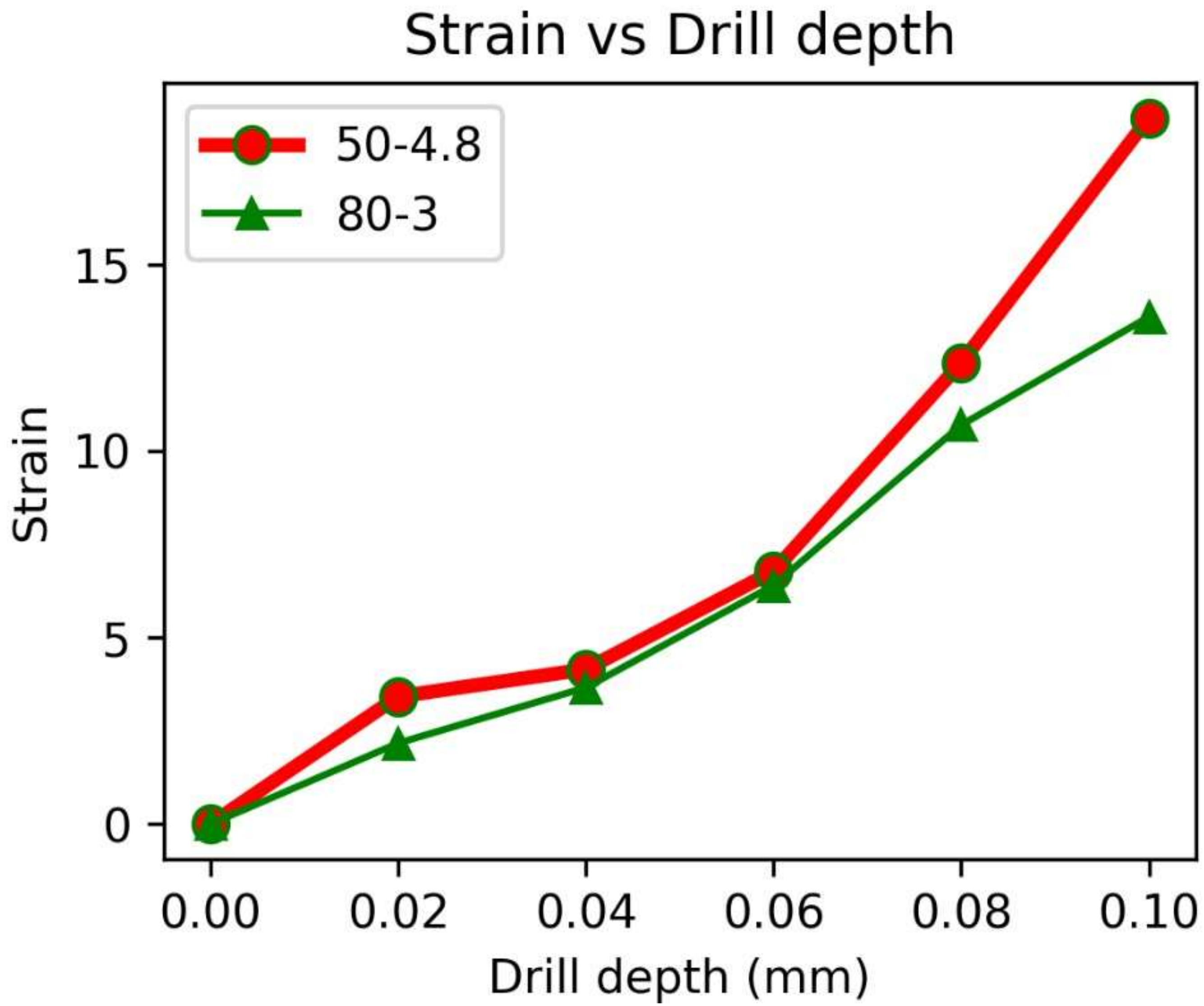
Comparison between Strain and Spindle speeds with different feed rates



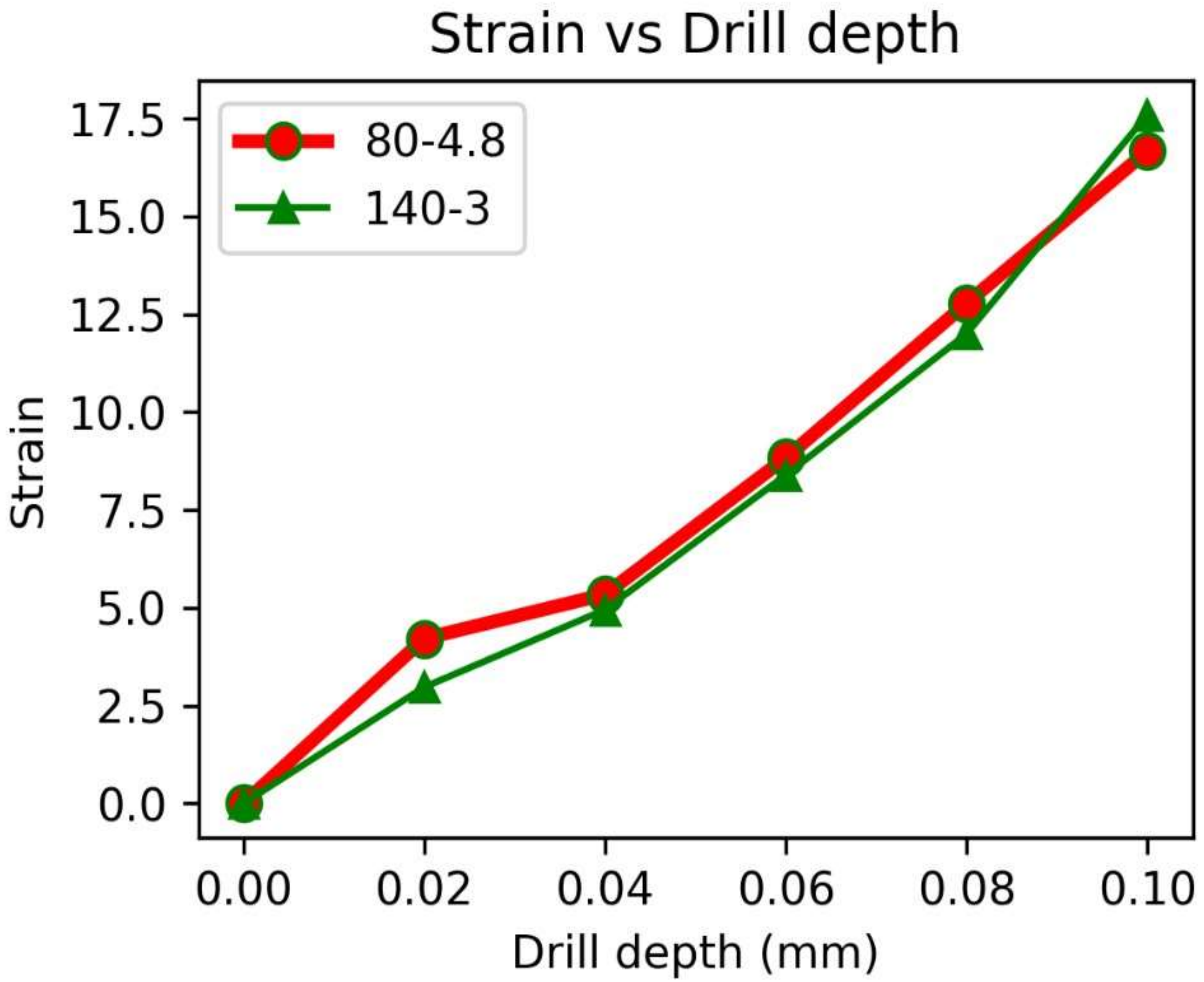
Comparison between Temperature and Spindle speeds with different feed rates



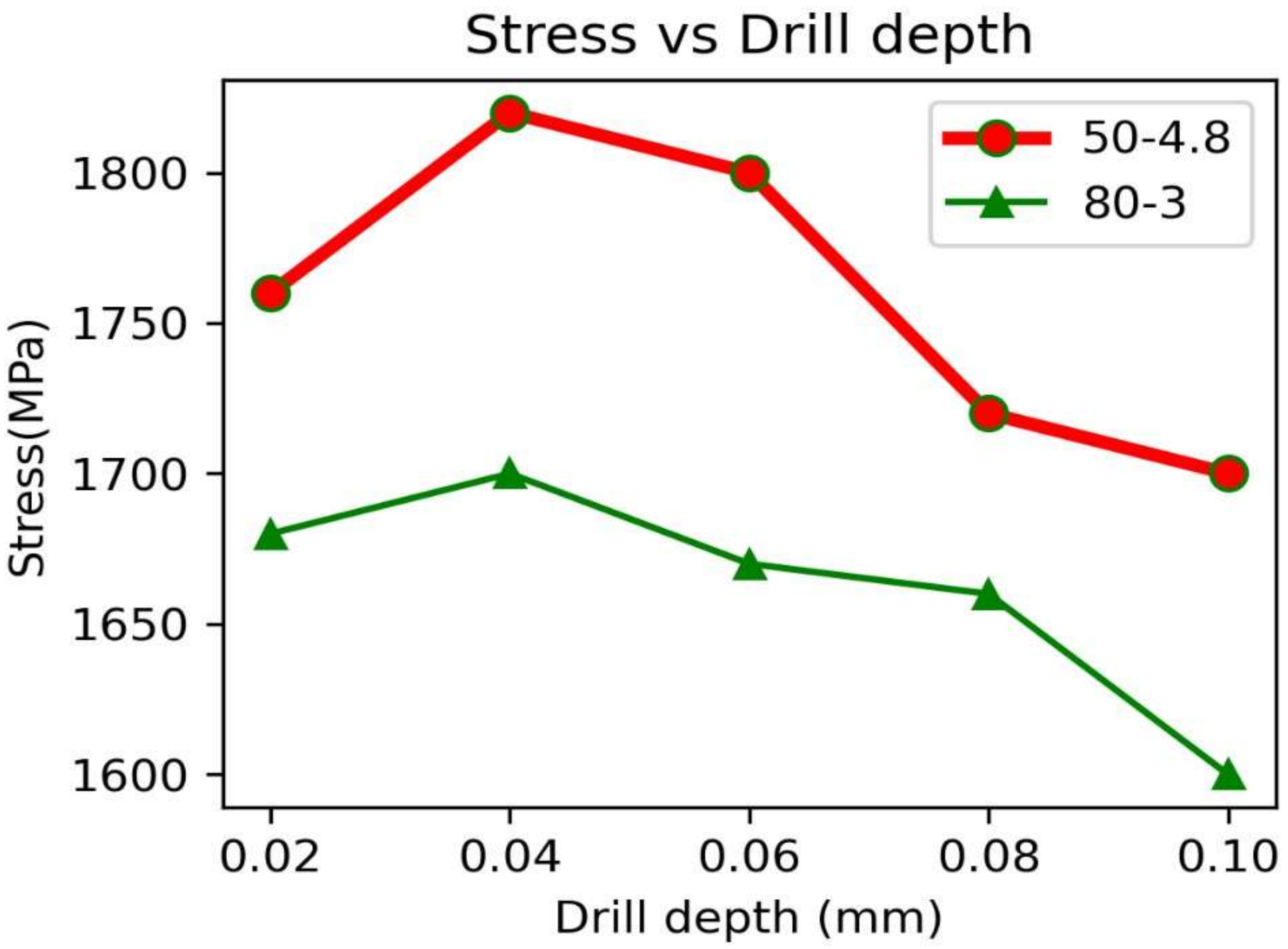
Comparison between Force and Spindle speeds with different feed rates



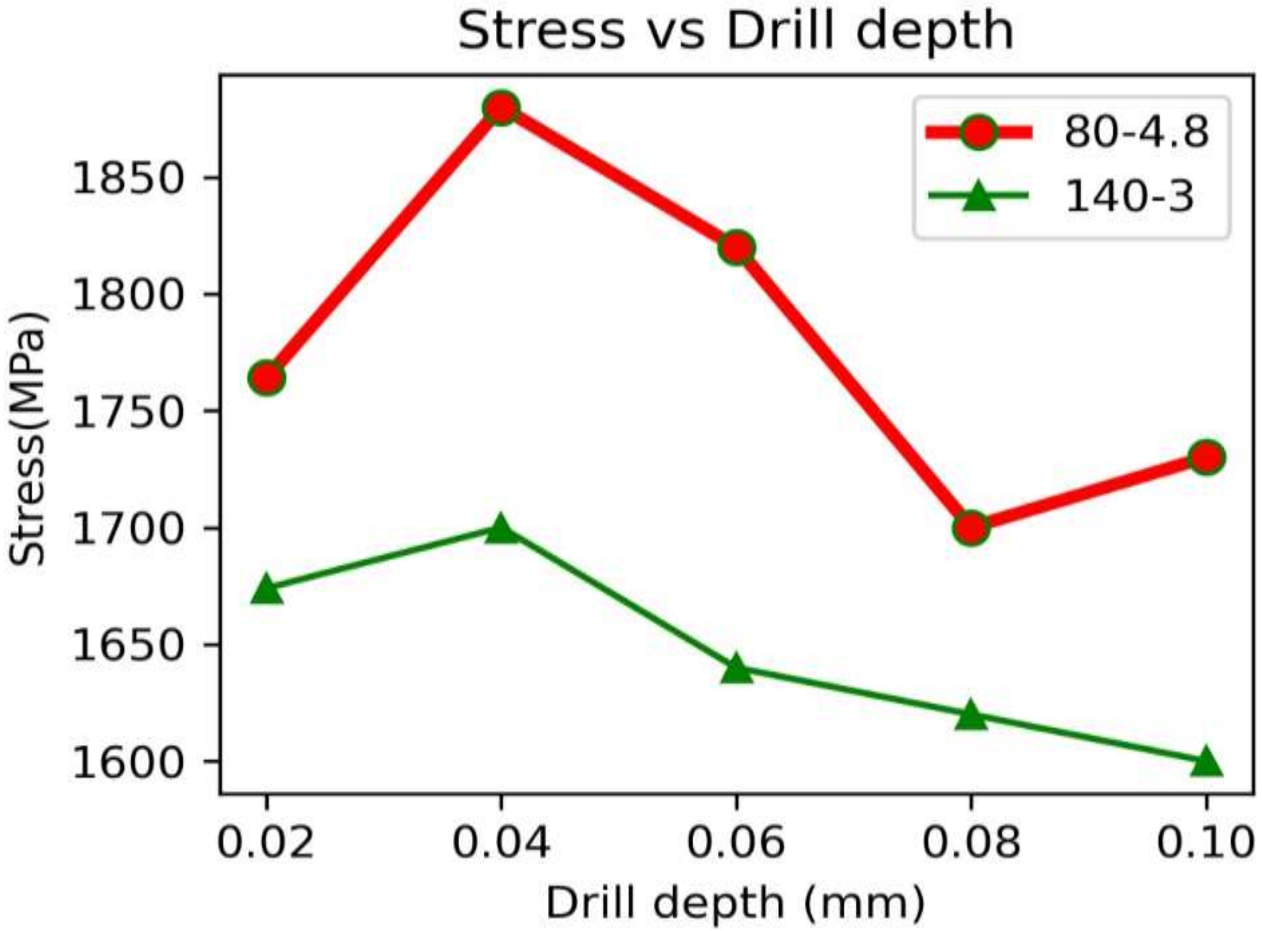
Graph between strain and drill depth. (50-4.8)- 50krpm and 4.8m/min, (80-3)- 80krpm and 3 m/min.



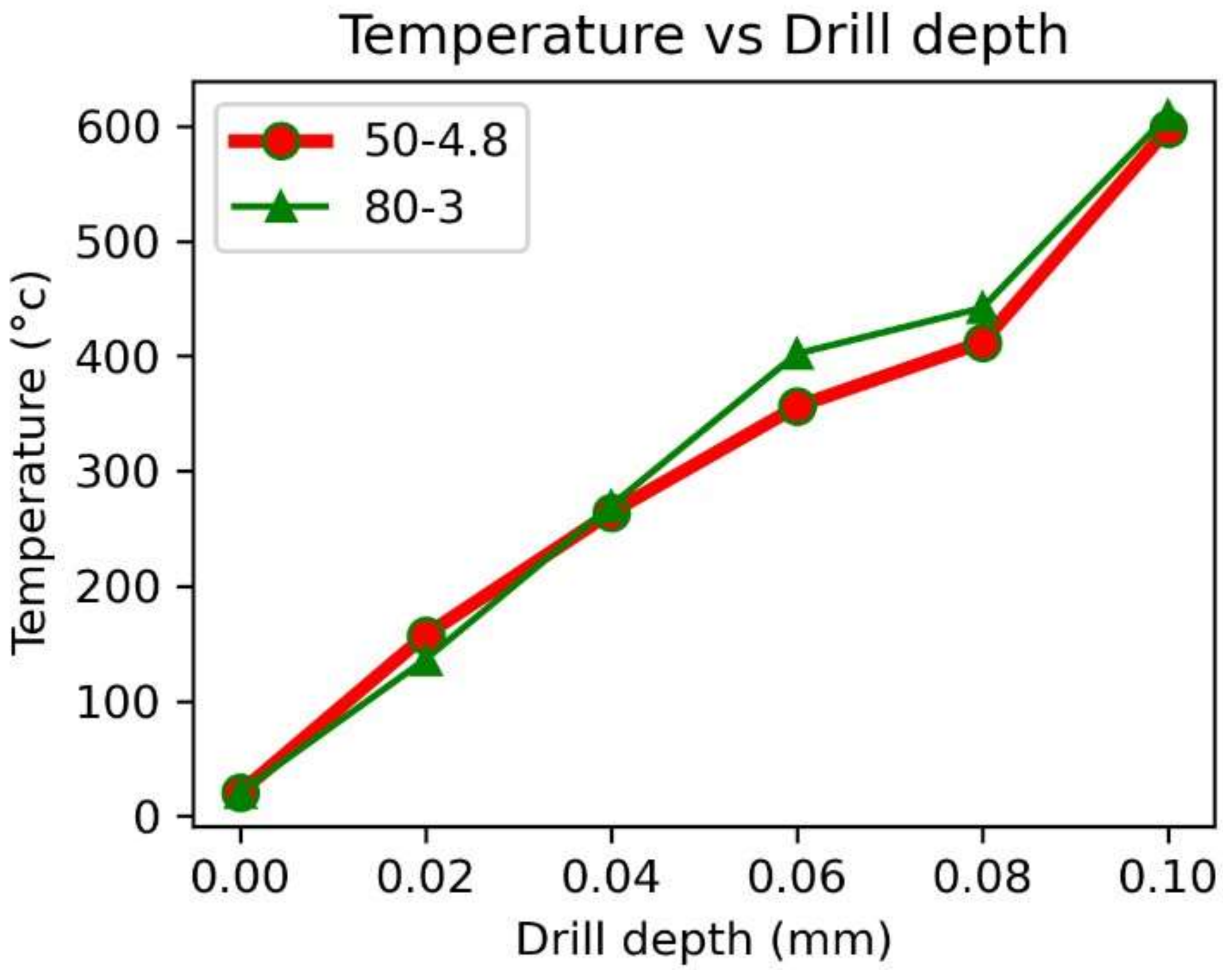
Graph between strain and drill depth. (80-4.8)- 80krpm and 4.8m/min, (140-3)- 140krpm and 3 m/min.



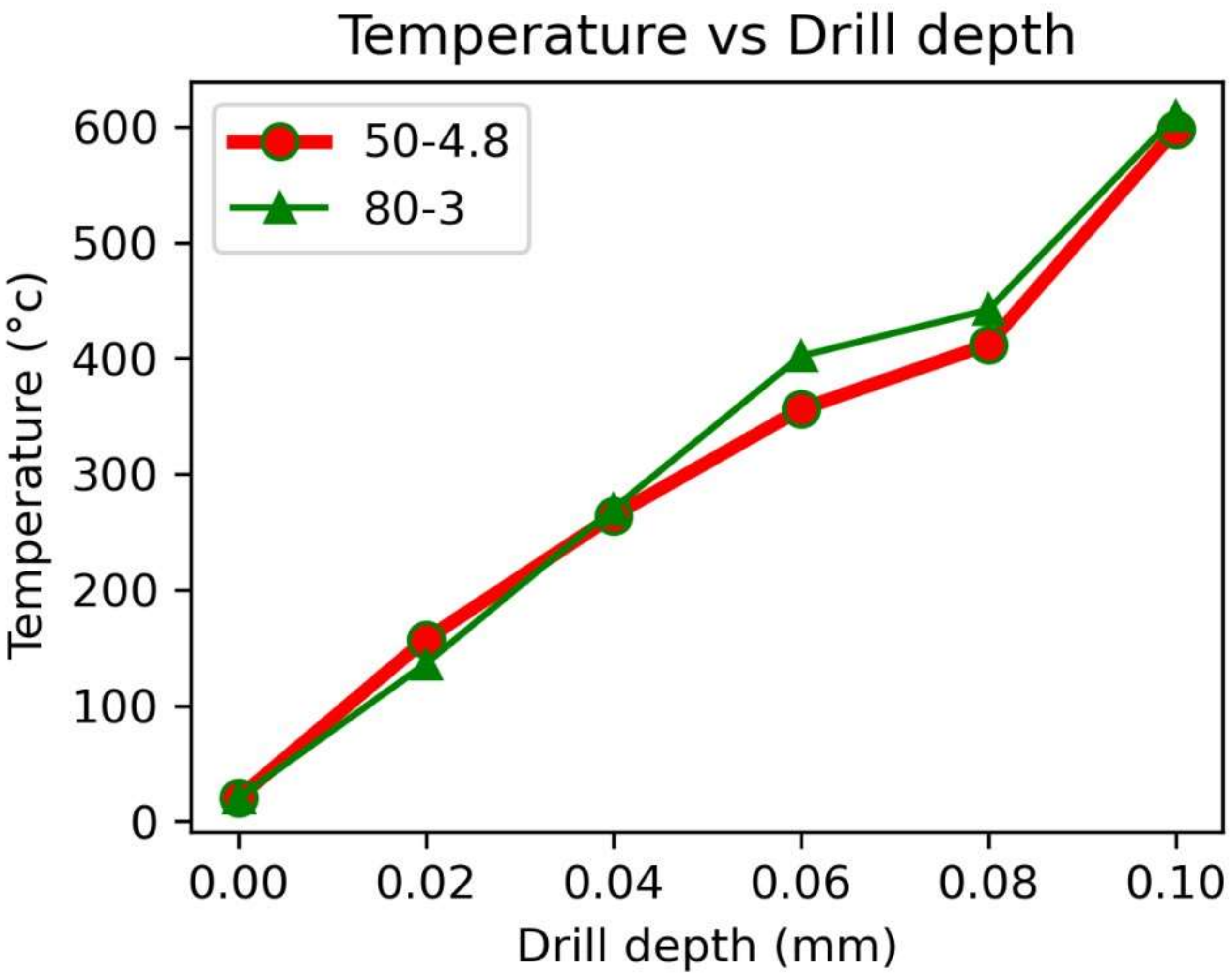
Graph between stress and drill depth. (50-4.8)- 50krpm and 4.8m/min,(80-3)- 80krpm and 3 m/min.



Graph between stress and drill depth. (80-4.8)- 80krpm and 4.8m/min, (140-3)- 140krpm and 3 m/min.



Graph between temperature in (°c) and drill depth. (50-4.8)- 50krpm and 4.8m/min,(80-3)- 80krpm and 3 m/min.



Graph between Temperature in (°c) and drill depth. (80-4.8)- 80krpm and 4.8m/min, (140-3)- 140krpm and 3 m/min.

Conclusion

- 1) The main cause of the rise in temperature, stress, etc., is the impact of feed rate.
- 2) The material model is crucial to the simulation process.
- 3) Due to adiabatic heating, increasing spindle speeds cause the temperature to rise and axial force on the tool to decrease.
- 4) The modified Johnson-Cook model gives acceptable results compared to the normal Johnson-Cook model.

Limitations

1) The size of the micro drill bit has a direct impact on the size of the workpiece. The size of the workpiece should be 20% to 50% larger than the size of the micro drill bit for chip removal. Additionally, the rpm for chip removal should be high.

2) Due to tool translational motion, the entire deformed material moves along the -ve Z direction if the Velocity boundary condition of the workpiece is not fixed in the Z direction.

3) We cannot notice the burr formation on the exit side if the workpiece's velocity boundary condition is fixed in the Z direction.

4) Large-sized workpieces can make adaptive meshing difficult. And the material removal from the workpiece is not visible to us.

5) If we select an elastic or elastoplastic material type, the simulation will take longer to run and chip removal will be more challenging.

6) Since Deform3D is primarily used to calculate values for stress, strain, temperature, and strain rate, we cannot expect the hole quality.

7) Simulated objects are thought to be made of the ideal material, free of any strain-hardening elements or residual stresses.

- Future work

1) If the simulation work's results coincide with those of the experiment, we can use the simulation technique by changing the parameters, which is safer than the actual work and less expensive.

2) Deform 3D software needs to be improved to detect chips in huge workpieces for the micro-drilling process

REFERNCES:

- I Rahamathullah and MS Shunmugam,” Thrust and torque analyses for different strategies adapted in microdrilling of glass-fibre-reinforced plastic”, DOI: 10.1243/09544054JEM2151.
- Jung Soo Nam, Pil-Ho Lee , Sang Won Lee,” Experimental characterization of micro-drilling process using nanofluid minimum quantity lubrication”, International Journal of Machine Tools & Manufacture 51 (2011) 649–652.
- M Imran, P T Mativenga, S Kannan, and D Novovic, “An experimental investigation of deep-hole microdrillingcapability for a nickel-based superalloy”, DOI: 10.1243/09544054JEM1217.
- “Hongyan shi, Hui Li and ShengZhi Chen” Temperature simulation and its application in on-line temperature measurement of micro drill bit (2014).
- “M. Hokka, D.Gomon, A.shrot, T. Leemet, M.Baker” Dynamic behaviour and high speed machining of Ti-6246 and alloy 625 superalloys: Experimental and modeling Approaches (2013).