FEM simulation of force during shaping operation

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Abstract:
A cantilever beam type load cell dynamometer was designed and fabricated using beam theory of bending for measuring forces during shaping operation. The strain gauges were used for forces at different load. The experimental data were recorded on a computer during all experiments. The designed dynamometer calibrated to measure cutting & thrust forces. 3D simulations of shaper machining are performed by using DEFORM 3D V-10.2 software. The effects of various back rake angles, various tool shape, and radius were analyzed for cutting force, thrust force and forces ratio by using single variable experiments. Theoretical analyses have done for cutting force, thrust force and ratio and results shown that similar trend observed with experimental results.

Keywords: *Force Analysis, Force ratio, shaping operation.*

1. INTRODUCTION

Analytical methods to solve the complex problem are not very easy and have their own limitations. Finite element method is one of the techniques to solve the complex problem. To analyzing any system, the system equations which describe the distributions of stresses are well known and are available, and can be solved for simple shapes such as triangular, rectangular etc.The available system equations cannot directly solve the complicated shape. Finite element method replaces this single complicated shape to approximate network of simple elements, .i.e. finite element mesh. The initial step to design FEM mesh is that we have to consider and select the type of element to be used such as one dimensional / two dimensional triangles or quadrilateral etc. All three-dimensional shapes are the combination of various types of elements. The accuracy of the calculation depends on the number of element, the smaller each one gives the more accurate result. Unfortunately, more elements required more calculations, hence it increases simulation time. Optimal solution is one in which the combination of enough element exists and adequate accuracy with reasonable computing time. After computing the optimal solution if we increase the number of element in FEM mesh, it increases the computing time only and will not improve the accuracy. It means the programme reaches towards convergence which is a essential requirement in the FEM solution [5].

FEM simulation is an innovative method for simulating the precision component in manufacturing industry as per the market requirement. FEM machining simulation can fulfill this requirement with reducing the cost of experimentation. FEM Machining simulation uses the flow stress model. These models are very important to predict chip formation, force analysis and thermal analysis during any machining process. Johnson cook model is one of the generalized important models in machining simulation. Johnson cook model calculates the flow stress by putting the value of Johnson cook constant from (*Split Hopkinson pressure bar)* SHPBtest for a particular material. These Johnson cook constants are known as plastic constants. Accuracy of the Johnson cook model depends on the plastic behaviors of the material.

2. Materal & Method

2.1 Simulation outlines

To depict the machining of workpiece by shaper machine, 3-D FEM simulation is carried out. For this modeling of shaper tool and workpiece is carried out in creo parametric software. This modeling is used to carry out the simulation. 3-3D simulations of shaper machining is performed by using DEFORM 3D V-10.2 software. Result of forces obtained by simulation compared by experimental results.

2.2 Parameters setting for simulation

Initial input parameters for simulationstudy are listed in Table 4.1

Table 4.1 Machining parameter for shaping simulation study

S.No	Machining parameter	Value
1	Cutting speed(m/min)	5.34
2	Feed (mm/stroke)	0.3
3	Depth of cut, mm	0.5

2.3 Cutting model used for simulation

Metal cutting process is a cutting deformed process of material, and usually identified as plastic strain. Generally, Johnson-Cook model used for material flow stress modeling in metalcutting simulations. The equation of Johnson cook model is given as below.

$$\sigma = (A + B\epsilon^{n}).\,(1 + C\log\frac{(\epsilon^{\cdot})}{(\epsilon_0\ )}).\,[1-(\frac{T-T_0}{T_{m-T_0}})^{m}] \quad (3.3)$$

Where, A = Yield strength of the material,B= Strain hardening modulus,

C= Strain rate sensitivity constant, $\in^{*}$= plastic strain, $\epsilon^{\cdot}$= strain rate,

ϵ_0 = Reference plastic strain rate, T = Workpiece temperature, T_m = Melting temperature,

T_0 = Room temperature, m = Thermal softening coefficient, n= Strain hardening index

For mild steel 1018 workpiece, standard value of A, B, C, n, m constant are listed in the Table 2.

Table 2 Johnson cook model constant for mild steel 1018 workpiece material [8]

Initial yield stress(A),MPa	Hardening modulus(B),MPa	Strain sensitivity index, (C)	Strain hardening index, (n)	Thermal softening constant, (m)
217	234	.076	0.643	1

2.4 Simulation procedure

Machining model with SI system is selected for shaping process. In simulation finite element tetrahedral mesh type with 32000 elements are selected for the workpiece. Work piece geometry created by using geometry primitive process. Tool modelling is done in creo parametric software and saved the tool geometry file in STL format. Deform 3D uses this STL file by importing from saved path. All surface of work piece are considered with free convective environment having value of convective coefficient as equal to 40w/m^2°C and ambient temperature of 30°C. Simulated cutting tool speed is given 89 mm/sec by using movement command. Movement of work piece considered fixed from base of the work piece in x, y, z direction i.e. by putting velocity zero in x, y, z, direction for base. Figure 1 shows simulation windows in which tool and workpiece geometry are created for further processing in simulation. For this finite simulation modelling in intra object tool, coulomb friction can be selected between 0.4-0.6, in our work 0.6 value is selected.

The simulation control is carried out by deciding the completion or tool displacement time of simulation. If tool displacement per step is too high, leads to less accurate result and tool displacement is too low it increases the simulation time. By setting the tool displacement per step, this is taken as 1 to 3 % of feed or 0.075 which is automatically set by software. As soon as step of preprocessor completes, it generates a data base and simulation starts.If preprocessing find error at any step, the data base file will not be generated, and screen shows an error massage.

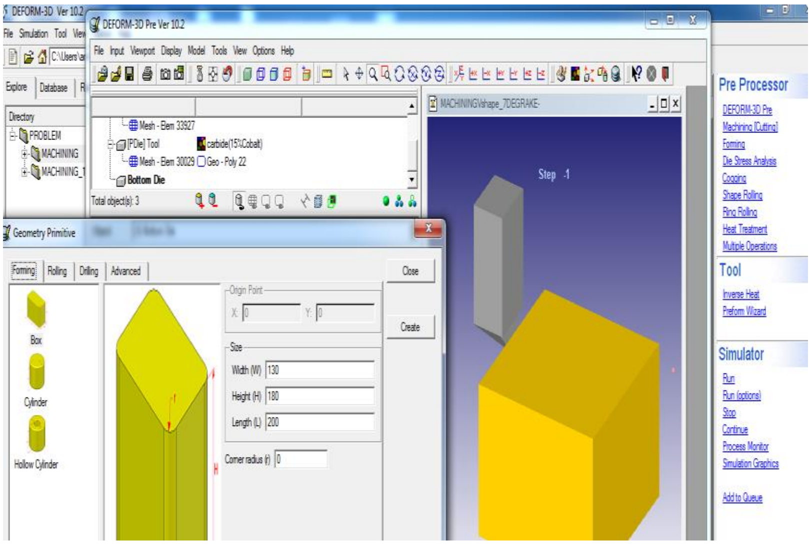


Fig.1 shows simulation windows

After debugging the error preprocessor will generate again a new data base file and simulation starts from the first step. As soon as the tool passes one complete cut over the whole length of the workpiece, distribution of tool chip interface temperature and cutting and thrust force magnitude will be displayed on screen by post processor.

(Experimental condition) Speed = 5.34 m/min, Feed = 0.3 mm/stroke, Depth of cut = 0.5 mm Back rake angle = 3°
(For V- shape tool)

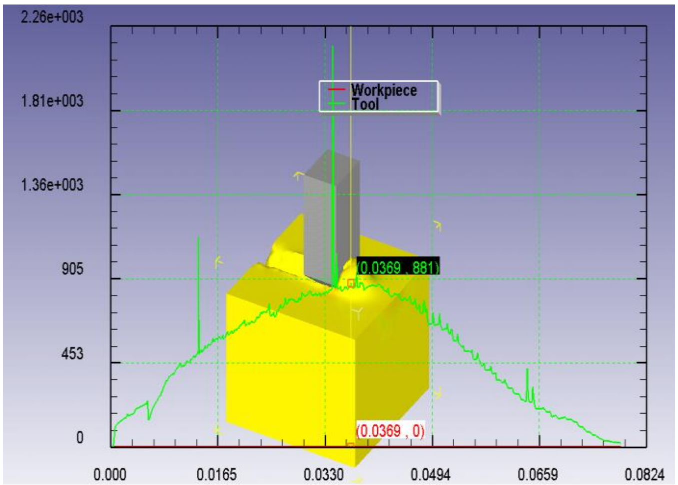
3.1 3D FEM simulation

Fig.2 and Fig. 3 shows simulated pictorial graph for cutting and thrust force during shaping operation. Force reading recorded, when simulation reaches to a steady state condition. Vertical yellow line represents the maximum cutting and thrust force during the machining. In initial stage of cutting the tool comes in contact with the workpiece and forces start increasing on the tool tip. As soon as the process further progresses for cutting, the maximum cutting force attains after reaching the steady state condition. After steady state the force decreases and reaches to zero at the end of cutting stroke. From the simulation graph, maximum, minimum, and average force value drawn and a sample value listed in Table 3.

Table 1 Simulated values for cutting and thrust force

Simulated Reading	Cutting Force, F_p(N)	Thrust Force, F_q(N)
Maximum	881	332
Minimum	199	48.40
Average	540	190.2

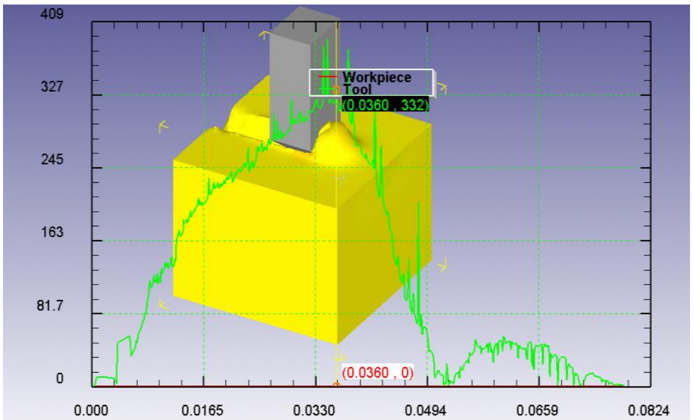
Cutting force (N)



Simulation time, (sec.)

Fig. 2 Simulated cutting force v/s simulation time during machining

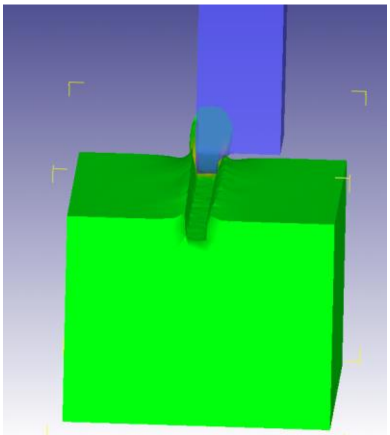
Thrust force (N)



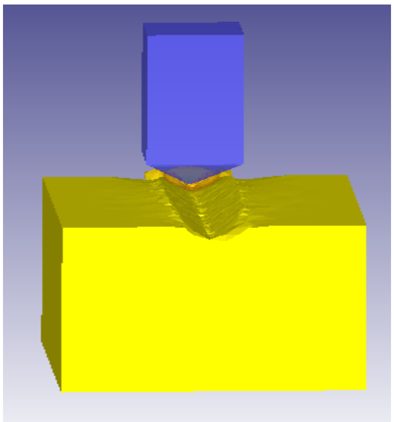
Simulation time, (sec.)

Fig.3 Simulated thrust force v/s simulation time during machining

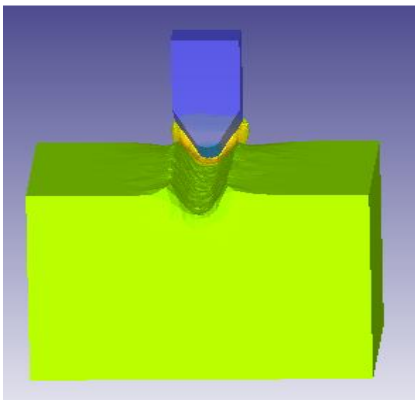
Following picture shows the slot / groove generated from simulation for machining of workpiece with various shapes of tool in DEFORM 3D software. The simulated machined slot was obtained of the same shape as of the tool.



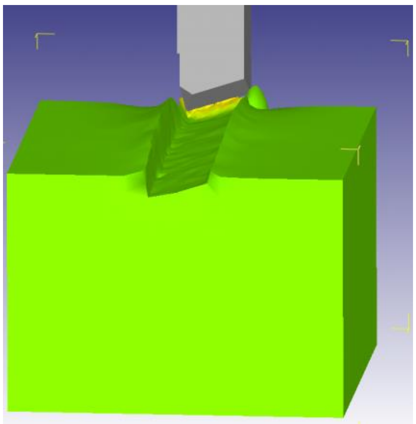
(a) Slot by Parting tool



(b) Slot by V-shape tool



(c) Slot by Radius (2.5mm) tool



d) Slot by Right Knife tool

Fig. 4 Machining in simulation with various shapes of tool.

3.2 Simulation for various back rake angle of tool

(a) Cutting force

In Table 4 appendix (A) data presented for simulated, experimental and theoretical value for cutting force.

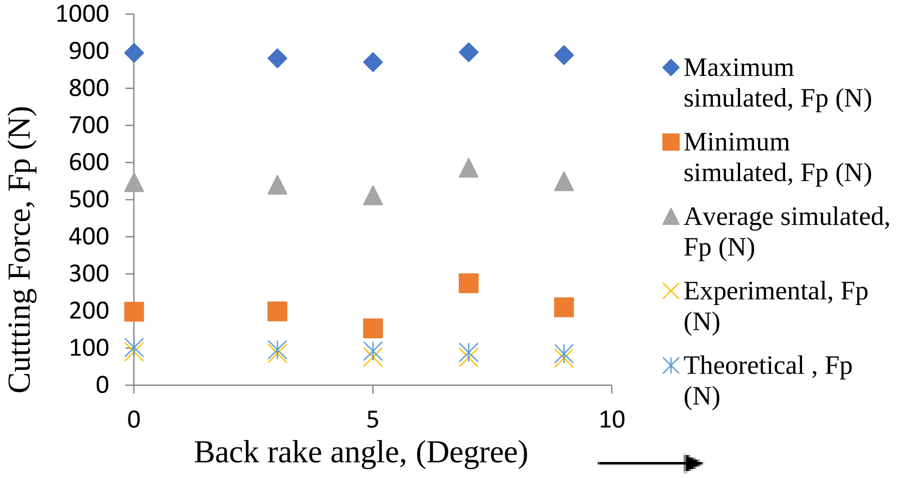


Fig. 5Simulated cutting force v/s back rake angle.

It can be seen from Fig. 5 that graph showing the variation between cutting force v/s various back rake angle of tool. The simulation results for maximum, minimum and average experimental value and theoretical value of cutting forces are plotted in the point form only. The result shows that simulated results, experimental results and theoretical results are nearly close, with a good degree of agreement between the all values and almost similar trend of variation with back rake angle of tool is observed.

(b) Thrust force

In Table 5 appendix (A) data presented for simulated, experimental and theoretical value for thrust force with various back rake angle of tool.

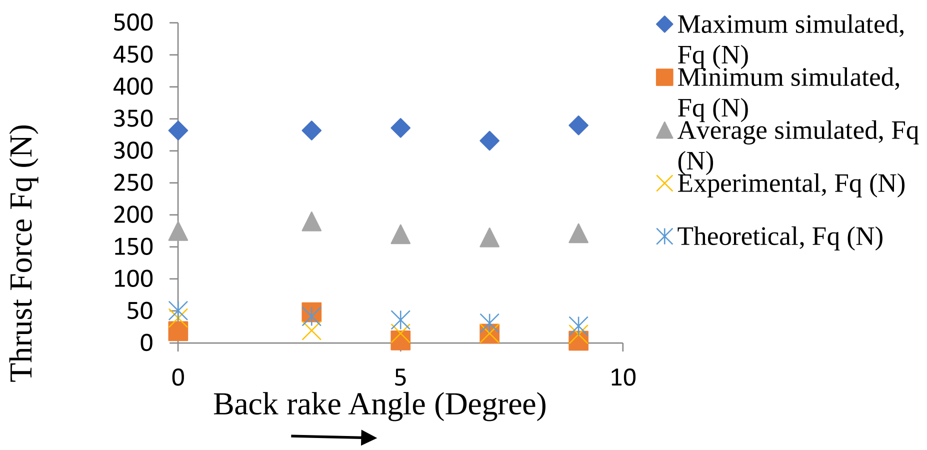


Fig. 6 Simulated thrust force v/s back rake angle.

From Fig.6 it can be seen that graph showing the variation between thrust force v/s various back rake angle of tool. The simulation results for maximum, minimum, and average value of thrust force values are plotted in point form only. Results show that simulated results, experimental results and theoretical results are nearly close. Data shows similar trend of variation and a good degree of agreement between all the results.

(c) Force ratio

Force ratio is the ratio of thrust force and cutting force, i.e. cofficient of friction as per well established theory in metal cutting. This is an important parameter to visualize insight of machining process.In table 6 appendix (A) data presented for simulation, experimental and theortical value for force ratio with various back rake angle of tool.

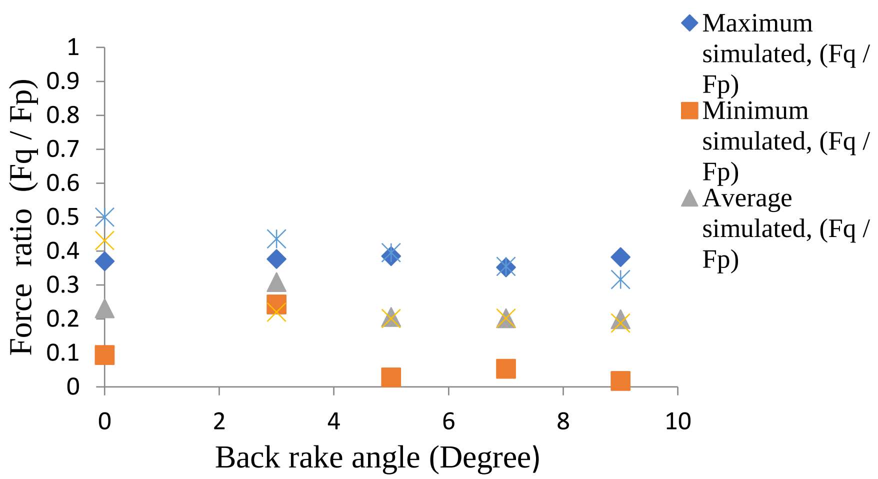


Fig.7 Simulated force ratio v/s back rake angle.

It can be seen from Fig. 7 that simulation results, experimental results and theoretical results are nearly closed. Results are in a good degree of agreement.

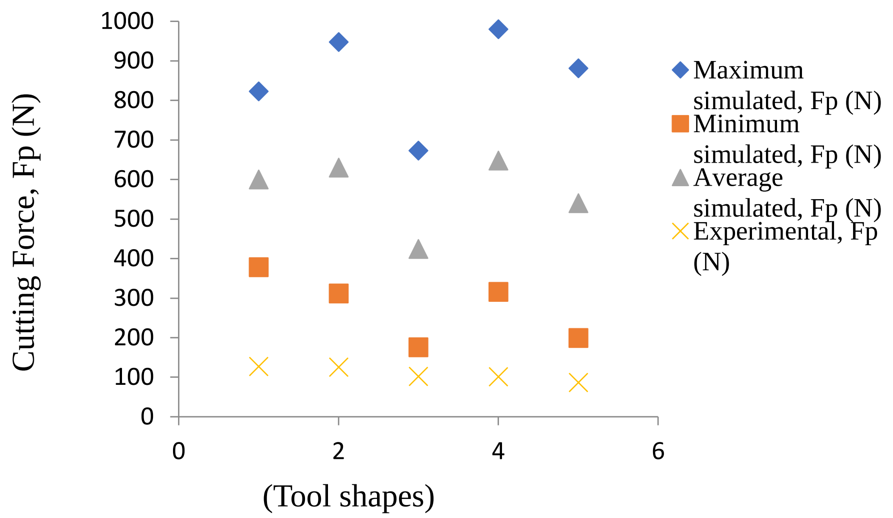
The variation of data trend is also showing similar variation between simulation, experimental and theoretical results i.e. as the back rake angle of tool increases the force ratio decreases.

3.3 Simulation for various tool shapes

(a) Cutting force

As explained earlier in 3.1, the simulation of machining with various tool shapes for machining different shape of slot.

In simulation study for tool shape, cutting force, thrust force and force ratio recorded as listed in Table 7 in appendix (A).



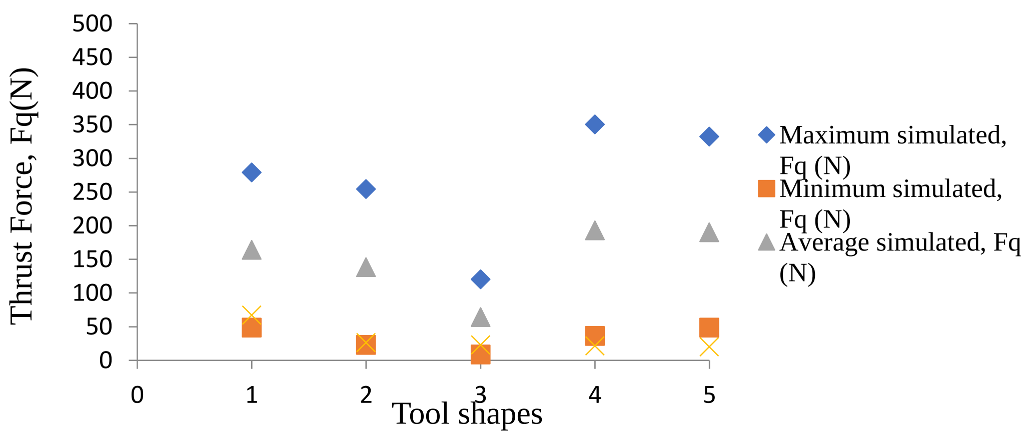
1.Radius 2. Grooved .3.Parting 4.Right knife 5. V-shape

Fig. 8 Simulated cutting force v/s shapes of tool

It can be seen from Fig.8 that graph is between cutting force v/s various shapes of tool. The simulated and experimental results for cutting forces are plotted in the point form only. Results show that simulated and experimental result are nearly closed and show a good degree of agreement between the values. Simulation data variations are similar as of experimental data variation.

(b) Thrust force

Simulated and experimental results of thrust force with various shapes of tool are listed in Table 8, in appendix (A).



1.Radius 2. Grooved .3.Parting 4.Right knife 5. V-shape

Fig. 9 Simulated thrust force v/s shapes of tool

It can be seen from Fig 9 that graph is between thrust force v/s various shapes of tool. The simulated and experimental results for thrust forces are plotted in the point form only. Results show that simulated and experimental results are nearly close and show a good degree of agreement between the values.

(c) Force ratio

Simulated and experimental values of force ratio with various shapes of tool are listed in Table 9, in appendix (A).

It can be seen from Fig. 10 that graph is between force ratio v/s various shapes of tool. The simulated and experimental results for force ratio are plotted in point form only. Results show that simulated and experimental results are nearly close and show a good degree of agreement between the values.

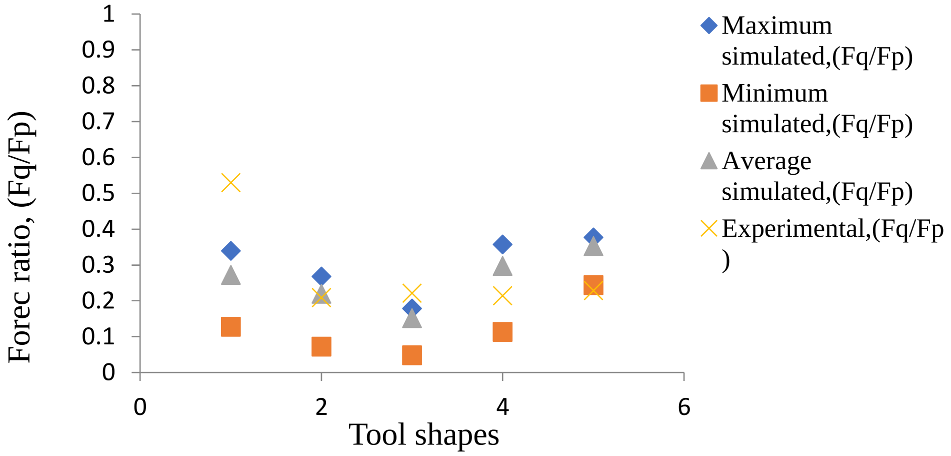


Fig. 10 Simulated force ratio v/s various shapes of tool

3.4 Simulation for various tool nose radius

(a) Cutting force

In Shaper machining tool nose radius is important from the strength point of the tool,which affects the impact force during machining.Tool nose radius also affects the surface quality which is generated by shaper machine, large the nose radius increases the force.Simulated and experimental results of cutting force values shown with various tool nose radius are listed in Table 10, in appendix (A).

It can be seen from Fig 11 that graph is between cutting force v/s various tool nose radius. The simulated and experimental results for cutting forces are plotted in point form only. Results show that simulated and experimental results are nearly close and show a good degree of agreement between the values.

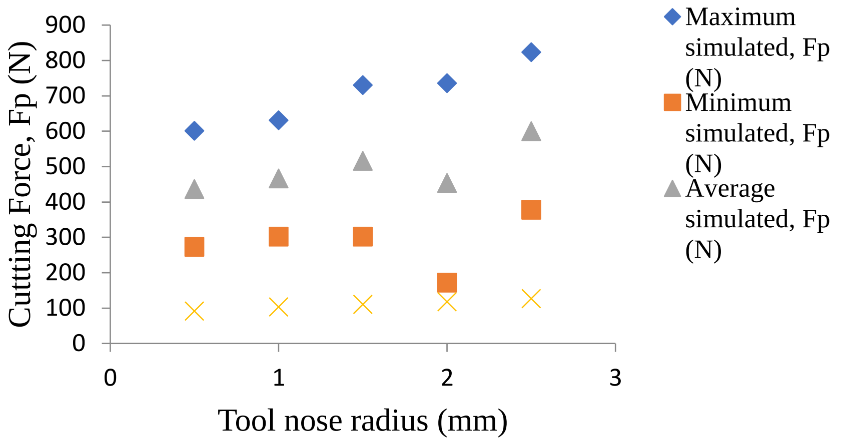


Fig. 11 Simulated cutting force v/s tool nose radius.

a) Thrust force

Simulated and experimental results of thrust force with various tool nose radius are listed in Table 11, in appendix (A).

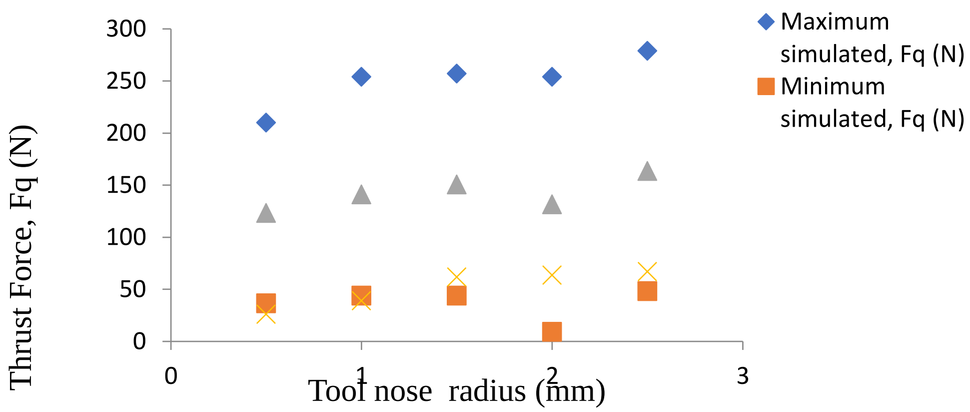


Fig.12 Simulated thrust force v/s tool nose radius.

It can be seen from Fig. 12 that graph is between thrust force v/s various tool nose radius. The simulated and experimental result for thrust forces are plotted in the point form only. Results shows that simulated results and experimental results are nearly close and show a good agreement between the values, and variation of data trend is almost of similar pattern.

(C) Force ratio

Simulated and experimental results of force ratio with various tool nose radius are listed in Table 12 in appendix (A).

It can be seen from Fig.13 that graph is between force ratio v/s various tool nose radius. The simulated and experimental results for forces ratio are plotted in the point form only. Results show that simulated value and experimental value are nearly close and show a good agreement between the values.

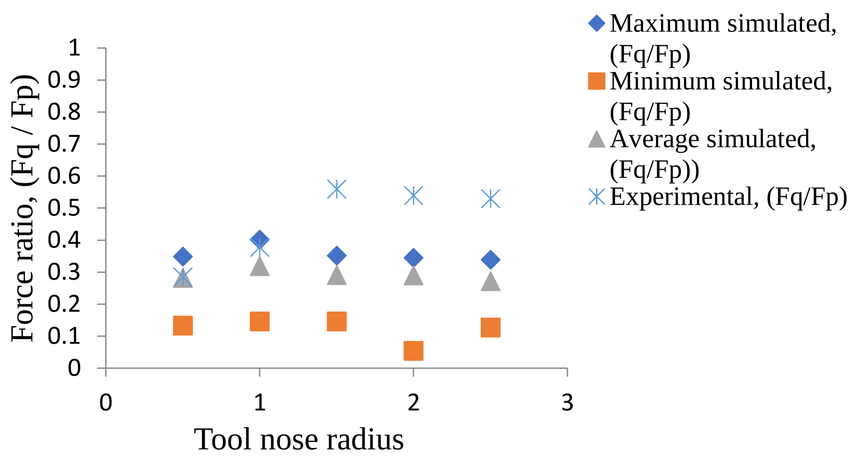


Fig. 13 Simulated force ratio v/s tool nose radius

4. Conclusion of FEM simulation

- Simulation results obtained are plotted in the form of point only to check the closeness of the simulated value and experimental value. These are found to be close in within range.
- Johnson cook model is found to be fit for analyzing simulation behaviour during machining.
- Variation of cutting and thrust force and force ratio graph presenting the simulation process behaviour found well comparable with experiments results for the shaping operation. Results are in good agreement.
- Simulation results for force ratio are compared with experimental result and found that simulation results for back rake angle, tool shape, tool nose radius are 1.64 times, 1.2 times, and 0.83 times of experimental results respectively. In summarized, we can say that average simulated results are 1.22 times of experimental results.

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