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Numerical Simulation and Comparison of Carbide and HSS Tool Wear Rate while Drilling with Difficult to Cut Super Alloy Titanium Based on Archard Model

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Abstract— *A Carbide and HSS tool wear rate simulation using Archard´s wear model is proposed, finite element modelling is done using commercial finite element software ABAQUS/explicit. ABAQUS interface was used to simulate the contact pressure. For measuring wear depth of tool's, drilling operation is performed experimentally then wear depth is measured on profilprojecter. Comparing the wear rate, based on Archad model. Result model shows that at 2000 rpm, 0.15 mm/rev feed rate and 45 mm drilling length Carbide tool is suited but at 3000 rpm, 0.20 mm/rev feed rate, 45 mm drilling length and 4000 rpm, 0.25 mm/rev feed rate, 55 mm drilling length HSS tool is suited because of lower wear rate than Carbide tool.*

Keywords— Finite Element Analysis, Titanium Drilling, Archard´s Model, Wear Rate, Carbide and HSS Tool.

I. INTRODUCTION

Titanium alloys are used extensively in aerospace, automobile and medical application because of combined high special strength (strength-to-weight ratio), fracture-resistant characteristics and exceptional resistance to corrosion. However, titanium alloys are usually considered as extremely difficult to cut material because of their low thermal conductivity and high chemical reactivity with cutting tool materials. Tool wear is major issue in dealing with titanium.

Being one of the new hole-machining methodologies, drilling is widely used machining process, which account for 40-60% of total material removal process. In the past, lot of experiments need to be conducted to obtain a series of related data during the drilling studies, which bring about huge raw material consumption. Finite Element simulation can not only save the raw material but also improves accuracy of result. Furthermore, finite element analysis can also obtain the measured data which is difficult to obtain in experiment.

In this study, A 3D finite element model of drilling of titanium alloy with carbide and HSS tool is developed using ABAQUS. The FE model is based on Lagrangian formation with explicit integration method. The simulation are conducted under different rpm, feed rate and length of drilling in order to analyze and compare the wear rate of Carbide and HSS tool based on Archard´s model.

II. WEAR MODEL

Tool wear is major issue in production process which can be minimized up to some extent by selection of correct tool at appropriate process parameter. For predicting wear rate Archard wear low is most commonly used which is expressed as [5]:

$$k_D = V / F_N . s \qquad (1)$$

Where k_D dimensional wear rate, V is the wear volume, F_N is the normal load, s is the sliding distance:

$$k_D = A . \Delta h / F_N . s \qquad (2)$$

V is replaced here by A, area and Δh is wear depth

$$k_D = \Delta h / (F_N/A) . s \qquad (3)$$

While F_N/A is local contact pressure expressed as P

$$k_D = \Delta h / P . s \qquad (4)$$

The process of wear rate calculation is begins by calculation of contact pressure between contact surfaces, the commercial ABAQUS analysis software is implemented to calculate the contact pressure. The wear height is calculated experimentally and then equation (4) is used to calculate wear rate. The flow chart of the finite element wear simulation procedure consisting of steps shown in figure1, the drilling parameter used for finite element simulation and experiment were in Table1.

Table.1: Process Parameter

Process Parameter	LEVEL 1	LEVEL 2	LEVEL 3
Spindle speed (rpm)	2000	3000	4000
Feed rate (mm/rev)	0.15	0.20	0.25
Length of drilling (mm)	35	45	55

III. FINITE ELEMENT MODEL

In this study a 3D models of drilling process is developed using a commercial finite element software ABQUS/Explicit. Due to the dynamic nature of the process, dynamic explicit element integration has been proposed for this study. Details of FE model are discussed as follows.

A twist drill bit with two cutting edges was adopted in drilling process. Geometric parameter of drilling tool were: the diameter is 3.1 mm, rake angle 20°, clearance angle 25°, helix angle 25° and tip angle 135°.The finite element model of work piece geometry dimension is 6.1 mm diameter and 55 mm length. The work piece and tool are set same as the actual working condition for both Ti-Carbide and Ti-HSS. Here work piece is created with deformable part interfacing with drill bit for FEA analysis. The coulomb friction model is used and constant friction coefficient 0.1 for Ti-Carbide and 0.15 for Ti-HSS is used. The tool is having rotational moment while the work piece is fixed in all direction, the encaster (U1=U2=U3=UR1=UR2 =UR3=0) loading condition is given. The overall FE model is shown in Figure 2.

3.1 Property Model

To model the thermo-visco plastic behavior of titanium alloy Ti6Al4V, the Johnson-Cook material law was used for material constitutive model of finite element simulation, which assumed a von misses type yield criterion and an isotropic strain hardening rule. This relationship given by following equation (5).

$$\sigma = [A + B(\varepsilon^n)][1 + C ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}] [1- (\frac{T-T_{room}}{T_{melt}-T_{room}})^m] \quad (5)$$

where σ was the flow stress; ε is the plastic strain, $\dot{\varepsilon}$ is the strain rate (s-1), $\dot{\varepsilon}_0$ is the reference plastic strain rate (s-1), T is the temperature of work piece (°C), T_m is the melting temperature of the work piece (°C), T_{room} is the room temperature (°C). Coefficient A is the yield strength (MPa), B is the hardening modulus (MPa), C is the strain rate sensitivity coefficient, n is the hardening coefficient, m is the thermal softening coefficient.

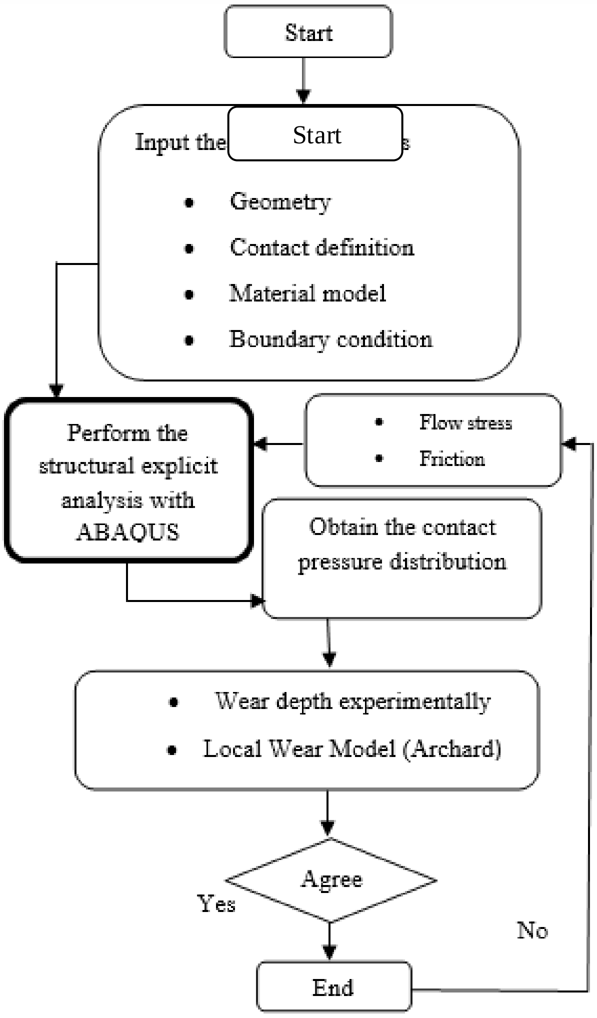

Fig.1: Flow Chart of Wear Rate Simulation.

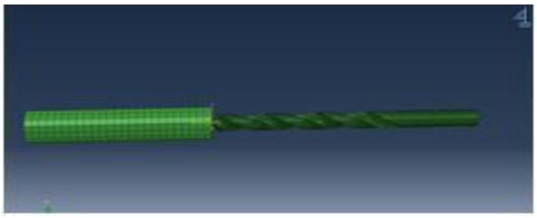

Fig.2: FEA Model.

As the plastic strain reached to its maximum value, damage is initiated. The equivalent plastic strain at the damage is calculated from the equation (6).

$$\varepsilon_D^{-pl} = \left[d_1 + d_{2exp}\left(d_3 \frac{p}{q}\right)\right] [1 + d_4 \ln(\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\varepsilon}_0})(1 + d_5 \frac{T-T_{room}}{T_m-T_{room}}) \quad (6)$$

Where d_1-d_5 are the failure parameters of Johnson-Cook damage model, p is the hydrostatic pressure, q is the Misses stress, $\dot{\varepsilon}_0$ is the reference strain rate, and $\dot{\bar{\varepsilon}}^{pl}$ is the strain at the time of failure [4].

Johnson-Cook constitutive material model and damage model parameter of Ti6Al4V are given in the

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Table 2. The properties of the work piece and tool material used in this study are given in Table 3

Table.2: Johnson-Cook Constitutive Material Model and Damage Model Parameter of Ti6Al4V.

A (Mpa)	**782.7**
B (Mpa)	498.4
C	0.028
n	0.28
m	1
d_1	-0.09
d_2	0.25
d_3	-0.5
d_4	0.014
d_5	3.87

Table.3: Material Properties.

Material properties parameters	Ti6Al4V	Carbide	HSS
Density (kg/m^3)	4420	1570	8140
Young modulus (Pascal)	122,000,000,000	669,000,000, 000	207,000, 000,000
Poisson ratio	0.31	0.26	0.27

IV. EXPERIMENTAL SET UP

A series of experiment was conducted to evaluate the wear depth of Carbide and HSS tool. The test was carried out on DECKEL MAHO-DMC 835V (continues speed up to 14000 rpm and 14kw spindle power) CNC machining center. After drilling operation is done the tool wear depth is measured using profile projector, by comparing the dimension of tool before and after drilling operation wear depth is measured. Figure 3 shows experimental setup of drilling.

(A)

(B)

Fig.3: Photograph of Experimental Setup (A) Profile Projector (B) Drilling Setup.

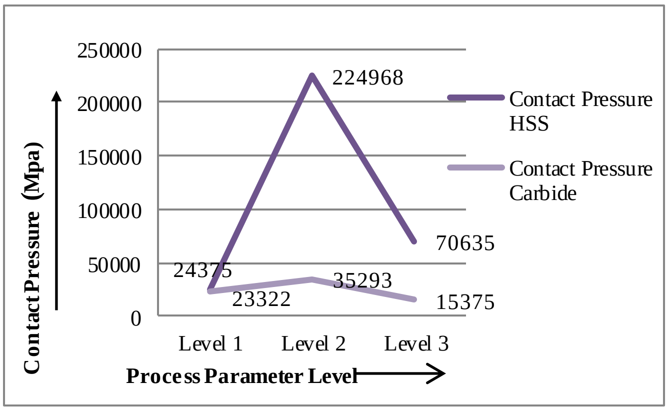
V. RESULT AND DISCUSSION

5.1 Contact Pressure

The FE model provides a result of contact pressure, the following figure shows the variation contact pressure with different level of process parameter for both Ti6Al4V-Carbide and Ti6Al4V-HSS obtained from simulation respectively,

As shown in figure 4, 5, 6 the result showed that while drilling at all process parameter level 1, level 2 and level 3 the maximum contact pressure is for Ti6Al4V-HSS that is 24375, 224968, 70635Mpa.

While drilling with Ti6Al4V-Carbide the graph showed that at initial drilling condition contact pressure is maximum but as process parameter increases the contact pressure decrease.



Graph 1 Contact Pressure vs. Process Parameter at different Levels.

The graph 1 showed that there is variation in contact pressure that is at level 1 for Ti6Al4V-HSS contact pressure is 24375 Mpa at level 2 there is large amount of increase in contact pressure up to 224968 Mpa and at level 3 the contact pressure is decreases up to 70635 Mpa.

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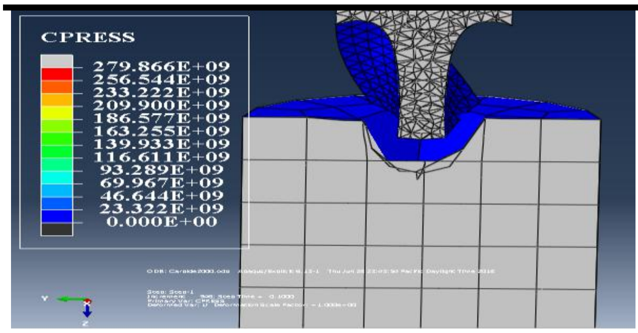
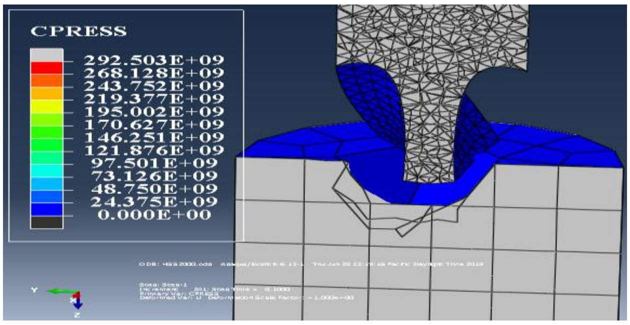
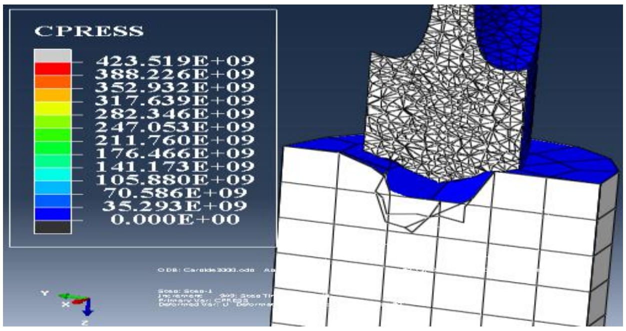


(A)

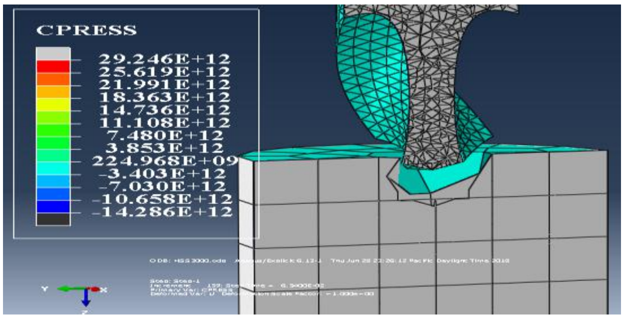


(B)

Fig. 4: Contact Pressure at Level 1 (A) Ti6Al4V-Carbide and (B) Ti6Al4V-HSS.

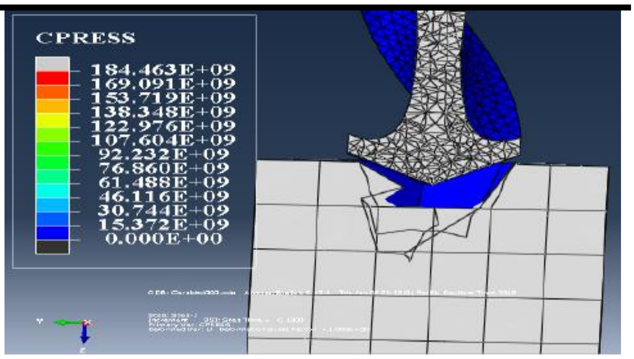


(A)

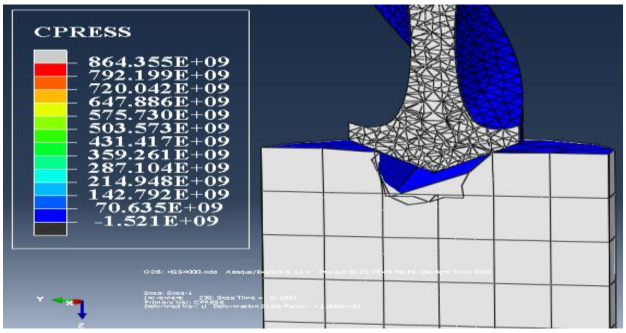


(B)

Fig. 5: Contact Pressure at Level 2 (A) Ti6Al4V-Carbide and (B) Ti6Al4V-HSS.



(A)



(B)

Fig. 6: Contact Pressure at Level 3 (A) Ti6Al4V-Carbide (B) Ti6Al4V-HSS.

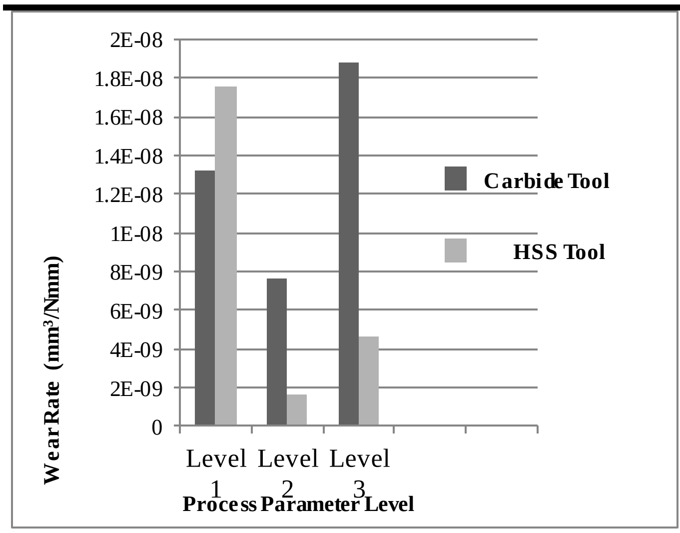
5.2 Wear Rate

Wear rates of Carbide and HSS tool at different process parameters are calculated according to Archard wear model as shown in following Table 4:

Table.4: Wear Rate Comparisons.

	Wear Rate (mm^3/Nmm)	
Level	Ti6Al4V-Carbide	Ti6Al4V-HSS
1	1.317E-08	1.756E-08
2	7.630E-09	1.631E-09
3	1.885E-08	4.675E-09

Table shows the variation of tool wear rate with Archard model the comparison can be done between both Carbide and HSS tool. That is at level 1 the wear rate of HSS tool is greater than Carbide tool that is 1.756E-08 mm^3/Nmm and at level 2 and level 3 wear rate of Carbide tool is more than HSS up to 1.885E-08 mm^3/Nmm.



Graph 2 Wear Rate Comparisons Between Carbide and HSS.

From level 1 to level 2 wear rate of both tool is reduced but at level 3 wear rate of both tool is increased. The maximum wear rate that is 1.885E-08 of Carbide tool occur at 4000 rpm, 0.25 mm/rev feed rate and 55 mm drilling length.

VI. CONCLUSION

The conclusion can be drawn as follows:

(1) A three-dimensional finite element model of drilling process is developed for Ti6Al4V with two cutting tools carbide and HSS. Comparison of both tool wear rate is done based on Archard model.
(2) The contact pressure changes are compared for both tools. At selected level of process parameter, the contact pressure of HSS tool is more than Carbide tool. The maximum contact pressure is 224968 Mpa of HSS tool occur at 3000 Rpm, 0.25 feed rate and 45 mm drilling length.
(3) Also the wear depth of Carbide and HSS tool are calculated experimentally,
(4) Archard wear model showed that at initial rpm 2000, feed rate 0.15 mm/rev and drilling length 35mm Carbide tool is suited, but at 3000 rpm, 0.20 mm /rev feed rate, 45mm drilling length and 4000 rpm, 0.25 mm/rev feed rate, 55 mm drilling length HSS tool is suited because of lower wear rate than Carbide tool.

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