Design, Develop and Simulate Microdrilling Cutting Tool

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Abstract. Microdrilling has an important role in the world of modern industry, especially in terms of miniaturizing existing products or components. Through this research explain the design, development of design and simulate microdrilling cutting tools. By using four geometries that are different from the previous model of microdrilling tools, a development, modeling and simulation were carried out and analyzed using Finite Element Analysis (FEA) using ABAQUS Software. Titanium alloys (Ti6Al4V) and tungsten carbide (WC) materials were chosen as one of the materials for the workpiece and cutting tools respectively. Microdrilling device is a constant variable, as for the amount of flutes and point angles is an independent variable. Cutting force, cutting temperature and Von Voltage misses from the micro model are analyzed from the simulation results based on these independent variables. After observing it turns out that fewer flutes will cause a high value to cut the temperature, cut the strength and also Von Mises.

1 Introduction
The tendency of miniaturization of products or components was widely introduced to the market since hundreds of years ago, and demand has greatly increased. Micromachining is currently very widely used, currently very popular in the aircraft, health, industrial, automotive industries and even in space. [1]. Product miniaturization is an appropriate technology that plays an important role at present, this is indicated by its work using high precision to produce work parts, this process uses a very small scale and is very accurate. This technology will continue to grow in the future and will continue to develop.

Microdrilling is very popular nowadays, because it plays an important role in the industry today, especially in electronics, printed circuit boards (PCBs), nozzles, manufacturing microwave components, EDM equipment and many others. [2]. The drilling process is one of the basic mechanical machining technologies that aims to increase productivity by having high precision and accuracy in machining. Micromachining words refer to machining which for cutting tools is very small, which is less than 1 mm in size. In other words, this machine is special, whereas conventional machines cannot be used to do this process, it deals with accurate and precise results for very small and difficult scales. However, drills with these micro sizes are inherently more susceptible to drill breakages and this contributes shorter tool life and frequent replacement of cutting tools. This is observed, microdrilling and macrodrilling have very identical features. Although downsizing the dimensions of the drill bit from macro to micro can affect the microdrilling process. However, the
source of the problem is the reduction in mechanical strength, other influences also about the effect of the relative thickness of the net, while the drill deflection occurs and cannot be avoided in the holes and interactions produced with holes [2]. A very noticeable difference is in microdrill and macrodrill in the geometry and failure mode. Larger shank diameters are owned by Microdrills, where the facilitation that is facilitated right from the drill bit is not like in macrodrill where flute and shank have the same diameter.

This was observed from the literature that damage to the tool depends on the drill geometry. In this work, the number of flutes and point angles are independent variables at a constant diameter of 0.5 mm. This is analyzed based on finite element modeling. Microdrilling uses the Finite Element Method (FEM) to perfectly examine and analyze processes. Instead of analyzing the effects on cutting tools, shorter cutting life and high probability for short periods of fatigue can be known through this method and can reduce errors.

2 Methodology

Four different geometries of the FE 3D model of cutting tools and workpieces were developed using CATIA V5R20 and the model was imported into ABAQUS software for analysis. The workpiece and model cutting tools are modeled as 3D finite element entities that can be deformed in ABAQUS using hexahedral element shapes for all models in meshing. Ti6Al4V titanium alloy is often a workpiece material, uses a diameter of 1.5 mm and has a thickness of 0.2 mm while WC tungsten carbide is interpreted as a raw material for cutting tools. The chemical configuration of Ti6Al4V is exposed in Table 1. Table 2 illustrates the geometric features of the cutting tool model and Figure 1 describes the tip view of the cutting tool. Meanwhile, the material properties for Ti6Al4V and WC can also be seen in Table 3.

| Al  | V   | Fe  | C    | Mo  | Si   | Ti  |
|-----|-----|-----|------|-----|------|-----|
| 6.37| 3.89| 0.16| 0.002|~0.01| 0.01 | Bal. |

| Tool geometry | Tool 1 | Tool 2 | Tool 3 | Tool 4 |
|----------------|--------|--------|--------|--------|
| Drill diameter | 0.5 mm | 0.5 mm | 0.5 mm | 0.5 mm |
| Number of flute | 2 | 4 | 6 | 8 |
| Point angle | 110º | 110º | 110º | 110º |
| Helix angle | 43º | 43º | 43º | 43º |

Figure 1: Microdrilling tool models
Table 3: Material properties

| Mat.        | Dens. $\rho$ [kg/m$^3$] | Young’s modulus, $E$ [MPa] | Poisson’s ratio, $\sigma$ | Thermal conductivity, $\gamma$ [W/(m.K)] | Thermal expansion [1/°C] | Specific heat, $C$ [J/(kg.K)] |
|-------------|------------------------|---------------------------|---------------------------|----------------------------------------|--------------------------|-------------------------------|
| Ti-6Al-4V   | 4430                   | 110000                    | 0.3                       | 7.3                                    | $1 \times 10^{-5}$     | 580                           |
| WC          | 15500                  | 650000                    | 0.21                      | 50                                     | $5 \times 10^{-6}$     | 203                           |

The Johnson-Cook (JC) material model is castoff for material plasticity and harm conditions. The JC model is appropriate for machining because of its ability to illustrate high strain/strain levels [6]. The JC model can be used with

$$\sigma = (A + BE^n) \left[ 1 + C \left( \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right) \right] \left[ 1 - \left( \frac{T - T_0}{T_{melt} - T_0} \right)^m \right]$$

(1)

where $T$, $T_0$ and $T_{melt}$ are the room temperature, distortion temperature, and temperature of each melting point. $\varepsilon$ is the equal strain, $\sigma$ is the equal voltage, $\dot{\varepsilon}$ is the flexible strain rate and $\dot{\varepsilon}_0$ is the reference strain rate. The constants $A$ and $B$ mean the material produces the stress and strain that occurs respectively. The mechanical features of the material are illustrated by the voltage amount complex coefficient $C$, the exponent strain hardening treatment, $n$ and the temperature make softer coefficient, $m$ [6]. The JC parameters for Ti6Al4C and WC can be seen in Table 4.

Table 4: JC constitutive material model parameters

| Mat.        | A [MPa] | B [MPa] | C   | n   | m   |
|-------------|---------|---------|-----|-----|-----|
| Ti6Al4V     | 862     | 331     | 0.012| 0.8 | 0.34|
| WC          | 1506    | 177.7   | 0.016| 0.12| 0   |

Plastic strains equivalent to the initial damage can be known to use the following formula

$$\dot{\varepsilon}_{01} = [D_1 + D_2 \exp \left( \frac{D_3}{\dot{\varepsilon}_k} \right)] \times \left[ 1 + D_4 \ln \left( \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right) \right] \times \left[ 1 + D_5 \left( \frac{\theta_w - \theta_0}{\theta_m - \theta_0} \right) \right]$$

(2)

The model for JC shear disappointment uses five limitations ($D_1$ - $D_5$) to make one model of initiation of harm that occurs as shown in Table 5.

Table 5: JC damage model parameters

| Mat.        | $D_1$  | $D_2$  | $D_3$ | $D_4$ | $D_5$ |
|-------------|--------|--------|-------|-------|-------|
| Ti6Al4V     | -0.09  | 0.25   | -0.5  | 0.014 | 3.87  |
| WC          | 0      | 0.0057 | -1.48 | 0.36  | 0     |

Boundary conditions and loads
Table 6 shows mesh property models that are always used to carry out simulations. The type of simulation that is often used is simulation of Dynamic, Temp-disp, and Explicit in Step-1. The surrounding surface of a workpiece is specified in the directions x, y and z. The rotation and program
of the cutting tool is in the positive y path and is limited to the location point (RP). This makes it easy for the tool to move only in the y-direction. The speed used (ν) is 900 mm / minute, while the angular velocity of 15000 revolutions / minute is treated in the RP of the cutting tool. The details of the boundary conditions are shown in Table 7. Existing temperatures of 300 K are treated for both workpieces and the cutting tool is the initial temperature. The friction coefficient used is 0.15 this coefficient is the treatment between workpiece and tool. In Figure 2 it can be seen that an assembly model of a finite element of a cutting tool and workpiece is used in this simulation.

### Table 6: Mesh properties

| Model | Shape       | Element code | Global size | Number of elements |
|-------|-------------|--------------|-------------|--------------------|
| M 1   | Hexahedral  | C 3 D 8 R T  | 0.08        | 451                |
| M 2   | Hexahedral  | C 3 D 8 R T  | 0.06        | 660                |
| M 3   | Hexahedral  | C 3 D 8 R T  | 0.05        | 2451               |
| M 4   | Hexahedral  | C 3 D 8 R T  | 0.04        | 5136               |
| Workpiece | Hexahedral   | C 3 D 8 R T  | 0.05        | 3828               |

### Table 7: Limit circumstances for cutting tools and workpiece

| Boundary Condition | 1 (Workpiece) | 2 (Cutting Tool) |
|--------------------|---------------|------------------|
| Type               | Symmetry/Asymmetry/En CASTRE | Velocity/Angular velocity |
| Step               | Step-1        | Step-1           |
| Data               | ENCASTRE      | V2 = 900         |
|                    | (U1=U2=U3=UR1=UR2=UR3=0) | VR2 = 15,000     |

Figure 2: The assembly of finite element models

## 3 Result and Discussion

### 3.1 Effect of tool geometry on cutting temperature

In this session, the geometry result that occurs on the cutting temperature tool will be examined. In Figure 2 shows a graph of the cutting temperature of the existing step time from the machining of the finite element model which occurs at the feed speed of 90 mm / min. This shows that the temperature increases significantly when penetration at the beginning and after that the workpiece will be fully penetrated, the increase in temperature that occurs becomes slower than the previous conditions. It can be investigated that the Tool in Model 1 with two number of flutes and 110° point angle shows the
maximum cutting temperature at step period 0.001s. However, both the Tools in Model 3 and Model 4 Tools have the lowest cutting temperatures at the same step period at 0.001s. Areas exposed to hotness among the interface between the workpiece then the cutting tool are in accordance with the thermal properties of the existing material. The highest temperature occurs at the edge of the flute where the temperature distribution in the cutting tool is as illustrated in Table 8. Figure 4 shows the resume of the maximum temperature shown from the simulation results. However, the results contrast with previous studies in which Oh et. Al. [9] states that the two-fluted treatment gets the lowest cutting temperature than before because of the level of heat formation that occurs. Contradictions occur because the diameter of the drilling tool has a difference, the diameter is used (Ø3.6mm vs. Ø 0.5mm) and the other possibility lies in the geometry tool. High cutting temperatures can make tool wear faster than cutters and it is unpopular.

![Figure 3: Cutting temperature](image)

Table 8: Temperature distribution
Figure 4: Summary of extreme cutting temperature on each tool.

**Result of tool geometry on cutting force**

Figure Graph 5 shows the cutting strength of the step time which is the output of the simulation model performed. Simulation shows that the force will increase slowly during initial penetration and will decrease when the workpiece has been penetrated or broken. On the observations made, there were second, four, six and eight flute devices with the maximum cutting strengths of 1.073 N, 0.865 N, 0.669 N and 0.402 N. The output was in accordance with previous studies where Anand and Patra [10] conducted a study and stated that two threaded solid carbides with teeth that did not have a 0.5 mm
diameter layer had the highest cutting strength. Small cutting styles can be used and feasible because they can make an influence on the material difficulties that will be made. However, a very high cutting force can make the tool lifetime short and show a low value on the superficial of the machine.

![Maximum Cutting Force (N)](image)

Figure 5: Summary of extreme cutting force on each tool

**Result of tool geometry on Von Mises**

Figure Graph 6 shows a picture of the Von Mises stress distribution on a workpiece. The determined voltage of Von Mises is for two, four, and six and eight - fluted, where the number is 1.065 Pa, 0.986 Pa, 0.962 Pa and 0.972 Pa respectively as in Figure 7. Mises stress will increase gradually at the beginning, then there will be a continuous decrease when the hole is fully penetrated from the surface.

| Tool                      | Top view of workpiece | Tool                      | Top view of workpiece |
|---------------------------|-----------------------|---------------------------|-----------------------|
| Two-fluted micro-drill with 110º point angle | ![Image](image) | Six-fluted micro-drill with 110º point angle | ![Image](image) |
| Four-fluted micro-drill with 110º point angle | ![Image](image) | Eight-fluted micro-drill with 110º point angle | ![Image](image) |

Figure 6: The Von Mises stress circulation on the workpiece
4 Conclusions

Four models of successful microdrilling tools are created using geometries that are different in terms of the number of flutes that are available using CATIA. The results of this process are based on cutting temperatures, cutting forces and Von Mises stresses that have been studied and analyzed using ABAQUS software. Because the effects of the geometry of a device that has a difference can produce a different cutting force, thus, the results obtained show that the maximum cut-off force is in Tool 1 (2 flute), while the minimum cut-off force that occurs is in Tool 4 (4 flute). Through the simulation results it can be decided that cutting tools with a advanced amount of flutes can cause lower temperature cutting values. Effects of different tool geometries on Von stresses The workpiece shows that a device with more flutes can contribute to the value which is lower than Von Mises's voltage. In other words, the conclusion is that with a smaller number of flutes it can cause a high value of cutting the temperature, cutting the strength and also Von Mises.

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