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Design and Development of Milling Cutter Tool

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***Abstract*: When we analyze an end cutting tool statically, we must take into account a variety of factors such as heat distribution, cutting force and torque applied to the tool, wear, and vibration. The goal is to design and analyze a milling cutting tool. SolidWorks-21 was used to design the cutting tool, which in this case was an end mill tool, as well as to do the static analysis. The external loadings are as follows: The end mill cutting surface is subjected to torque of 26 N/m. One of the tool surfaces is subjected to 1250 N of force. After running the simulation in SolidWorks – 21, the lowest FOS and maximum resulting displacement were 12 and 0.0969mm, respectively. It is evident from the preceding result that the tool is less likely to break.**

***Keywords*: Cutting force, vibration, end mill tool, static analysis, loadings.**

1. Introduction

In the milling process, the chip bearing process occurs due to lateral plastic flow of material that forms burr at the edge of the shear zone. The performance of a cutting tool affected by three factors that play the important role:

1. Hardness
2. Wear resistance
3. Chemical inertness
4. Fracture toughness of the workpiece material.

Because of the combination of high temperature, high workpiece strength, work hardening, and abrasive chips, notching at the tool nose and depth of cutting region was a common failure mode when machining nickel-based alloys. Special physical circumstances, such as stress and high temperatures, are the most typical causes of tool wear.

It is critical to keep track of tool life in order to avoid losing time on tool replacement and resetting the tool during machining.

Carbide tips type cutting tool usually suffers flank wear as shown in figure below.

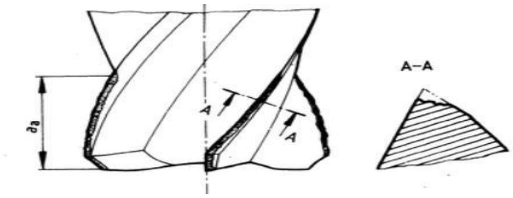

Fig. 1.

The AISI P20, which was milled utilizing a carbide coated insert in the research, is a good example of a high-speed steel to machine mold. The following are some of its characteristics:

1. At room temperature, it has a tensile strength of 1044 Mpa.
2. Hardness ranges between 280 and 320 HB.

With increasing cutting speed, feed rate, axial depth, and radial depth of cut, tool life diminishes. The chemical composition of the carbide coated tool has an impact on its wear rate. When constructing a milling cutting tool, there are three key elements to consider during the machining process, the temperature distribution was monitored, Torque generated ,the amount of cutting force applied to the tool and Cutting force exerted on the tool.

This is critical in order to avoid tool failure. The temperature in the cutting zone at the tool-chip interface can reach 1000 degree C during machining. The torque recorded when workpiece material stainless steel AISI 618 is end-milled with carbide inserts PVD coated with a layer of TiN is listed in Table 1. Because 23Nm is the maximum result from Table 1, we conclude that the tools must be able to tolerate a torque of 23Nm in order to avoid tool failure.

Table 2 displays the cutting force, and we can see that the tools must be able to bear forces more than 1250N in order to avoid tool failure. This is proven by Kadirgama's experiment with Hastelloy C-22HS as a workpiece material. According to Fuh and Hwang's experiment, when a 20mm helix angle is utilized and a 30o helix angle is employed, the maximum milling force is 722.7N. The forces acting on the tool in the orthogonal cutting method, according to Dombovari and Stepan, can be illustrated as shown in Figure 2, where the shear force, Fs, and normal force, Fn are as follows:

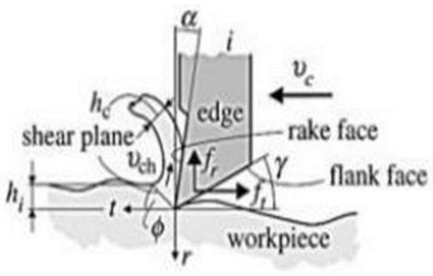

Fig. 2. Forces acting on a tool in 2D cutting

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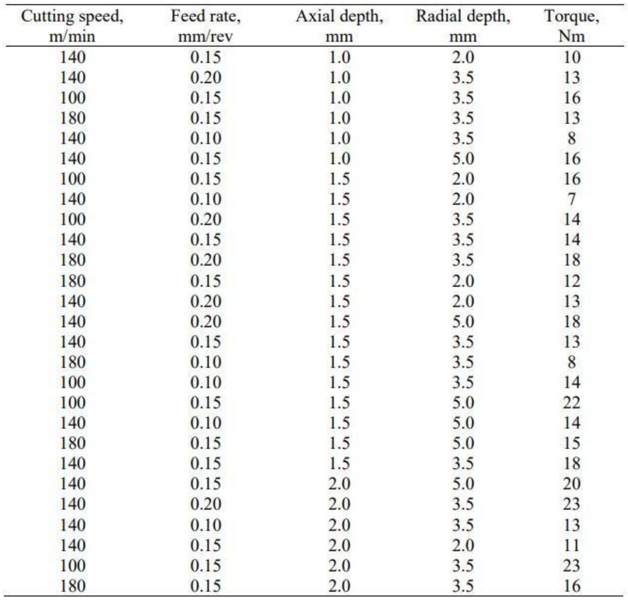
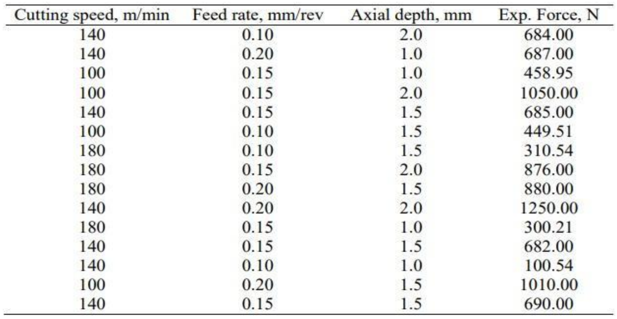
Table 1
Experimental torque measured



Cutting speed, m/min	Feed rate, mm/rev	Axial depth, mm	Radial depth, mm	Torque, Nm
140	0.15	1.0	2.0	10
140	0.20	1.0	3.5	13
100	0.15	1.0	3.5	16
180	0.15	1.0	3.5	13
140	0.10	1.0	3.5	8
140	0.15	1.0	5.0	16
100	0.15	1.5	2.0	16
140	0.10	1.5	2.0	7
100	0.20	1.5	3.5	14
140	0.15	1.5	3.5	14
180	0.20	1.5	3.5	18
180	0.15	1.5	2.0	12
140	0.20	1.5	2.0	13
140	0.20	1.5	5.0	18
140	0.15	1.5	3.5	13
180	0.10	1.5	3.5	8
100	0.10	1.5	3.5	14
100	0.15	1.5	5.0	22
140	0.10	1.5	5.0	14
180	0.15	1.5	5.0	15
140	0.15	1.5	3.5	18
140	0.15	2.0	5.0	20
140	0.20	2.0	3.5	23
140	0.10	2.0	3.5	13
140	0.15	2.0	2.0	11
100	0.15	2.0	3.5	23
180	0.15	2.0	3.5	16

Table 2
Experimental cutting force (Kadirgama)



Cutting speed, m/min	Feed rate, mm/rev	Axial depth, mm	Exp. Force, N
140	0.10	2.0	684.00
140	0.20	1.0	687.00
100	0.15	1.0	458.95
100	0.15	2.0	1050.00
140	0.15	1.5	685.00
100	0.10	1.5	449.51
180	0.10	1.5	310.54
180	0.15	2.0	876.00
180	0.20	1.5	880.00
140	0.20	2.0	1250.00
180	0.15	1.0	300.21
140	0.15	1.5	682.00
140	0.10	1.0	100.54
100	0.20	1.5	1010.00
140	0.15	1.5	690.00

Knowing the resultant forces is not enough to model a tool during design; knowledge of the forces involved is required to design a tool that can withstand the relevant forces.

Solid and coated carbide also have a higher hardness than high-speed tool steels, allowing for faster cutting speeds and material removal rates (HSS). The rake angle of the tool has an impact on the friction and contact zone between the chip and the tool. We discovered that as the radial rake angle increased, the side burr thickness decreased linearly. When the radial rake angle was between -30 and 30 degrees, however, it was practically constant.Wear processes between the workpiece and the cutting edge are important because they influence tool material selection for high-speed cutting.

To increase tool life, coating carbide tools was first created using the Chemical Vapor Deposition (CVD) technology, and most multi-layer coating materials contained a combination of TiC, TiN, Ti(N,C), and Al2O3 with varied deposition sequences.TiC coatings provide for great flank wear resistance, whereas TiN coatings allow for negligible crater wear. A12O3 or ALON, on the other hand, remain chemically stable even at high temperatures because to their low avidity, and repeated coatings with ALON exhibit reduced crater wear.

Tools with an oxide coating perform better when used for dry cutting operations. Fracture and chipping are seen in around half of all tool damage cases, and they are caused by thermal fissures in the straight cutting edge.

Properties of high precision parts are improved by cold treating them to temperatures ranging from -125 to -196 degrees Celsius to increase hardness and improve hardness homogeneity. The cryogenic treatment is what it's called. Unlike coating, this ensures that the tools will retain their quality following regrinding or resharpening. H13 tool steel samples that were deep cryogenically treated increased the wear characteristics of the steel by producing homogenous and very tiny carbide particles.

2. Methodology

Using Marrow correction and fatigue analysis on the cutting tool, an integrated Finite Element (FE) based analysis assists us in producing optimal tool material. Under the set cutting parameter, it can forecast deformation, stresses, and strain in the workpiece, as well as the load on the tool. Techniques based on the Finite Element Method (FEM) can provide more detailed information on not just cutting forces but also tool stresses and temperatures. When employing a fresh cutter, the static cutting force increases as the axial depth of cut increases. The attempt made in this project design and development is to employ cryogenic treated H13 tool steel as the material for the end mill because it may give a uniform material hardness distribution when compared to coated tools, which is ideal for resharpening and regrinding. SolidWorks-19 is used to model the end cutting tool in as much detail as feasible. Figure 3 shows the planned H13 tool steel end mill.

Fig. 3. 3D modeling of a 25mm diameter and 180mm long end mill generated by using Photo View 360 in SolidWorks-19

3. Static Analysis

Static analysis was done on the intended end mill to estimate the likelihood of the tool breaking or failing under static loading. SolidWorks 2021 Simulation was used to do the finite element analysis. According to the literature reviewed, which included books and research articles included in the references, the maximum force and torque exerted on the tool throughout the cutting operation were considered. External loads were applied to one of the tool surfaces, resulting in torque of 26 N/m and forces of 1250 N.

The following are the physical parameters of the H13 tool steel that was used:

1. Density-7800 kg/m^3

2. Tensile strength-1990 Mpa
3. Yield strength
4. Shear modulus: 81.0 Gpa
5. Poisson's ratio: 0.3

Figure 4 depicts the location on the end mill tool where force and torque were applied to conduct the simulation. The green arrows denote the fixture region where the tool was held in a fixed position to simulate the tool holder holding effect for a more realistic result.

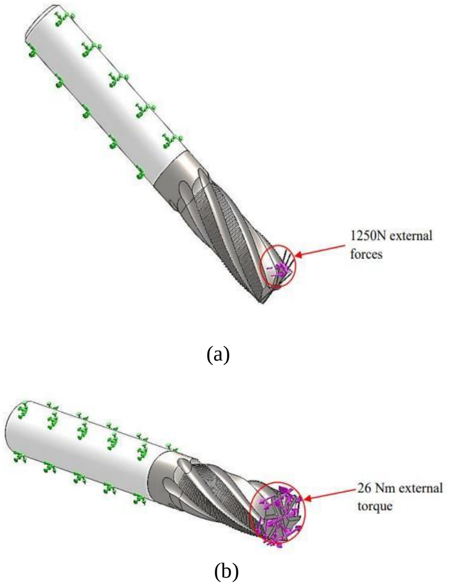


Fig. 4. FEM external load setup (a) Force and (b) torque

4. Result and Discussion

The result of the simulation using SolidWorks 2021 Simulation is presented in Figure 5 below, which includes the FOS and the resulting displacement in millimeters (mm).

The key section of the design, as shown in Figure 5 (a), is near the end of the tool holder, which has the lowest FOS. It also demonstrates that the particular region is where stress concentration occurs, implying that special care should be made in tool design and material selection. The FOS color tone also illustrates that the stresses are higher in the area where the tool design geometry changes. Figure 5 (b) indicates, on the other hand, that the highest resultant displacement occurs at the cutting tool edges' tips.

As indicated in Figure 5, the minimum FOS is 12 and the highest resulting displacement is 0.0969mm, based on the simulation using SolidWorks 2021. The tool is less likely to break as a result of the results gathered.

In actuality, even a single vibration can cause premature tool failure when it is subjected to dynamic loads, vibration, and heat stress. Even high temperatures in tools can cause them to wear out quickly, limiting their useful life. This is why temperature distribution is critical in determining a material's compatibility for a tool and limiting the tool's application.

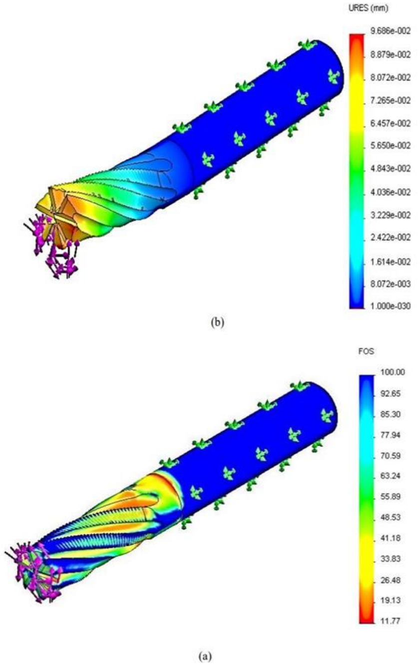


Fig. 5. Solidworks-19 simulation result (a) FOS and (b) resultant displacement

5. Conclusion

In this research, we aimed to create a milling-specific cutting tool. After reviewing the literature, we opted to use cryogenic treated H13 tool steel for the end mill since it can produce a more uniform material hardness distribution than coated tool steel. We achieved a decent FOS of 12 and a displacement of 0.0969 mm as a result.

We attempted unsuccessfully to use a more specialized software, Thirdwave AdvantEdge, which would have provided a superior result in terms of thermal stress, toll performance, and vibration. In conclusion, our study's goal was accomplished.

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