Heat analysis of single point cutting tool coated with different natural bio composite

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Abstract. The paper presents the selection of suitable coating material for a single-point cutting tool. The coated tool exhibited superior wear and heat resistance. The coating is done over an uncoated tool. Single point cutting tool coating is done according to the points and regions we found getting affected due to cutting tool operation and due to thermal effects on it due to heat. The analysis of a coated tool is compared using three different coatings. The normal cutting tool is selected and subjected to various load and thermal conditions. The properties to determine the stress, deflection, heat flux and temperature sustained is the determination of single point cutting tool of various materials.

1. Introduction

In today’s world where the world is moving towards automation and towards biological synthesised materials which don’t harm the environment and at the same time do the work more efficiently and conveniently. We are looking for these types of solution in various operations in various domains starting from biomedical, automotive, fishery, marine etc.

Taking this forward, there was an intention to do something in the manufacturing industry which is the backbone of every country economy and contribute up to 15% -20% of GDP. In today’s world, we are artificially creating materials and testing them at various temperatures, RPMs and pressures [1,4]. Each of them had their pros and cons. So, we shortlisted various materials from our list of various materials that we had in the list of materials these were virtually tested and finally coated in materials to obtain properties [2,3].

It was tested for structural and thermal to obtain its various properties at various conditions and to obtain how it reacts at various RPMs, temperature and forces and finally draw a conclusion about its usage and coating at various proportions [8].

1.1 LITERATURE SURVEY:

For mechanical machining, the quality of cutting tool material is the most important issue that we need to address. In this research paper a few new materials namely Rabbit teeth, Rat teeth and Hafnium...
carbonitride for the single-point cutting tool are proposed. We are going to get the composition of rat and rabbit teeth composition and going to artificially create using chemicals. For data regarding various load and thermal conditions to be used in the case of static and thermal analysis various journals, we referred [1,2,6,7,9].

1.2 Cutting Tool
A metal block of specific shape and dimension is chosen on which cutting inserted is inserted or engraved utilizing various mechanical properties. It is generally made up of HS steel, carbides etc. This is under the influence of various forces and under thermal loads that tend to affect its efficiency and other properties that lead to various defects in future if not corrected at the right time. It has two essential parts which are the handle and cutting tip[5,12] as shown in Figure 1.

![Cutting Tool](image)

**Figure 1.** Body of Cutting Tool

2. Problem statement
Use of coatings on cutting tool to make it more efficient by reducing effect of structural loads as well as thermal load on it under various conditions

3. Methodology
A step by step procedure was carried out from design to simulation using tools like CATIA V5 and ANSYS 18.2 version. Simulation model is validated with the convergence criteria to compare the existing materials with newly proposed alternative materials.

4. Material selection
We have used 3 different materials, that are hafnium carbonitride which is a ceramic material, Rat teeth and Rabbit teeth artificially created in the laboratory these are Biomaterial. Hafnium carbonitride is a ceramic composite material also called as HFC. Hafnium and carbon make up primary the chemical combination of HFC with has a melting point of 3900 °C, it is a binary compound and has good thermal conductivity and high resistance to the oxidation process. It has the highest melting point among all the known compounds to the human race (4200°C). It is suitable for cutting tool manufacturing. Rat and Rabbit teeth are also used as a material because of its cutting strength that we see in them. They are capable of cutting the steel wires, that’s why we selected this as a material as shown in Table 1 and the composition in Table 2.

| Cutting tool | Cutting Tip |
|--------------|-------------|

**Table 1.** Material Selection

**Table 2.** Composition of Materials


Table 1. Materials that were considered for testing

| SLNO | materials                  | Density (g cm$^{-3}$) | Young’s modulus (MPa) | Poisson’s ratio | Shear modulus (MPa) | Thermal conductivity (w/m°C) |
|------|----------------------------|------------------------|-----------------------|----------------|---------------------|-----------------------------|
| 1    | Hafnium carbonitride.      | 12.7                   | 3.5E+05               | 0.18           | 1.4831E+11         | 22                          |
| 2    | Rat teeth                  | 2.07                   | 0.7                   | 0.49           | 1.1667E+07         | 34.7                        |
| 3    | Rabbit teeth               | 1.9                    | 63                    | 0.45           | 2.1724E+07         | 26                          |

Table 2. Material Combination

| Material                  | Calcium % in ash | Magnesium % in ash | Phosphorous % in ash | Calcium/Phosphorous | Magnesium in terms of Calcium | Total calcium | Calcium to phosphorous corrected value |
|---------------------------|------------------|--------------------|----------------------|---------------------|------------------------------|---------------|----------------------------------------|
| Rabbit incisor            | 35.07            | 2.470              | 19.87                | 1.764               | 4.062                        | 39.132        | 1.969                                  |
| Rabbit molar              | 35.75            | 1.46               | 20.14                | 1.775               | 2.4                          | 38.16         | 1.893                                  |
| Rat 12-weeks incisor      | 36.19            | 2.244              | 19.67                | 1.840               | 3.698                        | 39.90         | 2.027                                  |
| Rat 15-week incisor       | 34.81            | 2.362              | 19.63                | 1.774               | 3.896                        | 38.72         | 1.973                                  |
| Hare dentine              | 36.4             | 1.787              | 19.24                | 1.891               | 2.948                        | 39.36         | 2.045                                  |

4.1 3D modelling

Based on the dimensions provided by the Alok International Private Limited, the model was built in CATIA V5 using features like extrude, extrude cut and revolve. Also, the model was cleaned up by removing the parts and features which were not needed for the analysis to minimize the computational time. The final model for the analysis is given in Figure 1.

4.2 Preparation Methodology:

In this paper, we analyzed the static stress on the single point cutting tool and also the thermal and structural analysis. Three different innovated materials were chosen and were used for the cutting tool and did the statics and structural analysis of each material. The three materials are:

- Hafnium carbonitride.
- Rat teeth
- Rabbit teeth

From the above materials, Hafnium carbonitride is composite materials, rat teeth and rabbit teeth are the biological materials which we will artificially create in lab setting. These differ in strength and...
behavior aspects. The single point cutting tool used in the lathes are normally failed under the lack of hardness and strength and this research helps you to analyses that, the cutting tool is created in the CATIA software as per the standard cutting tool terminology.

4.3 Static analysis:
In the three types of analysis first, we go through the static analysis of the single point cutting tool in the practical case there are 3 types of forces acting on the cutting tool tip and tool shank those are

1. Cutting force
2. Thrust force
3. Feed force

The technique that enables the relative contribution of control factors to the overall measured response. After updating the model in the ANSYS we need to mesh the complete tool, the four faces of the cutting tool shank are fixed and the forces are applied on the tip of the tool which is actually contacted with the work. The force applied in the direction against the tooltip that is 120N, and then we get the results of static analysis of the single point cutting tool, the tip of the tool will be having the maximum stress.

4.4 Thermal analysis:
In the cutting process, the heat is produced due to the direct contact of the cutting tool and the job and that’s lead to the failure of tool and reduction in the cutting tool life. Here in this analysis, we understand the behavior of the tool under thermal stress and temperature. In the thermal analysis, firstly prepossessing steps are done, those are loading the CATIA model, assigning the materials to the tool and then meshing the cutting tool.

5. Virtual analysis of the material:
The geometry and materials of single-point cutting tools are very important in achieving effectiveness, efficiency, and overall economy of machining.

In geometry various angles are considered:

- As the side and back rack angle increases the strength and tool life increases. Forces and power required for machining is decreased.
- As relief angle increases, the strength and forces are slightly decreasing and tool life slightly increases.
- By reducing end cutting edge or by increasing side cutting angle nose size increases and surface finish also increases.

- We provided  End & Side relief angle as 14° & 7°
- End & Side cutting angle as 16.61° & 16°
- Side & Back rake angle as 15° & 9°
- Nose radius as 1 mm.
5.1 Meshed model:

Medium element type mesh was carried out with curvature and proximity control was carried out to form the Figure 2 and the conclusion with respect to that in Table 3.

**Table 3. Nodes and Elements**

| Name         | Node | Element |
|--------------|------|---------|
| Cutting Tool | 26190 | 16732   |
| Cutting Tool | 64817 | 29468   |

To improve and check the convergence of the results, two methods were used

a) H-type: This technique involves altering the global size of the element set during the meshing process either with raising or lowering the size of an element without changing the type of mesh being used in simulations. Which results may not always converge [10,11].

b) P-type: This approach focuses on the form of mesh used in the analysis, keeping the size of the element constant. which means the order of the elements is changed Higher-order means more reliable results, but it needs more computational time, noticeably [13,14].

5.2 Boundary conditions for static structural and Thermal analysis:

In Figure 3 (a) the thermal boundary conditions are shown and in Figure 3 (b) Static structural boundary conditions are shown
While doing the structural analysis, we fix a specific part of the cutting tool by fixed support that is in constant rest. We apply force to the part that is being used for cutting, by means that part has direct contact to the Workpiece during the cutting process. These are the boundary condition of this cutting tool. Same as in thermal analysis the convection and temperature will be given as a boundary condition.

6. Virtual Analysis
6.1 Static Structural Analysis:
6.1.1 Equivalent Stress:

For this testing was carried out in 3 cases (Figure 4) for three different material that is hafnium carbonitride(ceramic), rabbit teeth(biomaterial) and rat teeth(biomaterial). By applying a load of 120N opposite to the Z direction, it was intended to find the stress on the front side of the material by keeping the shank of the cutting tool fixed. After studying all the 3 cases, it is found that rat teeth withstand more stress comparable to both rabbit teeth and hafnium carbonitride.

6.1.2 Total Deformation:

In this testing, it was carried out for three different material that is hafnium carbonitride(ceramic), rabbit teeth(biomaterial) and rat teeth(biomaterial) (Figure 5). After applying a load of 120N opposite to the Z direction, it was found that the strength of rat teeth is less, that it deformed more than the other two material. And hafnium carbonitride material has deformed less so it can be concluded that it has more strength.

Figure 3. a. Thermal Boundary condition b. Structural Boundary Condition

Figure 4 a: Hafnium carbonitride b: Rabbit teeth c: Rat teeth
6.2 Thermal Analysis:

6.2.1 Directional Heat Flux:

The case of directional heat deformation was conducted at 250° C for all the three samples (Figure 6), with convection of 1150 W/m²C, heat flow 50 W and heat flux 60 W/m². It was found that all the three samples give comparable results i.e. 1.9981*e5 in case of Rat teeth, 1.9878*e5 in case of Rabbit teeth and finally 1.9805*e5 in case of Hafnium Carbonitride. Hence from this comparison, it can be concluded that in case of directional heat deformation it is least in case of hafnium carbonitride and maximum in case of rat teeth [14].

6.2.2 Total heat flux:

The case of total heat deformation was conducted at 250° C for all the three samples (Figure 7), with convection of 1150 W/m²C, heat flow 50 W and heat flux 60 W/m². It was found that all the three samples give comparable results i.e. 15.1539*e5 in case of Rat teeth, 5.1468*e5 in case of Rabbit teeth and finally 5.1416*e5 in case of Hafnium Carbonitride. Hence from this comparison, it can be
concluded that in case of directional heat deformation it is least in case of hafnium carbonitride and maximum in case of rat teeth [15].

6.2.3 Temperature:

![Figure 8](image)

In the case of temperature produced when it was conducted at 250°C for all the three samples (Figure 8), with convection of 1150 W/m²C, heat flow 250 W and heat flux 60 W/m². It was found that all the three samples give comparable results i.e. 364.99°C in case of Rat teeth, 403.47°C in case of Rabbit teeth and 431.38°C [16,17,18]. Finally, in the case of Hafnium Carbonitride. Hence from this comparison, it can be concluded that in case of directional heat deformation it is least in case of Rat teeth and maximum in case of hafnium carbonitride.

7. ANALYTIC CALCULATION:

Heat flux is the amount of heat transferred per unit area per unit time from a surface. The amount of heat transfer per unit time and the area to or from which the heat transfer occurs. The SI unit of heat flux is W/m². heat flux is a vector quantity. The Fourier’s law is applied to their concepts for a solid substance the conductive heat flux. Heat in one dimension is expressed by Fourier’s law.

\[ \tau Hc = \frac{\lambda dT}{A} \]

Where,
- \( \tau Hc \) = conductive heat flux
- \( \lambda \) = Thermal conductivity constant
- T = temperature

1) Hafnium carbonitride:

\[ A=0.025m, \quad K=22w/mK, \quad T=250 \]

Heat flux \( q = \frac{\lambda dT}{A} \)

\[ =22*250/0.025 \]

\[ =2.2*10^4 \text{ w/m}^2 \]

2) Rabbit teeth:

\[ K=26 \text{ w/mk} \]

Heat flux \( q = \frac{\lambda dT}{A} \)

\[ =26*250/0.025 \]
=2.60*10^5 \text{w/m}^2.

3) Rat teeth:

\[ K = 34.7 \text{ w/mk} \]

\[ q = \lambda \frac{dT}{A} \]

\[ = 22*250/0.025 \]

\[ = 2.2*10^5 \text{w/m}^2 \]

8. Results:

Static structural analysis comparison:

We conclude all the results we get with respect to static structural analysis in Table 4.

| Material                  | Force N | Fixed support | Equivalent stress in MPa | Deformation in mm |
|---------------------------|---------|---------------|--------------------------|-------------------|
|                           |         |               | max         | min         | max     | min     |             |
| Hafnium carbonitride      | 120     | Four faces    | 15.66       | 5.7e-19    | 0.000305| 0       |
| Rabbit teeth              | 120     | Four faces    | 14.08       | 1.12e-16   | 1.67    | 0       |
| Rat teeth                 | 120     | Four faces    | 13.57       | 1.66e-15   | 147.55  | 0       |

Thermal analysis comparison:

We conclude all the results we get with respect to thermal analysis in Table 5.

| Material                  | Temperature °C | Convection W/m² | Total Heat flux W/m² | Directional heat flux W/m² | Temperature °C |
|---------------------------|----------------|-----------------|----------------------|---------------------------|----------------|
|                           |                |                 | max     | min     | max     | min     | Max            |
| Hafnium carbonitride      | 250            | 10              | 5.14e5  | 3755.3  | 1.980e5 | -30097 | 431.38         |
| Rabbit teeth              | 250            | 10              | 5.14e5  | 3755.3  | 1.987e5 | -30090 | 403.47         |
| Rat teeth                 | 250            | 10              | 5.15e5  | 3755.3  | 1.998e5 | -30080 | 364.99         |
9. CONCLUSION:

By the above analysis this could be conclude that these 3 materials are all good. The hafnium carbonitride is stronger as compared to the Rat and Rabbit teeth material, but it is not a bio material. The Rat teeth is also strong and capable of cutting the material but it deforms more. The rabbit teeth are good as compared to rat teeth. The analytically calculated heat flux is comparatively more than the analysis result. Therefore, we have the properties of the material. The thermal analysis is acceptable.

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