Heat Analysis of Single Point Cutting Tool Coated with Different Natural Bio Composite

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Abstract – *This paper presents a comprehensive investigation on the selection of a suitable coating material for enhancing the performance of a single-point cutting tool. The objective is to improve the wear resistance and heat resistance of the cutting tool by applying a coating over an uncoated tool. The study focuses on identifying the points and regions of the tool that are most affected by the cutting operation and the thermal effects resulting from the heat generated during machining. To evaluate the effectiveness of different coatings, three distinct coating materials were selected for analysis. The performance of the coated cutting tool was compared against that of the uncoated tool under various load and thermal conditions. The key properties considered for evaluation included stress distribution, deflection, heat flux, and temperature sustained by the cutting tool during machining. The selection of a suitable coating material is crucial to improve the tool's wear resistance and heat resistance. By applying a coating, it is possible to enhance the tool's ability to withstand the severe operating conditions encountered during machining processes. Additionally, the coating acts as a protective barrier, reducing tool wear and extending its lifespan. The experimental analysis involved subjecting the cutting tool to different load and thermal conditions to simulate real-world machining scenarios. The stress distribution and deflection of the coated tool were determined using advanced computational techniques, allowing for a detailed understanding of how the coating influenced the tool's mechanical behavior. Furthermore, heat flux and temperature measurements were conducted to assess the thermal performance of the coated tool. The coating was found to provide effective heat dissipation, thereby minimizing the risk of thermal damage to the tool and improving its overall durability. The results of the analysis clearly demonstrated the superiority of the coated cutting tool compared to the uncoated tool. The selected coatings exhibited enhanced wear resistance, reducing the occurrence of tool wear and subsequent deterioration in machining performance. Moreover, the coated tool displayed improved heat resistance, enabling it to sustain higher temperatures without significant deformation or loss of cutting ability. This research provides valuable insights into the selection and application of coatings for single-point cutting tools. The findings contribute to the development of improved machining techniques and strategies for enhancing tool performance. The information presented in this paper can guide manufacturers in selecting suitable coating materials for their cutting tools, thereby improving productivity, efficiency, and cost-effectiveness in machining processes. Overall, the investigation highlights the significance of coating materials in enhancing the wear resistance and heat resistance of single-point cutting tools. The study demonstrates the feasibility of utilizing coatings to improve the performance and lifespan of cutting tools in various machining applications.*

Keywords*- SPCT, Tool design, analysis, Static Structural, Thermal analysis.*

INTRODUCTION

Single point cutting tools (SPCTs) are versatile tools used in various machining operations such as turning, facing, boring, and threading. They consist of a sharp cutting edge called the point, flanks that flank the point, a rake face that helps push the chips away, flank angle determining chip flow and friction, and a back taper for insertion.

The historical development of single point cutting tools started with primitive stone tools used for basic cutting and shaping tasks. During the Industrial Revolution, carbon steel tools emerged, providing better performance. In the late 19th century, high-speed steel (HSS) tools were developed, offering improved cutting speed and tool life.

The early 20th century saw the rise of carbide tools, which revolutionized the industry with their increased hardness and wear resistance. Coating technologies emerged in the latter half of the 20th century, further enhancing tool performance through coatings like TiN,TiCN, and Al2O3.

In recent years, advanced materials like ceramic and cubic boron nitride (CBN) have been developed, offering exceptional hardness and heat resistance. Tool manufacturers continue to innovate with new designs for optimized chip control, cutting forces, and surface finish.

It's important to note that specific advancements and developments in single point cutting tools may vary based on regional, industrial, and technological factors.

METHOLOGY

When selecting materials for Single Point Cutting Tools (SPCTs), factors such as hardness, wear resistance, toughness, heat resistance, chemical stability, thermal conductivity, and cost are important. Hafnium Carbonitride (HfCN) offers enhanced hardness, wear resistance, thermal stability, and chemical inertness. Rat and rabbit teeth, though not suitable for cutting tools, possess self-sharpening properties and layered or complex structures that could enhance wear resistance and durability. However, materials specifically engineered for cutting tools, like high-speed steels or carbide inserts, are generally preferred due to optimized

Table 1- Materials that were considered for Testing

SN	materials	Density ($g\,cm^{-3}$)	Young'smodulus (MPa)	Poisson's ratio	Shear modulus (MPa)	Thermal conductivity (w/m^0c)
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

CAD MODEL

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

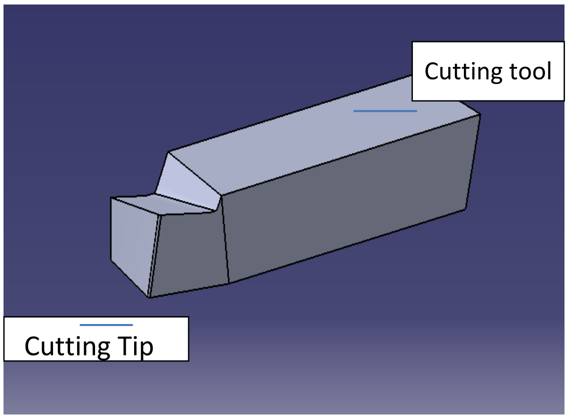


Fig. 1- Body of Cutting Tool

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 facesof 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 weget the results of static analysis of the single point cutting tool, the tip of the tool will be having the maximum stress.

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, prepossessing steps are done, those are loading the CATIA model, assigning the materials to thetool and then meshing the cutting tool.

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 toll life slightlyincreases.
- 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.

MESHED MODEL

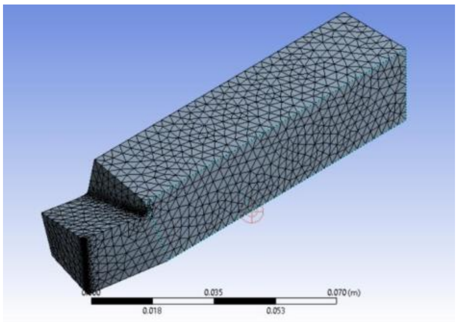


Figure 2. Meshing of Cutting Tool

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].

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

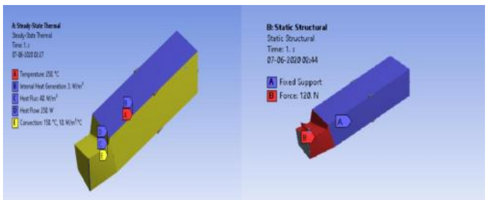


Fig.3 (a) fig.3 (b)

We fix a specified portion of the cutting tool by a fixed support that is at rest all the time while performing the structural analysis. By having the cutting portion in direct touch with the workpiece while it is being cut, we may apply force to the cutting part. These define the cutting tool's border conditions. Convection and temperature will be provided as a boundary condition, just like in thermal analysis.

STRUCTURAL ANALYSIS

Von mises stress

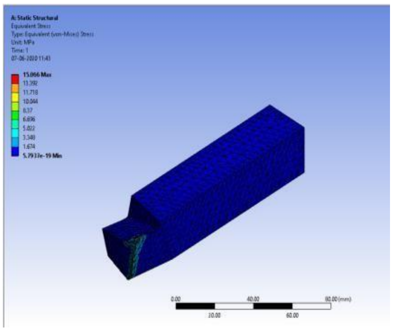


Fig. 4(a): Hafnium carbonitride Von Mises Stress

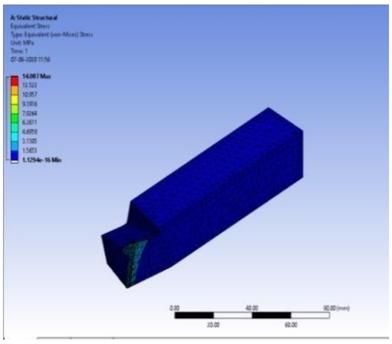


Fig.4(b): Rabbit Teeth von Mises Stress

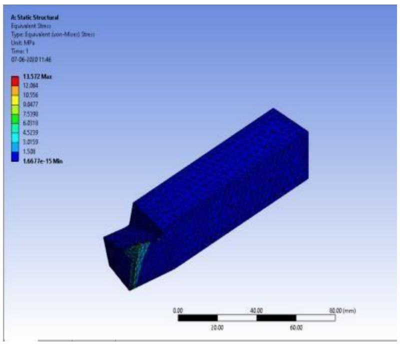


Fig. 4(c): Rat Teeth Von Mises Stress

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 bykeeping 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.

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.

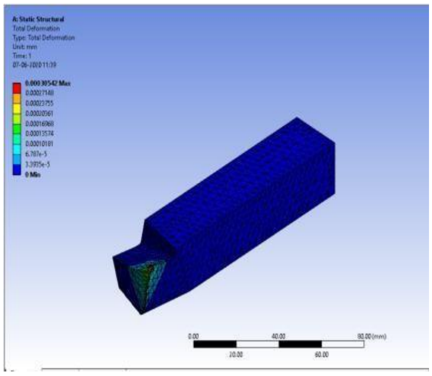


Fig. 5(a): Hafnium carbonitride Total Deformation

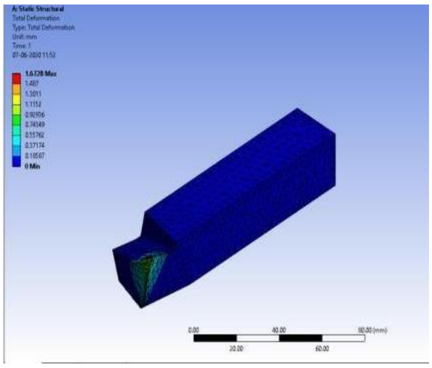


Fig. 5(b): Rabbit Teeth Total Deformation

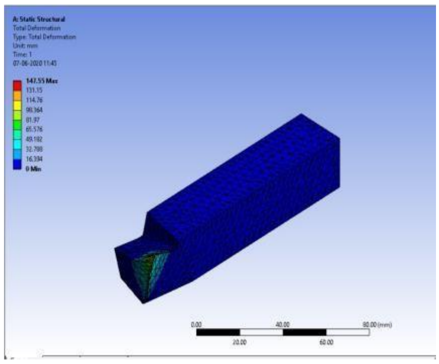


Fig. 5(c): Rat Teeth Total Deformation

THERMAL ANALYSIS

Directional Heat Flux

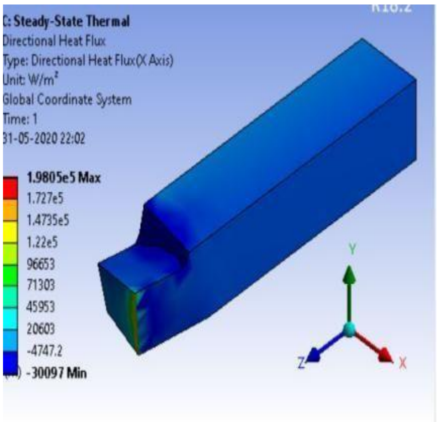


Fig.6(a): Hafnium carbonitride Directional Heat Flux

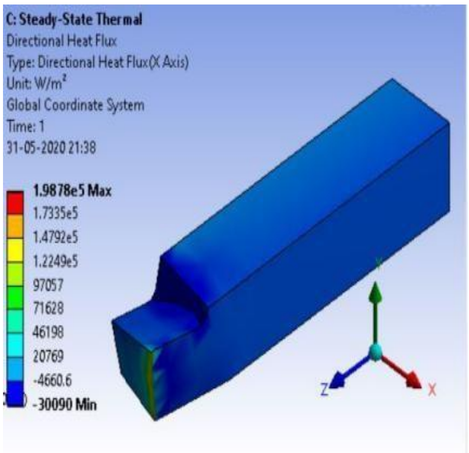


Fig.6(b): Rabbit Teeth Directional Heat Flux

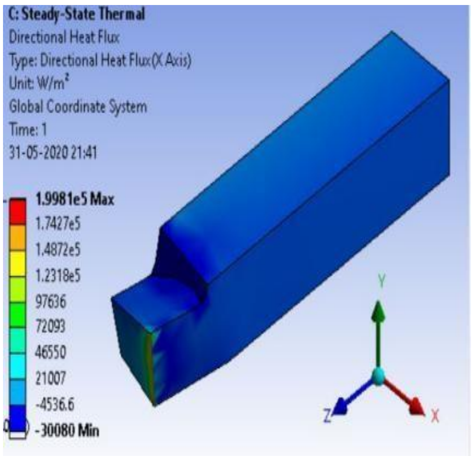
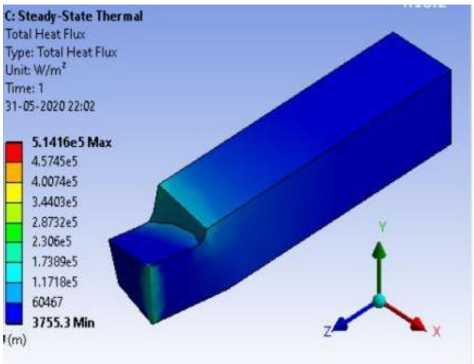
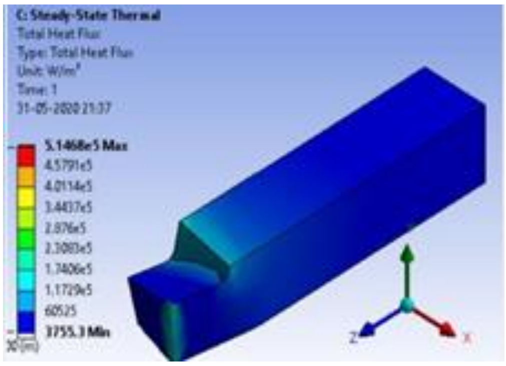


Fig.6(c): Rabbit Teeth Directional Heat Flux

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].

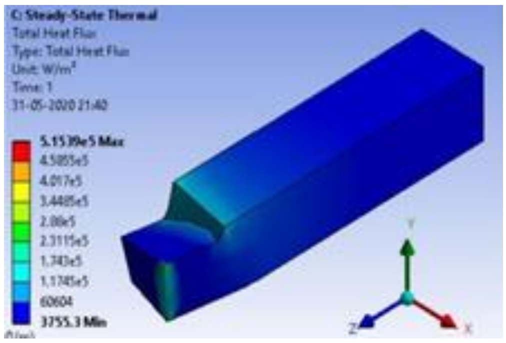
TOTAL HEAT FLUX

Fig.7(a): Hafnium Carbonitride Total Heat Flux

Fig.7(b): Rabbit Teeth Total Heat Flux

Fig.7(b): Rat Teeth Total Heat Flux

For all three samples, the case of total heat deformation was tested at 250° C with convection of 1150 W/m2C, heat flow of 50 W, and heat flux of 60 W/m2. It was discovered that all three samples produce comparable results, namely 15.1539*e5 for rat teeth, 5.1468*e5 for rabbit teeth, and finally 5.1416*e5 for hafnium carbonitride. As a result of this comparison, it can be inferred that directional heat deformation occurs least in the case of hafnium carbonitride and most in the case of rat teeth



[15].

TEMPERATURE

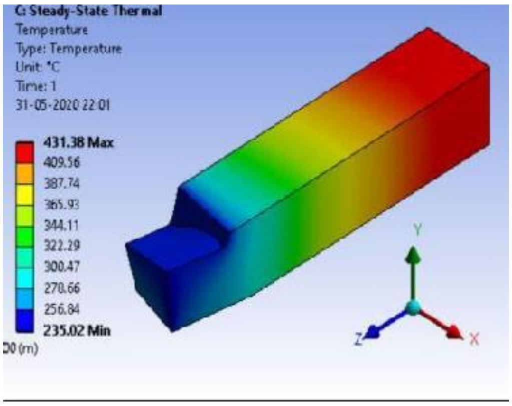


Fig 8. (a): Hafnium Carbonitride Temperature

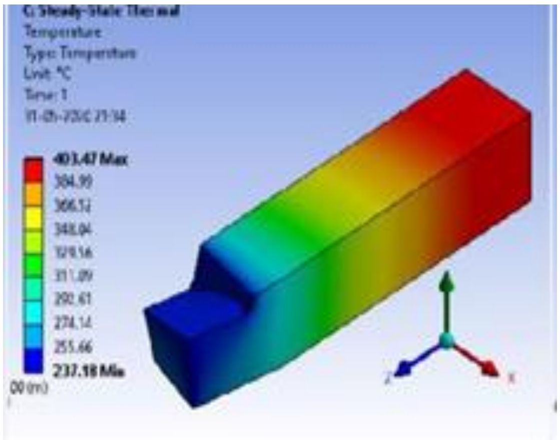


Fig 8. (b): Rabbit Teeth Temperature

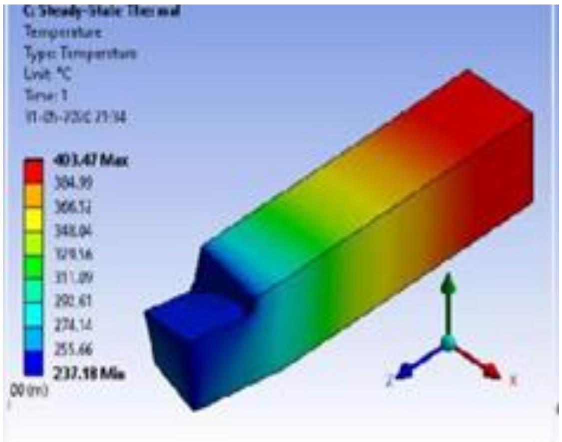


Fig 8. (c): Rat Teeth Temperature

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 thethree 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 thiscomparison, 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.

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.

$^{\tau}Hc = \lambda dT / A$

Where,

$^{\tau}Hc$ = conductive heat flux

λ = Thermal conductivity constant

T = temperature

1) Hafnium carbonitride:

A=0.025m,

K=22w/mK,

T=250° C

Heat flux (q) = λdT/A

= 22*250/0.025

= 2.2*105 w/m2.

2) Rabbit teeth:

K=26 w/mk

q = λdT/A

=26*250/0.025

=2.60*105 w/m2.

3) Rat teeth:

K=34.7 w/mk

=2.60*105 w/m2.

q = λdT/A

=22*250/0.025

=2.2*105 w/m2

STATIC STRUCTURAL ANALYSIS COMPARISON

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

Table 4. Static Structural Analysis Results

Material	ForceN	Fixed support	Equivalent stress inMPa		Deformation in mm	
			max	min	max	min
Hafnium carbonitride	120	Four faces	15.66	5.7e-19	0.000305	0
Rabbitteeth	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.

Table 5. Thermal Analysis Results

material	Temperature °C	Convection W/m^2	Total Heat flux W/m^2		Directional heatflux W/m^2		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

CONCLUSION

Based on analysis, it can be concluded that all three materials, namely Hafnium carbonitride, rat teeth, and rabbit teeth, have their own strengths and characteristics.

1. Static Structural Analysis:

- Hafnium carbonitride exhibits the highest equivalent stress among the tested materials, indicating a higher resistance to deformation under the applied force. It also shows minimal deformation, suggesting its suitability for applications requiring structural integrity.
- Rabbit teeth and rat teeth demonstrate lower equivalent stress but exhibit significant deformations. This could indicate that these materials may not be as mechanically robust as hafnium carbonitride.
- The fixed support condition applied to all materials may affect their stress and deformation behavior. Exploring different support configurations or boundary conditions could provide further insights into the materials' performance.

2. Thermal Analysis:

- The tested materials show similar convection and total heat flux values, indicating comparable heat transfer characteristics in the given thermal environment.
- The directional heat flux values vary, suggesting differences in heat dissipation along specific directions. The temperatures corresponding to the maximum directional heat flux also vary, indicating variations in thermal conductivity or heat dissipation capability.
- Further investigation into the thermal properties, such as thermal conductivity and heat transfer coefficients, of these materials could provide a deeper understanding of their behavior under different thermal conditions.

Based on analysis, it can be concluded that all three materials, namely Hafnium carbonitride, rat teeth, and rabbit teeth, have their own strengths and characteristics.

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