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Design and Analysis of Carbide Coated Tool on High Strength Alloy Materials Used in Multi Axis Machining

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Abstract: Industrial production is characterized by the challenge of machining high strength alloys. Molding and forging dies require high quality, high strength, and low wear materials, so that their mechanical properties are also good. It is important to analyze such alloys before machining in order to reduce tool costs and machining times. The present work focuses on coating high carbide tools used to machine alloys such as H30, SS1803 and titanium at variable speeds, depths, and feeds using the explicit analysis module of ANSYS. To optimize the optimal parameters, the Taguchi method of L9 DOE was used. In this work, a Ø6 mm tool with nickel coating has been used at varying speeds of 1800, 2200, 2500 RPM with a feed rate of 300,400,500mm/min and 0.3,0.4,0.5mm depth of cuts. It has been observed that maximum damage and interaction forces occur when deformations occur in tools and compared with tools that have not been coated.

Keywords: Carbide Coated Tool, High strength alloys, Taguchi method, ANSYS

1. Introduction

The manufacturing industry is constantly striving to decrease its cutting costs and increase the quality of the machined parts as the demand for high tolerance manufactured goods is rapidly increasing. The increasing need to boost productivity, to machine more difficult materials and to improve quality in high volume by the manufacturing industry has been the driving force behind the development of cutting tool materials Numerous cutting tools have been developed continuously since the first cutting tool material suitable for use in metal cutting, carbon steel, was developed a century ago Cemented carbides are the most popular and most common high production tool materials available today The productivity enhancement of manufacturing processes is the acceleration of improved cutting tools with respect to the achievement of a superior tribological attainment and wear-resistance. Milling is the machining process of using rotating cutters to remove unwanted material from the workpiece by feeding in a direction at an angle with the axis of the tool. It covers a wide variety of different operations. As the requirement for versatile cutting tool increases, cutting tool suppliers also continuously developed the products that can pass through the manufacturer's demand. Lots of materials have experimented upon some have passed the standards while others were simply dropped. Nowadays there are mostly two types of the materials are used as the cutting tool material that is as follows- 1.High-speed steel. 2.Carbide cutting tool. The carbide tool is made up of the powder metallurgy technique. When machining using carbide tools also known as the carbide tipped cutting tool. Carbide cutting tools edges are carbide tips which are brazed onto steel bodies used for under conventional cutting conditions. The majority of inserts presently used in various metal cutting operations are cemented carbide tools coated with a material consisting of nitrides (TiN, CrN, etc.), carbides (TiC, CrC, W2C, WC/C, etc.), oxides (e.g. alumina) or combinations of these and nano composite materials (ZTA). Coating cemented carbide with TiC, TiN and Al_2O_3 dramatically reduces the rate of flank wear High hardness is beneficial in resisting the abrasive wear. Retention of hardness even at higher temperatures is very important since the tool bit experiences a temperature in the range of 300-1000°C depending on the machining parameters and the materials to be machined Micro hardness values of different coatings measured at different temperatures They all exhibit a decrease with an increase of temperature, and the decrease of hardness was much more pronounced in the case of TiC. Interestingly, the micro hardness of Al2O3 was significantly lower than TiC at room temperature but retained almost 40 % of its room temperature hardness at 1000 °C. The main advantage of Carbide tools can be worked at higher speeds as compared to HSS tools, approximately 6 to 8 times higher speeds,Young's Modulus of Elasticity of Carbide tools is 3 times that of steel, making it stiff,Workpiece/parts machines using Carbide tools generate a surface finish of high quality and Carbide Tools have an exceptional resistance to abrasion.

2. Literature Review

In the present study, the performance of coated carbide inserts under varying cutting conditions has been reviewed. The machining of the hard materials at higher speed is improved by using the Coated tool. From the Investigation, It is observed that tool life is inversely proportional to the cutting speed and feed rate both, but cutting speed had a more significant effect on tool life than the feed **Rogério Fernandes Brito et al. [1],** The thermal properties of three layers of titanium carbide, (TiC), aluminum oxide (Al2O3), and titanium nitride (TiN) were analyzed, both individually and in group, considering a layer with equivalent thermal properties. Coated and uncoated cutting tools, titanium aluminum nitride (TiAlN) and aluminum chromium nitride (AlCrN), were used in the turning of AISI 4340 steel. **C. Chim1 et al. [2]** TiN, CrN, TiAlN and CrAlN coatings were deposited by vacuum arc. Their thermal stability and oxidation resistance were investigated after annealing in air at different temperatures (500°C-1000°C). TiAlN and CrAlN showed better oxidation resistance than their binary counter parts TiN and CrN. Cr-based coatings exhibited much better oxidation resistance than Ti-based coatings. **Audy J et al. [3]** The use of coated tools has advanced to the stage when surface coatings of increasing complexity are being routinely deposited on HSS tools. It is generally accepted by industry that popular TiN and Ti(C, N) coatings are now under increasing competition from TiAlN, TiAlCrN and more complex coatings based on TiN/TiAlN and or TiAlCrYN.. **Boing D. Zilli L [4].** Titanium nitride (TiN) widely used as hard coating material, was coated on tool steels, namely on high-speed steel (HSS) and D2 tool steel by physical vapor deposition method. The study concentrated on cathodic arc physical vapor deposition (CAPVD), a technique used for the deposition of hard coatings for tooling applications, and which has many advantages. It is used to analyze and quantify the properties. **Nickel et al. [5]** The nature and the underlying wear mechanisms of TiNcoated tools and the role of TiN in improving wear resistance and increasing tool life have been the subject of many investigations. For example, the wear modes of TiN-coated HSS, from the results of sliding pin-on-disc wear tests, were found to include adhesive and abrasive wear of the coating w12,13x. **Abdul Kareem Jaleel et al. [6]** Hard coating such as TiN, TiC and Al2O3 have been used. High-speed machining is constantly increasing in importance. These new techniques can be applied in place of conventional machining methods for manufacturing of various components at low cost or even making entirely new type products, e. g. machined from brittle materials. **K. Aslantas et al. [7]** Research in coated mixed ceramic tool, the thermal conductivity value of TiN coating material increases with increases in temperature. Therefore, the heat flow to the cutting tool increases and the temperature at the tool–chip interface decreases. The temperature difference between the upper and lower sides of the chip decreases and the chip upcurl radius increases. **Cem Karacal et al. [8]** Advanced coating technology has significantly improved the tool life expectancy. Titanium Nitride (TiN), Titanium Carbo Nitride (TiCN), Titanium Aluminum Nitride (TiAlN or AlTiN), Chromium Nitride (CrN), and Diamond coatings can increase overall tool life, decrease cycle time, and promote better surface finish. **S. PalDey [9]** In this paper, deposition of (Ti,Al)N coatings using different PVD techniques have been reviewed. The effects of deposition variables on coating microstructure and film properties were analyzed. (Ti,Al)N exhibited superior performance in many applications as compared with the other commercially available Ti based coatings. **Weiguang Zhu [10]** The use of Tin-coated tools causes a reduction in heat partition into the cutting tool compared with the uncoated tool about 17 percent at conventional cutting speed and 60 percent in the HSM region.

3. Methodology

A standard 3-axis CNC milling machine has a table that moves the part to provide one or two planes of movement and a tool that provides the other one or two planes of movement. 3-axis machines are ideal for simple tasks that don't require intricate detailing or depth. This experiment was conducted to study the effect of machining parameters on the wear mechanism and failure mode of coated carbide cutting tools when milling titanium alloy.

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Machining trials were carried out on a Haas 3-axis milling machine. Worn-out cutting tools limit the cutting speed and feed rate applied The performance of a carbide tool not only depends on the type and number of coating layers applied but also on the size of the carbide particles and the number of binders. Information regarding porosity, particle size and WC bond, carbide solid solution and metal binder can be obtained by polishing a sample

. Solid works:

Solid works uses a 3D design approach. As you design a part, from the initial sketch to the final result, you create a 3D model. From this model, you can create 2D drawings or mate components consisting of parts or subassemblies to create 3D assemblies. You can also create 2D drawings of 3D assemblies. When designing a model using Solid works, you can visualize it in three dimensions, the way the model exists once it is manufactured

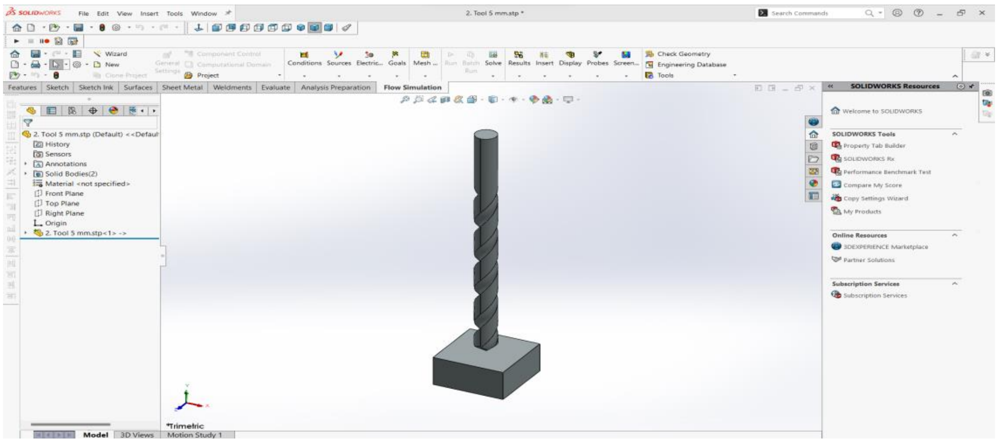

Figure1: Design model

Mesh generation is the practice of generating polygonal or polyhedral mesh that approximates a geometric domain. The term "grid generation" is often used interchangeably. Typical uses are for rendering to a computer screen or for physical simulation such as finite element analysis or computational fluid dynamics.

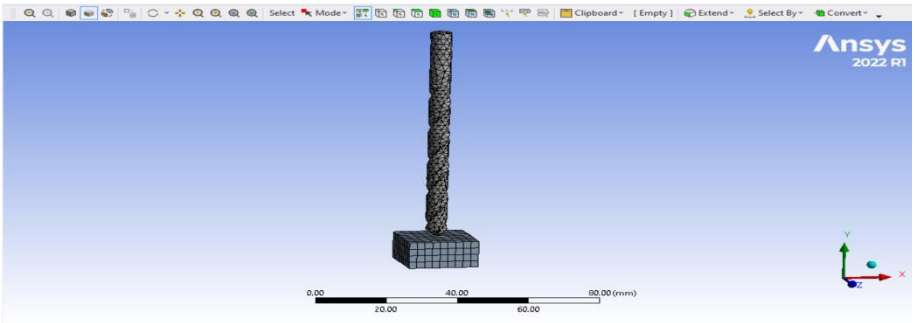

Figure 2: Meshing model

3.1 Properties of tools and materials

The hardness of cemented carbide can reach 86~93HRA at room temperature, which is equivalent to 69~81HRC. It can maintain high hardness at 900~1000°C and has excellent wear resistance. Compared with high-speed tool steel, the cutting speed can be 4 to 7 times higher, the life span is 5 to 80 times longer, and hard materials with a hardness of up to 50HRC can be cut. The compressive strength of cemented carbide is as high as 6000MPa, and the modulus of elasticity is (4~7)×105MPa, which is higher than that of high-speed steel. But its flexural strength is low, generally 1000~3000MPa

Stainless Steel 304:

There are many different grades and finishes of stainless steel available, but most people prefer to buy it annealed or cold wrought. Portion of stainless steel 304 with chromium (Cr) and nickel (18/8 stainless steel) (Ni).

Table 1: Physical Properties of Stainless Steel 304

Property	Value
Density	8.00 g/cm^3
Melting Point	1450 °C
Modulus of Elasticity	193 GPa
Electrical Resistivity	0.42 x 10^{-6} Ω.m
Thermal Conductivity	16.2 W/m.K
Thermal Expansion	17.2 x 10^{-6}/K

Tool Steel and Hard Alloy: H30

Table 2: Mechanical properties

Quantity	**Value**	**Unit**
Young s modulus	200000-200000	Mpa
Tensile strength	650-880	Mpa
Elongation	8-25	%
Fatigue	275-275	Mpa
Yield strength	350-550	Mpa

Taguchi's Design of Experiments

Exploratory research can be used to evaluate and improve process parameters. The most influenced process parameters on output responses are listed at different columns in an intended orthogonal array. Machine parameters such as machining speed, feed rate, and depth of cut all influence tool wear and surface roughness. It is better to use lower values when dealing with wear on the flanks or surface roughness Because of this, the preferred machining output responses are low surface roughness and cutting tool flank wear. As a result, the lower the S/N ratio, the better the results were thought to be. S/N ratio for the nominal output response can be calculated from the following characteristics.

$$\text{Smaller the better} \quad \frac{S}{N} = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

From S/N ratio, the actual influencing parameters and the best optimal range of selected parameters can be characterized.

Tool flank wear and nominal surface roughness are desirable reactions in turning operations. As a result, it was decided that the smaller the output responses, the better the S/N ratio, the better. Using ANOVA, the impact of each cutting parameter on output responses was determined. A series of confirmation tests compared the optimised results to an empirically predicted value.

Table 3: Taguchi parameters

	Level 1	**Level 2**	**Level 3**
Spindle Speed	300	400	500
Feed	1800	2200	2500

Depth of cut	0.3	0.4	0.5

Table 4: Taguchi L9 Orthogonal array

S. No	Speed	Feed	Depth of cut
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	2
9	3	3	1

Table 5: Taguchi L9Orthogonal array

S. No	Feed	speed	Depth of cut
1	300	1800	0.3
2	400	2200	0.4
3	500	2500	0.5
4	300	1800	0.4
5	400	2200	0.5
6	500	2500	0.3
7	300	1800	0.5
8	400	2200	0.4
9	500	2500	0.3

speeds of 1800, 2200, 2500RPM with a feed rate of 300,400,500mm/min and 0.3,0.4,0.5mm depth of cuts.

4. Results and Discussions

ANSYS Mechanical provides solutions for many types of analyses including structural, thermal, modal, linear buckling and shape optimization studies. ANSYS Mechanical is an intuitive mechanical analysis tool that allows geometry to be imported from a number of different CAD systems. It can be used to verify product performance and integrity from the concept phase through the various product design and development phases. The use of ANSYS Mechanical accelerates product development by providing rapid feedback on multiple design scenarios, which reduces the need for multiple prototypes and product testing iterations.

S. No	Speed	Feed	Depth of cut	Experimental TWR (mm^3/min)	Experimental SR (Ra)
1	1	1	1	0.113	2.463

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2	1	2	2	0.152	2.484
3	1	3	3	0.226	2.521
4	2	1	2	0.284	2.872
5	2	2	3	0.367	2.963
6	2	3	1	0.392	2.844
7	3	1	3	0.464	3.126
8	3	2	2	0.413	3.024
9	3	3	1	0.481	3.187

Table 4.2 Experimentation Taguchi analysis optimized results

S. No	Feed	speed	Depth of cut	**S/N Ratio**	**Mean**	**StDev**	**Ln(StDev)**	**Rank**
1	300	1800	0.3	1.20793	0.711667	0.849314	0.139068	8
2	400	2200	0.4	1.61663	0.993333	1.21465	0.186121	5
3	500	2500	0.5	2.64405	1.22	1.39379	0.304407	1
4	300	1800	0.4	3.46777	1.375	1.52814	0.399242	7
5	400	2200	0.5	6.67501	1.81167	2.05140	0.768489	2
6	500	2500	0.3	5.61557	1.76833	1.97126	0.646516	6
7	300	1800	0.5	7.58963	2.20833	2.49452	0.873789	9
8	400	2200	0.4	8.71001	2.375	2.75850	1.00278	4
9	500	2500	0.3	9.35475	2.44667	2.77972	1.07701	3

4.1 Simulation with explicit

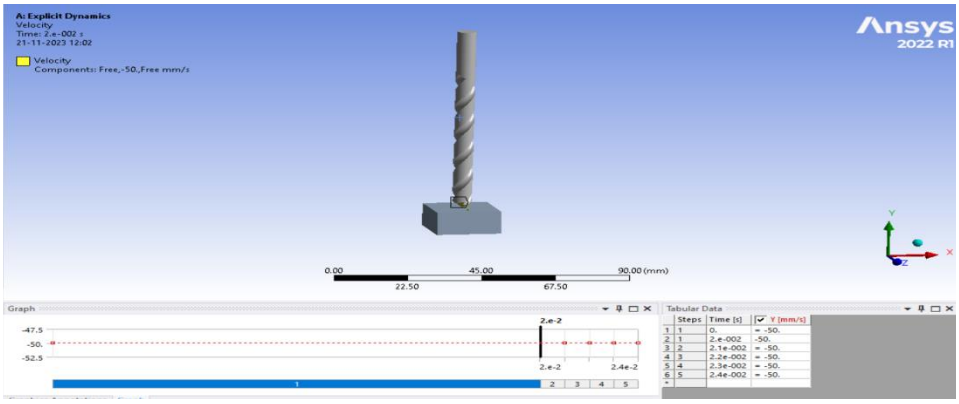

Figure 3: Velocity 50 mm/sec

Explicit dynamic analysis of Titanium alloy Carbide Coated Tool

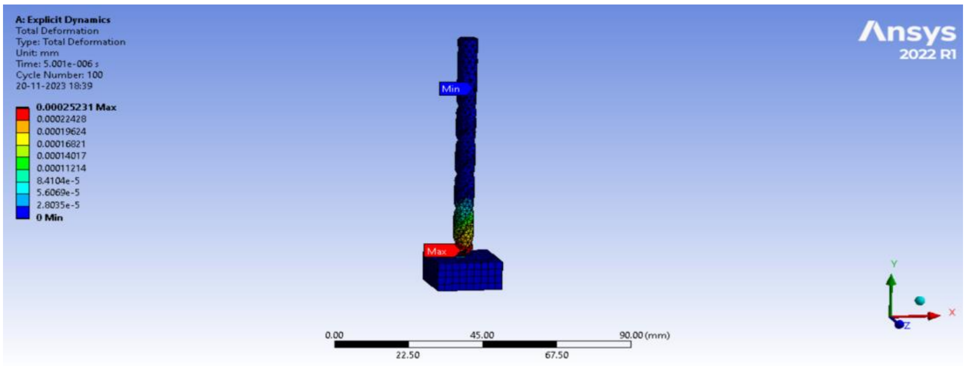

Figure 4: Total deformation

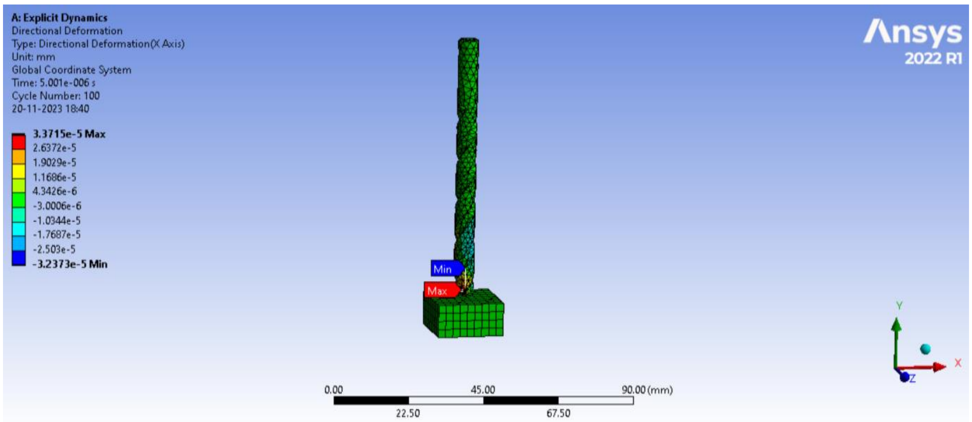

Figure 5: Directional Deformation

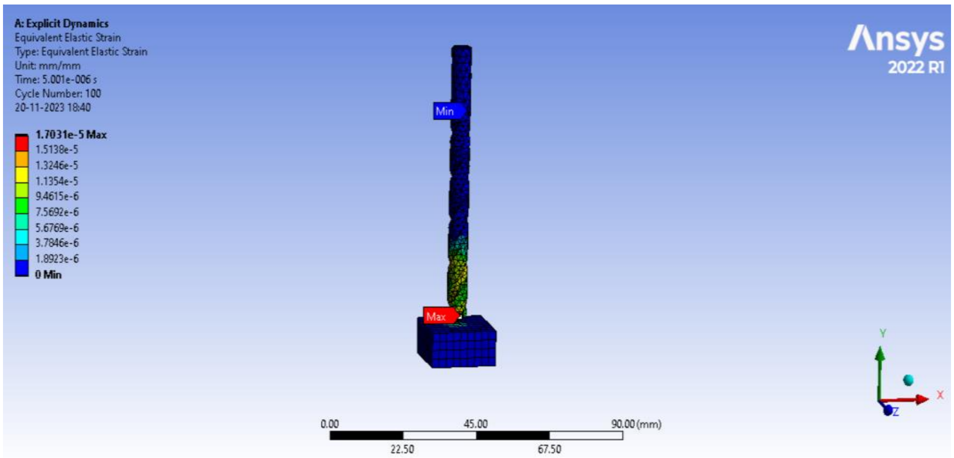

Figure 6: Equivalent stress

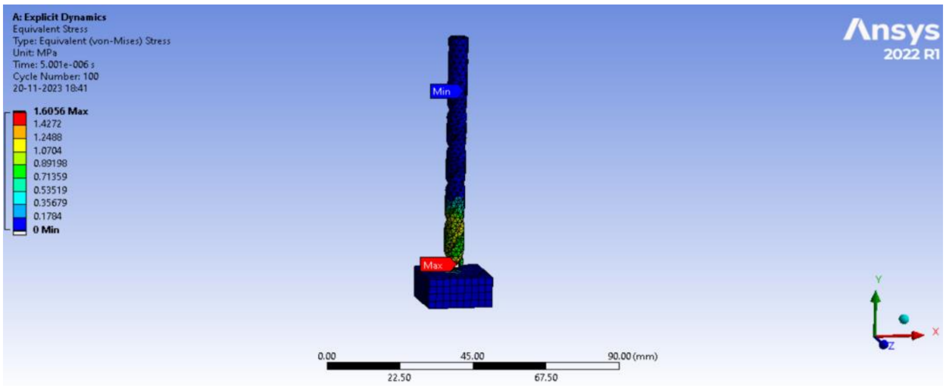

Figure 7: Equivalent elastic strain

4.2 Explicit dynamic analysis of SS1803 Carbide Coated Tool

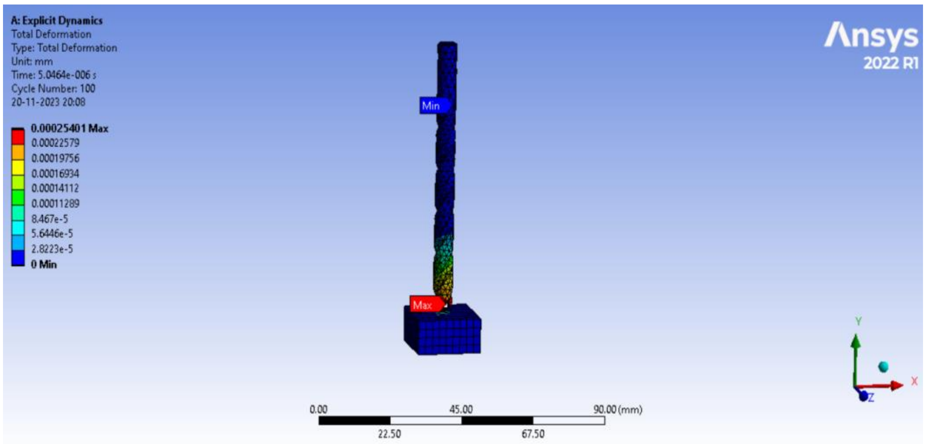

Figure 8: Total deformation

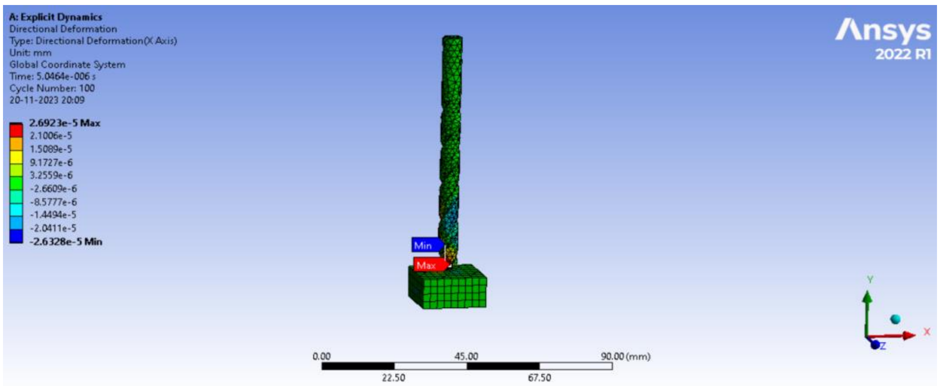

Figure 9: Directional Deformation

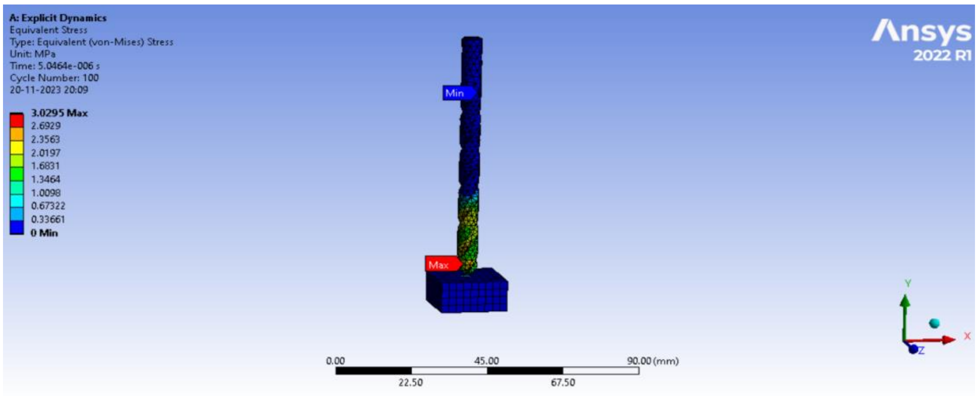

Figure 10: Equivalent stress

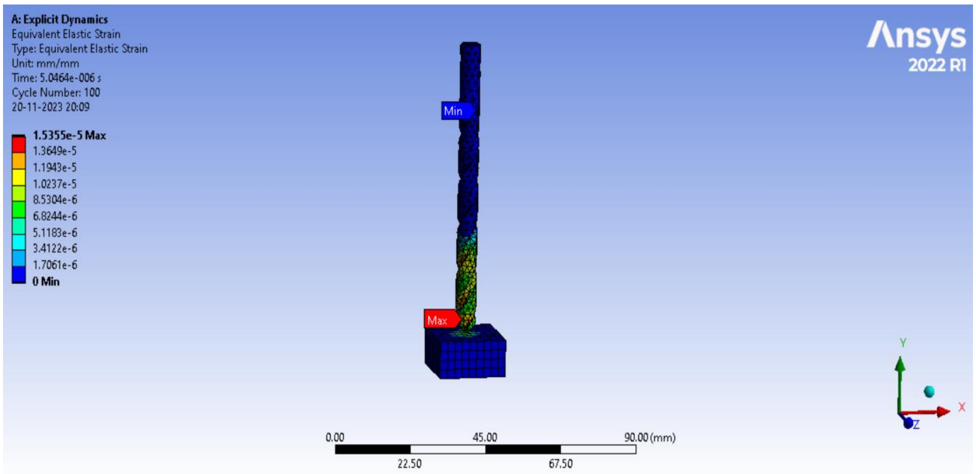

Figure 11: Equivalent Elastic strain

4.3 Explicit dynamic analysis of H30 Carbide Coated Tool

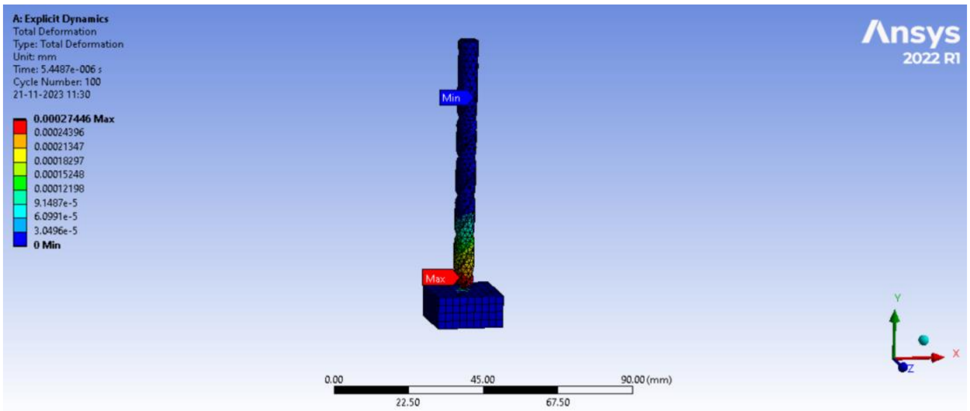

Figure 12: Total deformation

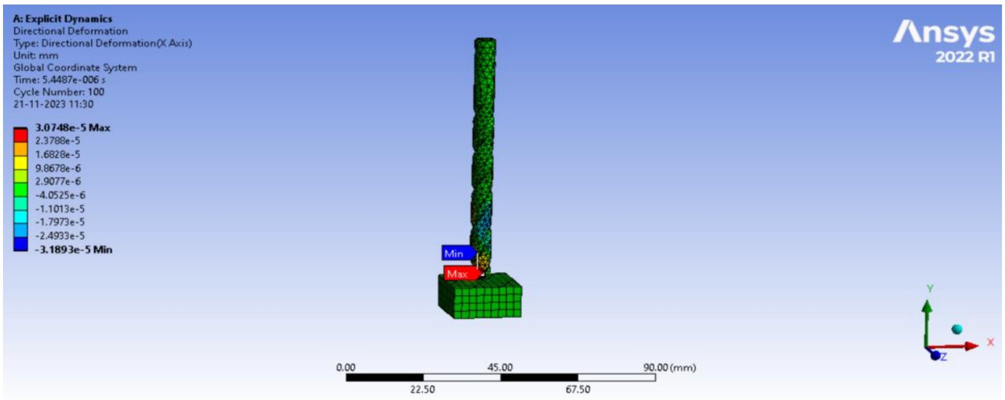

Figure 13: Directional Deformation

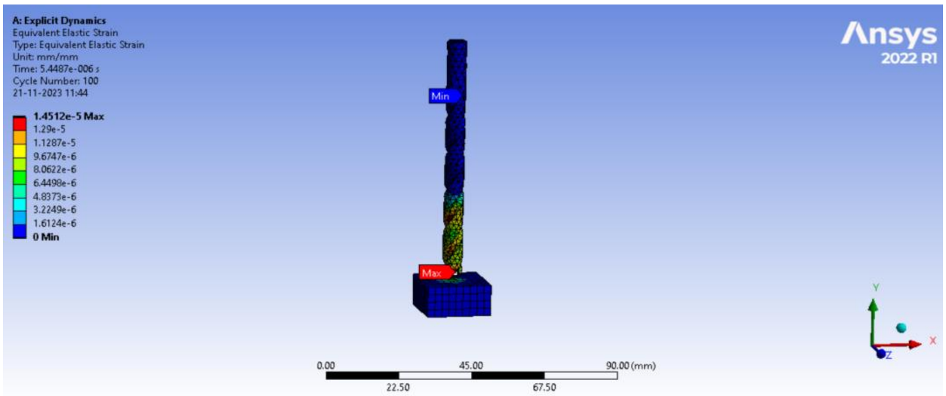

Figure 14: Equivalent stress

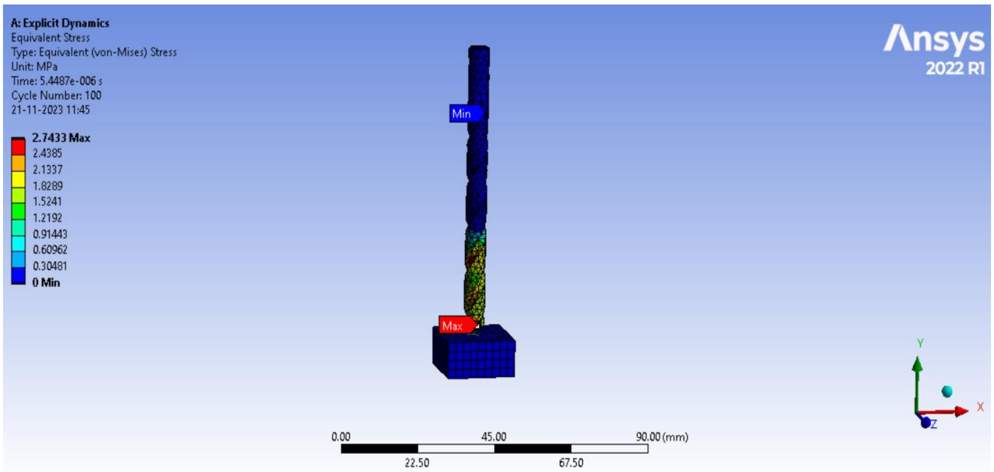

Figure 15: Equivalent Elastic strain

4.4 Explicit dynamic analysis of Titanium alloy Carbide Coated Tool

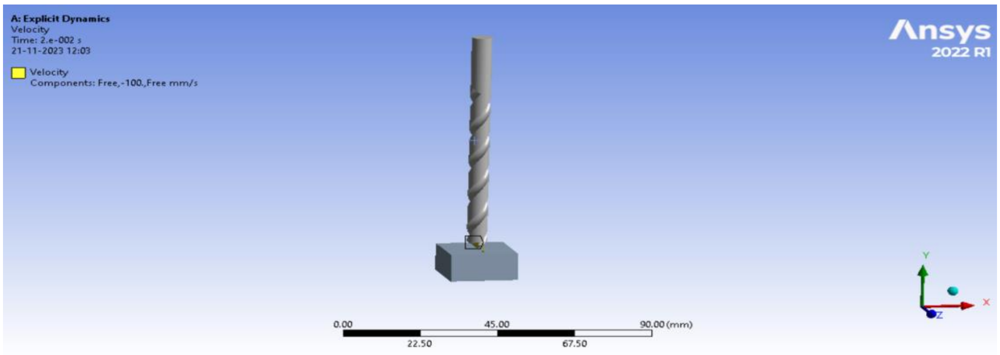

Figure 16: Velocity 100 mm/sec

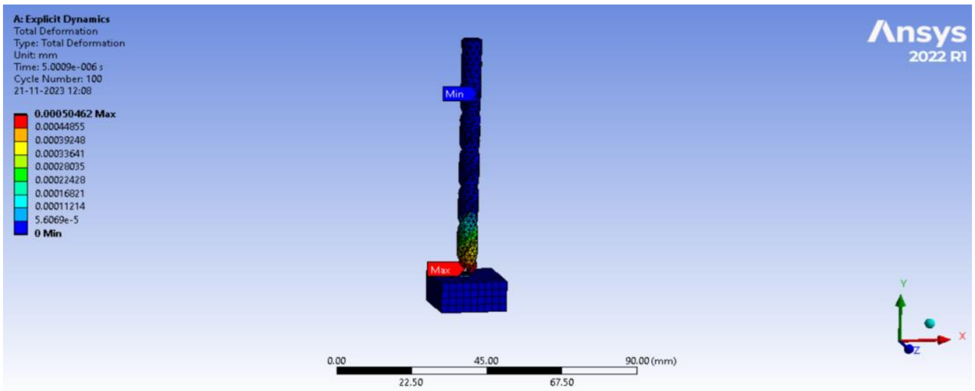

Figure 17: Total deformation

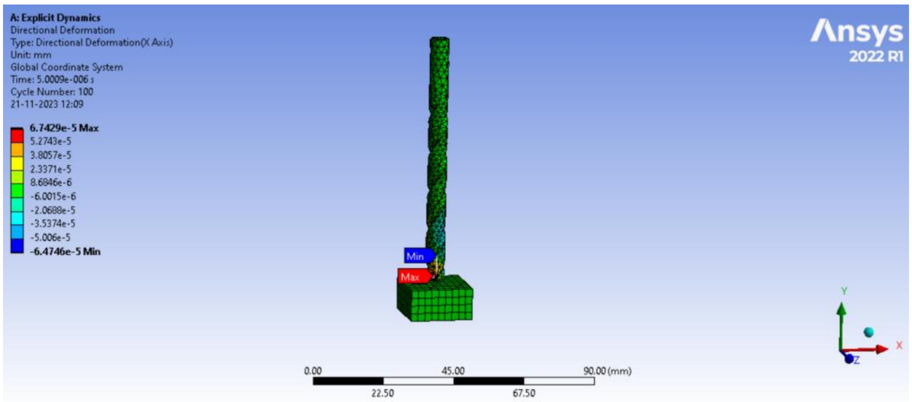

Figure 18: Directional Deformation

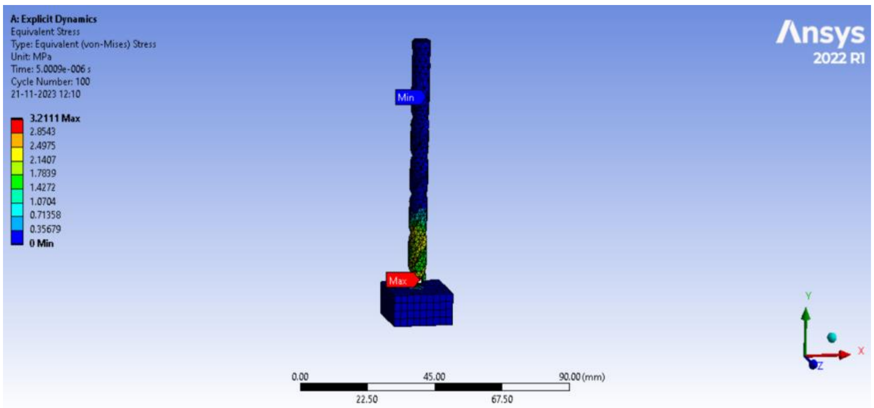

Figure 19: Equivalent stress

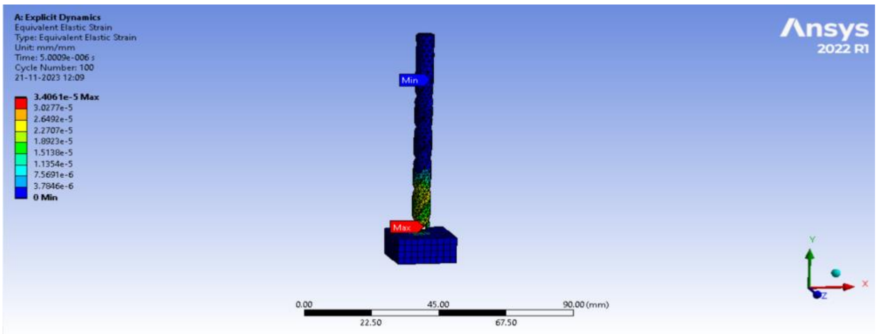

Figure 20: Equivalent elastic strain

4.5 Explicit dynamic analysis of SS1803 Carbide Coated Tool

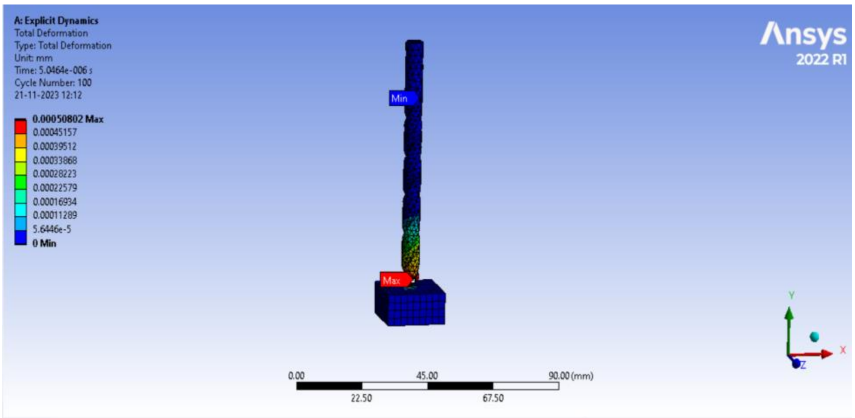

Figure 21: Total deformation

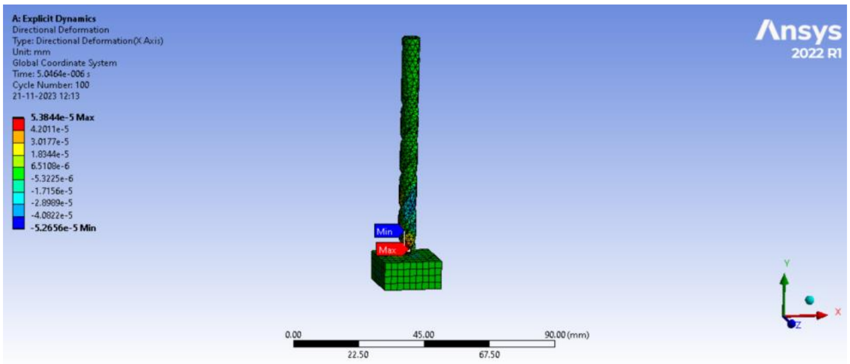

Figure 22: Directional Deformation

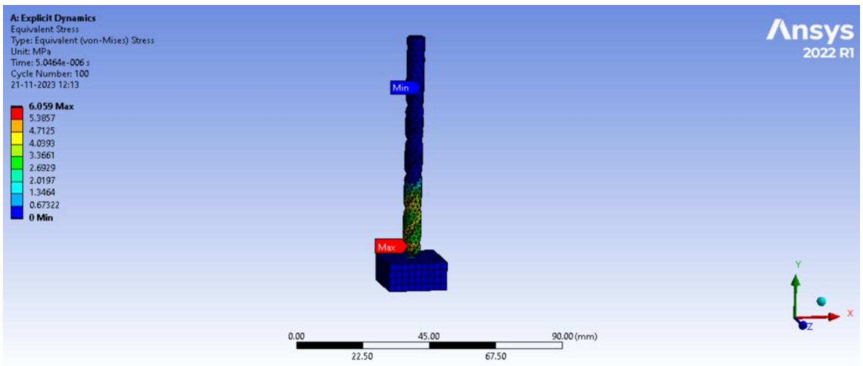

Figure 23: Equivalent stress

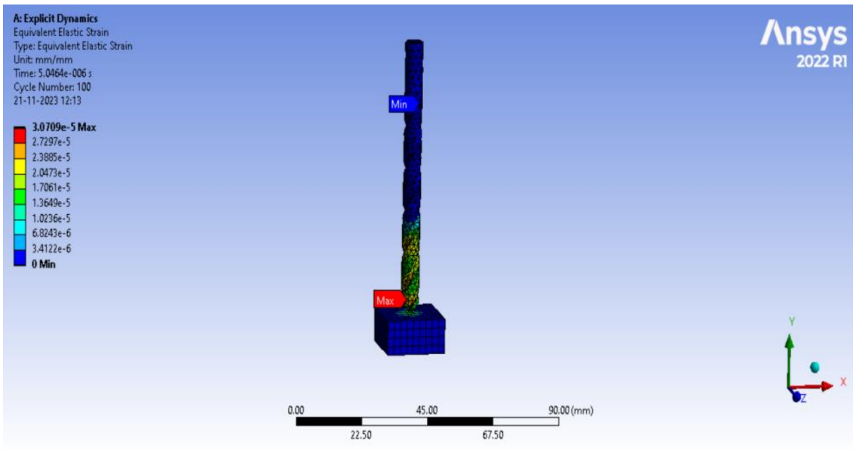

Figure 24: Equivalent Elastic strain

Explicit dynamic analysis of H30 Carbide Coated Tool

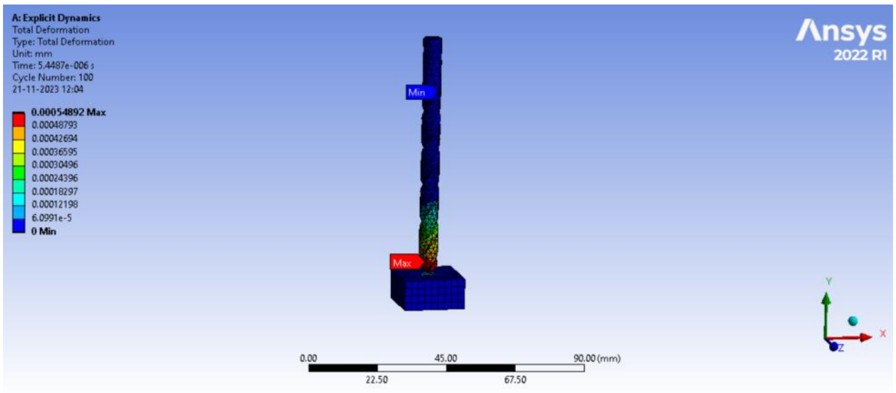

Figure 25: Total deformation

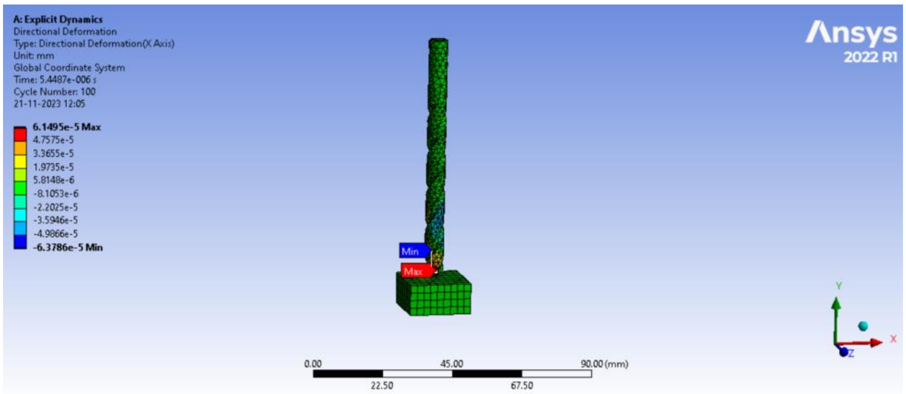

Figure 26: Directional Deformation

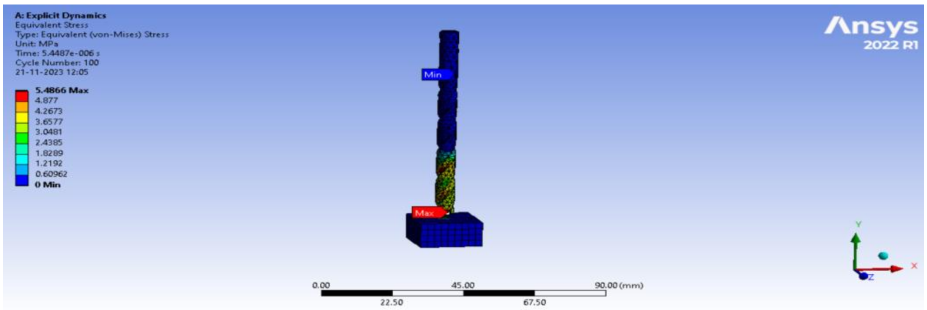

Figure 27: Equivalent stress

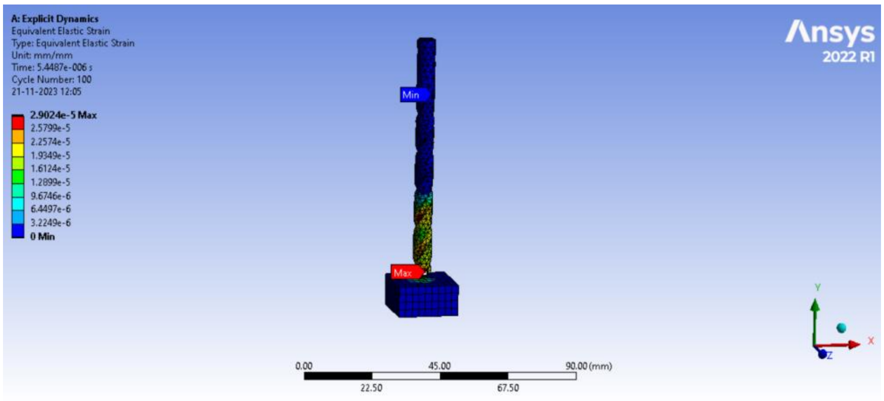

Figure 28: Equivalent Elastic strain

Table 6: Explicit dynamic analysis of Carbide Coated Tool At velocity 50 mm/sec

Materials	Total deformation (mm)	Directional Deformation (mm)	Equivalent stress (Mpa)	Equivalent Elastic strain
SS1803	2.523	3.371	1.703	1.605
Titanium alloy	2.540	2.692	1.535	3.029
H 30	2.744	3.074	1.451	2.74

Table 7: Explicit dynamic analysis of Carbide Coated Tool At velocity 100 mm/sec

Materials	Total deformation (mm)	Directional Deformation (mm)	Equivalent stress (Mpa)	Equivalent Elastic strain
SS1803	5.080	5.3844	3.070	6.059
Titanium alloy	5.046	6.742	3.406	3.211
H 30	5.489	6.149	2.902	5.4866

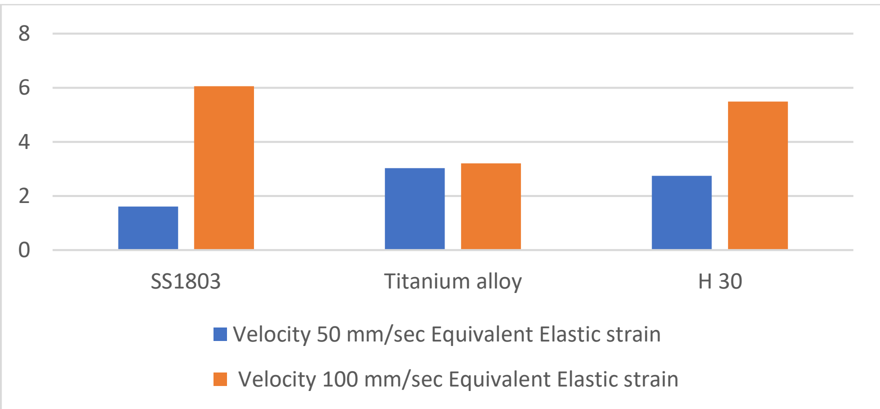

Figure 29: Variation of total deformation

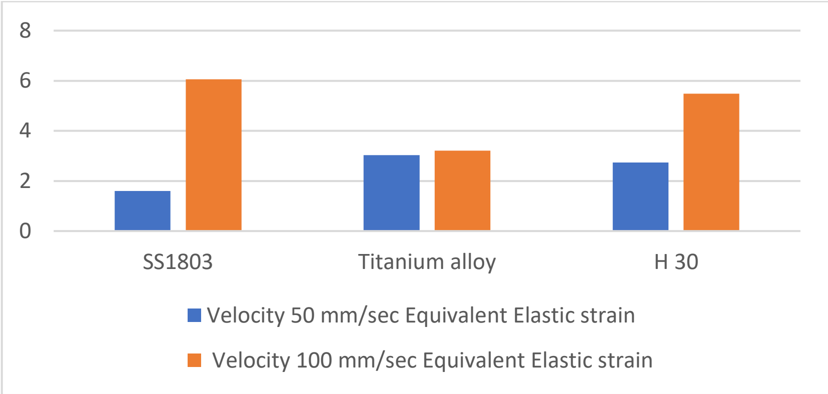

Figure 30: Variation of directional deformation

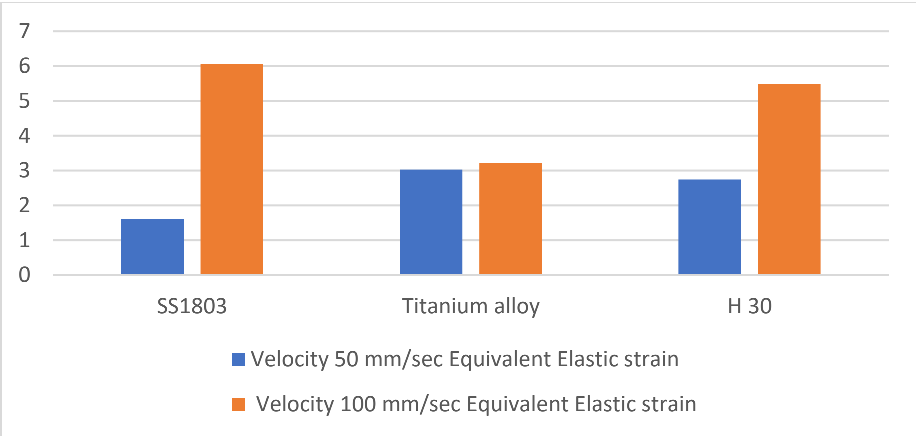

Figure 31: Variation of Equivalent stress (Mpa)

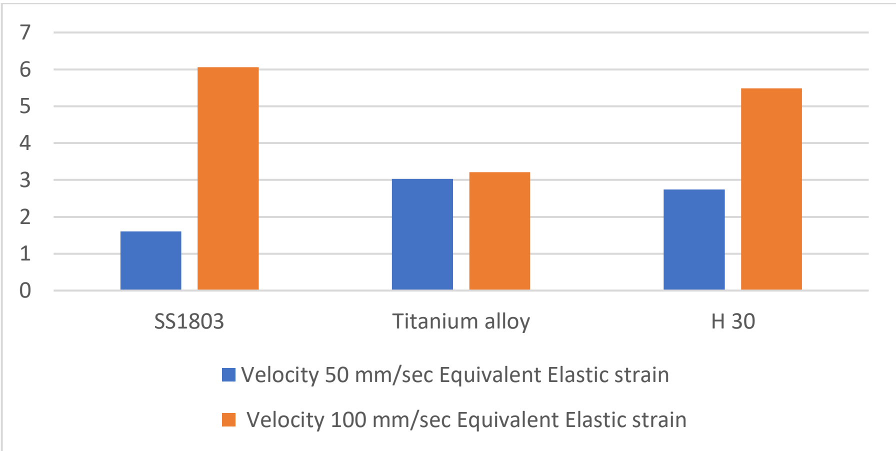

Figure 32: Variation of Equivalent Elastic strain

5. Conclusions

This project has reported on the machining of an annealed Carbide coated tool via coated cemented carbide tool under a dry environment. The following outcomes can be drawn from this research: Annealing resulted from the lowering of machining forces and surface roughness by changing a fine perlite structure into a coarse perlite structure, which reduced the hardness of AISI 4180 alloy steel. Feed was noted as the most influential cutting variable on the surface roughness of the machined components. The cutting speed was found to be the second most influential parameter influencing the machined surface quality. Whereas depth of cut shows a very minimal impact on the surface finish of machined components. SS1803 and Titanium alloy have nearly identical total deformations at both 50mm/sec and 100mm/sec velocities. Perhaps these two materials have comparable elasticity or resistance to deformation. H30 shows a significantly higher total deformation at both speeds compared to SS1803 and Titanium alloy. This might imply that H30 is a more flexible or softer material. The total deformation of all materials approximately doubles when the velocity doubles, suggesting a proportional relationship between the two. This could mean that higher forming speeds lead to more deformation. The Titanium alloy shows the highest deformation at 100 mm/sec velocity, suggesting it might be less resistant to force compared to others. Although SS1803 has the least deformation at 100 mm/sec, it does not maintain this resistance at 50 mm/sec. H 30 possibly offers middle-ground resistance, as its deformation rates are consistently in the middle at both velocities. The Titanium alloy displays the highest stress resistance at 100 mm/sec velocity, suggesting it might be the best for high-speed applications. SS1803, though not as performant as the Titanium alloy at 100 mm/sec, has the best resistance at 50 mm/sec. Perhaps it's more suitable for lower speed uses. H30 shows the least resistance for both speeds, indicating it might need strengthening or isn't suitable for heigh stress applications.

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