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HSS and HCS Cutting Tool Material Influencing Surface Roughness in Machining of GFRP

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Abstract - This work is concerned with the machining of Glass Fiber Reinforced Plastics (GFRP), with a primary interest in how surface roughness is affected by cutting tool materials. GFRP has found a niche in aerospace, automotive, and marine applications, and has obtained recognition for its ratio of strength to weight, resistance to corrosion, and thermal stability. Because of the peculiar structure of E-glass fibers in epoxy resin matrix systems, specific problems concerning the use of this material arise, such as delamination, fiber pull out, and wear of tools, thus requiring tailored machining techniques. The experiment compared performance between cut rods using high-speed steel (HSS) and high-carbon steel (HCS) while machining a GFRP rod (30 mm diameter, 240 mm length) using a lathe. Surface roughness parameters are Ra, Rz, Rt, Rpk, all measured by a Talysurf device. The results showed that HSS tools led to smoother surfaces and greater accuracy but that HCS tools were more economically viable for less rigorous jobs. These results touch upon the need for tool selection based on application and give some insight into further pros in terms of coatings, monitoring systems, and further sustainable machining approaches.

Index Terms- Ra, Rt, Rz, Rpk, High speed steel, High carbon steel, Regression analysis, Surface Roghness.

I. INTRODUCTION

GFRP (glass fiber reinforced polymer) is a type of composite material used in several engineering and industrial applications. This material is very thin glass fiber embedded in a polymer matrix that is mostly epoxy or polyester resin. Combining glass and polymer materials thus provides a very lightweight but at the same time extremely strong and durable structure. This performance makes it an excellent substitute for metals and alloys. Applications for GFRPs would comprise a range of aerospace, automotive, construction, marine applications, and even biomedical areas where high strength-to-weight ratios, long-term durability, and corrosion resistance.

The polymer matrix interconnecting the glass fibers protects them from external damage while effectively delivering loads. Structural integrity, stiffness, and specifically more mechanical performance are provided by the glass fibers. The glass fibers most identified with GFRP components belong to E-glass, which possesses great resistance to temperature functions, excellent electrical insulation, and good mechanical properties. In addition to the above, some manufacturing techniques of GFRP are Pultrusion, Compression molding, and Resin transfer molding, thus allowing the very complicated shapes with high precision, thus increasing its versatility.

GFRPs are preferred for the wear and corrosion resistant properties and are well-inhabited in extremely hostile and chemically and moisture-laden environments. These all things make a cheaper and trustable substitute of metals like stainless steel for industrial applications. But machining with the help of GFRPs introduces a challenge since it is brought due to the heterogeneity and anisotropic type of the polyester. Drilling, milling, and turning are some operations done with this material that give birth to the problem of delamination of fibers within the GFRP.

II. EXPERIMENTAL PROCEDURE

The hardness test using Rockwell hardness machine was performed to examine the mechanical property such as Hardness. A standard load of 160 kg was applied using a ¼ inch steel ball indenter via a calibrated Rockwell Hardness Testing Machine. The Rockwell scale hardness values let us understand the value of resistance offered by the material to deformation by indicating the further understanding of behavior in machining conditions.

Machining processes were done using lathe equipped with a 4-jawed chuck used for carefully aligning the GFRP specimens where turning operation was conducted utilizing High Speed Steel (HSS) and High Carbon Steel (HCS) cutting tools. The feed rate, cutting speed, and depth of cut are the main machining parameters which varied systematically in order to study their effects on surface quality and the specimens are machined into sections with decreasing diameters (26, 22, 18 mm).

Assessment of the surface roughness quality of the samples was performed after machining using a Talysurf surface measurement system. All of which had the specifications for surface roughness average (Ra), total height (Rt), and peak-to-valley height (Rz), Reduce peak height, (Rpk) which were supplied by Talysurf for precise information on surface texture, captured within the machine as a stylus of the Talysurf system scanned the machined surfaces, with the subsequent collection of data.

III. METHODS AND MATERIAL

1. Work Material

The material is a high-performance composite designed for mechanical and structural testing, consisting of continuous, unidirectional boron-free E-glass fibers embedded in an epoxy resin matrix. The fibers provide excellent strength, stiffness, and durability, while the epoxy matrix ensures strong bonding and toughness. This composite meets ASTM D578-00 standards, making it reliable for evaluating mechanical properties under various stresses. The specimen is a 30 mm diameter, 240 mm long round rod.

Figure 1: GFRP specimen

Tool Material

The tool material used for machining were High speed steel (HSS) and High carbon steel (HCS). The table 2 gives the Tool material specifications.

Table 1: Details of work Material

Sl. no.	Parameter	Description
1	Material	E- glass
2	Composition	Epoxy resin (25-19%)
3	Glass	75-81%

Table 2: Details of Tool Material

Element	HSS Composition (%)	HCS Composition (%)
Carbon (C)	0.6 - 1.5	0.6 - 1.5
Tungsten (W)	12-18	-
Chromium (Cr)	3 - 4.5	0.3 - 0.5
Vanadium (V)	1-05	0.1 - 0.3
Molybdenum (Mo)	5-10	-
Manganese (Mn)	-	0.3 - 1.0
Silicon (Si)	-	0.1 - 0.5
Phosphorus (P)	-	≤ 0.04
Sulphur (S)	-	≤ 0.05
Iron (Fe)	60 - 70	90 - 95

Machining Conditons

The experiment was conducted using a Rockwell Hardness Testing Machine. A standard 160 kg load was applied with a 1/4-inch steel ball indenter to test the hardness of composite materials. The hardness of the GFRP specimen value was measured with the help of red dial on the machine.

Table 3: Details of Rockwell Hardness testing

Sl. no.	Parameter	Description
1	Load	160kg
2	Indenter type	¼ inch ball type
3	Measuring Dial	Red dial
4	Hardness of material	95 RHN

Figure 2: Hardness tested specimen

TALYSURF

The roughness of the two GFRP specimens' surfaces was tested using the Talysurf® PGI Series 2000E. After point turning each specimen into three distinct sections of 30 mm each, the diameters were progressively reduced to 26 mm, 22 mm, and 18 mm. The values of surface roughness were measured and recorded for each section, including Ra (average roughness), Rt (total height of the roughness profile), Rz (mean peak-to-valley height), and Rpk (core roughness depth). These values provided a detailed analysis of the surface finish across the different diameters and machining conditions. The results were used to analyse the effect of turning on surface quality.

IV.RESULTS AND DISCUSSION

Experimental data collected from machining tests were used to analyse the effect of different variables on surface roughness. The data was analysed using multiple regression to create a mathematical model that predicts surface roughness based on these factors. To ensure the model's accuracy and reliability, a statistical method called Analysis of Variance (ANOVA) was used. ANOVA checks if the model is a good fit for the experimental data by analysing variations in the results. This process helps confirm that the predictions made by the model are valid and consistent. The study aims to optimize machining conditions optimized for a better surface quality of GFRP.

Surface Roughness

Surface Roughness is defined as the surface scratch or tiny bumps on a surface, which interact with other surfaces applied to it, thus changes the friction, wear, and performance of the components. This is significantly important in industries such as aerospace and automotive engineering.

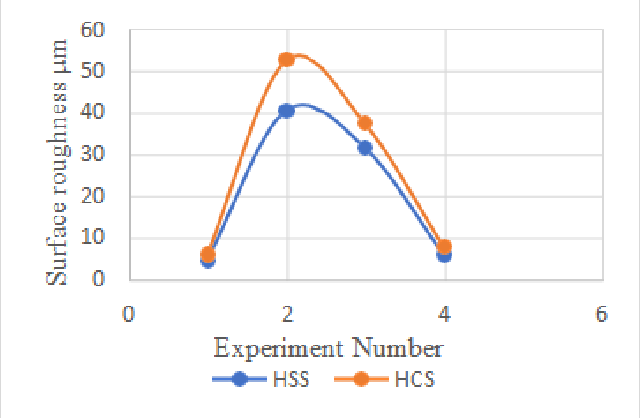

Figure 3: Comparison of Surface roughness values Ra, Rz, Rt, Rpk for HSS and HCS at point-1.

The important measurements include Ra, which is the average roughness; Rz, which is the height between peaks and valleys; Rt, which indicates the overall height range; while Rpk, indicates the wear-prone peaks, which help engineers to assess and control roughness. Managing this ensures that these parts fit better, last longer, and work well for improved product quality and performance.

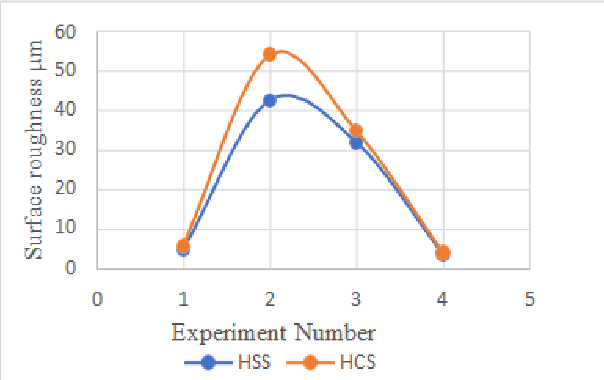

Figure 4: Comparison of Surface roughness values Ra, Rz, Rt, Rpk for HSS and HCS at point-2.

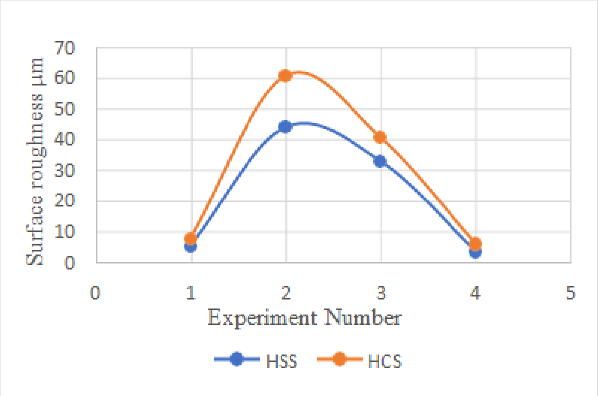

Figure 5: Comparison of Surface roughness values Ra, Rz, Rt, Rpk for HSS and HCS at point-3.

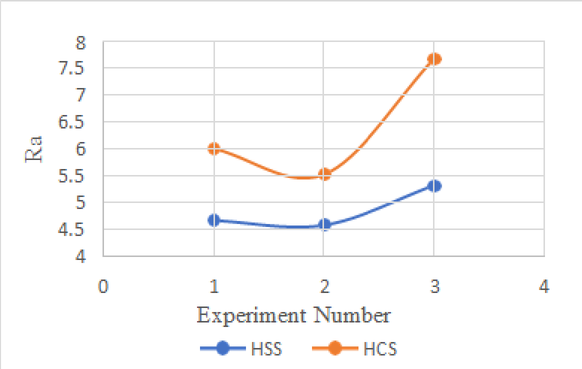

Figure 6: Comparison of Surface roughness Ra values for HSS and HCS.

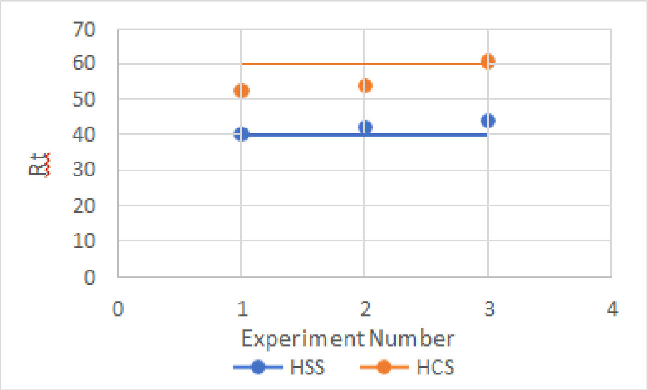

Figure 7: Comparison of Surface roughness Rt values for HSS and HCS.

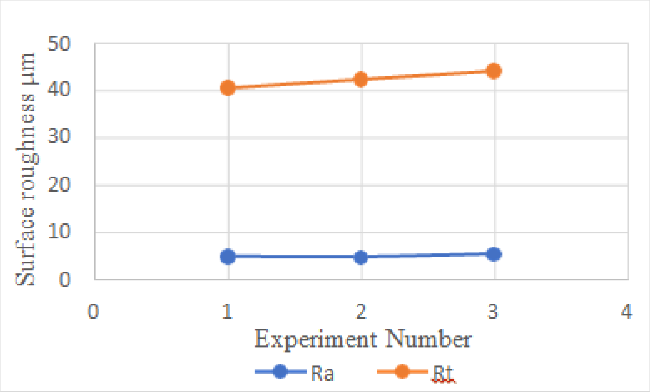

Figure 10: Comparison of Surface roughness Ra and Rt values for HSS.

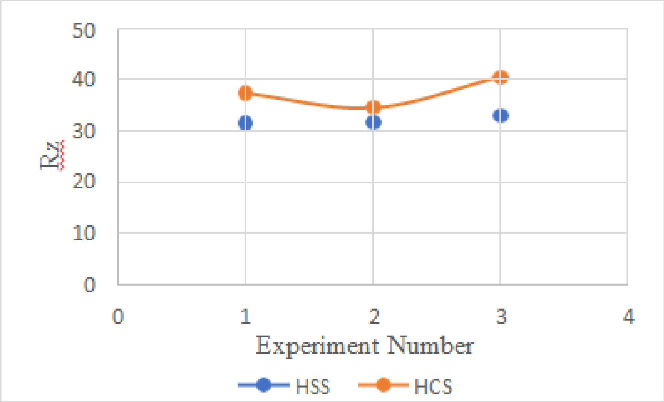

Figure 8: Comparison of Surface roughness Rz values for HSS.

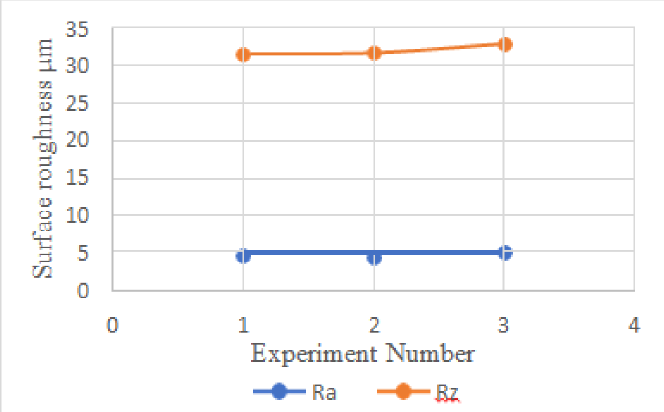

Figure 11: Comparison of Surface roughness Ra and Rz values for HSS

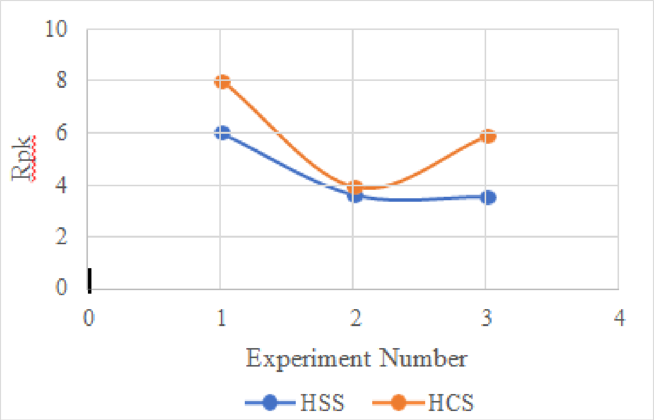

Figure 9: Comparison of Surface roughness Rpk values for HSS and HCS.

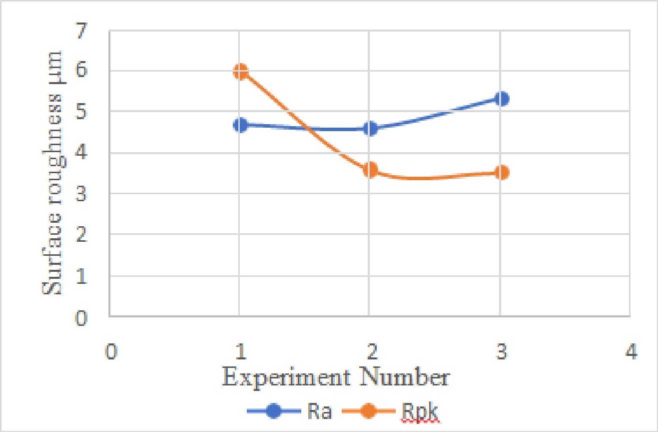

Figure 12: Comparison of Surface roughness Ra and Rpk values for HSS.

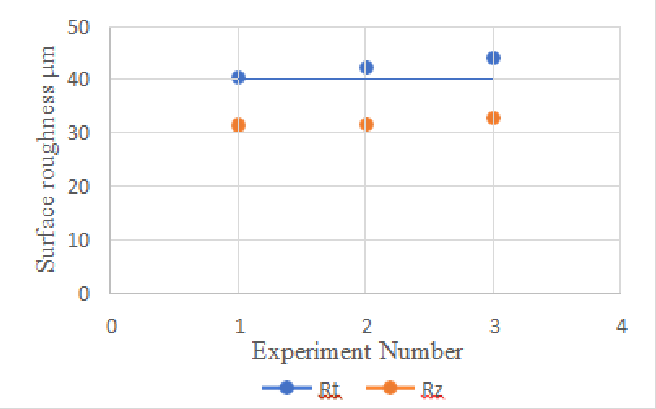

Figure 13: Comparison of Surface roughness Rt and Rz values for HSS.

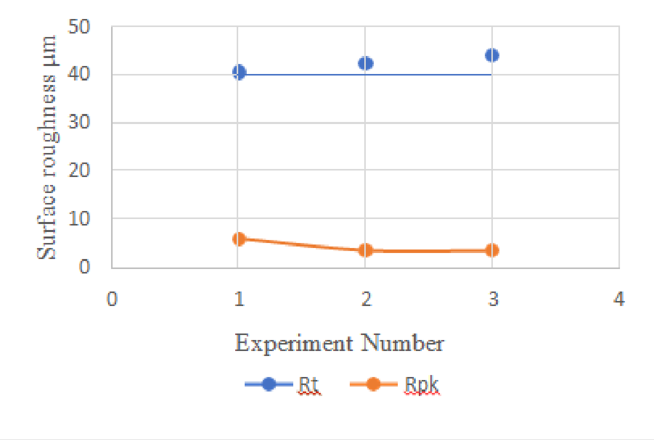

Figure 14: Comparison of Surface roughness Rt and Rpk values for
HSS

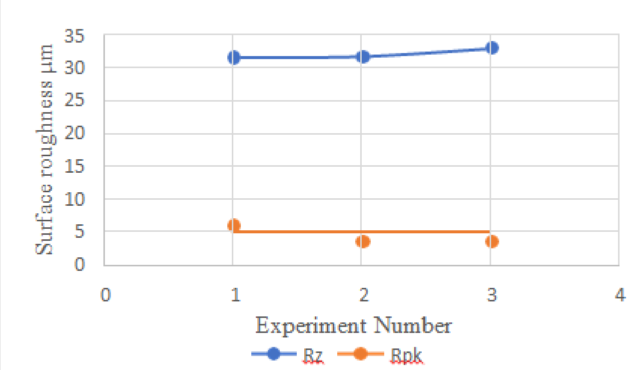

Figure 15: Comparison of Surface roughness Rz and Rpk values for HSS

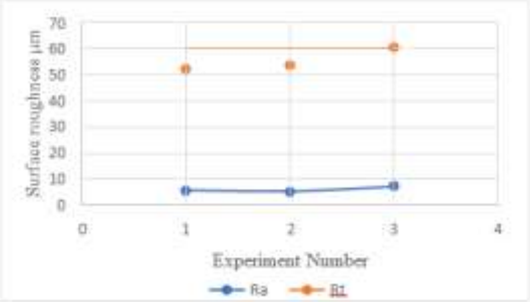

Figure 16: Comparison of Surface roughness Ra and Rt values for HCS

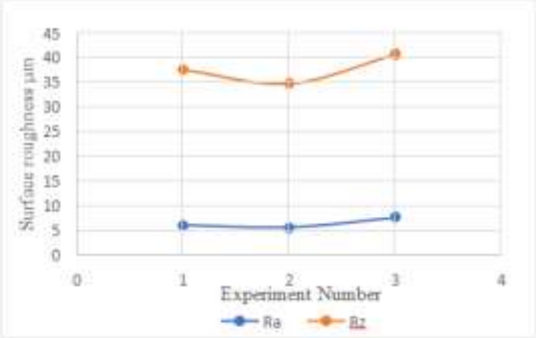

Figure 17: Comparison of Surface roughness Ra and Rz values for HCS

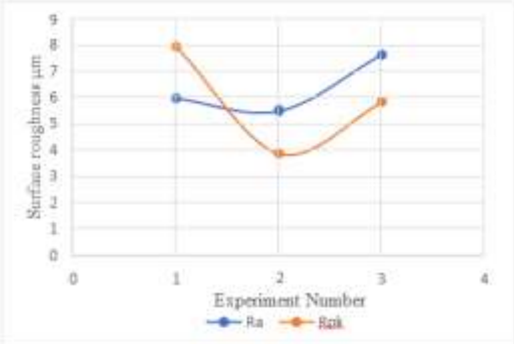

Figure 18: Comparison of Surface roughness Ra and Rpk values for HCS

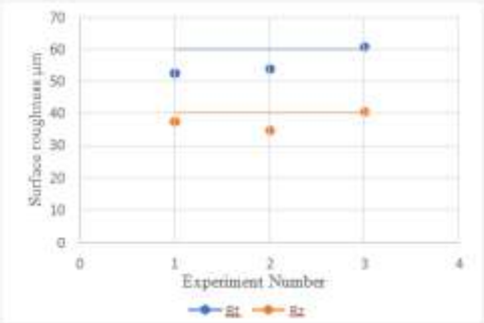

Figure 19: Comparison of Surface roughness Rt and Rz values for HCS

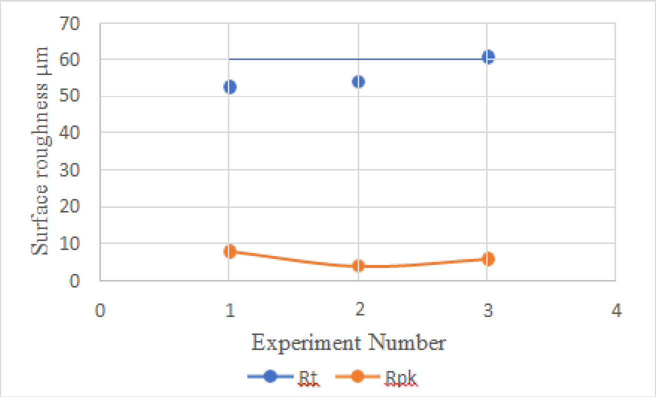

Figure 20: Comparison of Surface roughness Rt and Rpk values for HCS

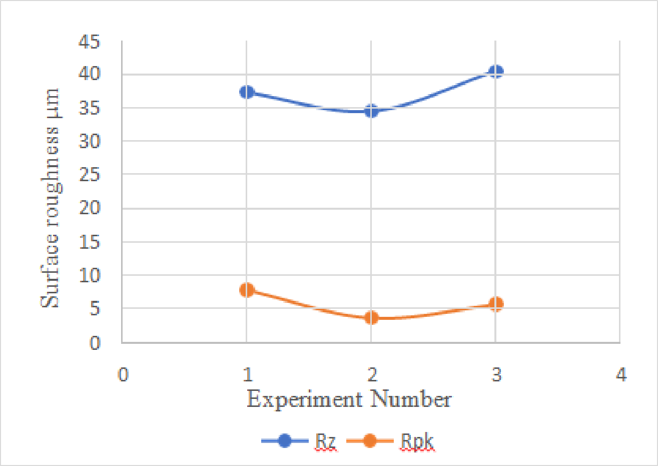

Figure 21: Comparison of Surface roughness Rz and Rpk values for HCS

The comparison of surface roughness parameters (Ra, Rz, Rt, Rpk) for GFRP composites machined with high- speed steel (HSS) and high-carbon steel (HCS) tools shows that HSS tools consistently result in lower surface roughness values. This indicates that HSS tools produce a smoother surface compared to HCS tools.

From the graphical representation, it is evident that the surface roughness parameters are significantly lower for the HSS tool across all metrics (Ra, Rz, Rt, Rpk). The trends in the graph demonstrate a clear advantage of using HSS tools for machining GFRP composites when a high-quality surface finish is required. The graphical analysis reinforces that HSS tools outperform HCS tools in terms of achieving better surface smoothness.

V. CONCLUSION

In conclusion it is important to select the precise material of the cutting tool for procuring the required surface finish in machining. High-Speed Steel (HSS) tooling shows finer and more uniform finish and thus suits precision industries like aerospace and electronics. But, High-Carbon Steel (HCS) tools are comparatively cheaper and can be used for general machining where surface finish is not of great concern. With such knowledge, manufacturers are able to optimally match the tools to the needs of projects, hence optimizing performance and economy.

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