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Wear Characteristics of 22MnB5 Boron Steels When Applied As Cutting Tool In Dry And Wet Machining Aluminum Alloy

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ABSTRACT

22MnB5 boron steel, an Ultra High Strength Steel (UHSS), is celebrated for its exceptional strength and wear resistance, making it highly valuable in automotive and other industries where lightweight materials are essential. Its superior wear resistance also makes it suitable for use in cutting tools. This study aimed to evaluate the performance of 22MnB5 boron steel as a turning insert for metal machining, specifically in relation to cutting speed and cutting environments. The 22MnB5 boron steel blanks were laser-cut into round shapes with a thickness of 2.6 mm and a diameter of 12 mm, following the RNGN 120300 standard. Machining tests were performed on AA 6061 aluminum alloy under both dry and wet conditions, with cutting speeds ranging from 100 to 450 m/min. The outcomes highlighted that 22MnB5 boron steel is effective for machining AA 6061, with tool wear stabilizing between 200 and 350 m/min. Tool wear ranged from 0.15 to 0.27 mm in dry conditions and was reduced to 0.08–0.18 mm in wet conditions. At lower speeds, built-up edges were the predominant wear mechanism, while at higher speeds, adhesive wear in the form of a tribolayer was more pronounced. These findings highlight the potential of 22MnB5 boron steel for efficient machining, particularly under wet conditions, offering valuable insights into improving tool life and reducing production costs.

Keywords: *22MnB5, Boron Steel, Machining, Tool Wear, Tribolayer*

1. INTRODUCTION

The use of cutting tools with high wear resistance has grown significantly due to their ability to extend tool life in machining, which in turn helps lower energy consumption in metal cutting. High Speed Steel (HSS) has become a well-established material in the machining industry, known for delivering a fine surface finish, low wear rates, and reduced cutting forces. The popularity of HSS cutting tools surged several decades ago when the forging industry discovered that stronger, harder steel could be produced and shaped in various ways. HSS offers a combination of high hardness and enhanced toughness, making it ideal for machining medium-strength materials such as aluminium alloys and plastics. Today, HSS is widely used in a range of machining operations, including turning, milling, drilling, and boring, and even in other high-wear applications like agricultural cutters and mining equipment.

Despite their advantages, High-Speed Steel (HSS) cutting tools encounter several challenges due to their relatively low hot hardness, which can impact their performance during machining operations. One significant issue is their susceptibility to wear and edge melting, particularly under conditions of high friction or extreme machining environments. This lower hot hardness means that HSS tools can experience accelerated degradation, such as the formation of built-up edges or the softening of the cutting edge, when subjected to elevated temperatures and prolonged cutting [1-2].

According to Qi et al. (2011) [3], alloying elements such as chromium, vanadium, titanium, and boron can improve the wear resistance of steels when they are added to their microstructure. Lijue et al. (2006) [4], for example, compared the wear behaviour of high-vanadium and high-chromium-based steels. The wear resistance of vanadium-based steel is four times greater than that of chromium-based steel, according to the authors. Fatigue spalling and abrasive debris dominate the wear mechanism, causing crack propagation in the steel structure. Ren et al. (2018) [5] and Yi et al. (2012) [6], on the other hand, have reported that the addition of boron as an alloying element improves the steel's hardness and abrasion resistance. When boron was added to the Fe structure, the solidification microstructures of the Fe–B alloy changed the distribution of eutectic boride, pearlite, and ferrite, affecting the formation of the boride volume fraction. As the specimen was heated, the martensite phase dominated the microstructure, significantly increasing its hardness. Such high hardness contributed to high wear resistance, particularly at high temperatures. With the development of boron-added ferrous alloys, 22MnB5 Boron Steel emerged as a new type of material, designed specifically for metal stamping applications. 22MnB5 was prepared in metal sheet condition with the original blank microstructure appearing in a fine homogeneous grain of major ferrite phase and minor pear ferrite and cementite. Ferrite has a basic body-centred cubic (BCC) crystal structure. When the 22MnB5 boron Steel is heated to 800oC, the Ferrite microstructure transforms into austenite, and the crystal structure transforms to Face-Centred Cubic (FCC) [7-8]. The microstructure of 22MnB5 transformed into the martensite phase after it was stamped and heat treated in a quenching environment. The FCC austenite undergoes a highly strained body-centred tetragonal (BCT). As a result, these steels have attained a tensile strength of 1500 MPa, a hardness of 80 HRC, together with high hot hardness, providing a distinct advantage when employed at elevated temperatures [9-10].

Several wear behaviour studies on boron steel have been conducted in the past. Hernandez et al. (2015) [11], used a dry sand wheel test to investigate the effect of temperature on the wear behaviour of boron steel. In general, the wear rate of boron steel decreased at lower temperatures ranging from 20 to 100°C due to the formation of a tribolayer on the plastically deformed surface. The wear rate increased as the temperature increased due to the recrystallization of the samples' ferrite grains. The combination of microcutting and microplows was demonstrated as the dominant wear mechanism. Elena et al. (2017) [12], investigated the friction and wear behaviour of 22MnB5 using specific pin on disc tests in another study. When tested against uncoated 22MnB5 samples, either hardened or not, the author discovered that the wear mechanism was dominated by abrasive wear and oxidative wear. During the friction test, translation movement between contacted surfaces could cause continuous oxide film detachment. Some of these films may adhere to the 22MnB5 disk. Additional friction would promote abrasive wear involving three-body interactions between the pin and disk samples.

In this study, the wear characteristics of 22MnB5 boron steel were observed via machining tests. 22MnB5 boron steel was shaped into round cutting tools and employed to machine AA 6061 aluminum alloy. Machining tests are being performed at various cutting speeds to understand their behaviour at high temperatures and pressures. The machining trials also included both dry and wet conditions to establish the best machining parameters.

2. METHODOLOGY

Initially, the 22MnB5 boron steel was sourced from the industry and subsequently subjected to hardening and heat treatment through a hot stamping process. It was then laser cut according into the shape of a RNGN 120300 tool, as shown in Figure 1. Figure 2 depicts a sample product of a 22MnB5 component being cut from a hot-stamped part. Figure 3 depicts 22MnB5 samples that have been shaped into RNGN 120300 insert. Tables 1 and 2 show the mechanical and chemical properties of 22MnB5 boron Steel, respectively.

Figure 1. Laser facility employed to cut 22MnB5 Boron steel.

Figure 2. Example of 22MnB5 component sourced form industry.

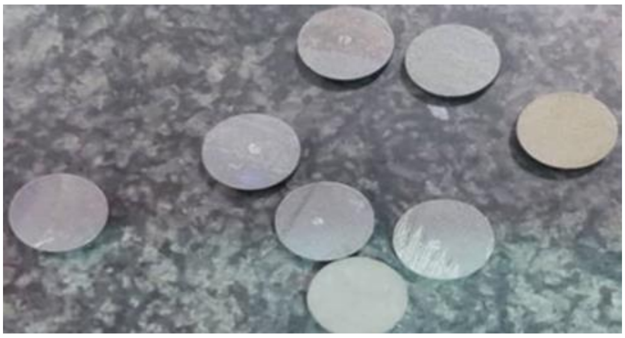

Figure 3. 22MnB5 Boron Steel with the shape of RNGN 120300 turning insert.

As a result, the RNGN 120300 insert was securely fastened within the CRDN252543 tool holder. The experimental setup involved conducting machining tests on a CNC turning machine, utilising aluminum alloy 6061 (AA 6061) as the material for the workpiece. This setup is illustrated in Figure 4. The machining tests were conducted under controlled conditions, with a fixed machining period of 40 seconds. The cutting speeds varied between 100 and 450 m/min, while the feed rate remained constant at 0.1 mm/rev. Additionally, a consistent depth of cut of 0.5 mm was maintained throughout the tests. Since the machining trials were conducted to assess the condition of the cutting tool under both wet and dry conditions, only a single machining trial was performed for each condition. Upon completion of the machining trials, the assessment of tool wear was conducted using a tool maker microscope, as depicted in Figure 5. The investigation of the wear mechanism was further conducted using a scanning electron microscope.

Table 1 The mechanical properties of 22MnB5 boron steel [8].

Young's modulus (MPa)	Yield Strength (MPa)	Ultimate Strength (MPa)	Failure strain (%)
97,0000	1,108	1,463	3.47

Table 2 Chemical composition of 22MnB5 boron steel (wt%) [9].

C	Mn	Si	Cr	Mo	B
0.22	1.58	0.25	0.19	0.004	0.0032

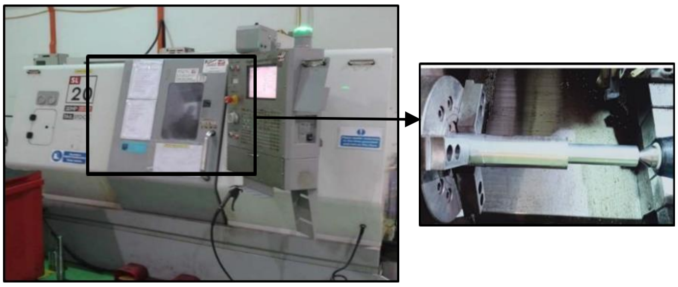

Figure 4. Set Up for machining test

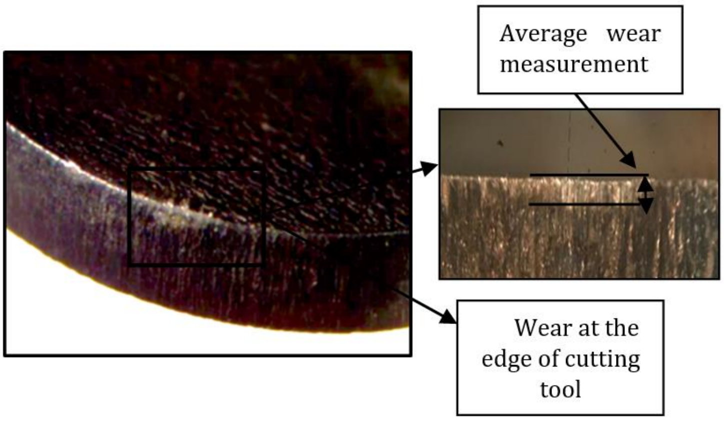

Figure 5. Measurement of tool wear by tool maker microscope

3. RESULTS AND DISCUSSION

Figure 6 illustrates the comparison of wear values across dry and wet conditions when machining 22MnB5 cutting tool with AA 6061 aluminum alloy. Observations indicate that wet machining results in less tool wear compared to dry machining. For wet machining, tool wear decreases as cutting speed increases, except at the 400 m/min speed where this trend does not hold.

The aforementioned observation at the Figure 6 indicates that the use of dry machining techniques leads to an unstable pattern of wear progression. Observations of the results suggest that the uncertainty in wear development may be attributed to the formation of a Built-Up Edge (BUE). A BUE is a layer of workpiece material that adheres to the rake face of a cutting tool due to the heat generated during the cutting process [13, 16]. As an illustration, when analyzing a speed of 250 m/min, the wear measurement attains its highest point at 0.271 µm. Further on, it can be observed that the wear value exhibits a gradual decline as the cutting speed is elevated to 300 m/min, to 0.139 mm, and further decline to 0.114 mm at 400 m/min. Further observation of BUE is shown in Figure 7.

In the context of wet machining, a noticeable trend of decreasing tool wear has been observed as cutting speed increases. At the beginning of machining, the tool recorded wear at 0.181 mm. At a cutting speed of 350 m/min, the measured tool wear decreased to 0.1 mm. However, the tool wear increased sharply to 0.184 mm at 400 m/min, before dropping back to a minimum of 0.081 mm at 450 m/min cutting speed. Similar like in the case of dry cutting, the uncertainty in wear development could be attributed to the presence of a BUE formation, which adheres to the surface and causes a significant rise in wear measurement [13, 16]. The structural integrity of the BUE deteriorates as speed increases, resulting in a reduction in wear when the speed reaches 300 m/min due to the progressive disintegration of the BUE. However, the effect of the BUE in wet machining appears to be less pronounced compared to dry cutting.

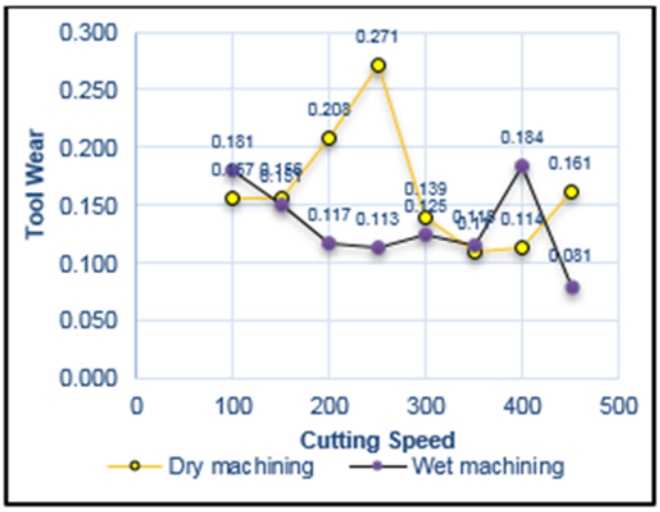

Figure 6. Comparison of wear values across dry and wet conditions when machining 22MnB5 turning inserts with AA 6061 aluminum alloy.

In summary, the observed wear during dry machining exhibited a range of 0.15 to 0.27 mm. In the context of wet machining, the observed tool wear exhibited a range of 0.08 to 0.18 mm. The use of coolant in wet machining has been found to result in a mean reduction of wear by 15.8%. The wear regime seems to have reached a stable state, with a cutting speed ranging from 200 to 350 m/min. Employing coolant fulfills two primary roles which are to cool the cutting zone and offers lubrication to decrease friction between the cutting tool and the workpiece. In addition, coolant serves the purpose of effectively removing debris from the entangled material at the cutting region [14]. On the other hand, the round cutting tool utilised in this study possesses a significantly larger nose radius (12 mm) in comparison to conventional cutting tools (ranging from 1.2 to 1.6 mm). Consequently, the increased nose radius of the tool resulted in a correspondingly larger contact area with the workpiece. Thus, a significant quantity of energy is necessitated in order to induce shear deformation in the metal, leading to the generation of elevated temperatures at the cutting interface [15].

Figure 7 illustrates the observed wear characteristics during the machining process of 22MnB5 boron steel under dry conditions, specifically at a lower cutting speed of 100 m/min. The application of laser cutting on boron steel leads to the emergence of prominent ridge formations on its surface. Observations made through scanning electron microscopy (SEM) indicate that the presence of built-up edges is highly noticeable at the cutting tool's edge. The presence of elevated cutting temperatures and pressures at the contact interfaces led to the formation of a built-up edge as molten metal adhered to the tool nose radius. The presence of molten metal adhered to the nose radius resulted in alterations to the shape and contact area, thereby impeding direct contact between the tool edge and the workpiece. Consequently, an increase in the cutting force and friction would be observed, leading to the accumulation of a higher cutting temperature. In the event that the machining process is extended, it is anticipated that this circumstance would lead to premature tool degradation, consequently compromising the quality of the workpiece's surface finish [16].

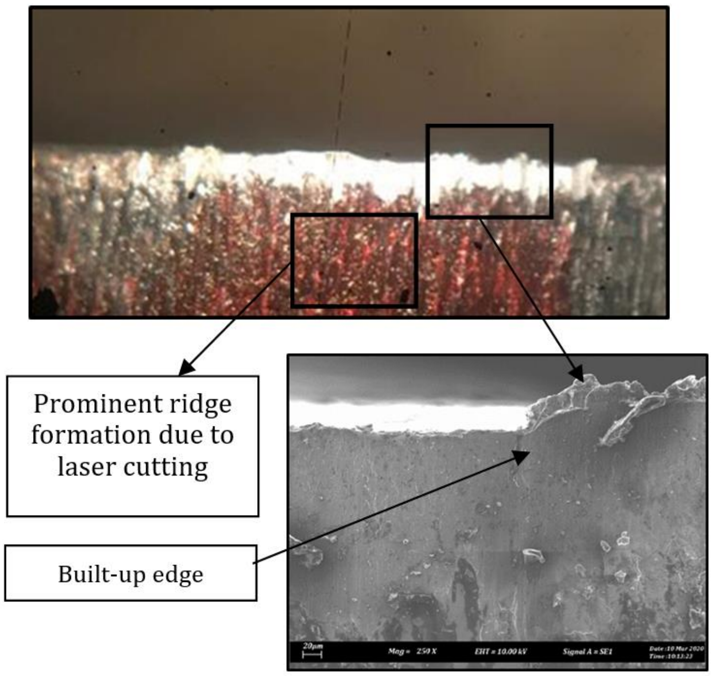

Figure 7. Wear analysis of machining Al 6061 aluminum alloy using a 22MnB5 turning insert (Cutting Speed: 100 m/min, Dry Conditions).

The introduction of coolant into the cutting region resulted in a reduction in tool wear, as evidenced by the presence of a clean area and the diminished impact of built-up edge formation. The dominance of the scratch mark and minor ridge formation in the flank region is illustrated in Figure 8. Upon examining a worn surface, it becomes apparent that there is evidence indicating the detachment of individual particles, which is manifested in the presence of free debris. When two alloys come into contact with each other, the phenomenon of adhesion takes place as a consequence of the friction process, leading to the transfer of material. Simultaneously, the contact surfaces exhibited the presence of liberated debris, which can be attributed to particle detachment. This phenomenon is believed to be primarily caused by the substantial rotational impact induced by the cutting speed. Moreover, the phenomenon of tribolayer oxidation has the potential to facilitate the buildup of loose particles on the surfaces that have undergone wear. During the shearing process, it is observed that the presence of loose debris can function as an abrasive agent, thereby causing the formation of ploughings on the surface of the alloy. The formation of grooves on contact surfaces can occur to a certain degree due to the intense ploughs caused by particle detachment [17].

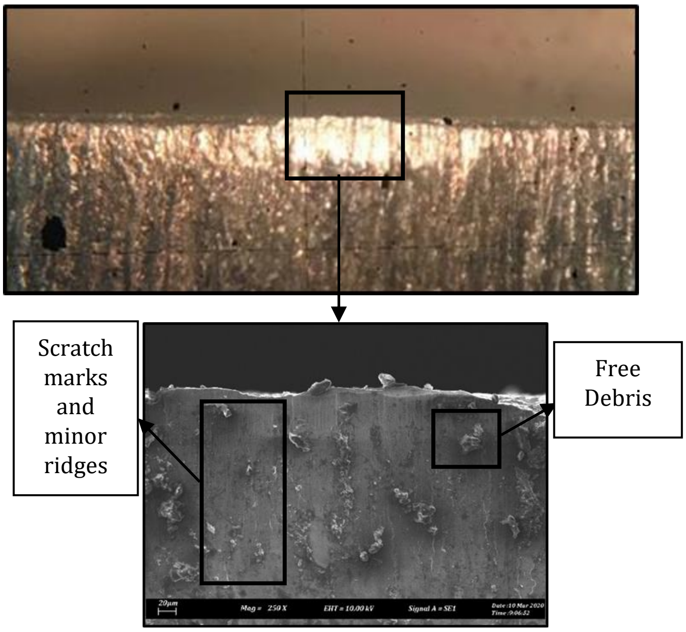

Figure 8. Wear analysis of machining Al 6061 aluminum alloy using a 22MnB5 turning insert (Cutting Speed: 100 m/min, Wet Conditions).

Figure 9 illustrates the wear characteristics observed during dry environment when machining 22MnB5 boron steel with AA 6061 at a cutting speed of 450 m/min. The provided illustration portrays a substantial layer of aluminium that seems to be firmly attached to the lateral surface of 22MnB5 boron steel. The observation suggests that adhesive wear was the predominant mechanism in the wear region throughout the brief cutting period. Adhesive wear is a phenomenon characterised by the detachment of a portion of AA 6061 from the workpiece, which is then captured at the cutting interface. The material that was confined within the given space commenced melting as a result of the elevated levels of temperature and pressure. In the study conducted by Abu Bakar et. al [18], it was observed that when the surfaces in contact were abraded, the molten portion of AA 6061 exhibited a sliding behaviour on the surface of the cutting tool. This sliding behaviour resulted in the formation of a tribolayer, which effectively reduced the rate of wear. Additionally, the layer serves to enhance thermal conductivity, facilitating the absorption of heat from the cutting zones and thereby reducing wear [19-20]. The findings presented in Figure 5 illustrate that the wear measurements obtained at a cutting speed ranging from 350 to 400 m/min fall within the range of 0.10 to 0.15 mm. Notably, these values are comparatively lower than those observed for other cutting parameters.

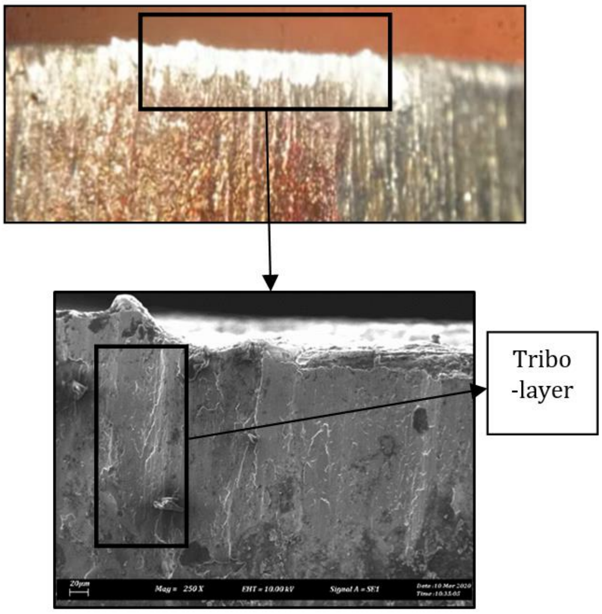

Figure 9. Wear analysis of machining AA 6061 aluminum alloy using a 22MnB5 turning insert (Cutting Speed: 450 m/min, Dry Conditions).

Figure 10 illustrates the wear characteristics observed during wet environment when machining 22MnB5 boron steel with AA 6061 at a cutting speed of 450 m/min. In contrast to Figure 9, the wear characteristics observed in both cutting conditions exhibited a clean appearance with minimal formation of adhesion layers. The aforementioned observation indicates that an increased cutting speed has a mitigating effect on the development of a tribolayer or built-up edge, particularly when operating under wet conditions. According to Bilgin (2015) [21], the reduction in size of the built-up edge was found to be more significant with cutting speed as compared to feed rate or depth of cut. At lower cutting speeds, it was observed that the molten layer of AA 6061 exhibited a tendency to adhere to the tool edge. During the course of the machining process, the gradual accumulation of the built-up edge layer facilitated the bonding of a section of the workpiece with the tool through atomic diffusion. The heat treatment effect at the cutting zone led to a microstructure change, causing certain built-up edges to partially harden [22-23]. When the cutting speed was increased, the elevated rotational force resulted in the fracture of the accumulated edge while simultaneously generating successive depositions of molten material. The aforementioned phenomenon has the potential to contribute to the fatigue failure of the cutting tool (24).

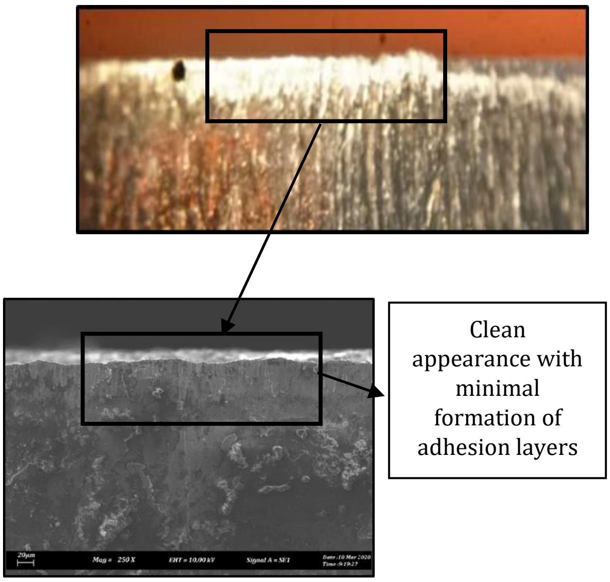

Figure 10. Wear analysis of machining AA 6061 aluminum alloy using a 22MnB5 turning insert (Cutting Speed: 450 m/min, Wet Conditions).

4. CONCLUSIONS

This study was conducted to evaluate the effectiveness of 22MnB5 boron steel as a turning insert to cut AA 6061 aluminium alloy. The 22MnB5 boron steel blanks were shaped into round RNGN 120300 tools and used to machine aluminium alloy. The findings suggest:

1. 22MnB5 boron steel that applied as turning insert is capable to machine AA 6061 aluminium alloy with 0.15 to 0.27 mm wear range in dry machining. The wear is slightly lower in wet machining, ranging from 0.08 to 0.18 mm.
2. At low cutting speeds, the predominant wear mechanism observed was the formation of a built-up edge.
3. At higher cutting speeds, adhesive wear, specifically in the form of a tribolayer, became the predominant wear mechanism.

Optimizing cutting parameters could further enhance the performance of 22MnB5 boron steel turning inserts. Additionally, this tool may be suitable for machining harder materials, which could provide further insights. Given that this steel can be produced in large quantities, it has the potential to reduce cutting tool costs. The steel's commercial potential extends to applications requiring high wear resistance, such as cutting blades, turbine blades, grinding tools, and other similar devices.

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