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Editorial

# Advanced Coating Materials for Machining Processes

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Nowadays, the manufacturing community is facing considerable challenges in dealing with excessive wear and premature failures of cutting tools governing the machining processes. Developing coating materials to improve the wear resistance of tool substrates could be a feasible strategy to cope with the harsh cutting conditions, which has become a topic of great interest in recent decades [1–3]. Tool coating refers to covering a thin layer of refractory metal or non-metallic compound with good wear resistance on the traditional tool substrate by vapor deposition methods [4]. As the coating can act as a chemical and thermal barrier, it avoids the direct contact between the tool and the workpiece and reduces the mutual diffusion at the tool-workpiece interface, thereby improving the anti-adhesion and wear resistance of cutting tools [5]. Additionally, green dry machining technology has attracted extensive attention among researchers in recent years due to the increased awareness of environmental protection, which has emphasized the importance of coating materials for diverse manufacturing operations as the tool edges tend to contact the workpieces directly without the presence of cutting fluids. For example, when dry cutting superalloys or titanium alloys, the cutting temperature can even reach over 1000 °C, which requires the tool coatings to have high red hardness and wear resistance, as well as excellent resistance to high-temperature oxidation. As a consequence, traditional coating materials can no longer meet the stringent requirements for use. This circumstance promotes the fast development of advanced tool coatings.

Advanced coating materials are generally featured by superior mechanical/thermal behaviors in comparison with conventional tool materials such as high-speed steel and tungsten carbide. Their outstanding characteristics can significantly improve the cutting conditions dominating the tool-chip and tool-work interactions during the material removal process. This can be evidenced by the remarkable reduction of cutting forces/temperatures, the improvement of cut surface quality as well as the extension of tool life [2,6,7]. To date, tool-coating materials are mainly compounds with high wear resistance, such as nitrides, carbides, oxides, carbonitrides, silicides, sulfides, borides, diamonds, etc. [3,6]. They can be classified into metal bond type, covalent bond type, and ionic bond type. The metal bond coating materials possess high melting points and low brittleness and have good comprehensive properties, such as TiN, VC, ZrC, WC, etc. The covalent bond coating materials have relatively high hardness and good chemical stability, such as $B_4C$, SiC, $Si_3N_4$, etc., while the ion-bonded coating materials have good chemical stability, high brittleness, and relatively low hardness, such as $Al_2O_3$, $TiO_2$, etc. In most cases, a coating material can contain multiple chemical bonds. For example, TiC has metallic, ionic, and covalent chemical bonds, but covalent bonds are the main ones, followed by ionic bonds and metallic bonds. The type of chemical bond determines the hardness, melting point, and chemical stability of the coating material.

The composition of tool coatings has been gradually diversified to meet the requirements of various cutting processes, which has gradually developed from the traditional binary system to the ternary and multi-element systems. Among them, the ternary and

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multi-element systems significantly improve the overall performance of coatings through the solid solution strengthening, grain refinement strengthening effects of doping elements, and the synergistic effect of various elements [8].

Additionally, the coating structure is gradually transformed from a single layer to a complex structure such as multi-layer, nano-composite, and gradient structures [9]. Nano-multilayer and nano-composite structures utilize the interfacial strengthening effect between nano-layers or different phase structures to achieve superhard and supermodulus characteristics of coatings, which have been favored by researchers for a long time. The composite structure and optimal design of multiple structures are also one of the ways to improve the comprehensive performance of tool coatings, such as multi-layered coatings, which combine the superhard effects of the multi-layer structure and the strengthening effects of the nanocrystalline/amorphous phase interface.

Moreover, superhard coatings such as diamond coatings, diamond-like carbon coatings, cubic boron nitride coatings, and soft coatings with self-lubricating effects have also been extensively studied in order to expand the scale of industrial applications. In recent years, high-entropy alloy coatings, which have much higher hardness, strength and wear resistance than traditional coatings, have become the latest research focus in the field of tool coatings [10].

Finally, developing superior coating materials should match the geometrical features of tool edges, which requires the optimization of both tool geometries and tool coatings in order to achieve the overall performance improvement of a specific manufacturing process. Additionally, selecting proper coating materials should also match the machinability of specific workpiece materials. In the future, more endeavors need to be made to develop new coating materials and structures, improve basic theoretical research of tool coatings, and promote the industrialization of advanced coatings in the manufacturing fields.

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