Surface Modification of 6061 Aluminum Alloy using Plasma-based Ion Implantation and Deposition

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In recent years, with worsening damage to the environment of the earth due to energy consumption, efforts to reduce energy consumption have been made in industry. Aluminum alloy has a high strength-to-weight ratio, good corrosion resistance, and easy recyclability. So aluminum alloys are used for mechanical parts, but these alloys have poor wear resistance. To increase their wear resistance, a hard coating is applied to the surface of the alloys [1, 2] .

There are various methods in surface modification technology for the purpose of providing high-function characteristics such as wear resistance, a lower or higher friction coefficient, corrosion resistance, and thermal resistance on the surface of the material. Generally, coating with a hard material like ceramic on the surface of a material is often used as a surface modification technology. Diamond-like carbon (DLC) is applied in surface modification technology due to its superior mechanical characteristics such as wear and abrasion resistance, low friction, high hardness, etc. In order to improve the wear resistance of 6061 aluminum alloy, a new surface modification method is presented [3]. In this method, the inner layer of anodic oxide coating, the intermediate layer of CrN film, and the outer layer of DLC film were used. Moreover, this method is indicated for DLC coating of aluminum alloys having different Si contents [4]. However, with this method, it is necessary to reduce production costs. In addition, adhesion between the substrate and the DLC is slightly inferior. So, a new substrate-coating system was designed [5]. This substrate-coating system consists of nitriding pretreatment of the substrate, the intermediate layer of the silicon-based layer, and the outer layer of the DLC film using plasma-based ion implantation and deposition (PBIID). The performance of the coating-substrate system is dependent on the presence or absence of an Si-based layer and the DLC thickness. Therefore, it is necessary to clarify the influence of the presence or absence of the Si-based layer and the DLC thickness on the properties of surface modification. Furthermore, the durability of the DLC film is unclear.

In this study, three test pieces, namely a silicon-based layer thickness of 0, 0.6 and 0.6 μm, and a DLC film thickness of 4.0, 4.4, and 6.4 μm, were deposited on 6061 aluminum alloy. In order to determine the influence of the test pieces on the performance of surface modification, the micro-hardness, scratch resistance, friction coefficient, wear resistance, and abrasion resistance of the coating layer were experimentally investigated.

The main results obtained are as follows:

(1) In the hardness test using a nano-indentation tester, the DLC film hardness of each of the three test pieces was about 19 GPa and there was little difference in DLC film hardness.

(2) In the scratch resistance and adhesion test using the scratch tester, the load that caused the first cracking on the surface increased with the increase in DLC film thickness. And the load that caused the catastrophic failure became larger by inserting an Si-based layer.

(3) In the friction and wear test at a load of 10 N using a ball-on-disk tribometer, the frictional coefficient of test piece no. 3, which had an Si-based layer thickness of 0.6 μm and a DLC film thickness 6.4 μm, was the smallest and was almost constant among the three test pieces at a sliding distance of 120 km; that is, the sliding time was two continuous weeks.

(4) In spite of the long sliding distance, both the width and the depth of track wear of test piece no. 3 were very small. Furthermore, there was no remarkable adhesion on the wear track of test piece no. 3.

(5) In the wear resistance test using the SUGA abrasion tester at a sliding load 9.8 N and 19.6 N and a sliding number of 400 double strokes, no remarkable wear of test piece no. 3 could be found on the sliding surface from the surface profile.

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Tool Wear of Titanium/Tungsten/Silicon/Aluminum-based-coated End Mill Cutters in Milling Hardened Steel

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Hardened steels used for dies or molds are widely cut as a substitute for grinding. Polycrystalline cubic boron nitride (cBN) compact tools are used for cutting hardened steels, due to their higher hardness and higher thermal conductivity. However, in milling, major tool failure of cBN readily occurs by fracture because cBN has poor fracture toughness. Coated cemented carbide is an effective tool material for milling hardened steels because it has good fracture toughness and wear resistance. The physical vapor deposition (PVD) method is a widely used coating technology because of its lower treatment temperature, namely 470 K -870 K [1].

Recently, it has become possible to cut hardened steels with (Ti,Al)N-coated cutting tools. However, as machine parts are often cut at higher cutting speeds for mass production, tool materials must have excellent fracture toughness and wear resistance. A titanium/tungsten-based coating film, namely (Ti,W)N coating film, has been developed [2]. Titanium/tungsten-based coating film exhibits a superior critical scratch load. Moreover, the titanium/tungsten-based-coated tool was evaluated through machining of low-carbon steel AISI 5120H, and showed greatly improved performance [2]. However, the hardness of the (Ti,W)N coating film was lower than that of the (Ti,Al)N coating film. So, a (Ti,W,Si)N coating film, which is a titanium/tungsten/silicon-based coating film, has been developed [3]. This titanium/tungsten/silicon-based coating film exhibits both superior critical scratch load and hardness compared with TiN/(Ti,Al)N coating film. In cutting AISI 5120H, the wear progress of the (Ti,W,Si)N-coated cemented carbide tool is slower than that of the TiN- and (Ti, Al)N-coated tools [3]. Therefore, titanium/tungsten/silicon coating is an effective tool material because it has good wear resistance.

Furthermore, new titanium/tungsten/silicon/aluminum-based coating films, namely (Ti,W,Si,Al)N, (Ti,W,Si,Al)C, and (Ti,W,Si,Al)(C,N) coating film, have been developed [4]. However, it is not clear whether these coating films are effective tool materials for milling hardened steel.

In this study, in order to identify an effective tool material for cutting hardened steel (AISI D2, 60HRC), tool wear was experimentally investigated.

The main results obtained are as follows:

(1) In milling hardened steel at a cutting speed of 3.33 m/s, the tool wear width of the (Ti,W)N/(Ti,W,Si,Al)N-coated tool was smaller than that of the (Ti,W)N/(Ti,W,Si)N-coated tool. And, compared with the commercial (Ti,Al)N, the tool wear width of the (Ti,W)N/(Ti,W,Si,Al)N-coated tool was smaller than that of the (Ti,Al)N-coated tool.

(2) The tool wear of the (Ti,W)N/(Ti,W,Si,Al)N-coated tool increased with an increase in cutting speed.

(3) (Ti,W)N/(Ti,W,Si,Al)N-coated cemented carbide was an effective tool material for high-speed cutting below a cutting speed of 3.33 m/s.

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