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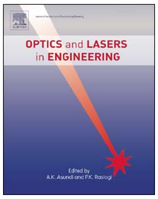

Formation of titanium carbide layer by laser alloying with a light-transmitting resin

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ABSTRACT

The weight reduction of mechanical components is becoming increasingly important, especially in the transportation industry, as fuel efficiency continues to improve. Titanium and titanium alloys are recognized for their outstanding potential as lightweight materials with high specific strength. Yet they also have poor tribological properties that preclude their use for sliding parts. Improved tribological properties of titanium would expand the application of titanium into different fields.

Laser alloying is an effective process for improving surface properties such as wear resistance. The process has numerous advantages over conventional surface modification techniques. Many researchers have reported the usefulness of laser alloying as a technique to improve the wear resistance of titanium. The process has an important flaw, however, as defects such as cracks or voids tend to appear in the laser-alloyed zone.

Our group performed a novel laser-alloying process using a light-transmitting resin as a source for the carbon element. We laser alloyed a surface layer of pure titanium pre-coated with polymethyl methacrylate (PMMA) and investigated the microstructure and wear properties. A laser-alloyed zone was formed by a reaction between the molten titanium and thermal decomposition products of PMMA at the interface between the substrate and PMMA. The cracks could be eliminated from the laser-alloyed zone by optimizing the laser alloying conditions. The surface of the laser-alloyed zone was covered with a titanium carbide layer and exhibited a superior sliding property and wear resistance against WC-Co.

1. Introduction

Titanium and its alloys have various excellent properties such as good corrosion resistance and high specific strength. Yet they also have poor tribological properties, which precludes their application to sliding parts [1].

Laser surface alloying is an effective process for improving wear resistance. The process is performed by melting the surface of a substrate with additional materials, mixing the components together, and rapidly solidifying the mixture [2]. The following advantages are obtained: low thermal strain, fine microstructure, and flexibility in the choice of substrates and additional materials [3]. The laser alloying process can also be applied selectively to circumscribed areas of a treated product.

Titanium has a strong affinity with carbon, nitrogen, and oxygen, and titanium compounds have high hardness [4]. There have been ongoing attempts to improve the wear resistance of titanium by synthesizing hard phases such as titanium nitride or titanium carbide using laser surface alloying processes with nitrogen or mixture gas [5–10] or other additives such as carbon powder materials [11–15].

Laser surface alloying is flawed, however, as the brittleness of these hard phases often leads to the formation of cracks in the laser-alloyed zone. This cracking has to be prevented by controlling the volume fractions of the hard phases. In laser-alloying processes with gas, an atmosphere-control chamber is often used to prevent the entrainment of the air. The work size, however, is restricted by the size of the chamber. In a laser-alloying process with powder materials, the laser-alloyed zone is often inhomogeneous due to the scattering of powder during the laser irradiation or the tendency of un-dissolved powder to remain.

Resins contain many carbon atoms, which enables their use as carbon sources for laser alloying in lieu of graphite powder. Non-crystalline polymer materials are generally transparent and almost completely penetrable by light in a wavelength range from the visible to near-infrared region. When laser light is irradiated to the laminate of a laser-transmitting material and a laser-absorbing material, the light is absorbed at the surface of the laser-absorbing material and heats the interface with the laser-transmitting material. This process is often applied as a technique for joining

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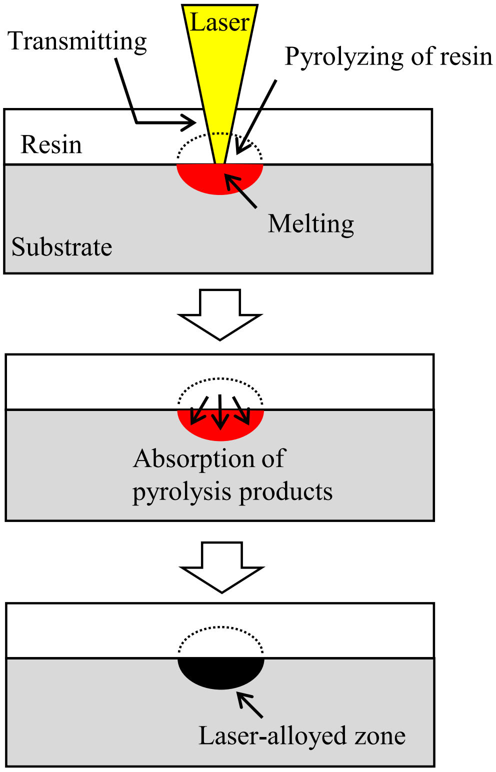

Fig. 1. Principle of the laser alloying process using a light-transmitting resin.

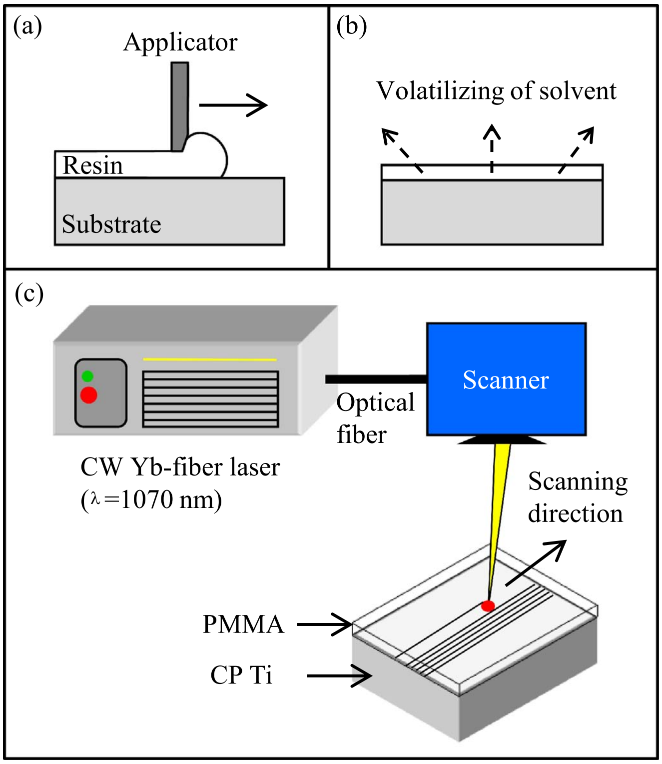

Fig. 2. Schematic illustrations of the experimental procedure. (a) Resin-applying process (b) Drying process (c) Laser-irradiation process.

plastics [16] or plastic and metal [17]. In this study we applied the process as a means of surface hardening.

Fig. 1 schematically illustrates the principle of the laser alloying process using a light-transmitting resin. If the resin has high transparency to the laser wavelength, the laser energy is absorbed at the surface of the titanium substrate transmitted through the resin layer and a molten pool of titanium forms. The heat of the molten pool at the resin-substrate interface decomposes the resin. The thermal decomposition of the resin yields many products such as carbon monoxide and hydrocarbon gas [18]. Carbon monoxide or hydrocarbon gasses such as methane are often used as chemical reactants in conventional gas carburizing processes [19]. Ono et al. were successful in surface hardening an ultra-low-carbon steel by laser irradiation with CH_4 gas [20]. We can therefore expect titanium carbide to form via the reaction between the thermal decomposition products of the resin and the titanium molten pool.

Advantageously, the amount of carbon elements contributing to the laser alloying reaction in this process can be controlled by the laser irradiation parameters regardless of the initial thickness of the resin. The composition of hard phases produced in the laser-alloyed zone is precisely controlled by the laser irradiation parameters to prevent cracking. The localization of the reaction at the resin-substrate interface is also advantageous, as the gas barrier effect of the resin layer eliminates any need for a shielding gas or atmosphere control chamber to prevent reactions with air [21].

Transparent resin materials such as polymethyl methacrylate (PMMA), polystyrene (PS), polycarbonate (PC), and polyethylene terephthalate (PET) are thought to be well suited for use in this laser alloying process. In this study we decided to use PMMA, a material with superior light transparency widely applied to optic applications. We laser alloyed a surface layer of pure titanium using PMMA with the objective of producing a crack-free, laser-alloyed zone and improving the wear resistance of titanium. The use of light-transmitting resin in place of a graphite powder allowed us to precisely control the amount of carbon elements contributing to the laser-alloying reaction. Investigations of the microstructure and wear properties of laser-alloyed zones obtained through this process confirmed the successful formation of a crack-free titanium carbide layer with a superior sliding property and wear resistance.

2. Experimental procedure

The specimens were cut into 25 mm × 25 mm squares from a 5-mm-thick plate of commercial pure titanium. The surface of the specimen was polished with SiC paper (P400) and cleaned with acetone.

The resin film was prepared from PMMA pellets with an average molecular weight of about 100,000 (Wako Chemical). PMMA is soluble in many organic solvents [22]. In this study we chose tetrahydrofuran (THF), a general solvent in wide use. Five grams of PMMA pellet was dissolved in 30 ml of THF and applied as a 1.5-mm-thick film on the surface of a titanium substrate using a film applicator (Fig. 2(a)). The specimen was dried slowly inside an incompletely closed container to prevent the entrapment of bubbles in the PMMA film (Fig. 2(b)). The thickness of the PMMA film after drying was about 0.2 mm.

The laser used in this study was a single-mode fiber laser (YLR-200-AC, IPG) that irradiates at a wavelength of 1070 nm with a maximum output power of 200 W. The laser beam was focused onto a 30 µm spot on the specimen and scanned over the surface with a galvano scanner (Squirrel, ARGES). The laser surface alloying was conducted with an applied power ranging from 30 W to 60 W in a continuous wave mode at a laser scanning speed ranging from 100 to 200 mm/s with a 50 µm pitch for each laser pass. No shielding gas was used in the process. Fig. 2(c) shows a schematic illustration of the laser alloying treatment.