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Deposition of DLC Coating on Turning Tool for MMC Machining

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Abstract: Aluminum based metal matrix composites (AMMC) have found its applications in the automobile, aerospace, medical, and metal industries due to their superior mechanical properties. Fabricated Aluminum based metal matrix composites require machining to improve the surface finish and dimensional tolerance. Machining should be accomplished by good surface finish by consuming lowest energy and less tool wear. This paper focuses the machining of Aluminum based metal matrix composites to investigate the effect of DLC coated tool.
Keywords: Diamond like carbon, Metal matrix composite, deposition, machining

I. INTRODUCTION

Historical examples of composites are rich in the literature. Major examples include the use of reinforcing mud walls in houses with bamboo shoots, glued laminated wood by Egyptians (1500 B.C.), and laminated metals in forging swords (A.D. 1800). In the 20th century, current composites were used in the 1930s when glass fibers reinforced resins. Ship and airplane were constructing out of these glass composites, commonly called fiberglass. Since the 1970s, purpose of composites has widely increased due to development of new fibers such as carbon, boron, and aramids (Aramids are aromatic compounds of carbon, hydrogen, oxygen, and nitrogen.) and new composite systems with matrices made of metals and ceramics [1].

AMMC is a combination of two or more micro, nano or macro constituents in metal phase [2]. The different forms of reinforcements being used are fiber, whisker and particulate [3]. Among the existing composites materials, ceramic particulate reinforced metal matrix composites (MMCs) are increasing used in various applications due to their superior mechanical properties [4], such as elastic modulus, hardness, tensile strength, high strength to weight ratio and wear resistance when compared to unreinforced alloys [3-6]. In the MMC particulate type reinforcements are predominantly used. Sic, Al2O3, ZrO2, B4C and Gr were the widely used particulate reinforcements.

Metal matrix composites are mainly used to offer advantages over monolithic metals such as steel and aluminum. These advantages include higher specific strength and modulus by reinforcing low-density metals, such as aluminum and titanium; lower coefficients of thermal expansion by reinforcing with fibers with low coefficients of thermal expansion, such as graphite; and maintaining properties such as strength at high temperatures. MMCs have several advantages over polymer matrix composites. These include higher elastic properties; higher service temperature; insensitivity to moisture; higher electric and thermal conductivities; and better wear, fatigue, and flaw resistances. The drawbacks of MMCs over PMCs include higher processing temperatures and higher densities.

Metal–matrix composites have received considerable attention in few past years because of their superior strength to weight ratio, higher modulus and better wear resistance. These properties, coupled with low density, and the ability to operate at elevated temperatures, has made these materials suitable for use in the manufacture of a range of components, from engine parts to sports goods. As the matrix element, aluminum, silicon, and titanium alloys are commonly used while the popular reinforcements are silicon carbide (SiC) and alumina (Al2O3) [7-10].

II. MACHINING AND COATING OF CUTTING TOOLS REVIEW

AMMC's are difficult to machine due to presence of abrasive hard particles such as Al2O3, ZrO2, B4C, Sic etc. These hard ceramic particles are difficult to cut due to hardness by conventional cutting tool [3]. Components fabricated by AMMCs require some post machining operations to achieve excellent dimensional tolerance and surface finish. One such operation is drilling, an essential machining operation for producing a hole on component for various purposes. Presence of hard ceramic reinforcements in MMC influence tool wear, surface finish and also the cost associated while machining. To attain high cutting performance in MMC the selection of process parameters should be optimized [11, 12]. In machining; tool wear, cutting force, formation of chip and surface finish are also considered as important parameters [13].

Machining is essentially required to obtain desired dimensional accuracy, form accuracy, surface finish to satisfy functional requirements. This semi-finishing and finishing operation is normally done by traditional machining processes like turning or milling etc. Machinability is termed as 'ease' with which a material can be machined. Machinability is difficult to quantify because of the large number of variables involved. Generally, machinability characteristics of any combination of tool-work pair can be judged by (a) magnitude of cutting forces, (b) chip forms, (c) magnitude of cutting temperature (d) surface finish and (e) tool wear and tool life. Machinability will be considered desirably high when cutting forces, temperature, surface roughness and tool wear are less, tool life is long and chips are ideally uniform and short enabling short chip-tool contact length and less friction [14].

Traditional tool materials like high speed steel is not suitable for machining MMCs due to rapid growth of tool wear. Tomac and Tonnessen [3] experimentally investigated the machinability aspects of Al–SiC MMCs with PCD and coated tungsten carbide tools in context to tool wear, cutting forces and surface finish. PCD tool have shown 30 times higher tool life than carbides under similar cutting conditions. Abrasion was found to be the primary wear mechanism. Lin et al. [15] found that the flank wear is the primary mode of tool failure in machining Al/SiC MMC with PCD tool. With increase of cutting speed and feed, flank wear was found to increase. Discontinuous chip formation was observed due to the presence of uniformly dispersed SiC particles. Andrews et al. [16] investigated the comparative performance of PCD and Chemical Vapor Deposition (CVD) diamond coated carbide insert during machining MMCs. It was revealed that PCD inserts performed much better compared to CVD coated diamond inserts. Ding et al. [17] observed that PCD tool performed better compared to poly crystalline boron nitride (PCBN) tool in terms of tool life during machining MMCs. Builtup- edge formation and grooving wear was noticed in PCBN tools and eliminated by the use of coolant. Hooper et al. [18] investigated the machining of Al/SiCp-MMC using PCD and conventional tungsten carbide tools. Adhesion was found to be dominant wear mechanism during machining. PCD tool offered greater benefit in the machining of MMCs [14].

Figure 1 Schematic diagram for cutting MMC's (a) particle cut through (b) particle pull out [19]

Tool manufacturers have a broad choice of general and new coating materials, from traditional coating to more modern multilayer coatings. Among most frequently used coating films are carbon-based (diamond and diamond-like) materials, carbides, nitrides and multilayered coatings. Diamond is the hardest natural material known by now. Polycrystalline diamond (PCD) may be deposited in micro or nano-layers and increase dramatically wear resistance. Its deposition requires very higher temperatures and pressures. In machining, DLC films have proved to be excellent tool coatings for machining non-ferrous metals, non-metal materials and composite materials. DLC films have higher hardness (above 1500 HV), low friction coefficient (less than 0.2) and thermal stability between 400 and 700°C [20].

The main difficult of DLC coating on cutting tools is the adhesion of the film during cutting process. During machining hard materials or during discontinuous processes like milling, nano-films are peels off soon after the beginning of the operation. Researchers focus on finding depositing conditions that ensure good adhesive strength and prevent delaminating during cutting process. Some researcher recommended an intermediate layer Si, Ti, Zr, W, Nb, Cr or WC between tool material and DLC layer to improve adherence. Among nitrides titanium nitride (TiN) is the most used tool coating. It has hardness, toughness, inertness and good adhesion to substrate [20]

Among other tool coatings, amorphous carbon or DLC satisfy the most of requirements listed before and can be deposited on all types of tool materials, except high film adhesion. DLC coatings combine excellent tribological properties, electrical properties and chemical properties with mechanical properties. Applied on inserts, end mills, and drills, the DLC tools are environmental friendly allowing dry cutting and semi-dry cutting. Many studies on DLC films cutting performances led to different results showing an important dependence on the quality of the coated tools, the cut materials and cutting parameters and conditions. A review of recent literature reveals that most papers are focused on continuous machining processes of aluminium, bronze and composite materials. It was difficult to find articles on DLC applications for interrupted machining processes or for steel workpiece.

III. METHODOLOGY OF DLC DEPOSITION

A. Preparation Of The Substrates

The carbide substrates were cleaned with ethanol, soak in a cellulose tissue. Then they were cleaned with water and soap in ultrasonic bath for 15 minutes. The carbide substrates were trapped on the cathode using Kapton polyimide tape. Kapton polyimide tape is especially for vacuum application as it has properties like high temperature resistance (< 270ºC) and very high degassing property. The layers were obtained by plasma enhanced chemical vapor deposition (PECVD) technique. The a-C: H: F thin films were deposited using PECVD technology. PECVD processes were carried out in a computer-controlled plasma reactor named PEDRO (Plasma Etching and Deposition ReactOr). In Fig. 1 we can see a scheme of PEDRO reactor.

Apart from the PECVD, other techniques are available in the PEDRO reactor are magnetron sputtering, ion beam etching. PEDRO has a main spherical vacuum chamber of 500 lit of volume. Three load-lock chambers used to insert the samples and/or the cathodes. To pump out the reactor turbo-molecular pump are used and the load-lock chamber are empty by low vacuum pumping. By using this system the reactor pressure of 105 Pa can be mentioned. The cathode terminal is connected to high power supply. This cathode terminal is used to control the voltage required maintain the plasma. The control and indicator gauges like gas valves, pressure gauge and mass flow rate are controlled by LABVIEW software, which is interface with reactor. In LABVIEW software the programmed can be run for the deposition process.

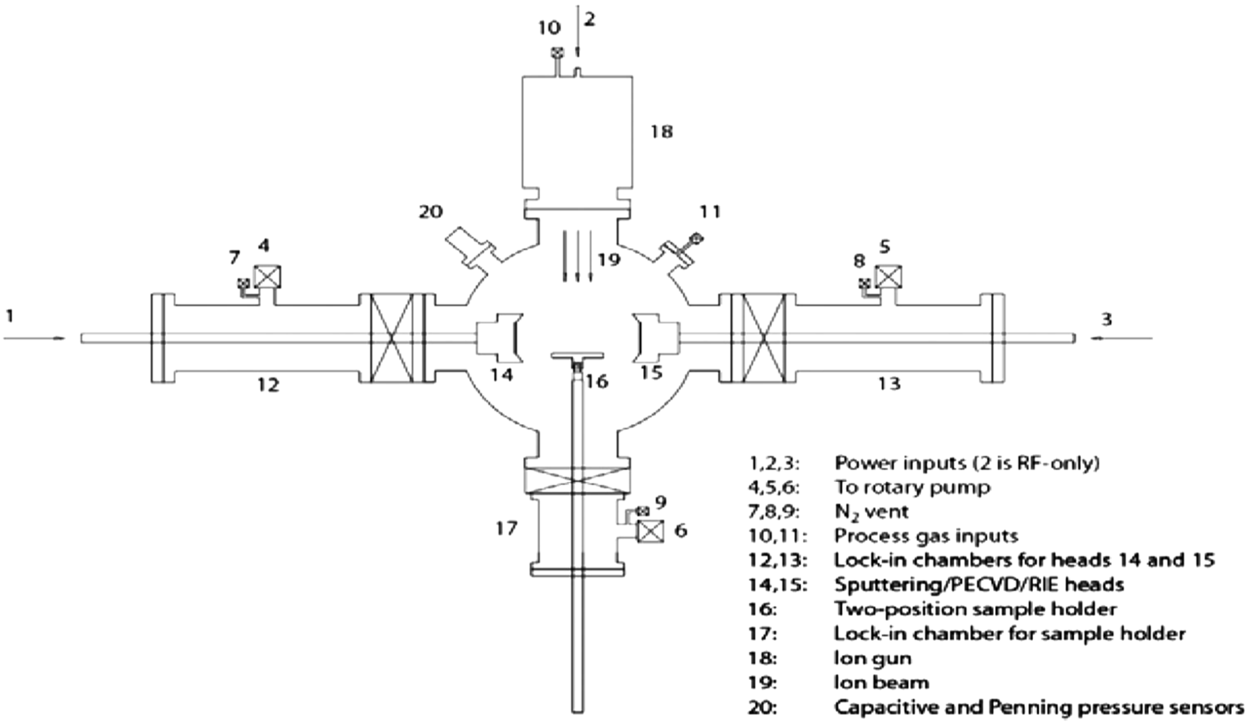

Fig 1. PEDRO reactor

Methane16 (CH4) and Hydrogen (H2) were used as film precursors. The deposition of the films was done at 10 Pa in power regulation mode at 60 W. Moreover, pulse frequency was fixed to 95 kHz. These conditions were previously observed to produce DLC films with average characteristics. In a preliminary study a-C:H:F films were grown on flat substrates. These layers were deposited unstable slowly the concentration of the precursor gases until the desired relative gas flow was achieved.

Outline of the deposition process:

1) Start: only methane without discharge (120 s)
2) Buffer layer: methane plasma (60 s)
3) Gradient interface: gradient between CH4 and H2 flows with plasma (120 s)
4) Stabilized proportion of gases with plasma (60 s).

A total time process of 6 min was set, previously calculated to obtain a thin film of approximately 100 nm. Substrate was kept at room temperature by means of a water-cooling circuit, in order to grow amorphous films.

IV. CONCLUSION

Diamond like carbon coating by PECVD was successfully deposited on carbide substrate. DLC will give DLC films will prevent adhesion of aluminium on tool, reduce cutting forces, improve machined surface roughness and accuracy, smooth the progress of chip flow and significantly reduce wear in Aluminum based metal matrix composite while machining. Since new chemical vapour deposition and physical vapour deposition methods continue to be developed, obtaining DLC film with superior adhesion on tools is just a matter of time. Beside technical aspects, environmental factors and economic factors will make the difference in tomorrow's manufacturing.

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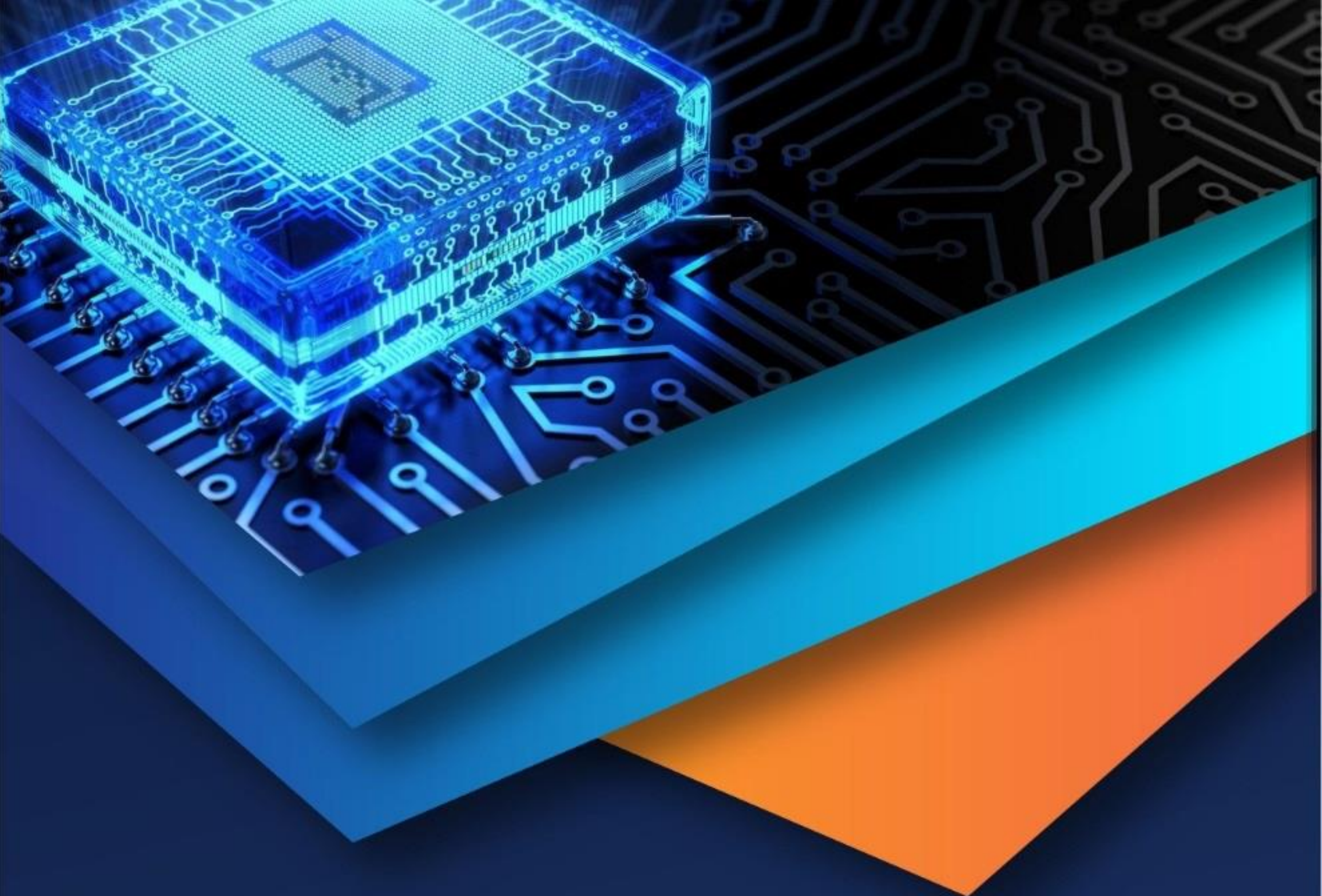

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