Diamond coated machine tooling essay

Diamond Coated Machine Tooling An Empirical Research Report Timothy J. Johnson April 12th, 2007 ME595 – Manufacturing Tribology Oakland University Introduction Diamond is the hardest material known to man, in this day and age. Typically, diamonds have been known to demonstrate hardness values up to 12000 HV (Vickers Hardness) or approximately 100HRC.

Diamond-coated Tungsten Carbide tools have demonstrated improved machining characteristics over coated tool steels commonly used today. With the increased use of composites, ceramics, and other ultra-hard / lightweight materials in numerous industries, diamond-coated machine tools are becoming more common since their performance improvements generally out weigh their increased cost. This paper is an empirical summary of various research papers related to diamond coating processes of machine tools and their applicability to current and advanced machining processes. Topics to be discussed are: Diamond Coating Process Overview, Applications of Diamond Coated Tooling, Diamond Coated Tooling Machining Capabilities, and some conclusions on the topic. Though a few different tool coating processes are mentioned in this paper, the main focus is on CVD (Chemical Vapor Deposition) Diamond Tooling and its advances in the manufacturing industry. Diamond Coating Process Overview Since natural diamonds are very expensive, the machining industry has developed a multiple methods of creating man-made or synthetic diamond materials.

These synthetic materials are then bonded to a substrate tool before they are suitable for machining. Discussed in this paper are threes different bonding techniques: Bonded Diamond Grit, PCD (Poly-crystalline Diamond)

Diamond Tools, and CVD (Chemical Vapor Deposition) Diamond tools. Bonded Diamond Grit Tools Bonded diamond grit tools are the most common diamond-coated machine tools used in the industry. Their basic construction consists of crushed synthetic or natural diamond particles glued to a variety of cutting, grinding and polishing tools. They are primarily used in the mining industry, but are also used for edge-finishing of carbon fiber composites and grinding hard materials like glasses and ceramics [2].

PCD (Poly-crystalline Diamond) Coated Tools PCD tools are similar to bonded diamond grit tools in that they both start with fine diamond particles. However, the PCD method involves forming the particles into a dense sintered material using a binder made from cobalt. These cemented compacts are then brazed into various shapes (for different kinds of cutting tools) and brazed onto solid carbide tool bodies. The PCD tools edge can then be ground down to a finished shape and even reground for tool sharpening purposes. PCD tools are over 50 years old and are prevalent in the aerospace industry for drilling rivet holes into carbon fiber composite materials.

The automotive industry also uses these tools for machining of aluminum composites which contain high silicone content (e. g. Al 390). These tools can be expensive, but are often the best option for very high precision cuts and high impact loading [2]. CVD (Chemical Vapor Deposition) Diamond Tools The main focus of this paper will be on CVD tools. Using CVD technology, diamonds are actually grown (nucleated) onto the surface of a machine-tool substrate.

For this process to be successful, careful attention must be paid to the substrate material selection. The process requires prolonged exposure to high temperatures so tungsten-carbide or ceramic tooling substrates are preferred. For optimum coating adhesion, C-2 grade tungsten-carbide must be used [2]. Also, the parts must be carefully prepared before attempting the CVD process. Typically, the parts are cleaned thoroughly, and then put through a 2-step chemical preparation process.

As shown below, in Figure 1, the first step involves roughening up the surface of the tool substrate for improved mechanical adhesion while the second step removes the cobalt from the surface for improved adhesion of the diamond material. Figure 1: Diagram of 2-Step Chemical Preparation Process of Substrate Surface Prior to Coating [2] Shown below, in Figure 2, is a schematic of the diamond growth process. As shown, the hydrogen and carbon reactants are exposed to high temperatures. Hydrogen is used to suppress the creation of graphite from the carbon atoms when heated. The chemical reaction results in the diffusion of the carbon atoms as a diamond coating on the tungsten-carbide substrate [1].

Figure 2: Schematic Diagram of the Diamond Growth CVD Process [1] For one study, an HFCVD (Hot Filament Chemical Vapor Deposition) process was used for the nucleation of diamond onto the material substrate. As shown below, in Figure 3, a heated tungsten filament was used to initiate the reaction of the methane mixture into hydrogen and carbon atoms which eventually ended up on the substrate surface as a diamond coating [1]. Figure 3: Schematic Diagram of the HFCVD Process [1] Diamond Tooling Applications For high speed cutting of ultra-hard materials with the best

precision possible, diamond-coated machine tools are optimum. However, since diamond materials react with ferrous metals during the high temperatures resulting from cutting processes, diamond-coated tooling is best-suited for non-ferrous metals and non-metal materials like aluminum, stainless steel, carbon-fiber, and ceramic.

However, the increasing demand of the aerospace and automotive industry for lightweight, high strength materials has shed a new light on diamond coatings on machine tools. As shown below, in Figure 4, the usage of aluminum in the automotive industry is rising exponentially, driving a new demand for diamond coated tools [1]. Figure 4: Expected Increase in Aluminum Usage In the Automotive Industry [1] Diamond Coated Tooling Machining Capabilities One study investigated the edge trimming capabilities of two different CVD diamond coated tools (D10 with 10? coating and D20 with 20? m coating of diamond) and compared the findings to a standard tungsten carbide cutting tool with medium grain size and 6% cobalt content (C2). The work piece used was a CFRP (carbon fiber reinforced polymer) material plate, 150mm x 65mm x 9mm thick. It was clamped to a tri-axial force dynamometer which was clamped to a machining fixture as shown below in Figure 5 [3]. CFRP Edge Trimming Experiment Figure 5: Experimental Setup and Cutting Parameters Used [3] Also shown, in Figure 5, is a table listing the cutting parameters used for the experiment.

Cutting forces, microscopic evaluation of cutting edges, and tool life were the parameters used to compare the different tool materials with the above-listed fixture and at the above-listed machining conditions. The two different feed speeds were selected to simulate different tool loading and a single spindle rpm [3]. Wear Characteristics The tool flank wear was measured by use of an SEV (scanning electron microscope) microscope to examine the cutting edges. With a feed rate of 1.

27 m/min and after a cutting length of 202 meters, the tools were removed from the fixture and examined. The results are shown below in Figure 6. As shown, the diamond coating delaminated from the tool for the thin diamond film specimen due to the high abrasion an t the higher feed rate. However, a smooth transition between the film and the substrate was maintained that had a negligible impact on the machining accuracy of the tool [3].

Figure 6: SEM pictures showing uniform flank wear roundness of edge for (a) C2, (b) D10, and (c) D20 after cutting 202 meters at 1. 27 meters per minute [3]. Figure 7: Variation of flank wear with cutting distance and feed speed for uncoated and diamond coated tools [3]. Shown above, in Figure 7, is a chart of the flank wear for the different tools at the 2 different feed speeds, F1 and F2. As shown, at both feed rates, the tungsten-carbide tool had the most flank wear. At 1.

27 m/min, the D10 and D20 materials had very similar wear properties (much lower wear rates than C2). However, at the higher feed rate, material D10 outperformed C2 and D20. Figure 8: Comparison of flank wear for uncoated and diamond coated tools after a cutting distance of 338 meters. Feed speed F1 = 1. 27 m/min [3]. After a cutting distance of 338 meters at a feed rate of 1.

7 m/min, the total flank ear was measured and the results are shown above in Figure 7. As shown, the diamond-coated tools outperformed the standard

tungsten carbide tools by over 200% at this feed rate and cutting distance. D10 showed slightly higher wear than D20, due to the afore-mentioned chipping of the diamond coating from the tool surface [3]. Surface Roughness Figure 9, below, shows the results from the surface measurement of the specimens after the edge trimming process. As shown, surface roughness generally increased with feed speed. This makes sense since higher feed speed results in a bigger chip thickness, which means that higher forces are required for chip removal.

Higher tool forces causes brittle fracture of the epoxy matrix [3]. Figure 9: Variation of surface roughness with feed speed and measurement direction for uncoated and diamond coated tools. Cutting distance = 202 meters [3]. Figure 10, below shows magnified views of the CFRP material after cutting. As shown, deeps cracks are obvious for the higher feed rate samples (Figure 10d, e, and f). Smearing of the matrix is also evident for both feed rates but more so for the higher feed rate.

The spacing between the cracks was approximately equal to the feed rate tooth spacing (0. 25mm) and they are inclined at an angle approximately equal to the cutter’s helix angle. This indicated that the cracks were caused by the individual cutting edges as they left the work piece [3]. Figure 10: Photomicrographs of the machined surface after a cutting distance of 202 meters. Cutting direction is from top to bottom [3].

Referenced Experiment SummaryThe study referenced revealed that when machining CFRP work pieces, diamond coatings provide a far superior tool life and are capable of much higher cutting speeds than tungsten-carbide tools. This was true at both low and high cutting speeds. Better surface finishes were achievable with the lower feed rate with the diamond coated tools. Based on the superior tool life and surface finish, diamond coated tools are best suited for finish machining or CFRP materials [3]. Aluminum 390 Drilling Experiment Another paper outlined an experiment where holes were drilled into a high silicone-content aluminum specimen repeatedly.

The thrust force required to drill the holes was monitored as the tools wore down and this data was used as an indicator of tool life. The following conditions were maintained for carbide drills and diamond coated drills: 10000 RPM, 250 cm/min, no coolant, 6. 1mm drill with simple 4-facet point to drill a 2. 5 cm blind hole. The results from this experiment are shown below in Figure 11.

As shown the carbide drills wore out in approximately 5 minutes, while the diamond coated drill maintained a much lower required thrust force for the entire process [2]. Figure 11: Data from drilling test into Al390 Economics CVD tools are typically priced 4 to 6 times higher than tungsten-carbide tooling. But, for that price, a 10x to 20x increase in tool life can be achieved. This translates into a net cost decrease of 40% – 80%.

Additionally, increased tolerance control and surface finish can be achieved. Furthermore, it has been shown that increased machining speeds can be achieved (15000 RPM) so there is also a productivity benefit to CVD diamond coated tooling [2]. ConclusionsIn conclusion, diamond coated tooling provides superior performance in tool life, machining speeds, and machining accuracy. With the increased demand for light weight non-ferrous materials in the aerospace and automotive industry, there is a increasing demand for diamond-coated tooling.

References [1] – SAE Brazil Publication 982876 – Diamond Chemical Vapor Deposition on Cutting Tools – Barquete, Resende, Corat, Trava / Airoldi, Carlos De Moura Neto 1998 [2] – SAE International Publication 2006-01-3153 – CVD Diamond Coated Rotating Tools for Composite Machining – Engdahl 2006 3] – SAE International Publication 2002-01-1526 – Edge Trimming of CFRP Composites with Diamond Coated Tools: Edge Wear and Surface Characteristics – Ahmad and Sridar 2002 [4] – Lubrication Engineering Publication Volume 40, 11, 681-685 – Reduction of Thermal Failure of Sintered Diamond Drill Elements – Bunting and Pope 1983 [5] – SAE International Publication 2003-01-0452 – The Surface Analysis of Powder Metallurgy (P/M) Components Machined by Diamond-like Carbon (DLC) Coting Cutting Tools – Chang, Smith, Littlefair, and Franks 2003