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A Study on the Fabrication of a Textured Cutting Tool using a Plasma Focus Machine

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Abstract

In this paper, a study on the possibility of producing a textured cutting tool using the nitriding effects of a 3 kJ Mather-type dense plasma focus device (DPF) in a low pressure nitrogen atmosphere is carried out using the INTI International University plasma focus machine. It has been found that the INTI International University plasma focus machine can be used to provide the hardening effect to steel as well as imparting a suitable surface texture to the steel thus enabling it to become a textured cutting tool for the machining of aluminum products.

Keywords

Hardening, nitriding, dense plasma focus, textured cutting tool

Introduction

Dry machining, without the use of metalworking fluids, is slowly being considered as a viable production approach in industry. Traditionally, the use of metalworking fluids to reduce friction in machining has the benefit of lengthening tool life. During the machining process, heat is generated at the tool-chip interface causing a substantial rise in temperature. This rise in temperature results in greater wear of the tool. Thus cutting fluids are employed to control the temperature and flush away wear debris.

However, cutting fluids pollute the environment and also pose a threat to the operator's health. Metalworking fluids can cause adverse health effects through skin contact with contaminated materials, spray, or mist and through inhalation from breathing the metalworking fluid mist. The safe disposal of metalworking fluids is another issue that needs to be tackled properly in order not to cause pollution in the environment. It is for this reason that dry machining is now being contemplated in order to reduce environmental pollution and health hazards.

Due to the friction between the tool and the work piece, dry machining reduces tool life because of the high heat it generates. Thus, in order to maintain a long tool life without resorting to cutting fluids, new approaches to tool design are required. One approach that has been found to work is to apply micro-texturing to the rake face of the tool thus resulting in a tool having a micro-grooved or micro-dimpled texture. Gajrani[1] reported that dry machining with a surface textured tool makes it a viable alternative to the use of cutting fluids. In the machining of aluminum products, aluminum chips have a tendency to severely adhere to the surface of the cutting tool often leading to tool failure. Aluminum is a soft and is also an easy to machine material but it has a tendency to form a built up edge. Sugihara[2] found that micro-textured surfaces on the tool improves the anti-adhesive property. To enhance the effectiveness of the textured cutting tool, solid lubricants can be further applied at the chip-tool interface.

The process for producing a textured tool usually involves the making of the hard tool first and then impressing the surface texture on the tool later. This surface texturing process can be done by pulsed laser(Liu[3]), electrochemical machining(Chen[4]), electro discharge machining(Koshy[5]) or even by mechanical micro indentation.

In this study, we will explore the effects of using an alternative method of producing a textured tool by using the dense plasma focus machine. A textured tool is required to have both hardness and texture. The dense plasma focus machine is a source of highly energetic ions from its pinch, thus making it suitable as an alternative means of implanting nitrogen ions onto the steel substrate. In a nitriding process, the introduction of nitrogen ions into the surface of steel has been known to improve the hardness of the steel (Bernal[6]) as well as its resistance to wear and corrosion. Shafiq[7] and Rawat[8] have successfully performed surface modification of steel using the plasma focus device.

At the same time, the ion beam produces a texture on the surface of the tool due to the high energy with which it impinges onto the tool. Thus, in one setup, both hardness and surface texture are produced at the same time.

Methodology

The metal material selected for this project is AISI 1020 cold rolled steel. The dimensions of the metal samples used in this study were length 70 mm x width 25 mm x thickness 7 mm.

The material was purchased from commercially available stocks of cold roll steel bars. The steel has been cold rolled to the appropriate thickness for sale according to the dimensional needs of consumers. However, the cold rolling process imparts an increase in hardness to the material by an effect known as work hardening. This work hardened steel has an uneven hardness due to different degrees of cold rolling on different sections of the material. Thus a test sample cut from the steel bar will not demonstrate a consistent hardness along its surface. This can be easily proven by hardness testing on different surface positions on the test sample surface. The steel samples were polished and tested for hardness. The hardness varied from 180 to 240 HV prior to annealing. To carry out a hardening experiment on a sample of uneven hardness will not yield meaningful results. Thus, in order to remove the effects of work hardening on the test specimens, the specimens were required to undergo the annealing process. Test specimens were placed in an annealing oven and heated to a temperature of 910 degrees Celsius for one hour and then cooled slowly.

After the steel samples were annealed, they went through the polishing process. The polishing process removed scratches caused by tool marks from machining and rough handling as well as any oxide layers that had been formed. The samples were polished to a near mirror finish. Following that, hardness testing was again carried out and this time, the hardness readings were much more consistent, at around 170 HV to 190 HV, along the surface. As expected, the hardness readings were lower and the range was narrower after the annealing process.

The first steel sample was placed in the dense plasma focus machine at a firing distance of 40 mm from the anode tip. Based on the numerical experiments by Akel[9] using the Lee Model code[10], the range of pressures was fixed from 0.5 to 2 Torr. The vacuum chamber was evacuated and filled with nitrogen and the absolute pressure was adjusted to 0.5 Torr. Thirty shots of ion beams were then fired at the steel sample in the dense plasma focus machine. After the initial steel sample, other steel samples were similarly processed but with different gas pressures and different distances from the anode tip. Although each test sample had its set of nitrogen pressure and firing distance, they were all fired with 30 shots each. The nitrogen pressures used were 0.5, 1.0, 1.5 and 2.0 Torr. The firing distances used were 40 mm, 60 mm, 80 mm, 100 mm and 120 mm. Using 4 different pressures and 5 different firing distances, a total of 20 steel samples were used. Figure 1 shows the setup of the equipment and the steel target.

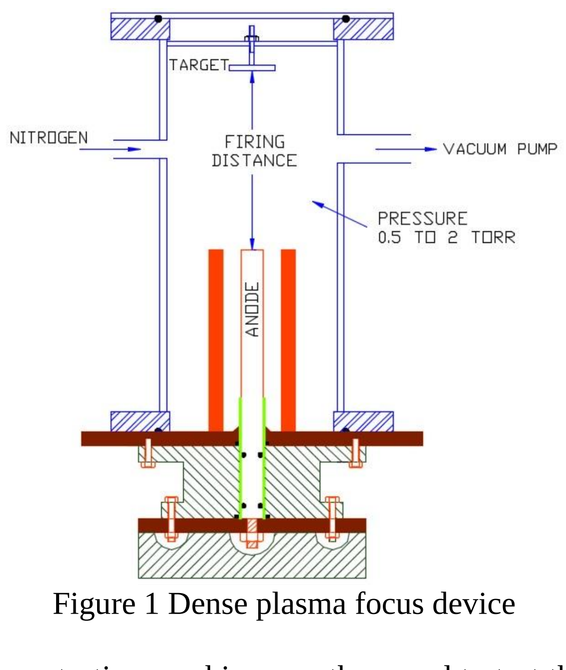

Figure 1 Dense plasma focus device

A Micro Vickers hardness testing machine was then used to test the hardness of the steel samples. In the Micro Vickers machine, a 0.2kgf load setting was used throughout the whole study. In order to have some form of coordinate system on the sample, the center of the firing was located visually (Figure 2). The center is considered the zero-point position for the purpose of convenience. The hardness was measured at every 1 mm distance from the center (or zero point) along the length of the sample.

Results

The firing process produces a micro-dimpled texture on the test sample as shown in Figure 2. Most of the samples tend to display this pattern although occasionally the dimples would look elongated (like short grooves) radiating from the center of the firing. It is easy to pinpoint the center of the firing effect by examining the test sample visually. The center region is the region which received the highest energy from the ion beam during the plasma shot. This energetic ion beam travelled to the steel target first to form a layer of iron nitride. It initiates the nitriding process on the surface of steel where the surface of steel will melt due to the high temperature, thus causing the steel to change in phase whereby ion energy is efficiently transferred for ion implantation. The melting and subsequent solidifying of the surface caused the initial smooth surface to take on a rough appearance at this center region. This surface texturing effect of the ion beam helps the low carbon steel take on the appearance of a textured tool.

Figure 2 Center observed

A series of ring patterns form around the center to allow one to easily pinpoint its location visually (Figure 3). The firing produced a small circular central region, or 'sweet spot', that has a very rough dimpled pockmarked texture. The pattern appeared to be random in nature and although not exactly uniform in appearance, there is a rough uniformity of dimples in the central region. Once out of the central region, the surface is smoother. A whitish pall is easily observed visually on the surface.

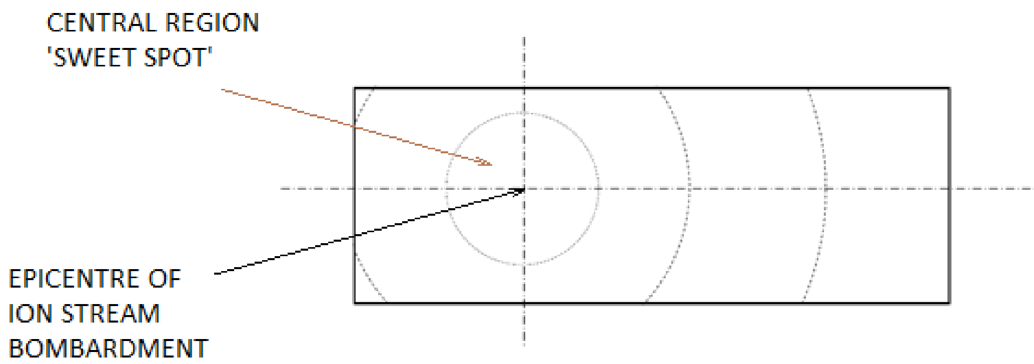

Figure 3 Central region and bands observed (drawn from Figure 2)

Nitrided steel tend to have a "white layer" on the surface and therefore, the presence of a whitish pall on the steel samples would imply that nitriding has taken place. That would also imply that a corresponding change in surface hardness was to be expected.

An EDX analyis done prior to firing(Table 1) indicated that there was no presence of nitrogen in the sample.

Table 1 EDX analysis before ion beam firing

Element	Weight %	Weight % σ	Atomic %
Carbon	11.468	0.220	37.568
Phosphorus	0.041	0.036	0.052
Sulfur	0.050	0.032	0.061
Manganese	0.572	0.067	0.410
Iron	87.869	0.230	61.909

After the steel has been treated in the plasma focus machine, EDX analysis on the sample surface revealed that there was a presense of nitrogen as shown in Table 2.

Table 2: EDX analysis after ion beam firing (30 shots at 1 Torr 40 mm)

Element	Weight %	Weight % σ	Atomic %
Carbon	4.044	0.237	15.110
Nitrogen	3.212	0.247	10.290
Phosphorus	0.051	0.038	0.074
Sulfur	0.052	0.034	0.073
Manganese	0.502	0.070	0.410
Iron	92.139	0.337	74.042

The presence of nitrogen serves to imply the presense of nitrides indicating that nitriding has taken place in the sample.

Upon measuring the surface hardness, it was found that there was a variation in the hardness with the variation in firing distance and pressure parameters. These measurements are necessary to determine the best hardness position to locate the tool tip of the intended textured tool. The surface hardness of the steel samples is presented in Figure 4 where the variation in distance and pressure is clearly indicated.

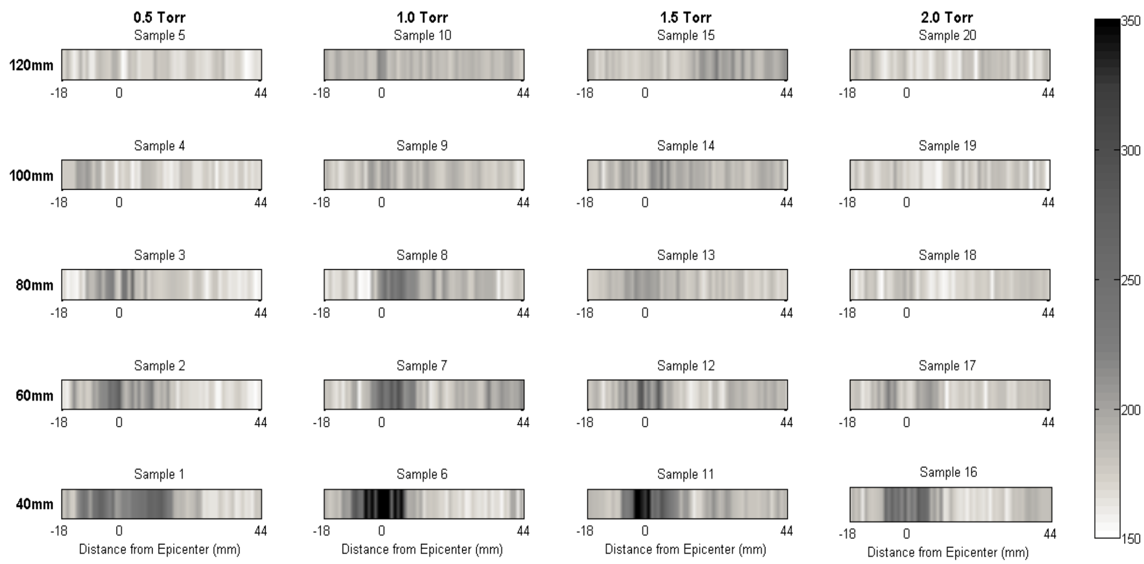

Figure 4 Micro Vickers hardness results in HV

From Figure 4, the steel pieces that are placed at a firing distance of 40mm above the anode provide the highest surface hardness values. Visual inspection revealed that the material experienced the greatest change in surface texture in a small circular region around where it was most impinged on by the ion beam. This circular region is about 10 to 20 mm in diameter and also coincidentally has the highest surface hardness to be found on the sample.

At the firing distance of 40 mm and at a pressure of 1.0 Torr of nitrogen gas, the greatest improvement in hardness was obtained. From these experiments, we can observe that both the improved hardness and surface texturing can be achieved by the dense plasma focus machine by using the same setup.

Discussion

The hardness improvement and the surface texture tend to occur at a small circular region only. Once out of this central region, hardness tapers off rapidly. For the mild steel to become a tool successfully, the tip of the tool has to be located at this central region.

The distance from the anode has an impact on the hardness attained. Shorter travelling distances of the ion beam tend to yield better hardness improvement. For longer distances, the focusing efficiency of the ion beam decreases (due to beam divergence) when it has to travel further to reach the steel target and this results in a lower hardness attained for such long distances.

The different results obtained from varying the nitrogen pressure showed that pressure also played a part in the nitriding process. The numerical experiments by Singh[11] has shown that the maximum beam energy was at a pressure of 1 Torr. Coincidentally, the experimentally derived result also showed that the highest hardness was obtained at a pressure of 1.0 Torr. As the pressure is increased, the current pinches become weaker resulting in ion beams with less energy. This has an effect on the hardening results.

The highest hardness values obtained had increased to more than 300 HV from about 180HV prior to nitriding. This hardness level for a cutting tool will make it suitable for machining softer materials such as aluminum.

A treated steel sample was then clamped onto a lathe machine to be used as a tool for turning aluminum as shown in Figure 5. The operation was possible, but a much more intensive testing program needs to be carried out before the tool can meet commercial expectations. For this study, the number of ion beam shots was fixed at thirty. This hardness can be increased further by increasing the number of ion beam shots.

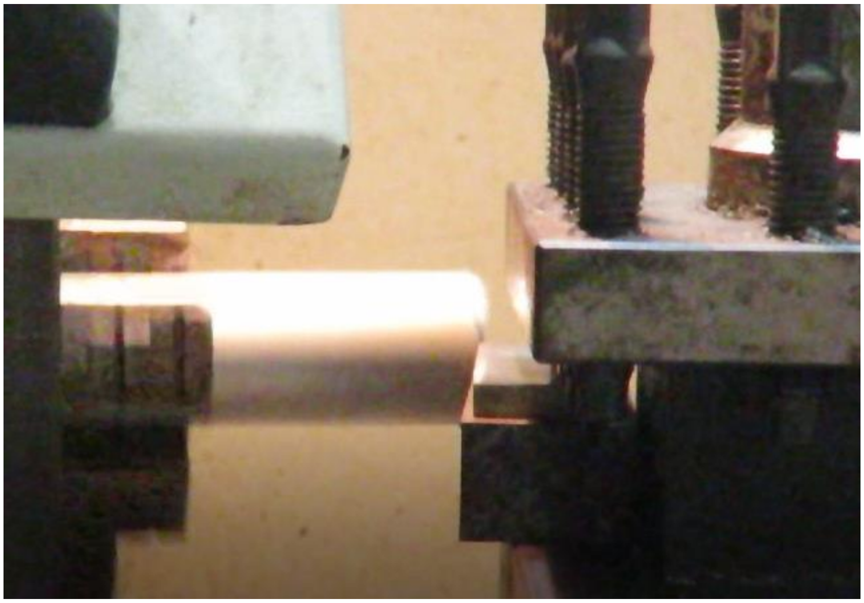
Figure 5 Using the Plasma focus tool to machine aluminum

Conclusion

The dense plasma focus machine was able to turn ordinary mild steel into a textured tool by imparting two effects:

- A micro-dimpled surface texture
- Improved hardness

The improved hardness was due to the nitriding effect of the dense plasma focus machine and the hardness that results depends on three parameters:

- Pressure
- Distance of the sample from the anode
- Lateral position

The best results obtained was from a pressure of 1 Torr of nitrogen. The further the distance of the sample from the anode, the less will be the hardness obtained. The hardness tends to concentrate in a small circular region that has been impinged by the ion beam This central region has a micro-dimpled textured appearance suitable for a textured cutting tool. A mild steel bar can thus be turned into a suitable textured cutting tool if it is suitably shaped like a tool with a tip. An ion beam can be fired at its tip using a 3 kJ Mather-type dense plasma focus device at the optimum settings of 40 mm from the anode at a nitrogen pressure of 1 Torr. The resulting textured surface and increase in hardness will render the mild steel as a cutting tool.

The purpose of this study was to show that a textured tool can be produced using only one simple setup that delivers both hardness and texture in the same operation starting from a very common raw material. The results may not match that of competing costlier methods. However, for less demanding situations, this approach may be sufficient.

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