Effect of anode distance on built-up edge in textured tools produced by plasma focus

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Abstract: In this paper, the concept of producing a textured tool from AISI304 stainless steel with a plasma focus machine is investigated. A nitrogen ion beam is aimed at a steel sample in an effort to harden it by nitriding and thus render it suitable for use a cutting tool. The results show that the hardness is only slightly enhanced. However, the pitted surface caused by the ion beam gives the steel sample a surface texture that is suitable for a film of solid lubricant to anchor itself. This leads to a decrease in the formation of the built-up edge when performing a dry cutting process on a ductile material such as aluminium. In this dry cutting process, a built-up edge of aluminium material tends to form and adhere to the steel cutting edge and this affects the overall performance of the steel tool. By varying the distance of the anode to the steel tool in the plasma focus nitriding process and then measuring the corresponding amount of built-up edge formed, it is found that, at shorter anode distances, the built-up edge effect is less pronounced.

Keywords: plasma focus; nitriding

1. Introduction

In the machining operation, raw metal is shaped through a chip removal process by a cutting tool. This operation produces heat between the surface of the cutting tool and the raw stock material causing the thermal expansion of the stock material that results in dimensional inaccuracies of the machined product. The generated heat causes a substantial rise in temperature. This rise in temperature results in the softening of the cutting tool thus leading to greater tool wear. For this reason, metalworking fluids are used to remove the heat generated from the machining process as well as to reduce frictional forces in the machining operation. However, the use of metalworking fluids in the machining process, aptly termed ‘wet machining’, carries with it health and environmental risks.

The machine operator's health is affected adversely through skin contact with contaminated materials, spray, or mist and through inhalation from breathing the metalworking fluid. The disposal of metalworking fluids, if not handled properly, can cause pollution to the environment. From an economic standpoint, the purchase of metalworking fluids results in a rise in operating costs in the machining process. For these reasons, dry machining is now being seriously considered in manufacturing operations in order to reduce health hazards, environmental pollution and operational costs. Dry machining, being a process done without the use of metalworking fluids, can be a viable production approach in manufacturing.

The drawback of dry machining is that the friction between the tool and the work piece generates high heat. This has the tendency to reduce the working life of a cutting tool. In order to prolong tool life without the usage of metalworking fluids, new tool designs are required. A few researchers have found that the simple act of applying micro-texturing to the rake face of the tool yields favorable results. A tool that has a micro-grooved or micro-dimpled texture is able to do without metalworking fluids if a film of solid lubricant is applied to the rake face of the tool. Gajrani et al. [1] reported good results with dry machining using a surface textured tool. Sugihara et al. [2] reported that micro-textured surfaces on the tool improves the anti-adhesive property. Some metals such as aluminum, due to its soft nature, have a tendency to adhere to the surface of the cutting tool thus resulting in a built-up edge on the cutting tool. The use of solid lubricants on the textured tool can reduce this tendency.

In the production of a textured tool, the tool is first shaped and hardened. Then a surface texture is introduced to the rake face later. This can be accomplished by pulsed laser [3], electrochemical machining [4], electro discharge machining [5] or even by micro indentation through mechanical means.

In this study, the usage of the dense plasma focus (DPF) machine to produce the textured tool is investigated. A textured tool is required to possess both surface hardness and surface texture for it to be functionally effective. The DPF machine is unique in that it has the ability to deliver hardness and surface texture in one set-up. The highly energetic nitrogen ions from its plasma current pinch are easily implanted onto the surface of a steel tool. This is a nitriding process and the introduction of nitrogen ions into the surface of steel is known to improve the hardness of the steel [6] as well as improve its resistance to wear and corrosion. Shafiq et al. [7] and Rawat et al. [8] have both shown that steel can be hardened by a DPF machine.

The DPF machine has an added advantage over other methods in that when its highly energetic ion beam impinges onto the surface of the steel tool, it produces a surface texture on the tool. Thus, using one device and in the same setup, both hardness and surface texture are produced in the same operation. This is a work advantage not usually found in other methods. The objective is to introduce the use of the DPF machine as a method for consideration in the production of textured tools.

2. Methodology

The steps taken in this study are detailed in Figure 1.

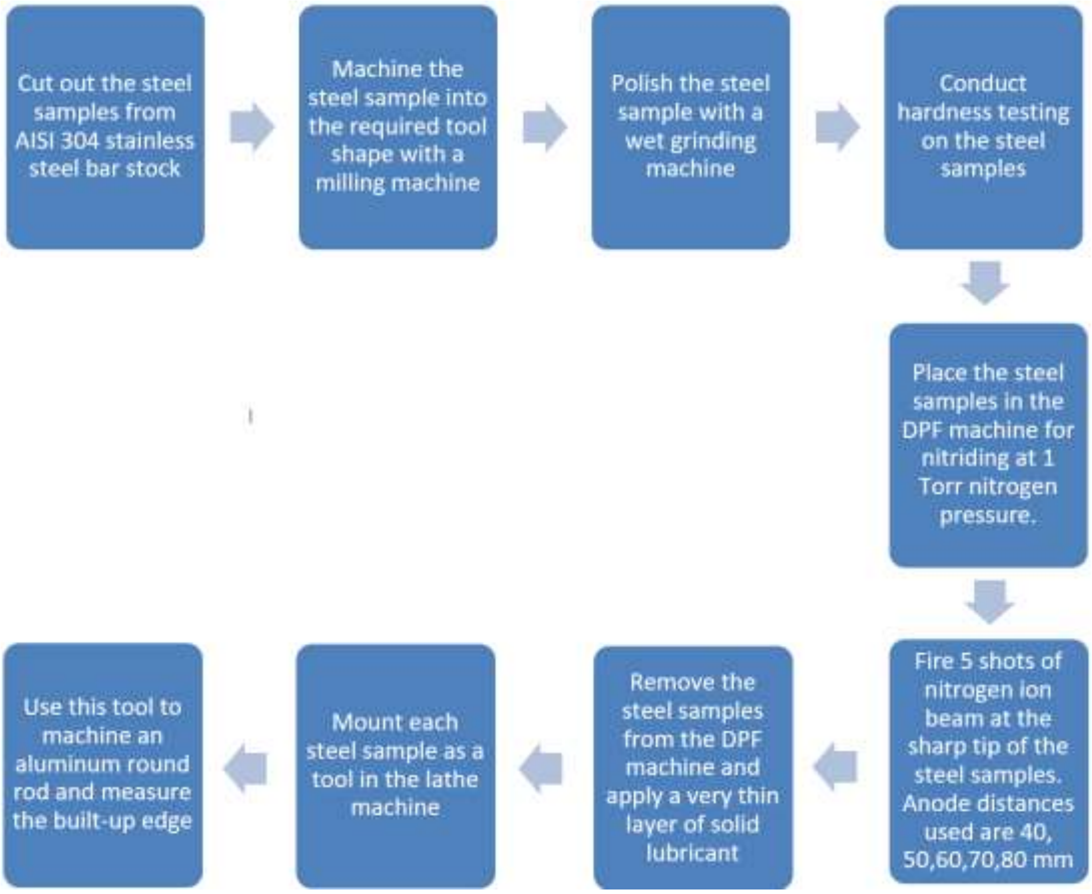

Figure 1. Steps in the methodology

For the purpose of this study, AISI 304 stainless steel was used as the material of the cutting tool. The material was cut from bar stock and machined to 10 mm thickness and dimensions (in mm) of a regular cutting tool as shown in Figure 2.

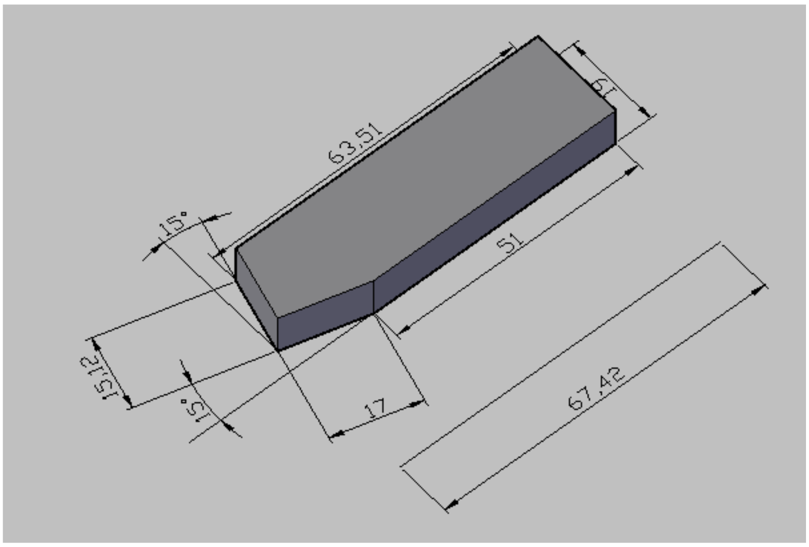

Figure 2. Dimensions of the AISI 304 stainless steel tool in mm

Previous experiments have indicated that good surface hardness from AISI 304 stainless steel can be obtained by firing a nitrogen ion beam at the steel target while operating the DPF in a nitrogen atmosphere of 1.0 Torr and setting the anode-to-target distance of 40 mm [9, 10]. The choice of 1.0 Torr nitrogen working pressure was initially based on the numerical experiments by Akel et al. [11] using the Lee Model code [12] and subsequently confirmed by experimentation to be appropriate for hardness improvement. For the purpose of this study, 5 ion beam shots are used to harden the cutting tool.

After measuring the initial hardness with a Micro Vickers hardness tester, the shaped tool is positioned above the anode in a 3kJ DPF machine as shown in Figure 3. The DPF machine is then filled with nitrogen gas at 1.0 Torr in its vacuum chamber, and then 5 shots of nitrogen ion beam are fired at the steel tool. The steel tool gains hardness as a result of the nitriding action in the DPF.

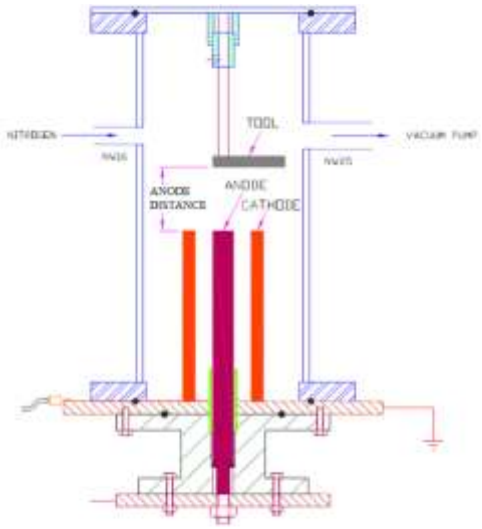

Figure 3. Steel sample tool placed in DPF machine

A Micro Vickers hardness testing machine is then used to test the hardness of the steel tool that has been nitrided. The anode distance is then varied for subsequent samples. For this project, anode distances of 40, 50, 60, 70 and 80 mm were used. After all the sample tools have been nitrided, they are used in a lathe machine to dry cut aluminium. A solid film lubricant is used to reduce the friction between the sample tool and the aluminium work piece in the cutting process. The sample is sprayed with a lubricant which contains molybdenum disulfide (MoS2) which dries and forms a solid lubricant layer on the tool surface. Each tool is set to operate with a cutting depth of 1 mm with the length of cut being 100mm (Figure 4). This cutting operation was performed 3 times and then the amount of built-up edge is measured on the tool.

Figure 4. Dry cutting of aluminium in a lathe machine

3. Result and Discussion

When the highly energetic ion beam impinges onto the surface of the steel tool, it produces a pitted surface texture on the tool. This pitted region is small and is a few cm2 at most. When the energetic beam of nitrogen ions travels from the anode area to the steel tool tip, it forms a layer of iron nitride. This initiates the nitriding process on the surface of steel whereby the steel surface melts due to the high temperature. The melting and subsequent solidifying of the surface causes the initial smooth surface to take on a micro dimpled texture at this pitted region. A visual inspection of the tools showed that at shorter anode distances, the stainless steel samples showed a rougher texture (Figure 5). The tool that had not undergone nitriding did not display any surface texture.

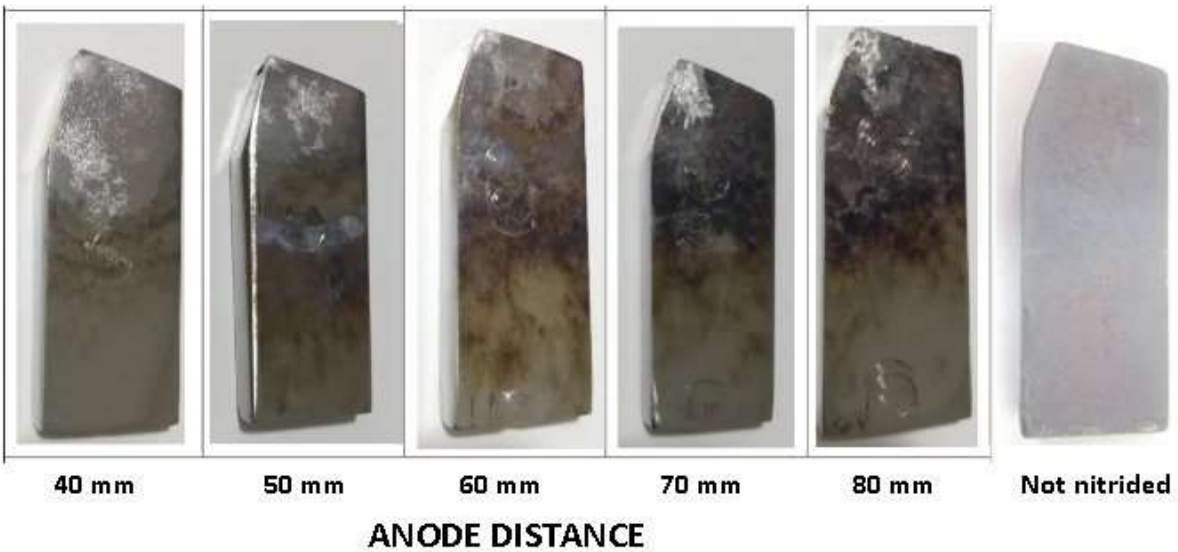

Figure 5. Visual inspection of the pitted tool end

It is noted that because the ion beam is aimed at the sharp end of the tool, the blunt end did not receive any nitriding effects. The pitting effects at the blunt end is also not noticeable. However, there was a slight discoloration. The hardness of the steel near the tool tip shows some improvement in hardness as shown in Table 1. It can be concluded that generally, the better hardness improvements coincide with the shorter anode distances of 40 and 50 mm. This result with AISI 304 stainless steel is remarkably similar to the results obtained with AISI 1020 low carbon steel obtained in another research [9].

Table 1. Example of the caption for the table

Sample no.	Anode distance (mm)	Hardness value before nitriding (HV)	Hardness value after nitriding (HV)	Percentage of difference (%)
1	40	176.5	213.9	21.19
2	50	137.3	175.1	27.53
3	60	153.1	170.8	11.56
4	70	144.9	171.6	18.43
5	80	167.2	166.0	-0.72
6	Not nitrided	178.9	178.9	0

When the steel sample tools are used in a lathe machine to cut aluminium, there is an increase in weight of the tool caused by the formation of the built-up edged adhering to the tool. The weight of this built-up edge is matched against the various tool samples as shown in Table 2. The sample that has not undergone plasma focus nitriding (sample 6) is also included in the table for comparison purposes. When the results are plotted on a chart in Figure 6, it is immediately obvious that the steel tools that has undergone the plasma focus nitriding process has a much lower built-up edge than the tool that has not undergone plasma focus nitriding. Generally, the greater the anode distance, the greater will be the built-up edge formation.

Table 2. The effect of anode distance on built-up edge formation

Sample no.	Anode distance (mm)	Weight before cutting (g)	Weight after cutting (g)	Difference (g)
1	40	64.0886	64.0892	0.0006
2	50	67.2523	67.2562	0.0022
3	60	61.5194	61.5204	0.0017
4	70	64.6934	64.6963	0.0029
5	80	59.4416	59.4465	0.0049
6	Not nitrided	67.1543	67.2040	0.0497

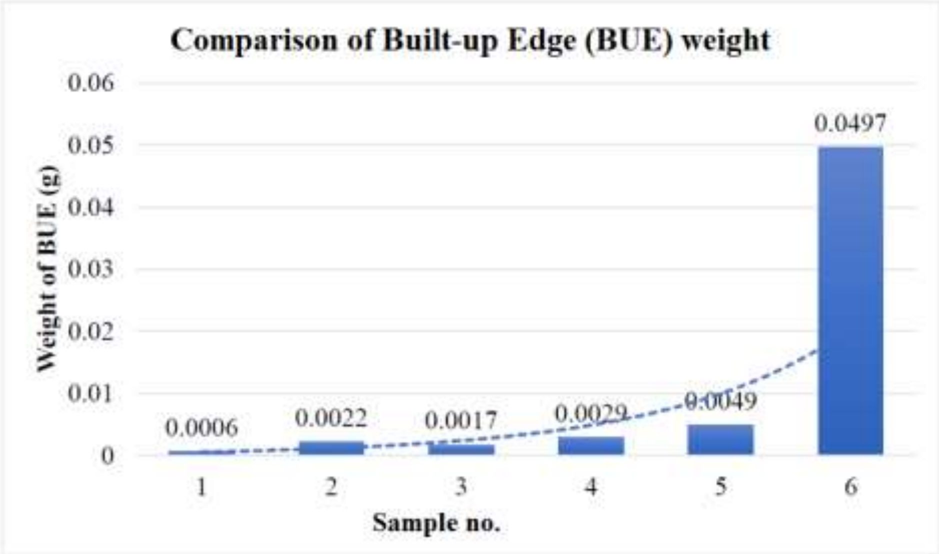

Figure 6. Chart showing the greater built-up edge with greater anode distances

In a generally observed trend of increasing built-up edge with anode distance, Sample 2 (anode distance of 50 mm) appears to buck the trend. However, the built-up edge does not follow an exact rate of formation and so this result anomaly is still acceptable. The general pattern is that the built-up edge increases with anode distance. The study shows that if the intention is to create a textured cutting tool with a plasma focus machine, then short anode distances are preferable.

4. Conclusions

Even though all six cutting tools produced in this manner can function without problems, it is a general engineering observation that the tools with the higher hardness tend to have slower wear rates. However, the biggest problem to the machinist is the presence of the built-up edge which leads to machining inaccuracy. Therefore, if AISI304 stainless steel is to be used as a tool after nitriding with the Dense Plasma Focus, it is best to mount the tool 40 mm away from the anode. At greater distances, not only is the hardness improvement less, there is also a bigger amount of the undesirable built-up edge. This study is conducted using 5 shots of ion beam for each sample. Future studies may want to also vary the number of shots to see if an even greater improvement can be obtained.

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