Title
The Effect of Dry Machining on Burr Size

Authors
Shefelbine, Wendy
Dornfeld, David A

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THE EFFECT OF DRY MACHINING ON BURR SIZE

Wendy Shefelbine
David Dornfeld

Department of Mechanical Engineering
University of California at Berkeley
Berkeley, California
wendy@me.berkeley.edu

ABSTRACT

Machining dry, without any coolant can be advantageous because of decreased costs associated with the use of coolant and a decrease in possible negative effects on worker health and the environment. Many problems associated with dry machining occur because of elevated temperatures. Because of increased ductility at elevated temperatures, the burrs formed are larger.

INTRODUCTION

Cost of Lubricating Coolant

Recently, as awareness of the environment has moved from reactive to compliant to proactive, manufacturers have been pushing to make processes environmentally more friendly (Young). The use of cooling lubricant (CL) in a machining process is expensive and the environmental effects are not completely known. As much as 16% of the cost of manufacturing can be attributed to the use of coolant, compared to tooling that accounts for 4% (Graham, Dry). The cost of the CL use comes from the coolant, hardware used to deliver it to the workpiece and tool, storage, and disposal (Kustas).

In addition to financial costs, the use of coolant can be bad for workers' health and the environment. The possible health hazards associated with some coolants include toxic vapors, dermatological problems, and bacteria cultures in the coolant. The environmental costs of coolant use include polluting the atmosphere and water, the cleaning of the swarf before recycling, and the disposal of coolant (Dry).

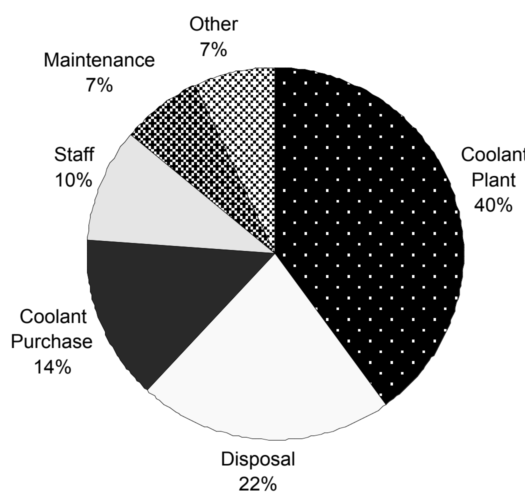


FIGURE 1. BREAKDOWN OF COSTS ASSOCIATED WITH COOLANT USE.

The costs of coolant use come from the equipment used to effectively deliver coolant to the machining operation as well as purchasing the coolant and disposing of used coolant. The cost breakdown of coolant use is shown in Figure 1 (Dry).

Dry Machining

There are a variety of processes available to avoid the use of coolant by flooding. Using a mist of coolant decreases some of the costs associated with coolant use but can still cause respiratory problems in machine operators (Kustas). Dry machining uses no coolant at all and can often be achieved by machining with tools and parameters that avoid problems associated with dry machining. Minimum Quantity Lubricant (MQL) is the process of pulverizing a small amount of oil in compressed air. This process uses about 10 to 40 mL of oil per hour of production and can be used where dry machining is not effective (Braga).

CHALLENGES OF DRY MACHINING

Many of the problems associated with dry machining occur because the metal reaches higher temperatures than during machining with cooling lubricant. For example, Klocke showed that the temperature of the tool can rise from 150°C with flood coolant to nearly 400°C when drilling AISI 1045. Without the lubrication, more heat is generated during the machining process and without the cooling effect, it cannot be as efficiently removed from the interface of the tool and the workpiece. The dimensional accuracy is often not as good during dry machining because of the high temperatures produced. Surface finish can also be negatively affected. The increase in temperature increases the ductility of the metal, changing the formation of chips (Klocke) and burrs.

Tool Life

The use of dry machining also has an effect on tool life. Tools that are made out of brittle materials such as coated cemented carbides, ceramics, CBN, and diamond often fail by cracking. During interrupted cutting with flood coolant, the temperature of the tool heats up when it is in contact with the workpiece and is then quickly cooled when it emerges from the cut. Cutting without flood coolant, the tool stays hot constantly rather than undergoing rapid thermal fluctuations. This limits the amount of cracking and improves tool reliability (Graham).

The Taylor Equation for tool life:

$$V*T^n=C_t$$

Where V is cutting velocity, T is time, n is a constant dependant on the tool material, and C_t is a constant that depends on tool material and workpiece material and the tool geometry (Stephenson). Recent research has shown that n actually changes when the failure mechanism changes from being dominated by the tool coating at low speeds to being dominated by the substrate at higher speeds. During dry machining, this transition occurs at a lower speed, making the tool wear faster at some speeds (Dry.

Although the tool life is shorter without coolant, it can be increased by changing the feed, speed, and tool geometry (Graham, Dry). When the increased cost associated with faster tool wear is limited as much as possible by adjusting cutting parameters, dry machining can lead to a net cost savings. Enough money can be saved by eliminating the coolant to make dry machining economically advantageous.

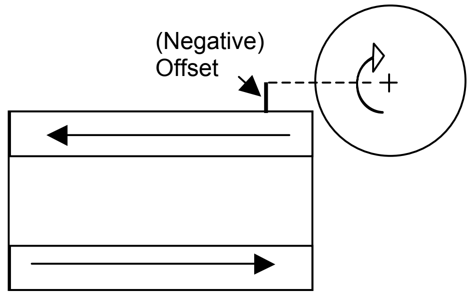
Many references (Klocke, Dry, Braga) state that dry machining of aluminum-silicon alloys is impossible because of the ductility. At the elevated temperatures present during dry machining and without lubricant, the tool sticks to the workpiece. This can lead to a built up edge (BUE) and short tool life.

BURR FORMATION

Experiments performed at DaimlerChrysler AG in Stuttgart, Germany show that burr are slightly larger when machined dry compared to machined with flood coolant.

Experiments

Experiments were conducted on a workpiece like the one shown in Figure 2. The burr thickness and height was measured at many points on each side using an optical microscope. Since the feed direction is parallel to the edge, the tool exits the material in the same manner along the entire edge.



2. EXPERIMENTAL SETUP.

Experiments comparing burr size with flood coolant and dry used tools worn from production use. One insert was used per tool to avoid dynamics problems. The material of the workpieces was AlSi9MgWa. The cutting conditions were:

TABLE 1. CUTTING CONDITIONS.

Tool Diameter	63 mm
Spindle Speed	9525 rpm
Feed	0.15 mm/tooth

The two offsets tested, 22 mm and -24 mm, correspond to nearly full and very small tool engagement, respectively.

Results

New Tool. Experiments run using new inserts with and without coolant show that, especially at high tool engagement, the burrs are larger when machined dry rather than with flood coolant. See Figure 3 below. At an offset of 22 mm (largest engagement tested), the burrs formed during dry milling are an average of 80% larger than with flood coolant.

Used Tools. Two worn tools, taken from production, were used. Experiments were run with these tools with and without flood coolant. When machined without flood coolant, the burrs formed during these experiments were an average of 9% larger than those machined with coolant, as shown in Figure 4.

The largest burrs found during dry machining were 11% larger than the largest burrs found when flood coolant was used. There was no significant difference in burr size for small and large engagement when using

Because of the elevated temperatures and increased ductility of the material being machined, the burrs formed during dry machining are slightly larger, about 10%, than the burrs seen with the use of flood coolant.

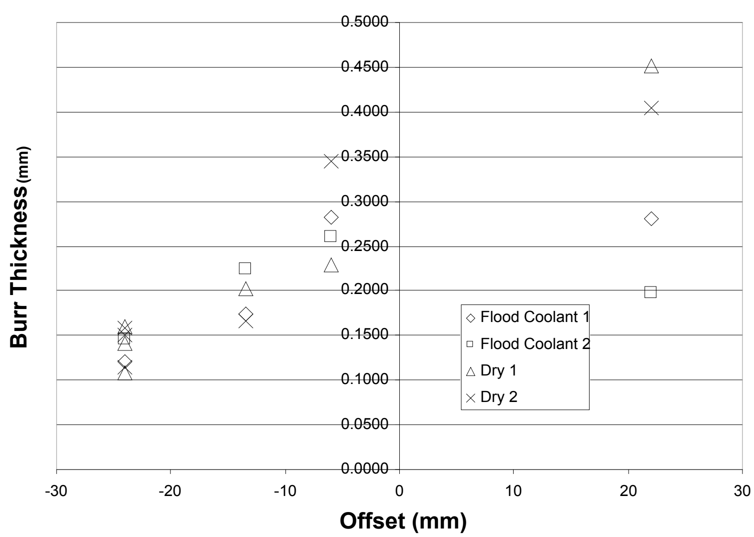


FIGURE 3. BURR THICKNESS FOR A NEW TOOL WITH AND WITHOUT COOLANT (FOUR OFFSETS).

Although this increase in burr size is not significant enough to eliminate the possibility of dry machining, it is an important factor to consider when investigating if dry machining is possible and what conditions are best for operation.

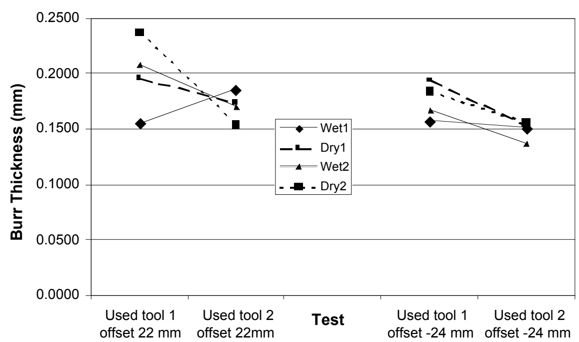


FIGURE 4. BURR THICKNESS FOR TWO OFFSETS AND TWO TOOLS WITH AND WITHOUT FLOOD COOLANT.

MACHINING CONDITIONS, DUCTILITY, AND BURR SIZE

Past research has found that above a certain critical cutting velocity, the temperature of the workpiece reached by machining decreases with increasing speed (King, Schmidt, Ming).

At low temperatures, the temperature increases as speed increases until a peak temperature near the melting point of the metal is reached. As shown in Figure 5, the temperature then decreases as the cutting velocity increases beyond a critical value. The critical velocity depends on the cutting conditions, but is in the order of 200 to 700 meters per minute (King, Schmidt, Ming).

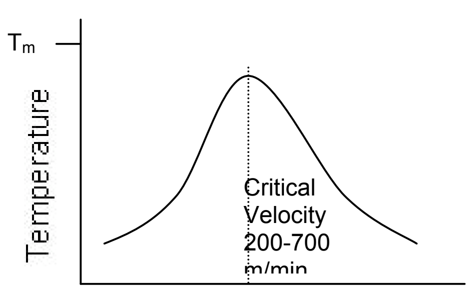


FIGURE 5. TEMPERATURE AND CUTTING VELOCITY.

The cutting velocity for the experiments shown above was 1885 m/min, well above the critical cutting velocity, so the experiments run at high speeds have lower temperatures.

Experiments were performed to show the effect of cutting velocity using the following cutting conditions.

TABLE 2. CUTTING CONDITIONS FOR EFFECT OF SPEED EXPERIMENTS.

Tool Diameter	63	mm
Spindle Speed	9525, 13750	rpm
Cutting Velocity	1885, 2721	m/min
Feed	0.15, 0.2	mm/insert
Depth of Cut	0.5, 2	mm

Figure 6 shows that the larger average burr size occurs when the speed is lower and temperature is higher. This is especially true for the smaller, 0.5 mm, depth of cut. Also, the largest burrs that formed during machining conditions that have the higher temperature were larger than the largest burrs that formed using the cutting conditions that yielded lower temperatures.

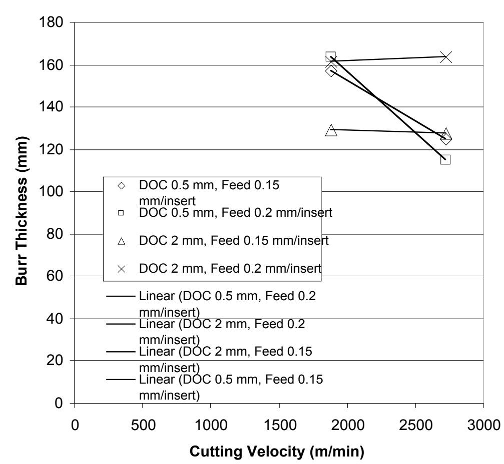


FIGURE 6. EFFECT OF SPEED AND TEMPERATURE ON BURR SIZE.

CONCLUSIONS

Dry machining can be advantageous because of decreased costs and environmental effects. While tool costs increase because of faster wear, this cost can be offset by the large amount of money saved by avoiding the systems related to coolant use. Challenges of dry machining stem primarily from increased temperature of the machining surface.

Burr size does increase during face milling of aluminum silicon alloys when no coolant is used, but not enough to eliminate the possibility of dry machining. This increase in burr size occurs because without flood coolant, the temperature of the workpiece increases, which increases ductility. It was shown that the increase in temperature and ductility in other experiments increased burr size.

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