Aluminum High Speed Machining

Metalworking Fluid Performance in Aluminum High Speed Machining

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Introduction

High speed machining (HSM) offers the potential for increased productivity and improved part quality in the production of aluminum engine and transmission components for the automotive industry. Definitions of high speed machining, as well as the benefits to be achieved through use of HSM, have both previously been documented.[1-3] While generally accepted that the use of high speeds and feed rates in a machining operation can yield increased rates of productivity, use of HSM can also result in improved machined surface finish and reduced machining forces.[4-6] Such effects are thought to result from reduced heat generation during cutting, reduced contact time between the tool and workpiece surfaces, and also from the limiting shear stress properties of the metal, which are often exceeded under high speed machining conditions.[7-9]

With regard to water-based metalworking fluids used in HSM operations, while an understanding currently exists of the importance of fluid properties such as coolant stability and foam behavior, less is known about the demands on the fluid for lubrication and cooling, and how these demands may differ from a fluid's use in conventional lower speed machining. To be more specific, with the knowledge that under high speed conditions lower machining forces and improved machined surface finish can be achieved, do the metalworking fluids used need to be as effective and as high quality as those currently used at lower speeds, specifically with regard to the lubrication and cooling provided?

With these questions in mind, this paper will discuss the differences in aluminum machining performance obtained at high versus low cutting speeds, as well as the influence of the metalworking fluid and its composition in enhancing machining performance. Thus, this paper will provide useful insight into how important highly engineered aluminum machining fluids are, and will be, as high speed cutting operations continue to be used in industry.

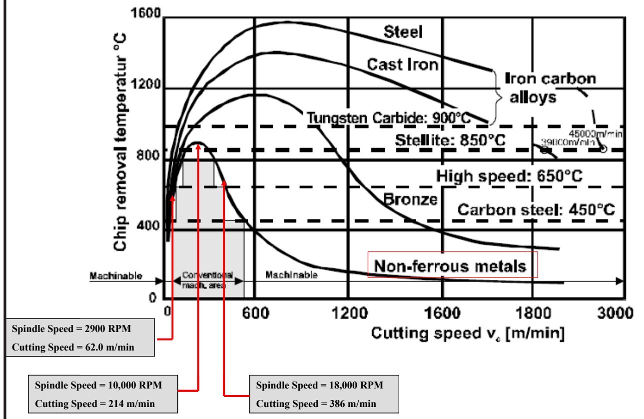
High versus Conventional Speed Machining

To better understand the influence of metalworking fluids in aluminum high speed machining, machining tests were performed at both lower conventional speeds and at high speed conditions. In considering some of the history of the origins of HSM, Dr. Carl Salomon, in his original investigations on high speed machining, determined that the heat generated between the chip and the cutting tool would increase with increasing cutting speed, up to a critical speed dependant upon the metal being cut.[10] With further increase a critical speed would be reached, at which point the chip removal temperature would decrease with further increasing speeds. Given this analysis, and the presumption that machining performance (forces, BUE formation, tool wear, etc.) are all largely influenced by the heat generated at the tool chip interface, it would be expected that overall machining performance would decrease with increasing cutting speeds prior to the peak cutting speeds, and then begin to improve as speeds exceed the peak value. To investigate this premise, machining tests were performed using cast 380 aluminum at cutting speed values below, equal to, and above the peak cutting speed value which Dr. Salomon plotted for non-ferrous metals. Using a 0.25" diameter carbide step drill, machining of Al 380 was performed using spindle speeds of 2,900 RPM, 10,000 RPM, and 18,000 RPMs, with these cutting speeds corresponding to one below, one at, and one beyond the critical speeds as they relate to chip removal temperatures, (as seen in Figure 1 below).

Figure 1

Chip Removal Temperature as a Function of Cutting Speed For Various Metals

(showing three cutting speeds used in Al 380 machining study)



To assess the machining performance at these three different cutting speeds, the axial machining forces, tool flank face wear, machined surface finish, and hole dimensions were measured. The axial machining forces, while providing a measure of the energy required for the operation, also provide a useful indirect measure of the mechanical and thermal demands on the tooling and the potential tool life to be expected in a given operation. As seen in Figure 2, which shows the mean axial machining forces measured at the three cutting speeds, the machining forces climb considerably when speeds are increased from 2,900 RPM up to 10,000 RPMs. However, as the speeds increase further to the HSM conditions (18,000 RPMs), the cutting forces level off and actually start to decrease. Thus it can be concluded that the mechanical and thermal demands on the tooling are reduced at HSM conditions and improved tool wear will likely be obtained. To support such conclusions, the tool flank face wear was measured following chemical removal of the built up edge from the tool cutting surface. As seen in Figures 3 and 4, which show the flank face wear length on the tools used at the three cutting speeds, wear is significantly reduced as the cutting speeds increase from 2900 RPM to 10,000 RPM with a further wear reduction obtained at the high speed conditions of 18,000 RPMs.

Figure 2

Machining Speed Effects on Axial Machining Forces

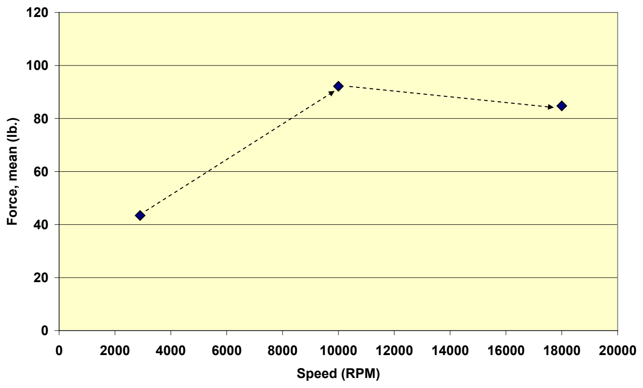


Figure 3

Tool Wear on Flank Face of Cutting Edge

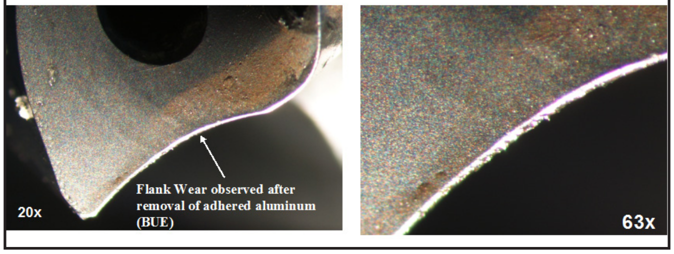
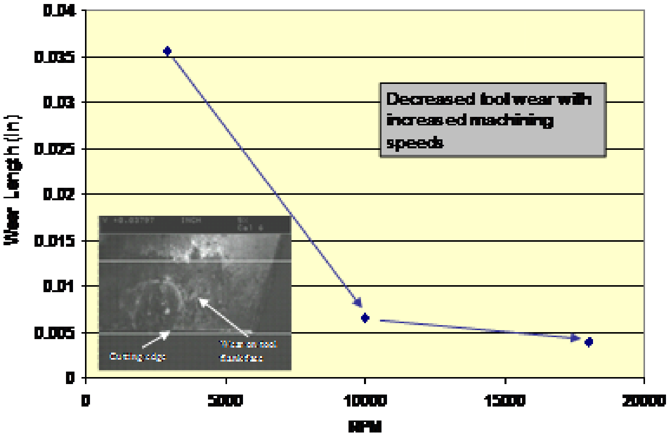


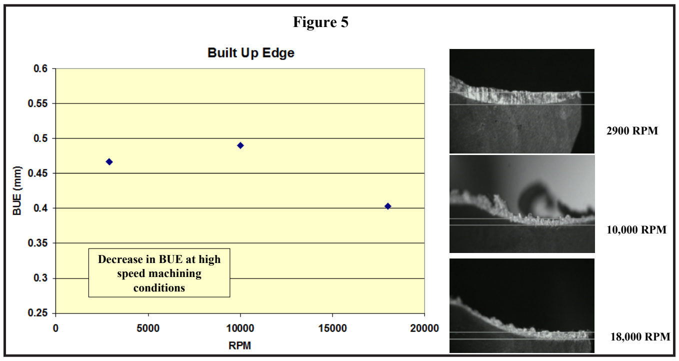
Figure 4

Machining Speed Effects on Tool Wear



While tool wear is an important issue in aluminum machining, the amount or degree of built up edge formed on the cutting tool can be an equally or often more critical parameter to be considered. Built up edge when formed often leads to a degradation of the machined surface finish, as well as loss of accuracy of size or dimensions of the holes produced. To assess the impact of HSM conditions on this parameter, the degree of BUE formed on the cutting tools, and subsequently the hole finish and form, were measured for each of the three cutting speeds utilized. While BUE formation is an extremely dynamic process with formation and loss of adhered metal from the cutting edge constantly occurring, examination of the tooling following the machining operation still offers a useful assessment of the tendency for this to happen. As seen in Figure 5 below, it is clear that the use of the high cutting speeds of 18,000 RPMs yield a significantly lower level of BUE formed on the cutting tool edge.

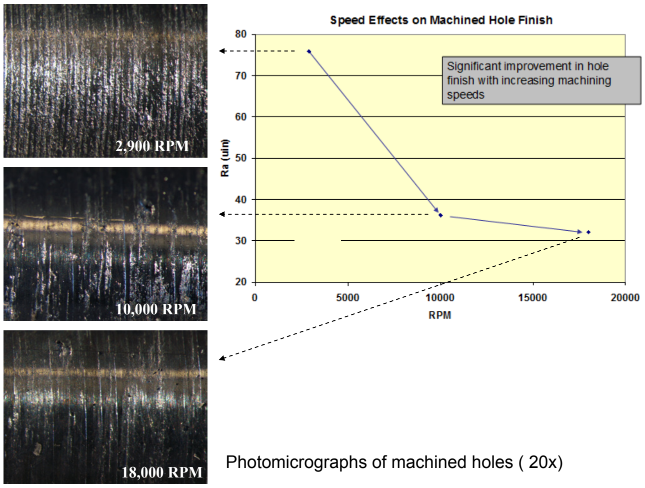
Figure 5



With a reduction in BUE formation at HSM conditions, it would be expected that machined surface finish and machined hole form (dimensional consistency from top to bottom of hole) would also improve at high cutting speeds. Figures 6 and 7 show respectively the machined hole finish and hole form obtained with the three cutting speeds studied. Consistent with the built up edge measured, the machined hole finish and hole form is improved at high cutting speeds (18,000 RPM) relative to those measured following lower speed cutting.

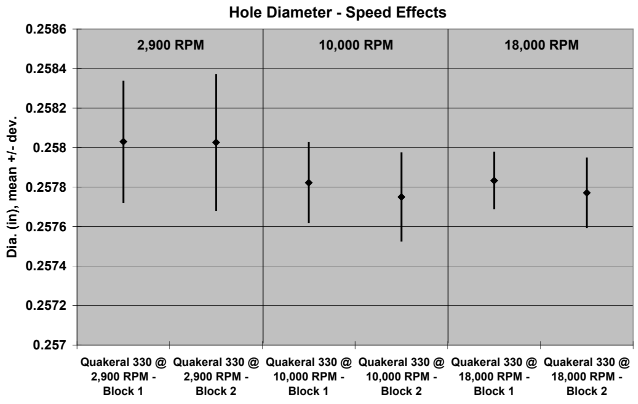
Figure 6

Machined Hole Surface Finish



Photomicrographs of machined holes (20x)

Figure 7



While it might be initially thought that high speed machining would yield significantly more severe machining conditions with resultant higher machining forces, tool wear, BUE, and poorer machined surface finish, it is seen from the results presented in this study that as the machining operation tends to higher cutting speeds, the overall quality of the tool and the hole produced improves. Thus consistent with previous studies and reports, high speed machining offers benefit with regard to the quality of the operation and part produced, as well as the gains in productivity which can be obtained.

Metalworking Fluids in High Speed Aluminum Machining

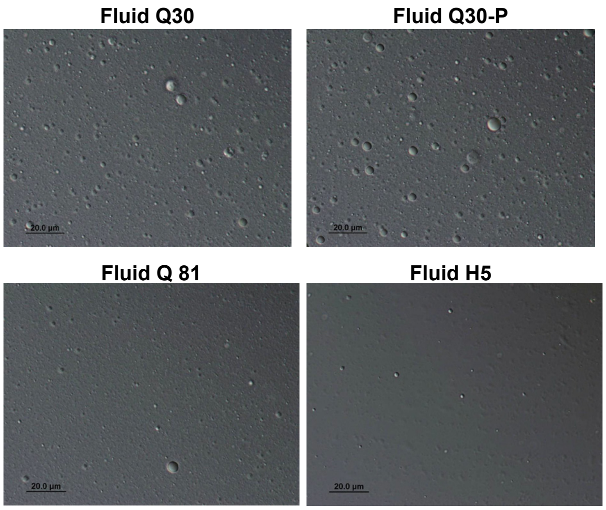
With an understanding that at high cutting speeds, lower machining forces, reduced tool wear, and improved machined surface finish can be obtained, a question to be asked is: do the metalworking fluids used need to be as effective and as high quality as those currently used at lower speeds, specifically with regard to the lubrication and cooling provided?

To address this question, high speed machining tests were conducted to assess the properties of various water-based aluminum machining fluids and determine if machining performance could be influenced by the quality of the fluid used. For this study, four fluids currently widely used in the industry and considered to represent the state-of-the-art in fluid technology for aluminum machining operations, were each tested under high speed machining conditions. While all four of these water-based fluids are considered to be effective, there are observable performance differences between them when utilized at lower, more conventional machining speeds. Such differences may arise from the composition and type of lubricating additives, their emulsion properties, or a combination of such factors. Nevertheless, it was felt that if the fluid used can be a significant factor in the level of machining performance obtained in HSM, then differences in their machining performances should be observed at the high cutting speeds of 18,000 RPMs.

Microphotographs of the fluids are shown below in Figure 8. While all four are considered to be oil-in-water macroemulsions, a noticeable difference in the sizes of the oil droplets dispersed in the water phase of the fluids can be seen. Such differences can influence fluid properties and performance, and therefore while not always of highest importance, is nevertheless useful information to obtain when assessing the nature and potential use of a water-based fluid.

Figure 8

Microphotographs of Aluminum Machining Fluids



Fluid Q30

Fluid Q30-P

Fluid Q 81

Fluid H5

7% Concentration in water of 125 ppm hardness **400x**

Following the machining of Al 380 at 18,000 RPM, the machined surface finish and tool flank wear were measured for each of the four fluids tested. The results (Figures 9 and 10) clearly show that tool wear and finish are significantly influenced by the fluid used, with Fluids Q81 and Q30-P yielding the best tool life and machined hole finish. Thus the use and selection of the metalworking fluid can impact the machining performance and potentially yield further improvements in the quality of the part produced as well as the tool life obtained. While the determination of the specific reasons for the fluid performance differences observed are not discussed, they are likely a result of compositional differences between the fluids giving rise to varied levels of the lubrication, cooling, and chip removal capabilities.

Figure 9

Tool Flank Wear - High Speed Aluminum Machining

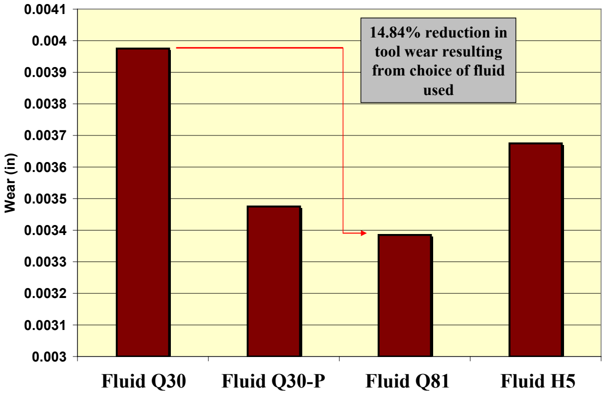
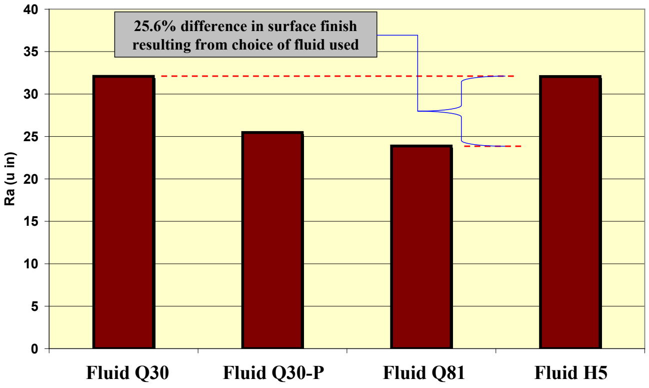


Figure 10

Machined Surface Finish - High Speed Machining



Conclusions

The results of machining tests conducted at lower, more conventional cutting speeds, and also at high speed machining conditions, show that along with gains in productivity under HSM conditions, improvement in the machining operation and quality of the part produced can be obtained. Such improvement is seen in the reduced wear and built up edge observed on the cutting tool used at the 18,000 RPMs, as well as in the improved machined surface finish obtained at HSM conditions.

While improved machining can be obtained at higher speeds, it was also seen in the test results obtained that the machining fluid used can still have a significant influence on important measured parameters, such as tool wear and part quality. Thus it is felt that the composition and resultant performance properties of the metalworking fluid will continue to play an important role in the quality of the operation, as the use of high speed machining continues to grow in industry.

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