Machining of Aluminum Alloys

T. J. SKINGLE AND R. W. THOMPSON

Machining of aluminum alloys was the subject of a technical session at the Materials and Processing Show and Congress held in Chicago on November 13, 1979. This article presents some of the highlights on machining of aluminum alloys discussed at this session. The papers presented were:

"Influence of Aluminum Casting Alloy Characteristics on Machinability"
John L. Jorstad, Reynolds Metals Company

"A Practical Approach to Aluminum Machining"
Daniel R. Stashko, Valeron Corporation

"Successful Broaching of Aluminum Automotive Engine Components"
Myron J. Schmenk, Cincinnati Milacron

"Drilling of 380 and 390 Aluminum"
Thomas J. Skingle, Acme-Cleveland Corporation

"The Skiving of Extruded Aluminum Tubing for Automotive Condenser Tubes"
Robert B. Jagers, Chrysler Corporation

"Ultra High-Speed Machining of Aluminum"
Robert I. King, Lockheed Missile & Space Co.

The machinability of aluminum and its alloys can vary over a large range. Alloy content, impurities, casting process, casting integrity, heat treatment, machine tool rigidity, and cutting tool geometry are some of the important factors that influence aluminum alloy machinability. Understanding and controlling these factors leads to cost effective metal removal.

Many tests or approaches currently used to establish the machinability of aluminum alloys still remain laboratory phenomena. It is difficult to translate the data from machinability tests to shop floor practice. It is also difficult to translate laboratory machinability data to the various production metal removal processes. For example, laboratory data dealing with chip length may not be an adequate evaluation criterion for end milling applications where the cut, by definition, is interrupted. Conversely, a laboratory test dwelling on tool wear may not be adequate for an application where built-up edge (BUE), chip galling, or surface finish determine tool life.

Aluminum has a strong tendency to stick to the cutting tool and form a BUE. The BUE is normally an unwelcome addition during cutting since it affects surface finish and carries away small portions of the tool as it intermittently breaks away. Six practical ways of controlling the BUE were suggested.

1. Increase rake angle.
2. Use small nose radii.
3. Polish the rake angle.
4. Use higher surface speeds.
5. Use copious amounts of coolant.

6. Use diamond tooling (by far the best weapon to combat BUE).

The mechanical and physical properties of elemental aluminum provide the basis for insight into aluminum alloy machinability. Aluminum has a modulus of elasticity one-third that of steel. Therefore, within aluminum’s elastic region, it deflects three times that of steel when subjected to the same cutting forces. This deflection strongly influences the ability to hold dimensional tolerances and subsequently the quality of part surface finish.

Although several aluminum alloys have room temperature strengths equivalent to that of some of the low carbon steels, aluminum alloys have low elevated temperature strengths. High temperatures are generated at the cutting tool workpiece interface. Since aluminum experiences dramatic strength reduction with increasing temperature, the high isolated temperatures at the chip-cutting tool interface result in low required force levels to machine aluminum.

Aluminum is also an excellent conductor. Heat is carried away from the cut and not readily conducted into the cutting tool. Cutting tools remain cool and, therefore, have extended life.

Alloying of aluminum has a pronounced effect upon machinability. However, the alloys remain of low modulus and reasonably high conductivity. A number of alloying elements are commonly added to improve or modify the properties of aluminum. Silicon, magnesium, and copper are perhaps the major alloying elements. Silicon is the most effective in improving the fluidity and castability, but it also forms hard silicon particles in the relatively soft aluminum matrix. When the silicon particles are large, they can be quite abrasive to the tool. Magnesium and copper are primarily added to aluminum alloys as hardening agents.

Aluminum alloying additions influence chip formation, material abrasiveness, surface finish, power consumed, and many other machinability related factors. Some of the alloying additions and their influences are:

<table>
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<th>Element</th>
<th>Influence</th>
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<tr>
<td>Bi</td>
<td>Adds lubricity and aids in chipbreaking.</td>
</tr>
<tr>
<td>Fe, Mn, Cr, Ni, Mg, Cu</td>
<td>Combine with each other and also with aluminum and silicon to form hard inter-metallic phases.</td>
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<tr>
<td>Mg</td>
<td>As little as 0.3 pct increases chip hardness, also decreases friction between chip and cutting tool, tightens curl of resultant chip.</td>
</tr>
<tr>
<td>Pb</td>
<td>Adds lubricity and aids in chipbreaking.</td>
</tr>
<tr>
<td>Si</td>
<td>Increases abrasion on the cutting tool. Machinability decreases as the size of the primary silicon phase increases.</td>
</tr>
<tr>
<td>Sn</td>
<td>Adds lubricity and aids in chipbreaking.</td>
</tr>
<tr>
<td>Zn</td>
<td>Has no positive or negative influence on machinability.</td>
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Processing also influences machinability. In general, for any given casting process, the slower the cooling rate the poorer the machinability. In the high silicon containing alloys such as 390, the primary silicon particles become finer as the cooling rate increases and, conversely, coarser as the cooling rate decreases. Tool life decreases as the size of the primary silicon phase increases. As a result, die castings machine easier than permanent mold castings which, in turn, are easier to machine than sand castings. In addition to easier machining, there is generally less stock removal required in die casting than in permanent mold or sand casting.

There is one item that most people machining aluminum will agree upon, that a Brinell hardness of 80 is the minimum hardness for good machinability; but hardness is not the sole judgment criterion. Machinability is dramatically influenced by internal structure. Modification of this structure through alloy addition, process selection, or subsequent heat treating can lead to readily machinable aluminum component parts.

It has been previously indicated that machinability of aluminum is difficult to define. Machinability is highly dependent upon the conditions one chooses for replacement of the worn tool. This is especially important when the machining processes of turning, broaching, and drilling are considered.

One area of agreement concerns polishing of the tool. Aluminum chips show lesser tendencies to bond to polished rake faces than to non-polished rake faces. For example, in turning, a 4 microinch rake face surface finish results in better tool life than that with a 16 microinch rake face surface finish.

Selection of surface speed is an area where different approaches appear to work in different applications. High surface speeds work well in turning with carbide or diamond tools. However, broaching and drilling require slower surface speeds.

Depth of cut is also an area in which there is no general agreement. For example, when broaching 390 alloys, a light depth of cut is necessary to prevent edge breakout and produce a smooth surface finish. Conversely, when drilling the same alloy, a heavy depth of cut is recommended.

Coolant is required in turning and drilling, but does not appear mandatory in broaching. In broaching, the