Cutting Tool Materials

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Training Objectives

After watching the video and reviewing this printed material, the viewer will gain knowledge and understanding of cutting tool metallurgy and specific tool applications for various types of metalcutting.

- High-speed steels, the forms of carbides, ceramics, cermets, and the superhard cutting tool materials are discussed
- tool selection for various applications are outlined
- types of tool failure modes are detailed

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Principal categories of cutting tools include single point lathe tools, multi-point milling tools, drills, reamers, and taps. All of these tools may be standard catalog items or tooling designed and custom-built for a specific manufacturing need.

The number one error when selecting tooling is calculating monetary savings based on lowest cost per tool, rather than on maximized productivity and extended tool life. To effectively select tools for machining, a machinist or engineer must have specific information about:

- the starting and finished part shape
- the workpiece hardness
- the material's tensile strength
- the material's abrasiveness
- the type of chip generated
- the workholding setup
- the power and speed capacity of the machine tool

Changes in any of these conditions may require a thorough review of any cutting tool selection.

Different machining applications require different cutting tool materials. The ideal cutting tool material should have all of the following characteristics:

- harder than the work it is cutting
- high temperature stability
- resists wear and thermal shock
- impact resistant
- chemically inert to the work material and cutting fluid

No single cutting tool material incorporates all these qualities. Instead, trade-offs occur among the various tool materials. For example, ceramic cutting tool material has high heat resistance, but has a low resistance to shock and impact. Every new and evolving tool development has an application where it will provide superior performance over others. Many newer cutting tool materials tend to reduce, but not eliminate the applications of older cutting tool materials.

As rates of metal removal have increased, so has the need for heat resistant cutting tools. The result has been a progression from high-speed steels to carbide, and on to ceramics and other superhard materials.

Developed around 1900, high-speed steels cut four times faster than the carbon steels they replaced. There are over 30 grades of high-speed steel, in three main categories: tungsten, molybdenum, and molybdenum-cobalt based grades. Since the 1960s the development of powdered metal high-speed steel has allowed the production of near-net shaped cutting tools, such as drills, milling cutters and form tools. The use of coatings, particularly titanium nitride, allows high-speed steel tools to cut faster and last longer. titanium nitride provides a high surface hardness, resists corrosion, and it minimizes friction.

In industry today, carbide tools have replaced high-speed steels in most applications. These carbide and coated carbide tools cut about 3 to 5 times faster than high-speed steels. Cemented carbide is a powder metal product consisting of fine carbide particles cemented together with a binder of cobalt. The major categories of hard carbide include tungsten carbide, titanium carbide, tantalum carbide, and niobium carbide. Each type of carbide affects the cutting tool’s characteristics differently. For example, a higher tungsten content increases wear resistance, but reduces tool strength. A higher percentage of cobalt binder increases strength, but lowers the wear resistance.

Carbide is used in solid round tools or in the form of replaceable inserts. Every manufacturer of carbide tools offers a variety for specific applications. The proper choice can double tool life or double the cutting speed of the same tool. Shock-resistant types are used for interrupted cutting. Harder, chemically-stable types are required for high speed finishing of steel. More heat-resistant tools are needed for machining the superalloys, like Inconel and Hastelloy.

There are no effective standards for choosing carbide grade specifications so it is necessary to rely on the carbide suppliers to recommend grades for given applications. Manufacturers do use an ANSI code to identify their proprietary carbide product line.

Two-thirds of all carbide tools are coated. Coated tools should be considered for most applications because of their longer life and faster machining. Coating broadens the applications of a specific carbide tool. These coatings are applied in multiple layers of under .001 of an inch thickness. The main carbide insert and cutting tool coating materials are titanium carbide, titanium nitride, aluminum oxide, and titanium carbonitride.

Ceramic cutting tools are harder and more heat-resistant than carbides, but more brittle. They are well suited for machining cast iron, hard steels, and the superalloys. Two types of ceramic cutting tools are available: the alumina-based and the silicon nitride-based ceramics. The alumina-based ceramics are used for high speed semi- and final-finishing of ferrous and some non-ferrous materials. The silicon nitride-based ceramics are generally used for rougher and heavier machining of cast iron and the superalloys.

Cermet tools are produced from the materials used to coat the carbide varieties: titanium carbides and nitrides. They are especially useful in

chemically reactive machining environments, for final finishing and some turning and milling operations.

Superhard tool materials are divided into two categories: cubic boron nitride, or "CBN", and polycrystalline diamond, or "PCD". Their cost can be 30 times that of a carbide insert, so their use is limited to well-chosen, cost effective applications. Cubic boron nitride is used for machining very hard ferrous materials such as steel dies, alloy steels and hard-facing materials. Polycrystalline diamond is used for non-ferrous machining and for machining abrasive materials such as glass and some plastics. In some high volume applications, polycrystalline diamond inserts have outlasted carbide inserts by up to 100 times.

All cutting tools are “perishable,” meaning they have a finite working life. It is not a good practice to use worn, dull tools until they break. This is a safety hazard which creates scrap, impacts tool and part costs, and reduces productivity. Aside from breakage, cutting tools wear in many different ways, including:

- edge wear and flank wear
- cratering or top wear
- chipping
- built-up edge
- deformation
- thermal cracking

Edge and flank wear are both normal, slow types of tool wear. If the work material is highly abrasive, as with certain cast-irons, this type of wear will accelerate.

Cratering occurs behind the cutting edge, and happens often in machining long-chipping steels. If the crater grows large enough and contacts the cutting edge, the tool fails immediately. Cratering can be overcome by using titanium or tantalum carbide tools.

Chipping on a tool edge is an unpredictable form of tool failure. It is sometimes started when a high point on an edge breaks away. A stronger carbide grade, different edge preparation, or lead angle change may eliminate chipping.

Built-up edge is a deposit of workpiece material adhering to the rake face of an insert. These deposits can break off, pulling out pieces of carbide from the tool. Ductile materials, such as softer steels, aluminum, and copper cause this problem. The use of higher rake angles, faster cutting speeds, and high pressure cutting fluid all help eliminate built-up edge.

Deformation of a tool or insert is due to heat build-up. Although very detrimental to the machining process, deformation is difficult to detect without the use of a microscope. Using a heat-resistant tool, or reducing the cutting speed often help to prevent deformation.

Thermal cracking occurs when inserts go through rapid heating and cooling cycles. Causes include interrupted cutting and poor application of cutting fluids.

Review Questions

1. High-speed steel cuts faster than carbon steel by a factor of:
   a. 2
   b. 4
   c. 8
   d. 10

2. High tungsten content in a carbide tool will:
   a. increase strength, but decrease wear-resistance
   b. increase wear-resistance, but decrease strength
   c. allow increased feed speeds while improving heat-resistance
   d. improve the chemical-resistance of the tool

3. Inconel and Hastelloy require cutting tools that are:
   a. tough
   b. wear-resistant
   c. heat-resistant
   d. shock-resistant

4. Ceramic cutting tools are very:
   a. porous for cutting fluid retention
   b. shock-resistant
   c. resistant to wear
   d. brittle

5. Polycrystalline diamond cutting tools can outlast regular carbide by a factor of:
   a. 10
   b. 20
   c. 50
   d. 100

6. For machining purposes, cast iron is considered:
   a. abrasive
   b. hard
   c. brittle
   d. soft

Answer Key

1. b
2. b
3. c
4. d
5. d
6. a