Sborník vědeckých prací Vysoké školy báňské - Technické univerzity Ostrava
číslo 1, rok 2006, ročník LII, řada strojní
článek č. 1493

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SELECTION OF CUTTING TOOL MATERIALS

VÝBĚR VHODNÉHO ŘEZNÉHO MATERIÁLU

Abstract

There are many pathways taken to select a specific cutting tool for a machining process to manufacture a part. Unfortunately, many of these paths are those of least resistance, or more likely, least effort on the part of decision maker. The choices are driven by many forces including eye-catching advertisements, friendly salesman, and curiosity. Many companies purchase cutting tools based solely on low bids, with little regards for performance. Nationwide, poor productivity, excessive tool-changing downtime, and unacceptable part quality often result due to the performance of cutting tools purchased with costs as primary determining factor.

Abstrakt

Existuje mnoho cest jak zvolit správný řezný materiál pro obráběcí proces jako část výroby. Bohužel mnoho z těchto cest jsou ty nejmenšího odporu, nebo malého úsilí toho, kdo o výběru rozhoduje. Volba nástrojového materiálu je hnána mnoha silami, včetně poutavé reklamy a usměvavého dealera. Mnoho společností prodávající řezné nástroje nabízí výhradně nízké cenové nabídky bez ohledu na výkon a vhodnost daného materiálu. Nízká produktivita, dlouhé prostoje při výměně nástrojů a zčásti nepřijatelná kvalita výroby je často výsledkem použití nevhodných nástrojů, které byly nakoupeny za nízké ceny jako primární určující faktor.

1 Introduction

Figure 1 provides a longitudinal perspective (not cutting speed recommendation) on the development of cutting tool materials. As metallurgical technology advanced, the improvement in the performance of cutting tools followed. Advancements in cutting tools depend entirely on improving the chemical composition and/or the manufacturing process of the tool material. Invariably, improvements in the metallurgical quality of a cutting tool material result in longer tool life or more importantly, higher speeds. Since the cutting speed is dominant influence on cutting temperature of the machining process, it naturally follows that tools that provide higher speed have more tolerance for higher temperature. Fig. 2 illustrated this relationship. Tool material with higher hot hardness will permit machining at higher productivity rates due to the higher allowable cutting speeds [2].

Selecting the correct cutting tool material for a specific machining operation is the first step in creating the most effective process plan for manufacturing a part. The cutting tool material is dependent on the work material to be machined and the operation to be performed. Often, there are several possible choices of tool materials that will successfully (but not cost-effectively) produce parts. Additional factors then must be considered and these include:

- machine tool horsepower, speed range, rigidity,
- productivity demands,
- tooling budget limitations,
- machine tool burden rate
- labor and overhead rate.

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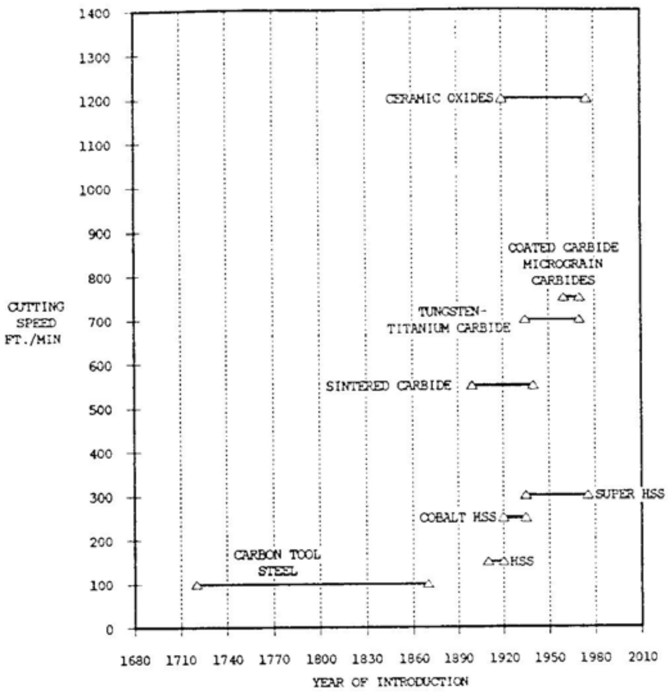

Fig. 1 Cutting tool development

Generally, the higher the combined hourly rate for the machine tool and operator, the greater the demand for higher productivity to reduce the cutting time per part. However, the size, performance capacity, and general condition of the machine tool may limit the productivity available from that particular machine. Whatever the limiting factor or factors may be, the wise process planner or programmer uses a valid cost analysis to determine his choice of either maximum productivity or minimum cost. Decisions made without an economic analysis will likely produce less than the maximum available output at a higher part cost than necessary.

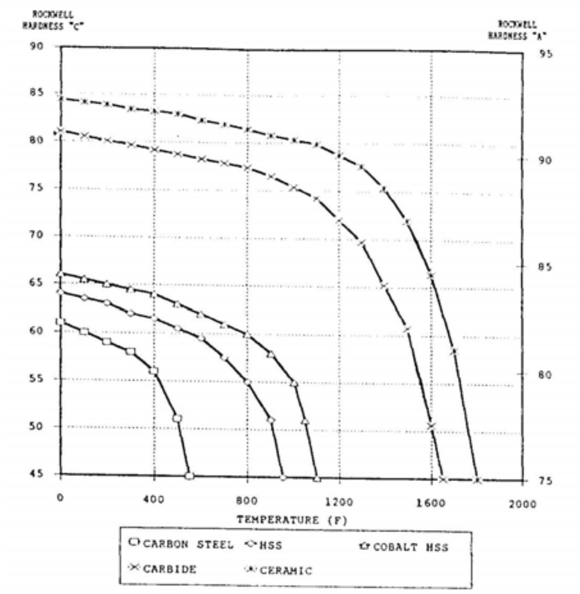

Fig. 2 Hot hardness of various tool materials

2 WORK MATERIAL/ALLOY

The most important consideration in selecting the correct cutting tool is the work material and its hardness. The material may be metallic or nonmetallic, ferrous or nonferrous. The majority of materials machined in the United States and whole world are ferrous materials, carbon, alloy, stainless steels, or cast irons. The cast irons may be gray, ductile, or malleable. There are usually two or three levels of tensile strength within many grades of alloy and stainless steels, as well as the three types of cast iron. Higher tensile strength levels invariably produce a higher hardness and a more difficult to machine material. A very thorough definition of the work material is a valuable aid in making an intelligent selection of the tool material.

The purpose of this chapter is to survey the major categories of cutting tool materials with comments concerning unusual properties or limitations of each group, and the normal applications of each group. The various tool materials that will be discussed include:

- high speed steel,
- uncoated carbide,
- coated carbide,
- ceramics,
- cermets,
- polycrystalline diamond,
- polycrystalline cubic boron nitride.

2.1 High Speed Steel

The earliest version of tool material used in machining was high carbon tool steel. This material was generally unalloyed steel and could be heat treated to a hard but shallow case. The addition of various alloying elements, particularly tungsten, chromium, and vanadium, added harden ability to the materials as well as much higher hot hardness.

Today's HSS tools are available in the normal ingot cast version and as the panicle metallurgy (PM) (a patented process) version. The ingot cast materials, while capable of doing a satisfactory job in most applications, are limited by the permissible composition and/or heat treatment to achieve higher wear resistance (hardness) also produces a lower toughness and therefore a more brittle HSS.

Hard coatings can be applied to the surfaces of finish ground HSS tools to improve their performance, particularly in machining ferrous alloys. The physical vapor deposition (PVD) process applies a single coating usually of titanium nitride (TiN). The coating is applied as the vapor solidifies on the tools within a vacuum chamber. Other coatings of titanium carbonitride (TiCN), zirconium nitride (ZrN), and chromium nitride (CrN) are also available. The PVD process operates at a temperature lower than the tempering temperature of the HSS and therefore does not degrade the hardness of the steel.

2.2 Uncoated Carbides

This tool material was first developed with tungsten carbide (WC) and cobalt as the binder. This material was satisfactory for machining gray cast iron, which was very common in the 1920's and 1930´s. The relative percentages of carbide to cobalt determine the wear resistance or toughness of the grades. Some categories contain only the WC and Co, and are suitable for roughing applications or interrupted cutting. The higher numbers are harder with more carbide and less binder, providing higher wear resistance, lower toughness, and are more suitable for semi finishing and finishing cuts. Uncoated carbides are still quite widely used in the machining industry. Virtually all of the carbide tipped tools, drills, reamers, milling cutters, saws, etc. Many machine tools, unable to fully utilize the higher performance, more expensive coated carbides, due to lack of speed or horsepower, are able to cut with uncoated carbide tools. Materials that are very abrasive or high in hardness, are not ideal applications for coated carbides and are often machined with uncoated carbides.

2.3 Coated Carbides

The most common tool wear on uncoated carbides is diffusion-related wear. The temperatures and pressures associated with the normal cutting parameters on ferrous alloys cause the cobalt binder on the surface of the carbide tools to diffuse out of the matrix with the hot chips produced during the cutting process.

As the binder diffuses from both the top and side surfaces, the grains of carbide are displaced gradually, leaving wear scars on the flank and nose of the tool and the crater on the rake face. Attempts were made to reduce this diffusion process, all with limited success, until the development of the chemical vapor deposition (CVD) process. This process deposits various vaporized compounds on the surfaces of the carbide tools in a vacuum chamber. The first successful coating was titanium carbide (TiC). In addition to TiC, titanium nitride (TiN) and aluminum oxide (Al_20_3) are now used in various combinations, with TiC serving as the base coat. The familiar gold colored exterior coating is usually TiN, although hafnium nitride (HfN), similar in appearance, is used by some manufacturers.

The PVD coating process, commonly used on HSS tools, was tested on carbide and found to consistently produce a damage free interface. Subsequent cutting tests with PVD coated tools confirmed that an increase in tool life resulted over the CVD coated tools. A special group of PVD coated carbides are recommended for heavy or interrupted cutting applications [3].

The substrates for the coated carbides are usually not cutting grades, but special compositions, that are tailored to the use of the coated tool, having high roughness and deformation resistance. The wear resistance of the tool is usually dependent on the coating and not on the substrate.

These inserts are available in a wide variety of chip control geometries in all standard insert configurations. There is little doubt that the coated carbides are the closest product to an all-purpose cutting tool material for ferrous alloys. Their success is the reason that coated carbides account for approximately 60% of all sales of indexable inserts.

2.4 Ceramics Tools

The major deficiency associated with the use of ceramic tools in production machining is low toughness. This results in chipping and breakage of the tools rather than wear. To alleviate this problem, several techniques have evolved to strengthen the cutting edge and produce wear rather than chipping or breaking. These include increasing the thickness or nose radius (round inserts have been produced) of the tool that can result in improved performance. However, the most recent and effective improvement in ceramic inserts is in the development of the edge preparation.

There are three types of edge preparation that eliminate the perfectly sharp edge where the sides of the insert intersect with the rake face. The earliest technique was the hone, performed carefully by hand with a fine grain diamond hone. This operation is now automated. A radius is formed at the intersection of the face and side of the insert. The size of the radius can be varied to accommodate the application.

The most common edge preparation is the T-land, which is a chamfer ground to a specific angle and width of the land. The angles vary from 10° to 35°, while the width of the land varies from 0,05-0,08 mm, and occasionally higher. The most common combination is 20° x 0,1-0,15 in. The width of the land varies somewhat with the feed rate of the operation and is usually wider as the feed increases. The angle of the land is subjective, but generally decreases if the width of the land is very high. Although this technique is very successful in protecting the cutting edge, it is not an exact science. As optimization efforts proceed in the field and the data base increases, a better definition of the exact T-land for a specific material/operation will ultimately emerge.

Inserts with ground T-lands can also have a subsequent honing operation which rounds the intersections of the land and the original faces of the insert. This added process eliminates any sharp intersections which may chip within the cutting zone.

2.5 Cermets

These tool materials derive their name from the use of ceramic materials with a metallic binder. Today's cermets are usually titanium carbide and titanium nitride with a binder material. They are an effective material for machining steels as they are both wear and crater resistant to the continuous chip formation of steels. Cermets are available in an assortment of insert shapes with chip control grooves and edge preparations. This tool material is capable of providing a performance equal to or greater than coated and uncoated carbides on steels in the soft to medium hardness range where other ceramics are usually ineffective.

The popularity or acceptance of cermets is not as widespread in the United States as their performance deserves. In Japan, cermets represent about 30% of tool sales, as compared to about 5% in the USA There are grades of cermets available which have adequate toughness for milling and interrupted cutting on steels up to approximately 40 Re hardness. Inserts are also available in positive rake geometry to minimize cutting forces and resultant part deflection.

2.6 Polycrystalline diamond

The hardest substances known are:

1) natural single crystal diamond,
2) polycrystalline diamond,
3) cubic boron nitride.

Polycrystalline tools are manufactured using extremely high temperatures and pressures [3], [1].

The random orientation of the PCD tools corrects one of the major deficiencies of the natural diamond, the possible presence of a cleavage plane within the single crystal. This plane creates a natural failure site and can weaken the tool with a disastrous effect on performance. Therefore, single crystal diamonds used as cutting tools must be correctly oriented by a diamond expert. Single crystal diamond is an excellent special purpose tool for creating super fine finishes on items such as optical components. Usually the diamond is bonded to a standard carbide insert as a single tip on the insert. The insert is then ground (and perhaps polished) to provide a very smooth finish on the diamond.

The PCD tool provides an excellent general purpose tool for machining nonferrous and nonmetallic, abrasive materials. The most common applications for PCD tools include copper and aluminum alloys machined at high cutting speeds. It is standard practice for aluminum automobile wheels. A deficiency of these inserts is the lack of chip control, a problem on soft materials like aluminum. Another common application for PCD tools is machining nonmetallics such as hard fiber reinforced plastics and materials such as granite and marble. Because PCD is much more abrasion resistant than carbide, it provides higher cutting speeds and/or longer tool life than carbides in the same machining operation [1].

PCD inserts cost 10-13 times more than carbide inserts and have only one cutting edge compared to the multiple wises on the carbides, this must be considered when deciding whether or not a PCD tool is cost effective. Often, there is no other choice for producing quality parts on a reasonable production schedule. PCD inserts are available in both positive and negative rake style. The diamond section can often be reground to extend the life of the insert and thus lower the cost per cutting edge.

2.7 Polycrystalline Cubic Boron Nitride

Cubic boron nitride tools are available in both tipped inserts (like PCD) and also in solid CBN inserts. The solid inserts cost about three times as much as the tipped insert, but offer multiple cutting edges and a much tougher cutting material. CBN inserts can be used successfully to turn nickel base alloys, but they have a difficult time competing with the cost of the whisker/alumina insert. A single tipped CBN insert can cost about 3 times as much as the whisker/alumina insert which can have 4-8 as many cutting edges. Therefore, CBN is generally not cost effective for production machining of nickel alloys.

A second application for CBN is machining hard ferrous alloys (65-68 HRC). Parts with this hardness are usually manufactured on a grinder rather than machined. However, the metal removal rate in machining nary be 10 times as great as the removal rate in grinding. Once again CBN must compete with lower priced ceramics on steels in the 55-63 Re range. The alumina/TiC ceramic is about l0% the price of a single tipped CBN insert and can have 4-8 cutting edges. It is wise to consider the entire economic picture of any machining operation in order to justify high performance high price cutting tool materials such as CBN [1].

3 CONCLUSION

The choice of the cutting material should always be made with as complete an economics analysis as the situation permits. This analysis should be made after the built-in constraints of machine tool capability (power and speed), production schedules and most importantly part quality are considered. Selecting a specific tool material on the basis of longer tool life when more than type will provide a satisfactory product is a safe choice when the tool-change time is long and tool life is short [5]. Fewer tool changes reduce non-productive down time. If tool-change time is very short, the selection should be a tool that will increase productivity, reduce cycle time and ultimately lower labor machine burden on the cost per part.

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