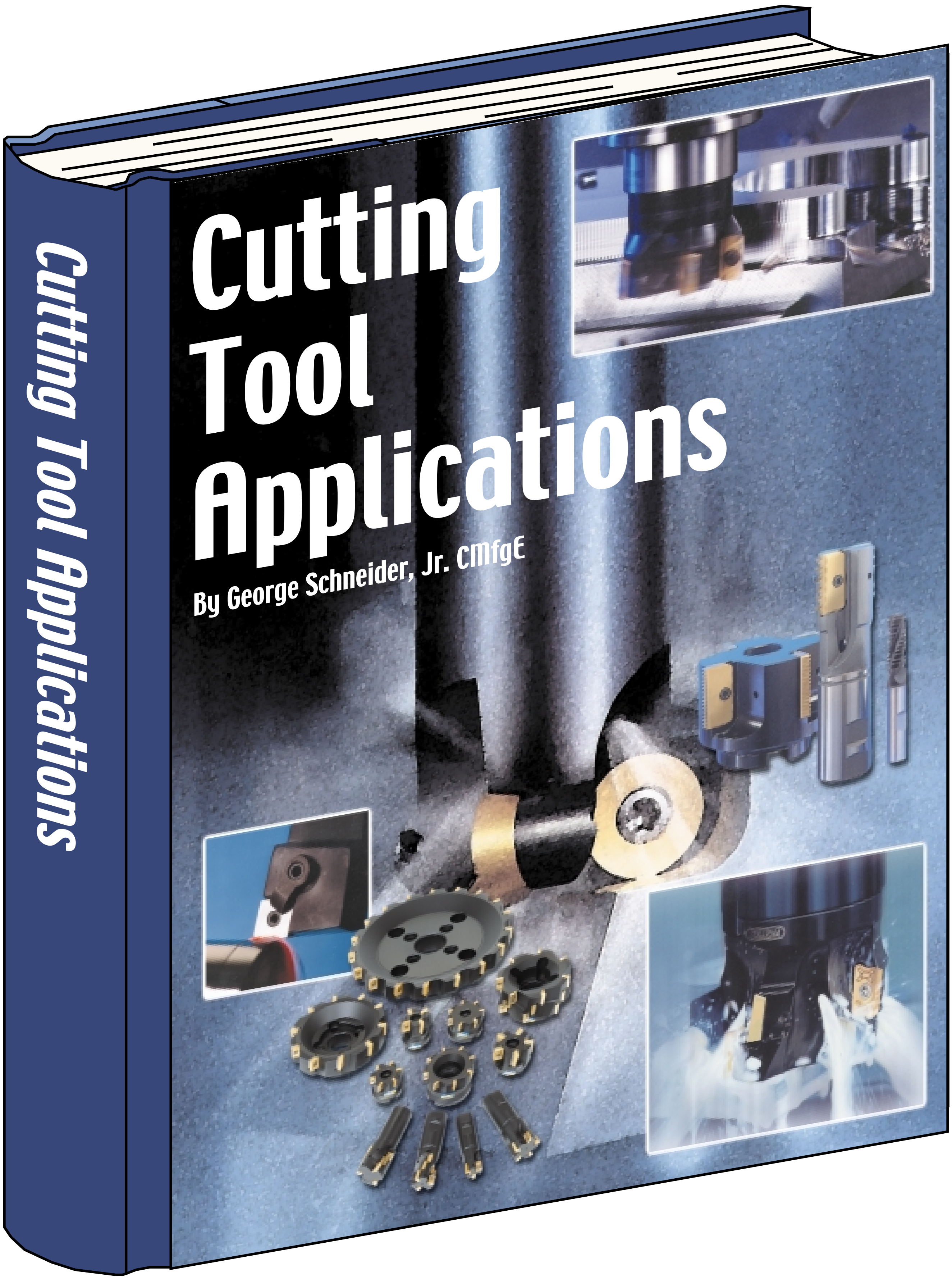
Cutting Tool Applications
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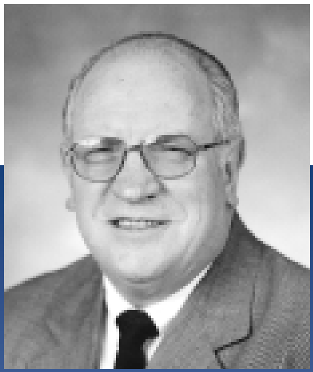
By George Schneider, Jr. CMfgE



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Chapter 1 Cutting-Tool Materials

1.1 Introduction

Many types of tool materials, ranging from high carbon steel to ceramics and diamonds, are used as cutting tools in today's metalworking industry. It is important to be aware that differences do exist among tool materials, what these differences are, and the correct application for each type of material.

The various tool manufacturers assign many names and numbers to their products. While many of these names and numbers may appear to be similar, the applications of these tool materials may be entirely different. In most cases the tool manufacturers will provide tools made of the proper material for each given application. In some particular applications, a premium or higher priced material will be justified.

This does not mean that the most expensive tool is always the best tool. Cutting tool users cannot afford to ignore the constant changes and advancements that are being made in the field of tool material technology. When a tool change is needed or anticipated, a performance comparison should be made before selecting the tool for the job. The optimum tool is not necessarily the least expensive or the most expensive, and it is not always the same tool that was used for the job last time. The best tool is the one that has been carefully chosen to get the job done quickly, efficiently and economically.

Author's Note

I wish to express my sincere appreciation to Prentice Hall and to Stephen Helba in particular, for giving me permission to use some of the information, graphs and photos recently published in Applied Manufacturing Process Planning *authored by Donald H. Nelson and George Schneider, Jr.*

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George Schneider, Jr.

A cutting tool must have the following characteristics in order to produce good quality and economical parts:

Hardness: Hardness and strength of the cutting tool must be maintained at elevated temperatures also called Hot Hardness

Toughness: Toughness of cutting tools is needed so that tools don't chip or fracture, especially during interrupted cutting operations.

Wear Resistance: Wear resistance means the attainment of acceptable tool life before tools need to be replaced.

The materials from which cutting tools are made are all characteristically hard and strong. There is a wide range of tool materials available for machining operations, and the general classification and use of these materials are of interest here.

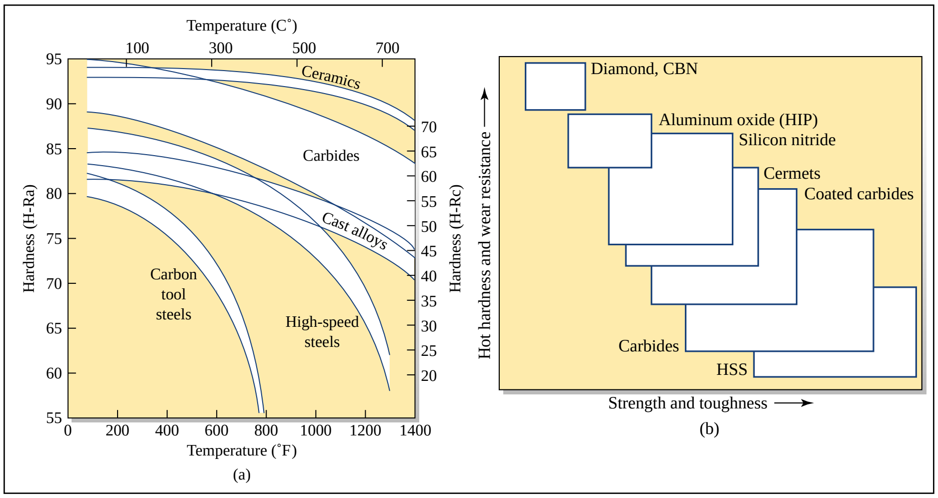

Figure 1.1. *(a) Hardness of various cutting-tool materials as a function of temperature. (b) Ranges of properties of various groups of materials.*

1.2 Tool Steels and Cast Alloys

Plain carbon tool steel is the oldest of the tool materials dating back hundreds of years. In simple terms it is a high carbon steel (steel which contains about 1.05% carbon). This high carbon content allows the steel to be hardened, offering greater resistance to abrasive wear. Plain high carbon steel served its purpose well for many years. However, because it is quickly over tempered (softened) at relatively low cutting temperatures, (300 to 500 degrees F), it is now rarely used as cutting tool material except in files, saw blades, chisels, etc. The use of plain high carbon steel is limited to low heat applications.

High Speed Tool Steel: The need for tool materials which could withstand increased cutting speeds and temperatures, led to the development of high speed tool steels (HSS). The major difference between high speed tool steel and plain high carbon steel is the addition of alloying elements to harden and strengthen the steel and make it more resistant to heat (hot hardness).

Some of the most commonly used alloying elements are: manganese, chromium, tungsten, vanadium, molybdenum, cobalt, and niobium (columbium). While each of these elements will add certain specific desirable characteristics, it can be generally stated that they add deep hardening capability, high hot hardness, resistance to abrasive wear, and strength, to high speed tool steel. These characteristics allow relatively higher machining speeds and improved performance over plain high carbon steel.

The most common high speed steels used primarily as cutting tools are divided into the M and T series. The M series represents tool steels of the molybdenum type and the T series represents those of the tungsten type. Although there seems to be a great deal of similarity among these high speed steels, each one serves a specific purpose and offers significant benefits in its special application.

An important point to remember is that none of the alloying elements for either series of high speed tool steels is in abundant supply and the cost of these elements is skyrocketing. In addition, U.S. manufacturers must rely on foreign countries for supply of these very important elements.

Some of the high speed steels are now available in a powdered metal (PM) form. The difference between powdered and conventional metals is in the method by which they are made. The majority of conventional high speed steel is poured into an ingot and then, either hot or cold, worked to the desired shape. Powdered metal is exactly as its name indicates. Basically the same elements that are used in conventional high speed steel are prepared in a very fine powdered form. These powdered elements are carefully blended together, pressed into a die under extremely high pressure, and then sintered in an atmospherically controlled furnace. The PM method of manufacturing cutting tools is explained in Section 1.3.1 Manufacture of Carbide Products.

HSS Surface Treatment: Many surface treatments have been developed in an attempt to extend tool life, reduce power consumption, and to control other factors which affect operating conditions and costs. Some of these treatments have been used for many years and have proven to have some value. For example, the black oxide coatings which commonly appear on drills and taps are of value as a deterrent to build-up on the tool. The black oxide is basically a 'dirty' surface which discourages the build-up of work material.

One of the more recent developments in coatings for high speed steel is titanium nitride by the physical vapor deposition (PVD) method. Titanium nitride is deposited on the tool surface in one of several different types of furnace at relatively low temperature, which does not significantly affect the heat treatment (hardness) of the tool being coated. This coating is known to extend the life of a cutting tool significantly or to allow the tool to be used at higher operating speeds. Tool life can be extended by as much as three times, or operating speeds can be increased up to fifty percent.

Cast Alloys: The alloying elements in high speed steel, principally cobalt, chromium and tungsten, improve the cutting properties sufficiently, that metallurgical researchers developed the cast alloys, a family of these materials without iron.

A typical composition for this class of tool material was 45 percent cobalt, 32 percent chromium, 21 percent tungsten, and 2 percent carbon. The purpose of such alloying was to obtain a cutting tool with hot hardness superior to high speed steel.

When applying cast alloy tools, their brittleness should be kept in mind and sufficient support should be provided at all times. Cast alloys provide high abrasion resistance and are thus useful for cutting scaly materials or those with hard inclusions.

1.3 Cemented Tungsten Carbide

Tungsten carbide was discovered by Henri Moissan in 1893 during a search for a method of making artificial diamonds. Charging sugar and tungsten oxide, he melted tungsten sub-carbide in an arc furnace. The carbonized sugar reduced the oxide and carburized the tungsten. Moissan recorded that the tungsten carbide was extremely hard, approaching the hardness of diamond and exceeding that of sapphire. It was more than 16 times as heavy as water. The material proved to be extremely brittle and seriously limited its industrial use.

Commercial tungsten carbide with 6 percent cobalt binder was first produced and marketed in Germany in 1926. Production of the same carbide began in the United States in 1928 and in Canada in 1930.

At this time, hard carbides consisted of the basic tungsten carbide system with cobalt binders. These carbides exhibited superior performance in the machining of cast iron, nonferrous, and non metallic materials, but were disappointing when used for the machining of steel.

Most of the subsequent developments in the hard carbides have been modifications of the original patents, principally involving replacement of part or all of the tungsten carbide with other carbides, especially titanium carbide and/or tantalum carbide. This led to the development of the modern multi-carbide cutting tool materials permitting the high speed machining of steel.

Figure 1.2. *Carbide blending equipment, better known as ball mill is used to ensure optimum dispersion of the carbon within the tungsten. (Courtesy American National Carbide Co)*

A new phenomenon was introduced with the development of the cemented carbides, again making higher speeds possible. Previous cutting tool materials, products of molten metallurgy, depended largely upon heat treatment for their properties and these properties could, in turn, be destroyed by further heat treatment. At high speeds, and consequently high temperatures, these products of molten metallurgy failed.

A different set of conditions exists with the cemented carbides. The hardness of the carbide is greater than that of most other tool materials at room temperature and it has the ability to retain it hardness at elevated temperatures to a greater degree, so that greater speeds can be adequately supported.

1.3.1 Manufacture of Carbide Products

The term “tungsten carbide” describes a comprehensive family of hard carbide compositions used for metal cutting tools, dies of various types, and wear parts. In general, these materials are composed of the carbides of tungsten, titanium, tantalum or some combination of these, sintered or cemented in a matrix binder, usually cobalt.

Blending: The first operation after reduction of the tungsten compounds to tungsten metal powder is the milling of tungsten and carbon prior to the carburizing operation. Here, 94 parts by weight of tungsten and 6 parts by weight of carbon, usually added in the form of lamp black, are blended together in a rotating mixer or ball mill. This operation must be performed under carefully controlled conditions in order to insure optimum dispersion of the carbon in the tungsten. Carbide Blending Equipment, better known as a Ball Mill, is shown in Figure 1.2.

In order to provide the necessary strength, a binding agent, usually cobalt (Co) is added to the tungsten (WC) in powder form and these two are ball milled together for a period of several days, to form a very intimate mixture. Careful control of conditions, including time, must be exercised to obtain a uniform, homogeneous product. Blended Tungsten Carbide Powder is shown in Figure 1.3.

Figure 1.3. *Blended tungsten carbide powder is produced by mixing tungsten carbide (WC) with a cobalt (Co) binder in a ball milling process. (Courtesy American National Carbide Co)*

Compacting: The most common compacting method for grade powders involves the use of a die, made to the shape of the eventual product desired. The size of the die must be greater than the final product size to allow for dimensional shrinkage which takes place in the final sintering operation. These dies are expensive, and usually made with tungsten carbide liners. Therefore sufficient number of the final product (compacts) are required, to justify the expense involved in manufacturing a special die. Carbide

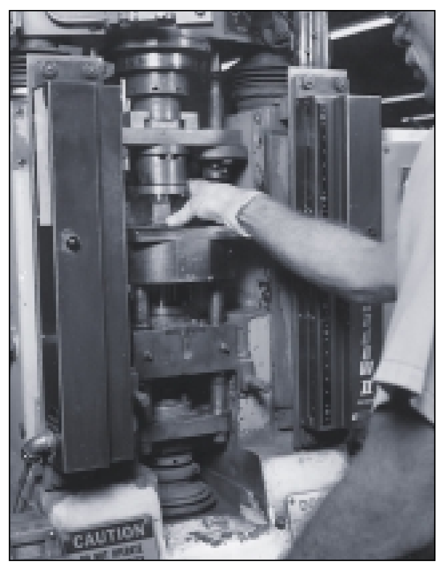

Figure 1.4. *Carbide compacting equipment, better known as a pill press, is used to produce carbide products in various shapes. (Courtesy American National Carbide Co)*

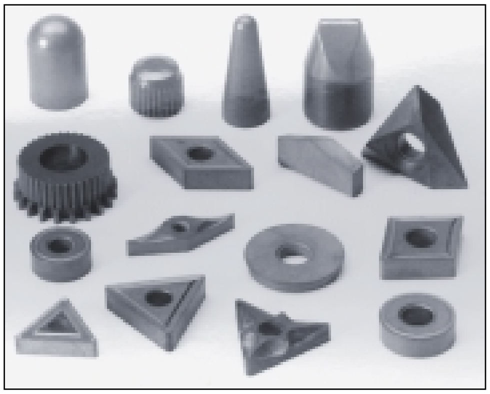

Figure 1.5. *Various carbide compacts, which are produced with special dies mounted into pill presses. (Courtesy American National Carbide Co)*

Compacting Equipment, better known as a Pill Press, is shown in Figure 1.4. Various pill pressed carbide parts are shown in Figure 1.5.

If the quantities are not high, a larger briquette, or billet may be pressed. This billet may then be cut up (usually after pre-sintering) into smaller units and shaped or preformed to the required configuration, and again, allowance must be made to provide for shrinkage. Ordinarily pressures used in these cold compacting operations are in the neighborhood of 30,000 PSI. Various carbide preformed parts are shown in Figure 1.6.

A second compacting method is the hot pressing of grade powders in graphite dies at the sintering temperature. After cooling, the part has attained full hardness. Because the graphite dies are expendable, this system is generally used only when the part to be produced is too large for cold pressing and sintering.

A third compacting method, usually used for large pieces, is isostatic pressing. Powders are placed into a closed, flexible container which is then suspended in a liquid in a closed pressure vessel. Pressure in the liquid is built up to the point where the powders become properly compacted. This system is advantageous for pressing large pieces, because the pressure acting on the powders operates equally from all directions, resulting in a compact of uniform pressed density.

Sintering: Sintering of tungsten - cobalt (WC-Co) compacts is performed with the cobalt binder in liquid phase. The compact is heated in hydrogen atmosphere or vacuum furnaces to temperatures ranging from 2500 to 2900 degrees Fahrenheit, depending on the composition. Both time and temperature must be carefully adjusted in combination, to effect optimum control over properties and geometry. The compact will shrink approximately 16 percent on linear dimensions, or 40 percent in volume. The exact amount of shrinkage depends on several factors including particle size of the powders and the composition of the grade. Control of size and shape is most important and is least predictable during the cooling cycle. This is particularly true with those grades of cemented carbides with higher cobalt contents.

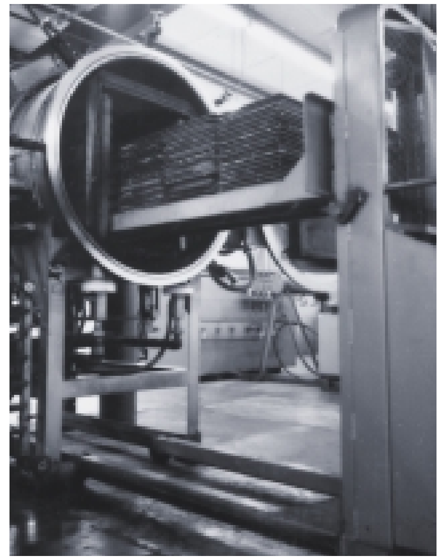

Figure 1.7. *Carbide parts are loaded into a sintering furnace, where they are heated to temperatures ranging from 2500° to 2900°F. (Courtesy American National Carbide Co)*

With cobalt having a lesser density than tungsten, it occupies a greater part of the volume than would be indicated by the rated cobalt content of the grade; and because cobalt contents are generally a much higher percentage of the mass in liquid phase, extreme care is required to control and predict with accuracy the magnitude and direction of shrinkage. Figure 1.7 shows carbide parts being loaded into a Sintering Furnace.

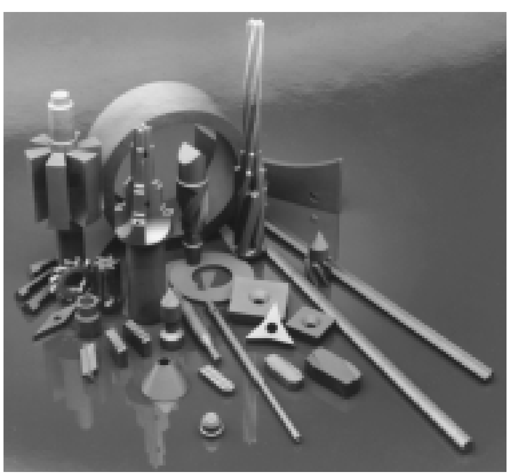

Figure 1.6. *If quantities are not high, presintered billets are shaped or preformed into required shapes. (Courtesy Duramet Corporation)*

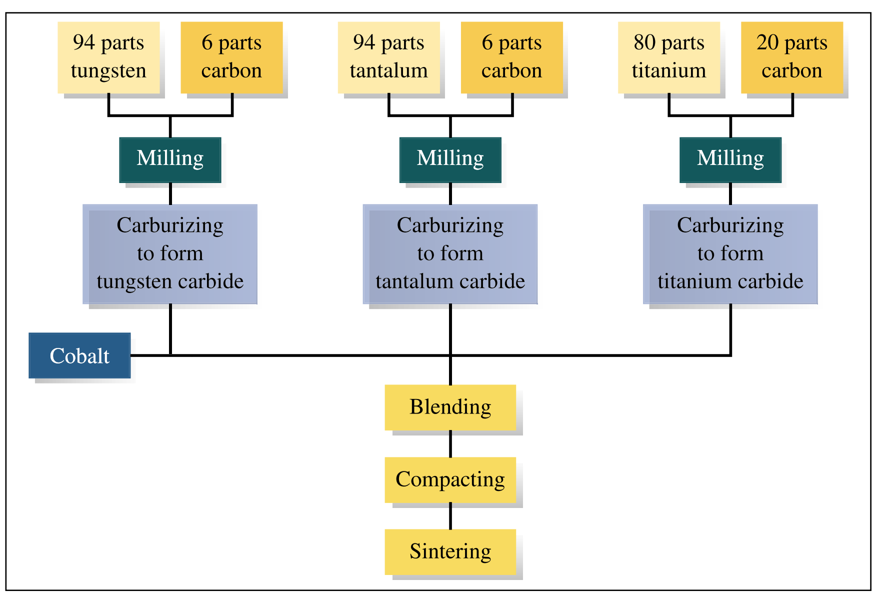

Figure 1.8. *Schematic diagram of the cemented tungsten carbide manufacturing process.*

A more detailed schematic diagram of the cemented tungsten carbide manufacturing process is shown in Figure 1.8.

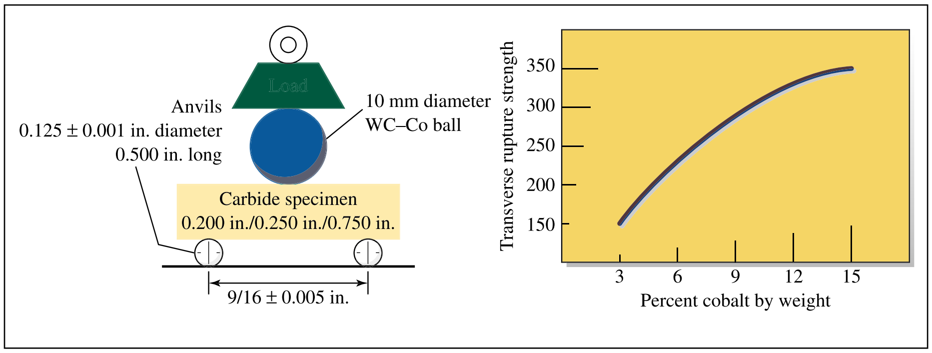

Figure 1.9. *The method used to measure Transverse Rupture Strength (TRS) is shown as well as the relationship of TRS to cobalt (Co) content.*

1.3.2 Classification of Carbide Tools

Cemented carbide products are classified into three major grades:

Wear Grades: Used primarily in dies, machine and tool guides, and in such everyday items as the line guides on fishing rods and reels; anywhere good wear resistance is required.

Impact Grades: Also used for dies, particularly for stamping and forming, and in tools such as mining drill heads.

Cutting Tool Grades: The cutting tool grades of cemented carbides are divided into two groups depending on their primary application. If the carbide is intended for use on cast iron which is a nonductile material, it is graded as a cast iron carbide. If it is to be used to cut steel, a ductile material, it is graded as a steel grade carbide.

Cast iron carbides must be more resistant to abrasive wear. Steel carbides require more resistance to cratering and heat. The tool wear characteristics of various metals are different, thereby requiring different tool properties. The high abrasiveness of cast iron causes mainly edge wear to the tool. The long chip of steel, which flows across the tool at normally higher cutting speeds, causes mainly cratering and heat deformation to the tool. Tool wear characteristics and chip formation will be discussed in Chapter 2.

It is important to choose and use the correct carbide grade for each job application. There are several factors that make one carbide grade different from another and therefore more suitable for a specific application. The carbide grades may appear to be similar, but the difference between the right and wrong carbide for the job, can mean the difference between success and failure.

Figure 1.8 illustrates how carbide is manufactured, using pure tungsten carbide with a cobalt binder. The pure tungsten carbide makes up the basic carbide tool and is often used as such, particularly when machining cast iron. This is because pure tungsten carbide is extremely hard and offers the best resistance to abrasive wear.

Large amounts of tungsten carbide are present in all of the grades in the two cutting groups and cobalt is always used as the binder. The more common alloying additions to the basic tungsten/cobalt material are: tantalum carbide, and titanium carbide.

While some of these alloys may be present in cast iron grades of cutting tools, they are primarily added to steel grades. Pure tungsten carbide is the most abrasive-resistant and will work most effectively with the abrasive nature of cast iron. The addition of the alloying materials such as tantalum carbide and titanium carbide offers many benefits:

- The most significant benefit of titanium carbide is that it reduces cratering of the tool by reducing the tendency of the long steel chips to erode the surface of the tool.
- The most significant contribution of tantalum carbide is that it increases the hot hardness of the tool which, in turn, reduces thermal deformation.

Varying the amount of cobalt binder in the tool material largely affects both the cast iron and steel grades in three ways. Cobalt is far more sensitive to heat than the carbide around it. Cobalt is also more sensitive to abrasion and chip welding. Therefore, the more cobalt present, the softer the tool is, making it more sensitive to heat deformation, abrasive wear, and chip welding and leaching which causes cratering. On the other hand, cobalt is stronger than carbide. Therefore more cobalt improves the tool strength and resistance to shock. The strength of a carbide tool is expressed in terms of 'Transverse Rupture Strength' (TRS). Figure 1.9 shows how Transverse Rupture Strength is measured.

The third difference between the cast iron and steel grade cutting tools, is carbide grain size. The carbide grain size is controlled by the ball mill process. There are some exceptions, such as micro-grain carbides, but generally the smaller the carbide grains, the harder the tool. Conversely, the larger the carbide grain, the stronger the tool. Carbide grain sizes at 1500x magnification are shown in Exhibits 1.10 and 1.11.

In the C- classification method (Figure 1.12), grades C-1 through C-4 are for cast iron and grades C-5 through C-8 for steel. The higher the C- number in each group, the harder the grade, the lower the C- number, the stronger the grade. The harder grades are used for finish cut applications; the stronger grades are used for rough cut applications.

Many manufacturers produce and

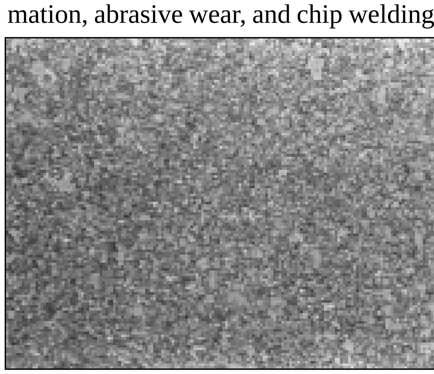

Figure 1.10. *Carbide grain size (0.8 micron WC @ 1500×) consisting of 90% WC and 10% Co.*

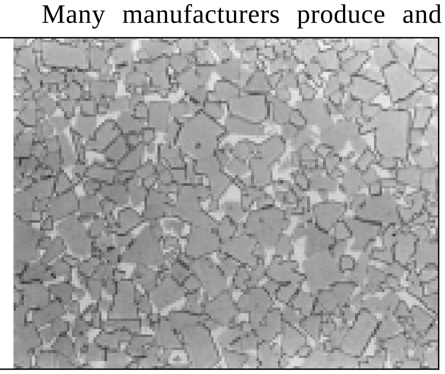

Figure 1.11. *Carbide grain size (7 microns WC @ 1500×) consisting of 90% WC and 10% Co.*

Classification Number	Materials to be Machined	Machining Operation	Type of Carbide	Characteristics Of: Cut	Characteristics Of: Carbide	Typical Properties: Hardness H-Ra	Typical Properties: Transverse Rupture Strength (MPa)
C-1	Cast iron, nonferrous metals, and nonmetallic materials requiring abrasion resistance	Roughing cuts	Wear-resistant grades; generally straight WC–Co with varying grain sizes	Increasing cutting speed	Increasing hardness and wear resistance	89.0	2,400
C-2		General purpose				92.0	1,725
C-3		Finishing				92.5	1,400
C-4		Precision boring and fine finishing		Increasing feed rate	Increasing strength and binder content	93.5	1,200
C-5	Steels and steel-alloys requiring crater and deformation resistance	Roughing cuts	Crater-resistant grades; various WWC–Co compositions with TIC and/or TaC alloys	Increasing cutting speed	Increasing hardness and wear resistance	91.0	2,070
C-6		General purpose				92.0	1,725
C-7		Finishing				93.0	1,380
C-8		Precision boring and fine finishing		Increasing feed rate	Increasing strength and binder content	94.0	1,035

Figure 1.12. *Classification, application, characteristics, and typical properties of metal-cutting carbide grades.*

distribute charts showing a comparison of their carbide grades with those of other manufacturers. These are not equivalency charts, even though they may imply that one manufacturer's carbide is equivalent to that of another manufacturer. Each manufacturer knows his carbide best and only the manufacturer of that specific carbide can accurately place that carbide on the C- chart. Many manufacturers, especially those outside the U. S., do not use the C- classification system for carbides. The placement of these carbides on a C- chart by a competing company is based upon similarity of application and is, at best an 'educated guess'. Tests have shown a marked difference in performance among carbide grades that manufacturers using the C- classification system have listed in the same category.

1.3.3 Coated Carbide Tools

While coated carbides have been in existence since the late 1960's, they did not reach their full potential until the mid 1970's. The first coated carbides were nothing more than standard carbide grades which were subjected to a coating process. As the manufacturers gained experience in producing coated carbides, they began to realize that the coating was only as good as the base carbide under the coating (known as the substrate).

It is advisable to consider coated carbides for most applications. When the proper coated carbide, with the right edge preparation is used in the right application, it will generally outperform any uncoated grade. The microstructure of a coated carbide insert at 1500x magnification is shown in Figure 1.13.

Numerous types of coating materials are used, each for a specific application. It is important to observe the do's and dont's in the application of coated carbides. The most common coating materials are:

- Titanium Carbide
- Titanium Nitride
- Ceramic Coating
- Diamond Coating
- Titanium Carbo-Nitride

In addition, multi-layered combinations of these coating materials are used. The microstructure of a multi-layered coated carbide insert at 1500x magnification is shown in Figure 1.14.

In general the coating process is accomplished by chemical vapor deposition (CVD). The substrate is placed in an environmentally controlled chamber having an elevated temperature. The coating material is then introduced into the chamber as a chemical vapor. The coating material is drawn to and deposited on the substrate by a magnetic field around the substrate. It takes many hours in the chamber to achieve a coating of 0.0002 to 0.0003 inch on the substrate. Another process is Physical Vapor Deposition (PVD).

Titanium Carbide Coating: Of all the coatings, titanium carbide is the most widely used. Titanium carbide is used on many different substrate materials for cutting various materials under varying conditions. Titanium carbide coatings allow the use of higher cutting speeds because of their greater resistance to abrasive wear and cratering and higher heat resistance.

Titanium Nitride Coating - Gold Color: Titanium nitride is used on many different substrate materials. The primary advantage of titanium nitride is its resistance to cratering. Titanium nitride also offers some increased abrasive wear resistance and a significant increase in heat resistance permitting higher cutting speeds. It is also said that titanium nitride is more slippery, allowing chips to pass over it, at the cutting interface, with less friction.

Ceramic Coating - Black Color: Because aluminum oxide (ceramic) is extremely hard and brittle, it is not opti-

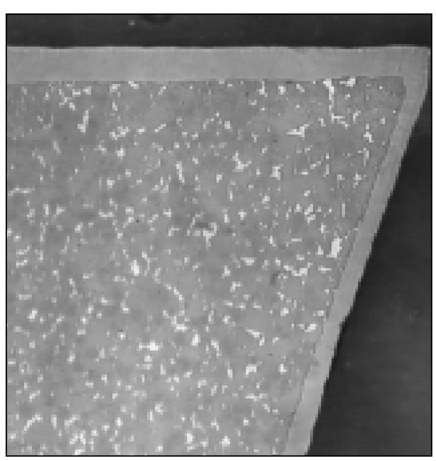

Figure 1.13. *Microstructure of a coated carbide insert at 1500× magnification. (Courtesy of Kennamental Inc.)*

Figure 1.14. *Microstructure of a multilayered coated carbide insert at 1500× magnification. (Courtesy of Kennamental Inc.)*

mal for interrupted cuts, scaly cuts, and hard spots in the workpiece. This is not to say that it will never work under these conditions, but it may be more subject to failure by chipping. Even with these limitations, aluminum oxide is probably the greatest contributor to the coated carbides. Aluminum oxide ceramic allows much higher cutting speeds than other coated carbides because of its outstanding resistance to abrasive wear and its resistance to heat and chemical interaction.

Diamond Coating: A recent development concerns the use of diamond polycrystalline as coating for tungsten carbide cutting tools. Problems exist regarding adherence of the diamond film to the substrate and the difference in thermal expansion between diamond and substrate materials. Thin-film diamond coated inserts are now available using either PVD (Physical Vapor Deposition) or CVD (Chemical Vapor Deposition) coating methods. Diamond coated tools are effective in machining abrasive materials, such as aluminum alloys containing silicon, fiber reinforced materials, and graphite. Improvements in tool life of as much as tenfold have been obtained over other coated tools.

Titanium Carbo-Nitride - Black Color Multilayered Coatings: Titanium carbo-nitride normally appears as the intermediate layer of two or three phase coatings. The role of titanium carbo-nitride is one of neutrality, helping the other coating layers to bond into a sandwich-like structure (Figure 1-14). Other multi-layer coating combinations are being developed to effectively machine stainless steels and aerospace alloys. Chromium-based coatings such as chromium carbide have been found to be effective in machining softer metals such as aluminum, copper, and titanium.

There are a few important points to remember about using coated carbides. Coated carbides will not always out-perform uncoated grades but because of the benefits offered by coated carbides, they should always be a first consideration when selecting cutting tools.

When comparing the cost between coated and uncoated carbides there will be little difference when the benefits of coated carbides are considered. Because coated carbides are more resistant to abrasive wear, cratering, and heat, and because they are more resistant to work material build-up at lower cutting speeds, tool life is extended, reducing tool replacement costs. Coated carbides permit operation at higher speeds, reducing production costs.

All coated carbides have an edge hone to prevent coating build-up during the coating process. This is because the coating will generally seek sharp edges. The edge hone is usually very slight and actually extends tool life. However, a coated insert should never be reground or honed. If a special edge preparation is required the coated carbides must be ordered that way. The only time the edge hone may be of any disadvantage is when making a very light finishing cut. Carbide insert edge preparations will be discussed in Chapter 2.

1.4 Ceramic and Cermet Tools

Ceramic Aluminum Oxide (Al_2O_3) material for cutting tools was first developed in Germany sometime around 1940. While ceramics were slow to develop as tool materials, advancements made since the mid 1970's have greatly improved their usefulness. Cermets are basically a combination of ceramic and titanium carbide. The word cermet is derived from the words 'ceramic' and 'metal'.

Ceramic Cutting Tools: Ceramics are non-metallic materials. This puts them in an entirely different category than HSS and carbide tool materials. The use of ceramics as cutting tool material has distinct advantages and disadvantages. The application of ceramic cutting tools is limited because of their extreme brittleness. The transverse rupture strength (TRS) is very low. This means that they will fracture more easily when making heavy or interrupted cuts. However, the strength of ceramics under compression is much higher than HSS and carbide tools.

There are two basic types of ceramic material; hot pressed and cold pressed. In hot pressed ceramics, usually black or gray in color, the aluminum oxide grains are pressed together under extremely high pressure and at a very high temperature to form a billet. The billet is then cut to insert size. With cold pressed ceramics, usually white in color, the aluminum oxide grains are pressed together, again under extremely high pressure but at a lower temperature. The billets are then sintered to achieve bonding. This procedure is similar to carbide manufacture, except no metallic binder material is used. While both hot and cold pressed ceramics are similar in hardness, the cold pressed ceramic is slightly harder. The hot pressed ceramic has greater transverse rupture strength. Various shapes of both hot and cold pressed ceramic inserts are shown in Figure 1.15.

The brittleness, or relative strength, of ceramic materials is their greatest disadvantage when they are compared to HSS or carbide tools. Proper tool geometry and edge preparation play an important role in the application of ceramic tools and help to overcome their weakness. Some of the advantages of ceramic tools are:

- High strength for light cuts on very hard work materials.
- Extremely high resistance to abrasive wear and cratering.
- Capability of running at speeds in excess of 2000 SFPM.
- Extremely high hot hardness.
- Low thermal conductivity.

While ceramics may not be the all-around tool for the average shop, they can be useful in certain applications. Ceramic tools have been alloyed with zirconium (about 15%) to increase their strength.

Figure 1.15. *Various sizes and shapes of hot- and cold-pressed ceramic inserts. (Courtesy Greenleaf Corp.)*

Many ceramic tool manufacturers are recommending the use of ceramic tools for both rough cutting and finishing operations. Practical shop experience indicates that these recommendations are somewhat optimistic. To use ceramic tools successfully, insert shape, work material condition, machine tool capability, set-up, and general machining conditions must all be correct. High rigidity of the machine tool and set-up is also important for the application of ceramic tools. Ceramics are being developed to have greater strength (higher TRS). Some manufacturers are offering ceramic inserts with positive geometry and even formed chip breaker grooves.

Cermet Cutting Tools: The manufacturing process for cermets is similar to the process used for hot pressed ceramics. The materials, approximately 70 percent ceramic and 30 percent titanium carbide, are pressed into billets under extremely high pressure and temperature. After sintering, the billets are sliced to the desired tool shapes. Subsequent grinding operations for final size and edge preparation, complete the manufacturing process.

The strength of cermets is greater than that of hot pressed ceramics. Therefore, cermets perform better on interrupted cuts. However, when compared to solid ceramics, the presence of the 30 percent titanium carbide in cermets decreases the hot hardness and resistance to abrasive wear. The hot hardness and resistance to abrasive wear of cermets are high when compared to HSS and carbide tools. The greater strength of cermets allows them to be available in a significantly larger selection of geometries, and to be used in standard insert holders for a greater variety of applications. The geometries include many positive/negative, and chip breaker configurations.

Silicon-Nitride Base Ceramics: Developed in the 1970's, silicon-nitride (SIN) base ceramic tool materials consist of silicon nitride with various additions of aluminum oxide, yttrium oxide, and titanium carbide. These tools have high toughness, hot hardness and good thermal shock resistance. Sialon for example is recommended for machining cast irons and nickel base superalloys at intermediate cutting speeds.

1.5 Diamond, CBN and Whisker-Reinforced Tools

The materials described here are not commonly found in a heavy metal working environment. They are most commonly used in high speed automatic production systems for light finishing of precision surfaces. To complete the inventory of tool materials, it is important to note the characteristics and general applications of these specialty materials.

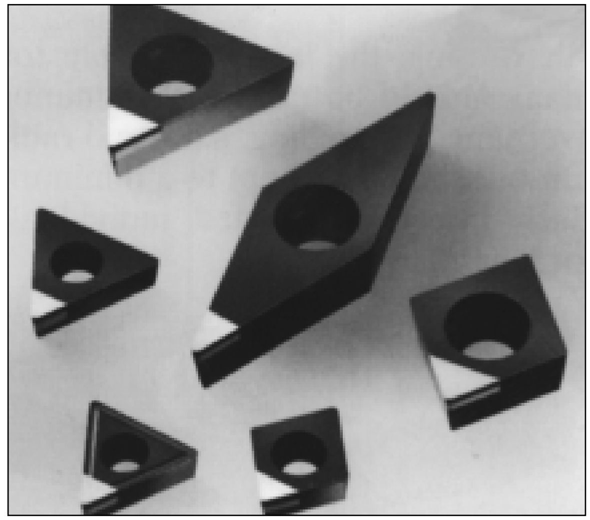

Figure 1.16. *Polycrystalline diamond material bonded to a carbide base of various sizes and shapes. (Courtesy of Sandvik Coromant Co.)*

Diamond: The two types of diamonds being used as cutting tools are industrial grade natural diamonds, and synthetic polycrystalline diamonds. Because diamonds are pure carbon, they have an affinity for the carbon of ferrous metals. Therefore, they can only be used on non-ferrous metals.

Some diamond cutting tools are made of a diamond crystal compaction (many small crystals pressed together) bonded to a carbide base (Fig. 1.16). These diamond cutting tools should only be used for light finishing cuts of precision surfaces. Feeds should be very light and speeds are usually in excess of 5000 surface feet per minute (SFPM). Rigidity in the machine tool and the set-up is very critical because of the extreme hardness and brittleness of diamond.

Cubic Boron Nitride: Cubic boron nitride (CBN) is similar to diamond in its polycrystalline structure and is also bonded to a carbide base. With the exception of titanium, or titanium alloyed materials, CBN will work effectively as a cutting tool on most common work materials. However, the use of CBN should be reserved for very hard and difficult-to-machine materials. CBN will run at lower speeds, around 600 SFPM, and will take heavier cuts with higher lead angles than diamond. Still, CBN should mainly be considered as a finishing tool material because of its extreme hardness and brittleness. Machine tool and set-up rigidity for CBN as with diamond, is critical.

Whisker-Reinforced Materials: In order to further improve the performance and wear resistance of cutting tools to machine new work materials and composites, whisker-reinforced composite cutting tool materials have been developed. Whisker-reinforced materials include silicon-nitride base tools and aluminum-oxide base tools, reinforced with silicon-carbide (SiC) whiskers. Such tools are effective in machining composites and nonferrous materials, but are not suitable for machining irons and steels.