Chapter I - Background

What is cemented carbide?

Tungsten carbide (WC), also referred to as cemented carbide, is a composite material manufactured by a process called powder metallurgy. Tungsten carbide powder, generally ranging in proportion between 70%-97% of the total weight, is mixed with a binder metal, usually cobalt or nickel, compacted in a die and then sintered in a furnace. The term "cemented" refers to the tungsten carbide particles being captured in the metallic binder material and " cemented" together, forming a metallurgical bond between the tungsten carbide particles and the binder (WC - Co), in the sintering process. The cemented carbide industry commonly refers to this material as simply "carbide", although the terms tungsten carbide and cemented carbide are used interchangeably.

If the permanent deformation of a material at failure is quite small, the material is labeled brittle; if the plastic deformation is very large, the material is called ductile. Carbide is classified technically as a "brittle" material since it exhibits little or no plastic deformation preceding the initiation of a crack and total failure. Without the presence of the metallic binder phase, tungsten carbide could be considered a ceramic material much the same as silicon carbide or aluminum oxide. The definition of a ceramic material is the marriage of a metal to a nonmetal, for example silicon (metal) carbide (carbon, nonmetal), aluminum (metal) oxide (oxygen, non-metal), or silicon nitride. A cermet is a composite material composed of ceramic (cer) and metallic (met) materials. It is the addition of the metallic binder, i.e. cobalt or nickel that makes the cemented carbide (WC- Co) a cermet and differentiates it from truly brittle materials, that is, the ceramic family of materials.

Cemented carbide is the preferred material for parts that must withstand all forms of wear (including sliding abrasion, erosion, corrosion/wear and metal-to-metal galling) and exhibit a high degree of toughness. It exhibits high compressive strength, resists deflection, and retains its hardness values at high temperatures, a physical property especially useful in metal-cutting applications. It provides long life in applications where other materials would not last or would fail prematurely.

The history of cemented carbide

Since the late 1800's when a French chemist, Henri Moissan, first synthesized it, tungsten carbide has been known as one of the hardest substances in existence, approaching diamond in this respect. In fact, he was seeking to produce man-made diamonds, but WC was the result. Since large solid pieces could not be produced, cast compositions containing tungsten carbide were tried, but were too brittle and porous for use as an engineered material.

Search for a substitute to replace the diamond dies employed in drawing tungsten wire for electric-lamp filaments led the Osram Lamp Works of Berlin to an interesting discovery. Karl Schroeter and Heinrich Baumhauer found that hard carbide, bonded or sintered together with a metal such as cobalt, was not only hard but acquired enough toughness to suggest its use as a cutting tool. The substance discovered by the Osram Company was known as Hartmetall and pointed the way to the development of the modern sintered carbides. Friedrich Krupp, A. G. Essen, acquired the original patent rights and undertook an extensive program culminating in the production of Widia (Wie Diamant, like a diamond), which consisted mainly of tungsten carbide particles thoroughly interspersed in a cobalt matrix which constituted from 5 to 15% of the total composition.

In negotiations with Krupp, all American rights accrued to General Electric, with Krupp retaining the right to export Widia to the United States. General Electric formed the Carboloy Company, which sublicensed Firth-Sterling Steel Company and the Ludlum Steel Company. At that time the American equivalents of Widia were known as Carboloy, Dimondite, and Strass Metal. Later, the trade name Dimondite was changed to Firthite. American patent applications were made as early as 1922, but it was not until 1926, after thorough production tests in the Essen workshops, that Krupp marketed Widia tungsten carbide commercially for the first time in Germany. Tungsten carbide was expensive, costing about $450 per pound, but even at that price its use could be justified economically. The practice of making only the tool tip out of cemented carbide was dictated as much by the cost of the material as it was by any other single consideration. Carboloy tools were tested in General Electric plants and came to public attention around 1928.

Following the introduction of Widia and its counterparts, Dr. Balke developed a tantalum carbide bonded together with metallic nickel. This material, called Ramet, resisted "cratering" and proved more successful in machining steel than did tungsten carbide, which exhibited a tendency toward early cavitation near the cutting edge, where steel chips came into intimate contact with the tool face. It was this characteristic of the first carbides that impeded an advance in their application to machining steel comparable with the strides made in machining cast iron, nonferrous metals, and abrasive materials. Thus tantalum-bearing carbide opened new fields in steel cutting. Single and multiple carbides of tantalum, titanium, and columbium were also to find use as crater preventives or resisters. In 1935, Philip McKenna, working at the time as a metallurgist for Vanadium Alloy Steel Company in Latrobe, PA, used a novel technique to manufacture crater-resisting carbides with improved strength and toughness and in 1937 introduced a tungsten-titanium carbide which, when used as a tool material, proved to be effective in steel cutting. He received a patent for this formulation and went on to form the McKenna Metals Company, now known as Kennametal Inc. Constant progress by the carbide manufacturers in improvement of their products has lowered the cost of carbides from the original $450 per pound to such an extent that they are no longer regarded as precious metals. Depending upon grade, shape, and size, the cost, with greatly improved quality and capacity dramatically increased, is but a fraction of what it was in 1929. Although tungsten carbide has become an extremely successful metalcutting tool, its roots are as a wear material, a wire draw die, which is still a successful application of this material to this day.

Although various carbide manufacturers may have different processing procedures, the final product is obtained by compacting the powder formulation by some technique and sintering the constituents into a solid mass in which cobalt, or a similar metal, bonds or cements the particles of carbide together. The manufacturing process is further described below.

Rigorous control is necessary throughout the manufacturing process since the quality of the final product can be greatly affected by seemingly insignificant factors. Purity, quantity, and particle size of the powdered materials must be closely watched. Mixing, milling, pressing, presintering, and sintering techniques are among the factors influencing the characteristics of the finished material. Carbide should be uniform in structure and grain size, free from porosity, and of maximum density, strength, and hardness. Modifications can be achieved by using various carbides and bonding materials, by varying the proportions of carbide to the cementing matrix, and by regulating the carbide particle size.

How is cemented carbide manufactured?

As mentioned previously, cemented carbide is made by a powder metallurgy process. The compaction process is performed under very high pressure in a mechanical press as shown in Figure I-1 or in an isostatic chamber to form a part with the consistency of blackboard chalk. A small amount of wax (paraffin) is added to increase the green strength and help in handling the compacted shape. In this "green" state, it can be formed or shaped by conventional methods such as turning, milling, grinding, and drilling (Figure I-2). The formed and shaped carbide is then sintered (placed in a vacuum furnace at a high temperature). During the sintering process, the carbide may shrink as much as 20% linearly, or nearly 48% by volume (Figures I-3 and I-4)

Mechanical Press

Figure I-1

Powder Shaping Mill

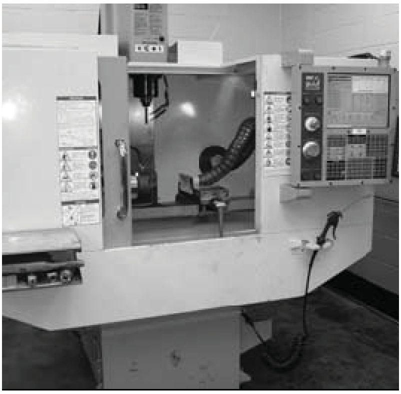

Figure I-2

Sinter-HIP furnace

Figure I-3

Note the difference in size as this part progresses through the manufacturing process from iso-pressed billet to partially machined in the "green" state to fully machined to final sintered size.

Figure I-4

For an "as-sintered" part, it is considered an industry standard to be able to hold a tolerance of ± 0.8% of the dimension or ± 0.005", whichever is greater. Tighter tolerances can be held on smaller pressed parts. After sintering, cemented carbide has achieved its full density and hardness. It can then be fabricated by diamond wheel grinding or electrical discharge machining (EDM) techniques, both of which are discussed fully in Chapter V.