Chapter II - Unique Properties of Cemented Carbide

MECHANICAL PROPERTIES

Hardness

This is one of the most important properties of cemented carbide. It is the one physical property that is thought to be the most important when it comes to abrasion resistance, although this property alone does not dictate the success of a carbide grade in a wear application. Hardness is determined by indenting a sample with a diamond penetrator per ASTM standard B-294. Hardness values for cemented carbide are usually expressed in terms of Rockwell “A” or Vickers values. Steels are measured in a similar fashion and are expressed in terms of Rockwell ”C”. Figure 2-1 depicts the approximate conversion of Rockwell “A” to “C”. It can be seen that a D2 tool steel heat treated and hardened to a Rockwell C value of 62 is still quite soft when compared to a 6% cobalt binder grade of carbide with a value of 92 Rockwell ”A”.

Hardness Conversion Chart (HR_A-HR_C)

Rockwell “A”	Rockwell “C”
91.8-92.8	79.5-81.5
91.5-92.5	79.0-81.0
90.5-91.5	77.0-79.0
90.2-91.2	76.5-79.5
89.8-90.8	75.6-77.6
89.0-90.0	74.0-76.0
88.5-89.5	73.0-75.0
88.0-89.0	72.0-74.0
87.5-88.5	71.0-73.0
87.0-88.0	71.0-72.0
86.0-87.0	69.0-71.0
83.0-84.5	63.0-66.0
81.5-83.0	61.0-63.0

Figure 2-1

Density

Density is determined according to the ASTM standard B311. Since cemented carbide is a composite material, and its constituent ingredients have varying individual densities, the density of cemented carbide varies with composition. Combining these materials in various proportions creates variation in the density of the cemented carbides in line with their composition. A density of 14.5 g/cc is typical for a 10% cobalt binder material. This value is twice the density of a 1040 carbon steel, which is an important consideration when weight is a factor in design.

Transverse Rupture Strength

The mechanical strength of cemented carbide is usually determined by this method rather than a tensile test commonly used for steel. The reason for this is that brittle materials are extremely sensitive to misalignment of the tensile test apparatus and sensitive to any notch or surface defect, which would cause a stress concentration and lead to incorrect test results. The transverse rupture strength (TRS) is determined by placing a standard sample (per ASTM B-406, ISO 3327) between two supports and loading it until fracture occurs, as shown in Figure 2-2. The value obtained is called the transverse rupture strength or bending strength and is measured as the load that is needed to fracture the sample. This is shown as load per unit area, expressed in psi or N/mm^2. Several tests are conducted and the value is taken as the average of all observed tests because cemented carbide exhibits a range of fracture values caused by the existence of micro-voids, inherent in all brittle materials.

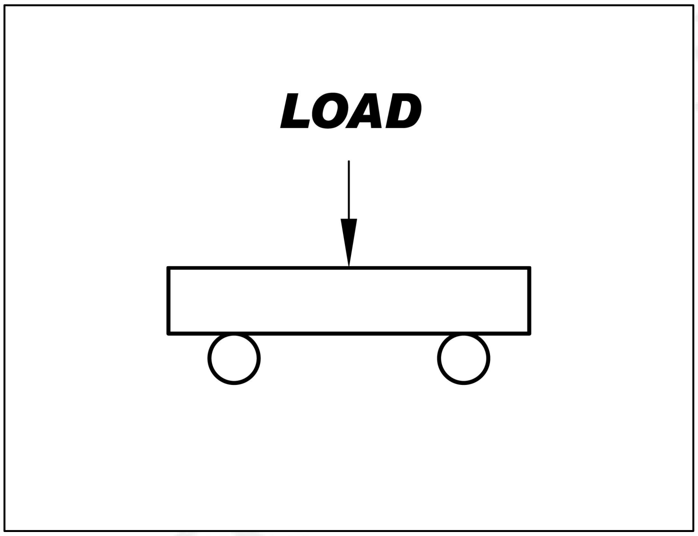

Figure 2-2

The values for transverse rupture strength of cemented carbide grades that appear in various suppliers' properties charts are based on the above standard test and thus, reflect the mechanical strength *for this sample size only*. Many designers, even those in the carbide industry, often regard the TRS values as the design strength value for a grade and use it in designating which grade should work in a particular application, expecting that value to hold true. In reality, these values decrease as the size of the part increases and the design strength value for larger pieces must be calculated due to the size effect. More on this in Chapter III. The TRS values increase with increasing binder content as shown in Figure 2-3.

Effect of Binder Content

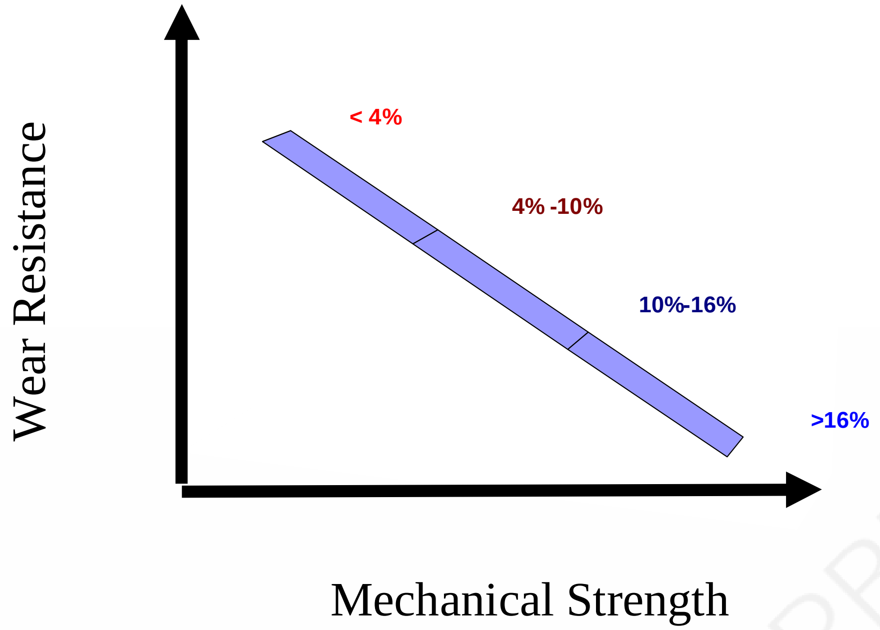

Figure 2-3

Another factor that affects the mechanical properties of cemented carbide, specifically the transverse rupture strength, is the grain size. The effect of grain size is shown in the chart below. As grain size increases, TRS values increase and wear resistance decreases.

Effect of Grain Size

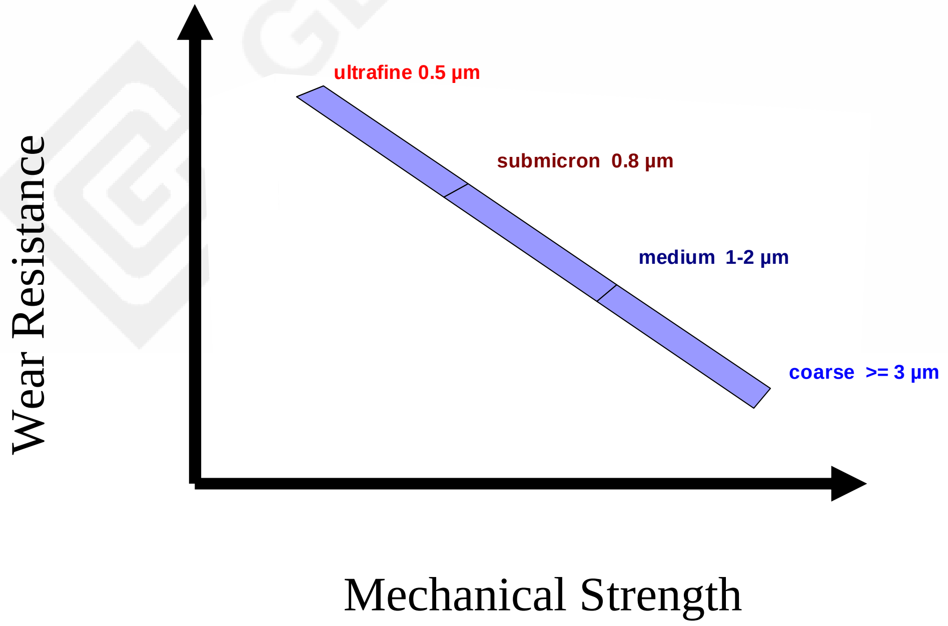

Figure 2-4

Compressive Strength

This property is also one of the most important attributes of cemented carbide. Ductile materials under compression loading merely bulge or swell without fracture but a brittle material will fail, due mostly to a shear fracture than true compression. Cemented carbide exhibits very high compressive strength when compared to most any other material and the value increases with decreasing binder content and decreasing grain size. (Figure 2-5) Depending on the grain size and binder content, values between 400K-900K psi 7 kN/mm^2) are typical for cemented carbide.

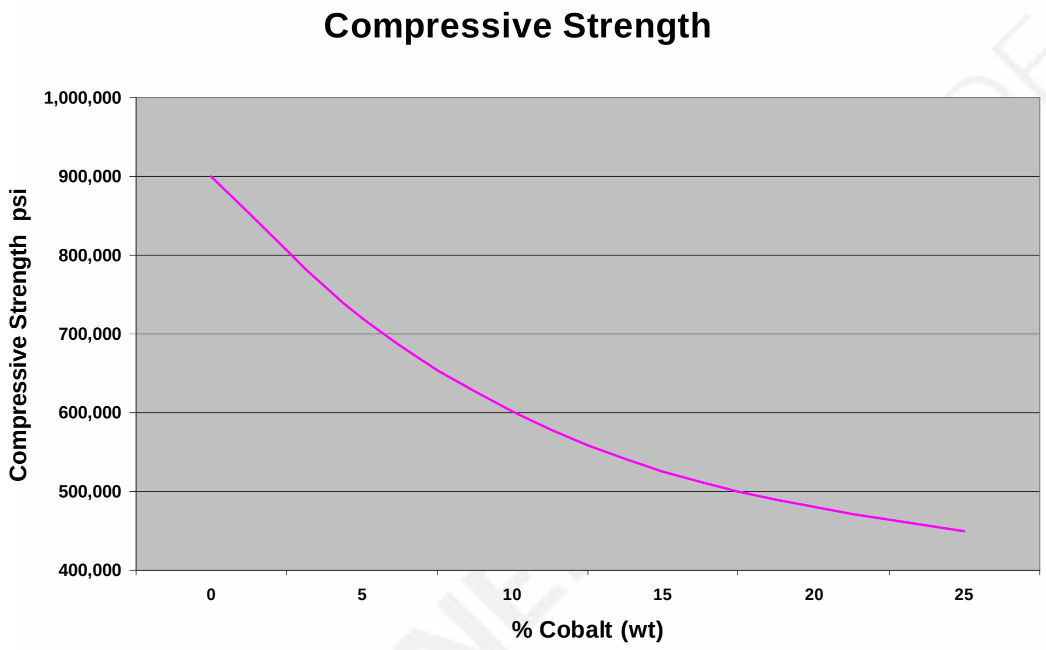

Figure 2-5

Modulus of Elasticity of Cemented Carbide

The modulus of elasticity or Young's Modulus (E) is a measure of the "stiffness" of a material and is measured as the rate of change of tensile or compressive stress "σ" with respect to unit strain "є" and is expressed as:

$$E = \frac{\sigma}{\epsilon}$$

The Young's Modulus for cemented carbide is as high as 94,000,000 psi (>650 kN/mm^2) and is 2 to 3 times higher than steel. It increases linearly with decreasing binder content. This property of carbide is used to resist deflection and is extremely useful when employing this material in a cantilever beam, such as a boring bar application.

Impact Strength

Finding exact solutions to impact problems can be extremely complex. Formulae for impact stresses show that stress varies directly with the modulus of elasticity hence, cemented carbide, having a high modulus of elasticity, is not suitable for all impact applications. However, given the hardness of cemented carbide, especially a higher binder grade containing 25% cobalt binder with a coarser grain structure, a surprisingly high degree of impact strength is exhibited. Transverse rupture is often mistakenly used as a measure of impact resistance when, in fact, fracture toughness is a better indicator of the ability of cemented carbide to withstand mechanical shock or impact. Fracture toughness varies according to grain size and binder content as shown in Figure 2-6.

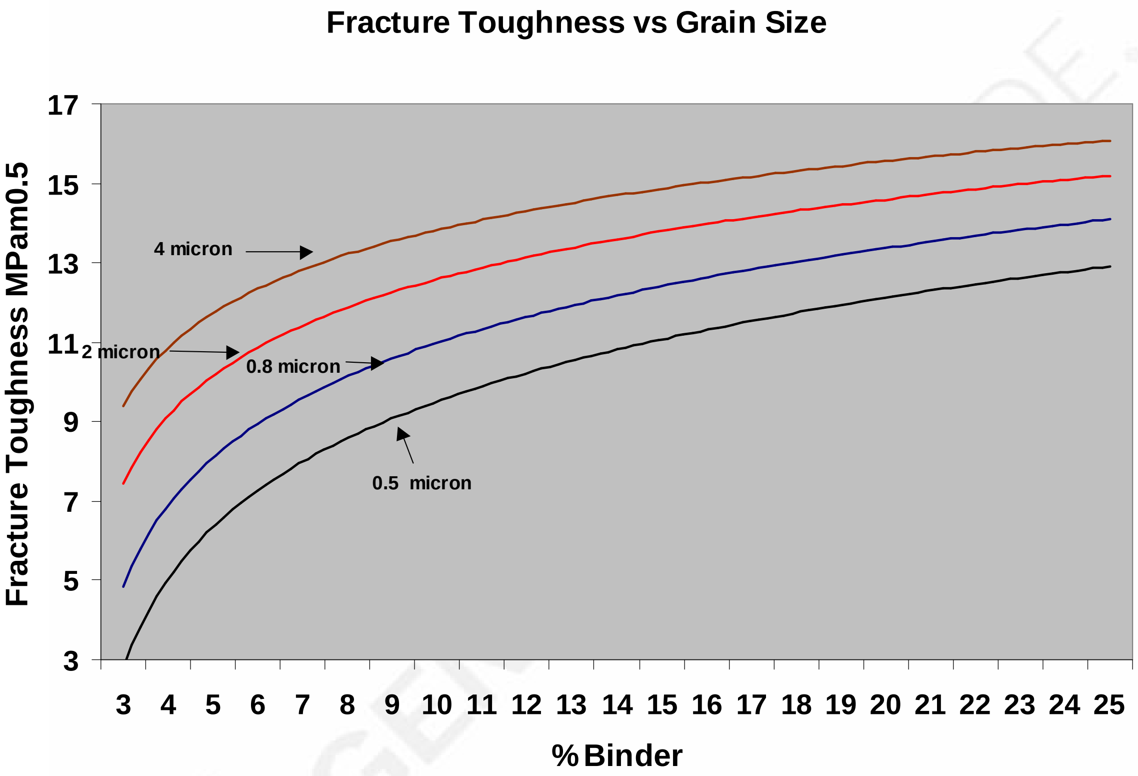

Figure 2-6

With the skillful use of design techniques, the impact energy imposed on the carbide can be transmitted in many instances to a more ductile mating part, thereby allowing the use of a higher wear resistant grade of carbide. This utilizes the best characteristics of both materials.

Fatigue Strength

When a material is subjected to repeated cycles of stress reversal or fluctuation, failure may occur even though the maximum stress is less than what would have caused a failure had the loading been constant. Fatigue properties are determined by subjecting test specimens to stress cycles and counting the number of cycles to failure. This usually results in a plot of values shown on an S-N diagram where failure stress is the Y axis and the number of cycles at which failure occurred is shown on the X axis. Several large companies in the carbide industry have conducted such tests and have reported their findings. Sandvik reports that the fatigue strength of cemented carbide under pulsating compression loading can be taken to be 65 – 85% of the static compressive strength at 2×10^6 cycles. No definite fatigue strength limit, which corresponds to an infinite life, has been found as in the case of steel and other metals. The fatigue strength increases with decreasing tungsten carbide grain size and decreasing binder content.

THERMAL PROPERTIES

Coefficient of Thermal Expansion

Cemented tungsten carbide has a very low coefficient of thermal expansion (CTE). This property is quite useful when shrink fitting a carbide die into a steel casing, which is described thoroughly in Chapter IV. Compared to steel, WC-Co cemented carbides have values of approximately half that of ferritic and martensitic steels while the ratio is closer to 1:3 for austenitic steels. The value for CTE increases with increasing binder content as shown in Figure 2-7 and can be increased with the addition of alloying agents.

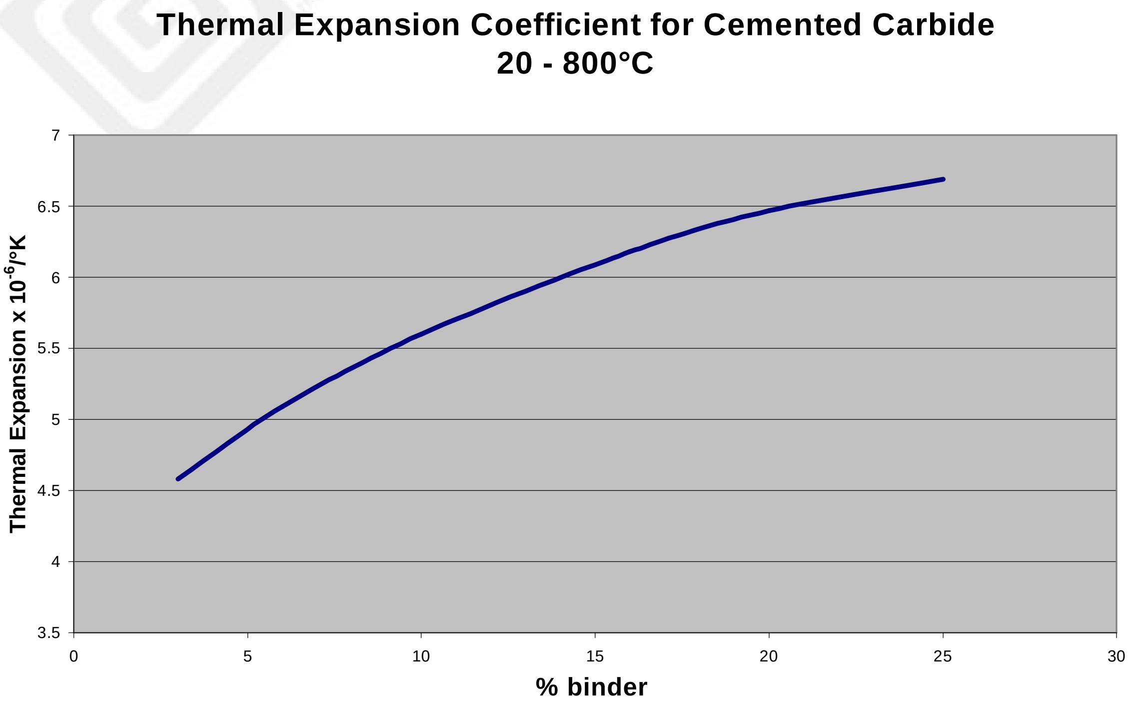

Figure 2-7

Thermal Conductivity

Pure WC is an excellent conductor of heat but WC-Co cemented carbides have a thermal conductivity factor of about one third that of copper. Grain size has no noticeable effect on this property, however, the presence of titanium carbide or tantalum carbide additives will decrease the thermal conductivity factor significantly.

ELECTRICAL AND MAGNETIC PROPERTIES

Electrical Resistance and Conductivity

WC-Co cemented carbides have low electrical resistance with a typical value of 20 µΩ cm. Consequently, cemented carbide is a good electrical conductor having a value of about 10% of the copper standard. This property is useful because it allows the use of EDM (electrical discharge machining) as a fabrication tool for cemented carbide. See more on this technique in Chapter V.

Magnetic Properties

Cemented carbides show ferromagnetic properties at room temperature due to the presence of the metallic binder phase, cobalt or nickel. This property is useful in non-destructive testing of a piece of carbide to determine magnetic saturation and coercivity.

Permeability

Low magnetic permeability is a characteristic of WC-Co cemented carbides that contain a ferromagnetic binder phase. It increases with the cobalt content and the typical range of values is 1.01 to about 12 when the standard is considered a vacuum with a value of 1. This property can be useful in abrasion resistant applications involving computer or disk drive media where magnetism would have a deleterious effect. A low magnetic permeability is important in a compacting die for pressing magnetic powders.

CORROSION PROPERTIES

More detailed information on corrosion resistance is presented in Chapter III but some fundamental information is presented here.

Tungsten carbide particles themselves are resistant to most corrosive media. It is the binder material that is susceptible to leaching in the presence of a strong acid or alkali solution. The binder material will leach from the surface of cemented carbide, leaving a skeletal structure, which is unsupported. The carbide particles will then abrade away quite readily, exposing new surface area to be attacked. When binder content is low, the carbide skeleton is denser. Low binder grades show a slightly higher combined wear and corrosion resistance than those grades with a higher binder content.

Straight WC-Co grades are corrosion resistant at neutral pH, which is a value of pH7. This is also true for WC-Co grades that contain additives like titanium carbide (TiC), tantalum carbide (TaC) or niobium carbide (NbC). Certain alloyed titanium carbide/nickel binder based grades possess the highest corrosion resistance down to about pH1. When compared to straight WC-Co grades these grades are brittle and have inferior thermal conductivity.

They are also hard to grind and braze, and are only used in specific applications where corrosion and wear resistance are a must and mechanical strength and thermal shock resistance are not as important.

When corrosion/wear is a prime design requirement, specially alloyed WC-Ni grades are the best choice. They are resistant down to pH2-3. In certain solutions, where pH value is less than 2, they have proven to be resistant to corrosion. Because they have WC as the hard principle, and nickel and cobalt are similar metals in most respects, their mechanical and thermal properties are similar to those of straight WC-Co grades.

The pH factor is one of the most important parameters when determining how corrosive a medium will be. Other major influencing factors include temperature and the electric conductivity of the medium. The latter is dependent on the ion concentration, i.e. the amount of dissolved salts in the solution. Therefore, it is hard to simply determine how corrosive a certain medium will be. No general rules apply to all situations, however, it is generally accepted that WC-Co cemented carbides should not be exposed to pH7 or below or leaching will occur. For a particular grade, it is recommended that tests be conducted with the intended medium.