CEMENTED TUNGSTEN CARBIDE: AN INNOVATIVE MATERIAL FOR CUSTOM CORE PINS IN THE PLASTIC INJECTION MOLDING INDUSTRY

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Abstract

Cemented tungsten carbide has revolutionized productivity in many applications throughout many industries and when used as a material for core pins has proven to reduce cycle time, increase core pin rigidity and extend core pin life in the plastic injection molding industry resulting in significant cost savings. To achieve profitability in the increasingly competitive global marketplace plastic injection molding companies must operate with maximum efficiencies and minimal unplanned downtime.

Introduction

Cemented tungsten carbide is a popular choice of material for dies and other wear parts in high volume manufacturing applications because of its wear resistance, corrosion resistance, high compressive strength, thermal conductivity and anti-galling properties. When the proper grade of cemented tungsten carbide is selected for core pins used in plastic injection molding applications it will provide exceptional performance and result in reduced cycle times.

The purpose of this paper is to provide background information on the material and to describe a process used in selecting the grade of cemented tungsten carbide that has high thermal conductivity properties for rapid heat dissipation and the Young's Modulus of Elasticity (stiffness) properties that will provide extremely low deflection during the injection process.

Background

Cemented tungsten carbide is a unique blend of fine grain tungsten carbide powder and a small amount of binder material, usually cobalt, also in powder form, which is processed and sintered. The sintering process binds the tungsten carbide grains with the binder material to form the ultra hard material. The tungsten carbide grains provide the hardness and abrasion resistance and the binder material grains provide the ductility or toughness. Figure 1 shows the microstructure of a typical medium grain size grade of cemented tungsten carbide at a magnification of 1500X. The dark angular shaped grains are the tungsten carbide and the lighter areas are the cobalt binder. This structural make up of the material is the reason why many people refer to tungsten carbide as "cemented tungsten carbide". Cemented tungsten carbide is available in many grades and is manufactured to almost any required combination of wear resistance, shock or impact resistance, and temperature resistance. The powder metallurgy process allows the carbide manufacturer to customize grades of cemented tungsten carbide to a specific application. Selecting the optimum grade then becomes the key to the success of each application.

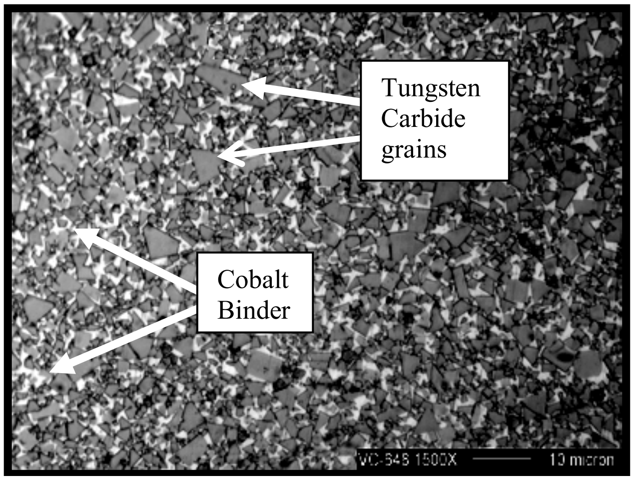

Figure 1. The microstructure of a 16% cobalt binder, 4 micron average grain size grade of tungsten carbide at 1500X magnification.

The grade selection process is a complex series of compromises that requires a thorough understanding of the application, including the actual mode of failure of the current part, and a complete knowledge of how to control the physical and mechanical properties of the available cemented tungsten carbide grades.

Mode of Failure of the Current Part

The first step in selecting the proper grade of cemented tungsten carbide is to identify the mode of failure on the current part. To determine the actual mode of failure; abrasive wear, corrosion or mechanical failure (breakage) a complete failure analysis study is conducted by the carbide manufacturer. The failure analysis process will identify the metallurgical and chemical properties of the material such as: binder material and content, grain size, hardness, density, transverse rupture strength (TRS), magnetic saturation and coercive force. From this data other important properties such as: compressive strength, modulus of elasticity (see Figure 5), thermal conductivity (see Figure 4) and the coefficients of thermal expansion can be determined.

A metallurgist will then identify the possible process control or quality issues, such as residual porosity (A, B or C type), binder lakes, clusters, eta phase, cross grade contamination, largest grain size and pits or voids.

A test to determine if corrosion and other conditions such as mechanical fractures or green flaws are present will also be conducted. After testing is complete the metallurgist will analyze the data and provide a comprehensive Failure Analysis report. The report will detail causes of failure and will include photomicrographs at 1500X magnification that provide visual evidence of the findings.

The mode of failure may be corrosion / leaching. Cemented tungsten carbide corrodes through a process called leaching. Leaching is the selective dissolution of the binder material from the cemented tungsten carbide microstructure. It is comparable to the destruction of the mortar in a stone wall. Eventually, these microscopic areas erode into larger voids and the part fails.

Leaching generally occurs through contact with acidic materials. These acids can be in the form of incompatible coolants or they can arise from poor handling techniques (water droplets left on the surface of parts, exposure to corrosive atmospheres, fingerprints, etc.). The cemented tungsten carbide manufacturers have developed several corrosion resistant grades designed to stand up to highly corrosive environments.

Corrosion tests are available to measure relative corrosion rates to determine the optimum grade to use with a particular coolant or the optimum coolant to use with a particular grade of cemented tungsten carbide. Nickel binder grades generally exhibit greater resistance to corrosion than standard cobalt binder grades. In some applications however, the environment has proven to be too corrosive for even the nickel binder cemented tungsten carbide grades. For those applications new grades have been developed that include nickel and chromium in the binder system. These grades have shown outstanding resistance to a variety of acids, organic coolants, aqueous coolants and caustic solutions.

Grade Selection Process

Once we have identified the actual mode of failure we can begin the grade selection process. By controlling two (2) key properties: grain size and binder percentage the characteristics of the tungsten carbide grade can be predicted and consistent.

The balance between the grain size of the tungsten carbide and binder material powders and the percentage of binder material must be achieved in order to get the desired combination of hardness, strength, toughness and shock resistance on a consistent basis.

The smaller the average tungsten carbide grain size, the higher the hardness and wear resistance, but the lower the shock resistance. The larger the carbide grain size, the greater the toughness and resistance to shock loads, but the lower the hardness and abrasive resistance. See Figure 2.

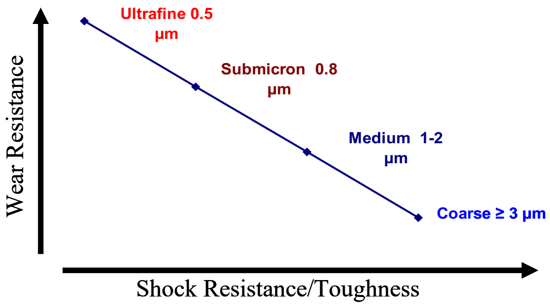

Figure 2. Effect of Grain Size. The larger the grain size the tougher the material.

Grain sizes are typically available in four categories; ultra fine with an average grain size of 0.5 µm or less, submicron with grain sizes of 0.8 µm, medium with average grain sizes of 1 – 2 µm and coarse at greater than 3 µm.

The other key element that allows us to control the properties of the cemented tungsten carbide grade is the amount or percentage of binder material. The percentages of binder material will range from 3% to approximately 25% in cobalt binder grades and from 6% to 12% when nickel is selected as the binder material. The general rule of thumb regarding binder percentage is the lower the percentage of binder material the harder and more wear resistant, but less impact resistance or toughness and therefore the higher the percentage of binder material the higher the shock resistance or toughness, but less wear resistance. See Figure 3.

When the grain size and percentage of binder material have been determined the next consideration is the specific binder material. Cobalt is the most widely used binder material for core pin applications due to the high thermal conductivity properties (see Figure 5). A cobalt binder material will also be recommended if abrasive wear is the problem. However, if corrosion is the issue a nickel binder will be used to slow down the corrosion process and as previously mentioned in the section on corrosion and leaching, if severe corrosion is evident in the application a nickel/chromium binder combination should be used. The use of Tantalum, Niobium and Titanium carbides will benefit applications that have conditions such as galling and high temperatures but should not be used for core pins as they adversely affect the thermal conductivity and strength properties.

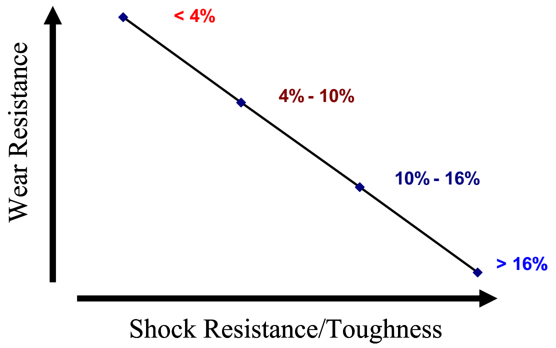

Figure 3. Effect of Binder Content. The higher the binder content the tougher the material.

Conclusions

Cemented tungsten carbide is a proven material in solving premature wear problems because a grade can be customized for specific applications. Through failure analysis we can determine the mode of failure and tailor a grade that will solve the particular problem causing the failure. By controlling the relationship between the grain size and the binder percentage we can consistently control the final properties of the material and therefore predict the performance.

Many variables must be considered when selecting the proper grade of tungsten carbide for die, wear parts and tooling applications. Every application should be evaluated carefully to optimize the composition that will most likely provide the balance between hardness (wear resistance), strength (toughness) and corrosion resistance.

In the case of core pins for plastic injection molding the two key properties for successful performance are thermal conductivity (see figure 4) and Young's Modulus of Elasticity (see figure 5).

Glossary of Terms

TUNGSTEN CARBIDE (WC) is the major ingredient of cemented tungsten carbide and provides the hardness and wear resistance.

COBALT (Co) is a binder material that bonds the tungsten carbide particles together and provides ductility and strength to the cemented tungsten carbide.

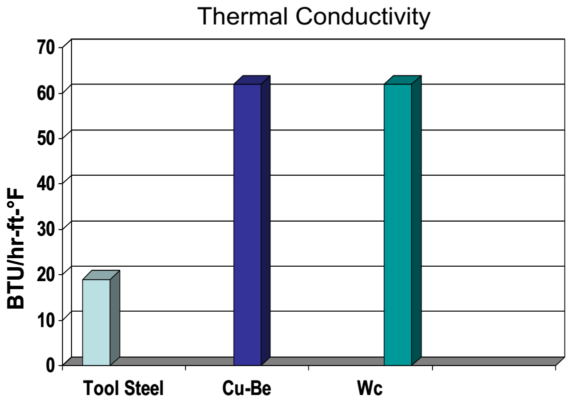

Figure 4. The high thermal conductivity properties of cemented tungsten carbide allow the heat in the part to be removed rapidly from the injection molded parts with internal cavities.

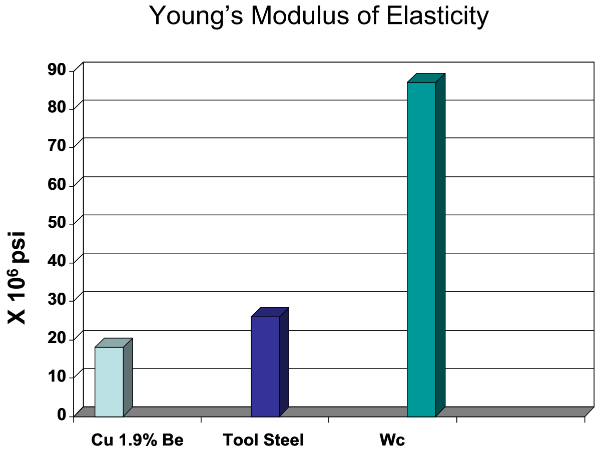

Figure 5. The Cemented tungsten carbide material is 3X more rigid than tool steel and beryllium copper alloys providing extremely low deflection during the injection process.

HARDNESS is the resistance of cemented tungsten carbide to penetration by a diamond indenter under a specified load. It is measured on the Rockwell A scale in the US and on the Vickers scale in Europe. Hardness is primarily a function of composition and grain size. High binder contents and coarse grained grades produce low hardness values while low binder content and fine grained grades result in higher hardness readings. The hardness of cemented tungsten carbide is directly related to its abrasive wear resistance.

DENSITY or specific gravity is the weight per unit volume of cemented tungsten carbide measured in grams per cubic centimeter (g/cm^3). All grades approach their theoretical density when properly sintered.

TRANSVERSE RUPTURE STRENGTH (TRS) testing is a commonly used procedure for evaluating the mechanical strength of the cemented tungsten carbide grade. The test is performed by applying a measured concentrated load on the center of a bar specimen supported between two stationary bars spaced a fixed distance apart.

MAGNETIC SATURATION is the degree to which the cobalt binder is saturated with carbon. For known cobalt content, magnetic saturation values indicate exactly how much carbon the sintered product contains – from unacceptably low values where eta phase is present to unacceptably high values where free carbon is present. Magnetic saturation is used primarily as a process control tool.

COERCIVE FORCE is the strength of the magnetic field required to demagnetize a fully magnetized cemented tungsten carbide sample. The coercive force measurement depends on many factors, including composition, grain size distribution, residual porosity levels, and others. It is sometimes used as an alternative indication of hardness, but is best interpreted in combination with other properties as a measure of overall grade uniformity.

COMPRESSIVE STRENGTH of cemented tungsten carbide is higher than virtually any other melted and cast or forged metals and alloys. As binder content increases the compressive strength is decreased.

MODULUS OF ELASTICITY is a measure of stiffness (rigidity), the resistance of a material to bend or deform elastically. Cemented tungsten carbide has high values approximately three (3) times greater than reported for steel alloys.

THERMAL EXPANSION of cemented tungsten carbide is typically ½ the thermal expansion of steel alloys. This must be considered when joining carbide to steel.

THERMAL CONDUCTIVITY of cemented tungsten carbide is two (2) to three (3) times that of most high speed steel alloys.

THERMAL SHOCK RESISTANCE is a measure of a material to withstand one or more drastic temperature changes without cracking. Cemented tungsten carbide is subject to heat checking.

RESIDUAL POROSITY is determined by visually examining a polished surface of cemented tungsten carbide at 200X magnification. The frequency of A type porosity (pores less than 10 microns in diameter), B type porosity (pores between 10 and 25 microns in diameter), and C type porosity (excess carbon) is determined. Porosity levels observed in the sample are compared to standards and a rating is assigned. The ratings range from 1 (very few) to 8 (undesirable). Edge strength or toughness decreases with increasing levels of residual porosity. At high levels of porosity, wear resistance may also be negatively affected.

FREE CARBON is a term to describe C type porosity in excess of C00.

PITS are any void in the microstructure whose longest axis exceeds 25 microns but is less than 100 microns.

MACROVOIDS are any void in the microstructure whose longest axis exceeds 100 microns.

ETA PHASE is a condition of carbon deficiency technically described as the intermetallic compound of cobalt, tungsten and carbon, and is usually caused by incorrect formulation of the carbide powder or improper sintering conditions. The affected areas of the cemented tungsten carbide are harder and more brittle than desired, leading to possible part failure.

CLUSTERS are defined as groups of three or more carbide grains that are much larger than the average grain size, and can be a weak spot in the microstructure. Clusters are caused by impurities in the powder or inconsistent distribution of powder.

BINDER LAKES are areas or pools of binder material within the microstructure that are larger than the average binder grain size.

CROSS GRADE CONTAMINATION is an area of distinctly different grade in the microstructure, is generally the result of ineffective cleaning of the powder processing equipment.

HARD FRACTURE is a fracture that developed after the part had been fully sintered. Hard fractures surfaces have a smooth texture and usually contain ripples or ridges.

GREEN FRACTURE is a fracture that developed before the part had been fully sintered. Green fractured surfaces are coarse when compared to hard fractured surfaces.

Acknowledgements

The following publications were used for reference materials:

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