7 Cobalt in Cemented Carbides

The ability to cut metal faster and faster is to a great extent at the heart of the economic growth in the 20th Century. Up until World War I, cutting tools were made from high carbon steels and cutting speeds of 25 ft/min were the norm. 1896 saw the start of tungsten carbide manufacture when Moissan in France melted/fused tungsten and carbon together to make diamonds. He didn't but WC resulted. Although mixtures of WC and MoC did get used for cutting, the great leap forward came when Schroeter and Osram produced a carbide material consisting of crushed tungsten carbide in cobalt. Iron was the first choice but it was cobalt for reasons which only became clear subsequently, which was the most successful binding material. The need for a binder is paramount as carbide alone is brittle and has little impact strength. The actual driving force however was not for cutting tools but as wire drawing dies.

Osram was cut off by a blockade from its sources of diamonds for dies and the carbide route was the alternative they developed. The cutting properties however were quickly exploited and by the 1920's, 150 ft/min cutting speeds were commonplace.

Although nickel has also been used as a binder, cobalt reigns supreme. Why should this be?

There are several criteria which govern the performance of a binder for carbides:

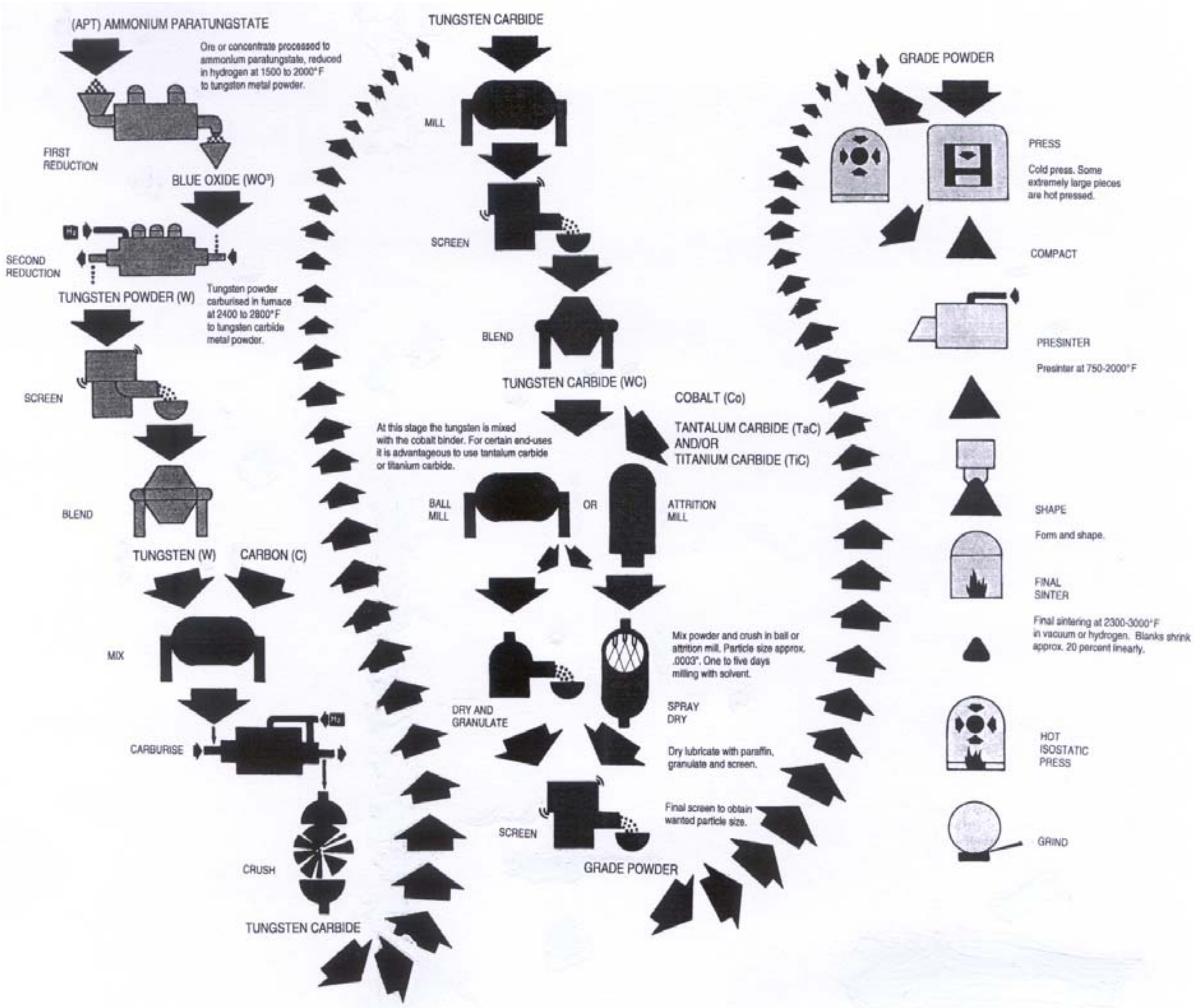
a) It must have a high melting point – Cobalt: 1493°C
b) It must have high temperature strength – Cobalt does
c) It must form a liquid phase with WC at a suitable temperature – Cobalt does at 1275°C. This pulls the sintered part together by surface tension and eliminates voids.
d) It must dissolve WC – Cobalt forms a eutectic with WC at 1275°C/1350°C and at that temperature dissolves 10% WC.
e) On cooling, WC should reprecipitate in the bond – in cobalt it does, giving hardness combined with toughness.
f) The binding agent should be capable of being ground very finely to mix with the hard carbide particles – cobalt can be produced very finely and grinds down to << 1μ. On grinding, it reverts to the close packed form which is brittle although in the carbide product, it retains the more ductile cubic form at room temperature.

Cobalt fulfils all the needs of a binder whilst others, like Ni, Fe, etc., only fulfil some. It is this fact that has kept it irreplaceable in carbides.

Production Methods

The accompanying flow chart outlines the production of sintered carbide parts. Cobalt powder itself is as vital ingredient and its size/shape/form, etc., influence the final properties. Originally, powders were made by reducing cobalt oxide in hydrogen. Ultra-fine powders regarded as essential for carbide bonding are made either by direct precipitation or by thermal decomposition and reduction of cobalt oxalate. The powders are around 2μ in size but during milling with the carbide break down even more finely. This is partly due to an induced phase change from FCC to CPH that occurs almost as soon as milling starts. This is the final requirement which cobalt fulfils, it can be produced as a fine powder (10 times finer than nickel) and milling reduces it further to .001μ. This allows intimate mixing and coating of the hard carbide particles.

The sintering part of the cycle is carried out in a vacuum or a reducing atmosphere of hydrogen. The cobalt dissolves tungsten and carbon from the carbide and produces a liquid phase around 1320°C. The surface tension of the liquid pulls the pressed part together and causes shrinkage of around 20%. On cooling, carbide is re-precipitated partly as a (WC + Co + C) eutectic.



From the original binary carbides, many other mixed carbides have developed – NbC, TaC, TiC, Cr_3C_2 – all aimed at giving certain properties allied to specific applications. More recently cutting tools have been coated with TiC to further improve cutting speeds (other coatings used are TaC, TiN, TiCN).

Properties

Many factors, both in terms of composition and processing techniques, affect carbide properties. Some of the basic variables are illustrated in Figure 1, 2 and 3.

Uses

The classic diagram in Figure 4 shows the variables linked to the many uses of cemented carbides. One would think that the main use was as a cutting tool but of the approximately 2,000 tonnes of cobalt ultra-fine powder produced, half goes to cutting and the rest to the many other uses of cemented carbides.

Grades

Table 1 shows a list (by no means exhaustive) of typical carbide grades with properties and relevant applications.

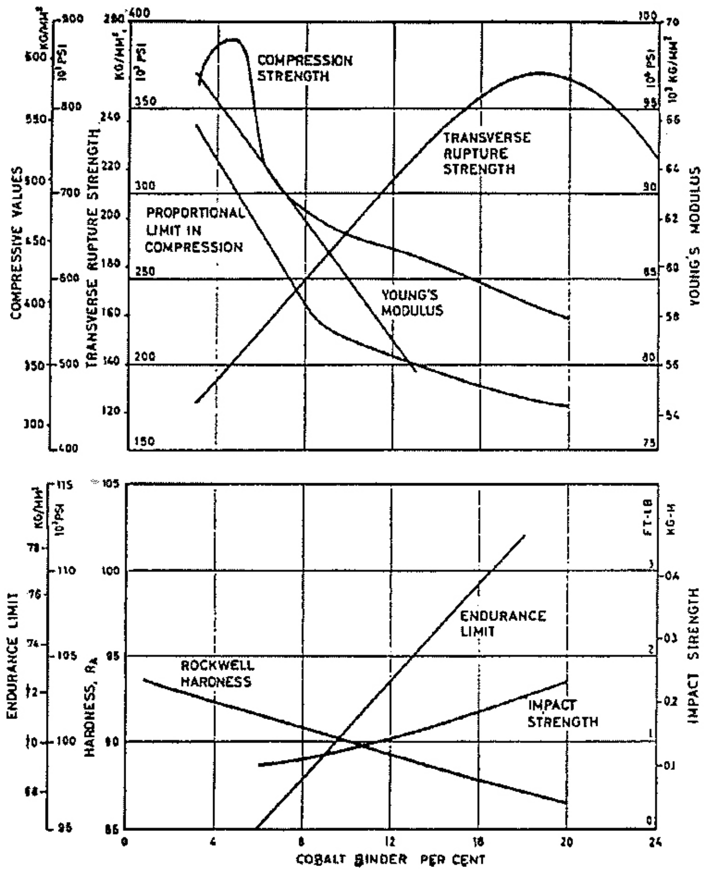


Fig. 1 – Variation in mechanical properties of straight tungsten carbide of normal particle size as the relative amount of cobalt increases

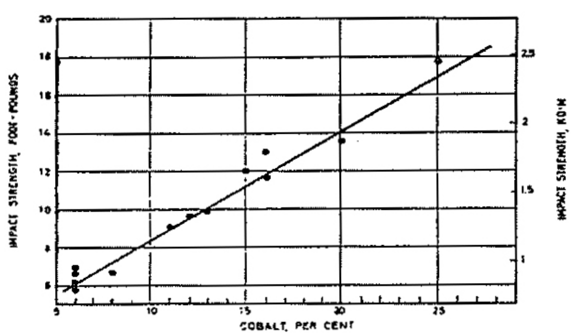


Fig. 2 – Effect of composition on impact strength of WC-Co alloys having a WC grain size from 1.4 to 3.1 microns

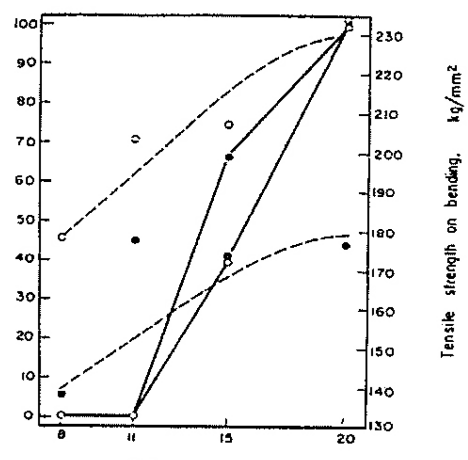


Fig. 3 – Relationship between strength & cobalt content for VK hardmetals produced from tungsten reduced by hydrogen at 650-820°C, with ordinary and intensive grinding of the mixtures

Table 1
Typical Carbide Composition & Uses of WC-base Cobalt Bonded Carbides

Co %	Ti %	Ta %	Nb %	Hardness Ra	Rupture Strength 10^3 psi	Uses
3				92.8		Precision boring
6				91.2		General machining
7				90.3		Cast iron M/C – i.e. tougher
9				89.5		Cast iron M/C – i.e. tougher
13				88.0		Wear applications
18				87.5		Heavy impact uses
20				86.0		Heavy shock – bar drawing
5.8	–	1.8	.3	92.0	250	General machining grade
6.0	100	7.2	2.4	93.0	200	Precision finishing
6.7	4.9	7.0	2.3	92.0	250	Form tooling
10.7	6.7	5.4	1.6	91.0	300	Interrupted cutting
13.0	3.2	–	–	89.5	310	Dies, heavy shock
15.0	–	3	–	–	–	Extrusion dies/can tooling

Main Applications

a) Machining Metal

The varying grades can balance hardness and toughness:
- Fine Cuts: Low cobalt, high hardness, low toughness
- Rough Cuts: High cobalt, lower hardness, high toughness

b) Metal Forming

Cold and hot drawing of wire, rod and tube. Cold rolling of metal solid and coated rolls. Press tools and cutting knives.

c) Mining

Rock drills – All types need toughness and wear resistance.

d) Wear Resistance

Valves, seats, seals, all situations when wear resistance and corrosion are important – Textile and paper industries, etc.

e) High Modulus Applications

Carbides are rigid and can be used as boring bars and guide tools.

7.1 Cobalt Bonded Diamond

A use related to carbides is the extension of cobalt's cementing role into diamond grinding wheels and saws. The former are often used to grind gem quality diamond and the latter in stone cutting.

Metal Bond Selection

The two basic functions of a metal bond are to hold the diamonds tight and to erode at a rate compatible with the diamond loss.

Figure 1 shows cobalt in relation to other bonding metals and demonstrates its high hardness and relatively low wear. These properties make it indispensable for diamond polishing.

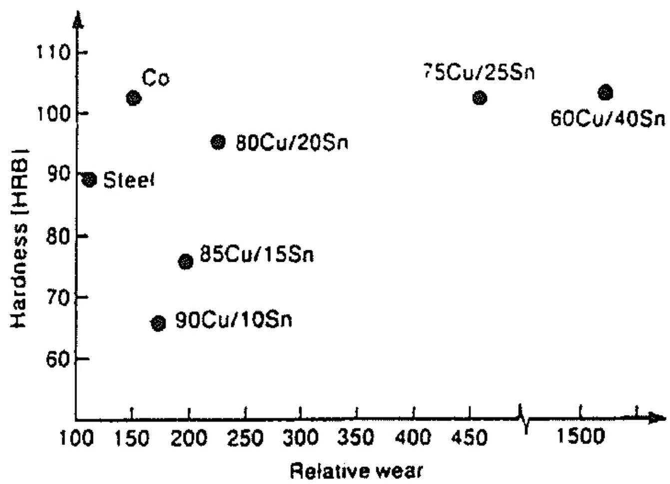


Fig. 1 – The relationship between wear resistance and hardness of bronzes and some metals. Results are relative to a wrought mild steel specimen (= 100)

Production

Saw segments are produced by blending fine powder and diamond and then producing segments by hot or cold pressing.

Polishing wheels are steel with diamonds impregnated into a surface cobalt layer.

This section is included for completeness but whilst "stone saws" are well documented (Materials Science of Stone Sawing IDR 1/01, Konstanty), diamond-polishing wheels are not and one supposes that like other processes in that industry it is a trade secret.