CMMT(MN)036

Measurement Note

Hardmetals

Property Review

Hardmetals have unique combinations of properties which make them one of the most useful tool materials produced by man. Many of their properties can be flexibly varied by straightforward changes in composition (eg volume fraction binder phase and hard phase grain size). This Measurement Note gives a brief synopsis of these properties.

Concrete Roof Tiles (Courtesy of Lafarge Braas Ltd)
Wear resistant hardmetal tooling is vital for maintaining the high levels of production required for the cost effective manufacture of concrete roof tiles.

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January 1999

NPL
National Physical Laboratory

HARDMETALS
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COMPRESSIVE STRENGTH

Compressive strength values of 4-8 kN mm^{-2} make them the strongest material available, witness their use in diamond manufacture as anvils and in hot rolls for metallic materials.

- TENSILE STRENGTH

Less than compressive strength, typically 2-3 kN mm^{-2}, but still much stronger than most other materials. Processing route is very important. HIPping or SINTERHIP required for highest values of strength.

HARDNESS

Can be varied between 1000-2000 HV by changing cobalt content and WC grain size. Like many other properties of hardmetal there is the flexibility to design specific hardness values by changing composition. As hard at the higher end as most ceramic materials yet much tougher.

TOUGHNESS

Difficult to measure quantitively as there is no agreed standard. Typical values of plane strain fracture toughness lie in the range 7-25 $MNm^{-3/2}$. These values are much higher than for similar hard materials like ceramics which have toughnesses of 2-8 $MNm^{-3/2}$.

FATIGUE STRENGTH

Few data available to judge properties but likely to be very good as this property usually correlates with strength.

HIGH TEMPERATURE STRENGTH

Excellent, although decreases steadily with increasing temperature. Sensitive to choice of hard phase. Cubic carbide additions such as (Ta, Nb)C and (Ta, Ti)C increase strength significantly.

- LOW TEMPERATURES

Hardmetals retain a good combination of properties at temperatures down to as low as that of liquid nitrogen. Hardness increases by about 20-30% with a concomitant decrease in toughness.

- IMPACT STRENGTH

Not well understood, probably related to tensile strength and fracture toughness. No standard test method available.

- ABRASION RESISTANCE

In severe abrasion environments it is the most wear resistant material available. This is because it has a unique combination of strength, hardness and toughness compared with other hard materials.

- STIFFNESS

It is one of the stiffest materials known, after diamond, with a Young's modulus about three times that of steel and six times that of aluminium.

- DENSITY

Hardmetals are very dense if they contain significant amounts of WC, upto 15 Mg m^{-3} is possible. Lower densities can be tailored by using higher Co contents or cubic carbides and carbonitrides for the hard phase, down to 4-5 Mg m^{-3}.

The high density endows hardmetal with a very satisfying feel when handling products but if specific properties (ie properties per unit weight) are required it is a disadvantage.

- SURFACE FINISH

Hardmetal can take a superb mirror finish, a consequence of its defect-free fine-scale structure. It has a deep grey lustre which is particularly attractive.

COEFFICIENT OF FRICTION

Hardmetals have a relatively low coefficient of friction, about 0.2, in unlubricated tests in contact with steel, as compared with typical steel against steel values of about 0.4. There is little systematic data of the effects of surface roughness, composition variations and temperature effects.

COATINGS

Hardmetals easily take a variety of coatings, eg electroless, electroplate, vapour or spray deposited. Both wear resistance and cosmetic coatings of many types are cheap and effective.

- SHAPE

Because hardmetals are manufactured by a powder metallurgy route there are few restrictions on shape and mass production technologies are possible. However, post-manufacture shape changes can be expensive if extensive diamond grinding is required.

- DIMENSIONAL STABILITY

Their use as high quality slip gauges indicates exceptional dimensional stability, provided grinding stresses are stress-relieved. The microstructures are inherently stable since they are formed by an equilibrium process at very high temperatures and are cooled to room temperature relatively slowly.

- EDGE RETENTION AND SHARPNESS

The fine scale of the microstructure and the high strength of the hardmetal enables very sharp edges and corners to be manufactured which have myriad uses in cutting and shaping processes (paper, wood and glass, for example).

- CORROSION RESISTANCE

Corrosion resistance in non-acids is excellent for all hardmetals. However, if a cobalt binder phase is used they can be prone to dissolution in even mildly acidic environments. This can be mitigated by using Ni-base or alloy binder-phases which are inherently corrosion resistant.

- JOINING

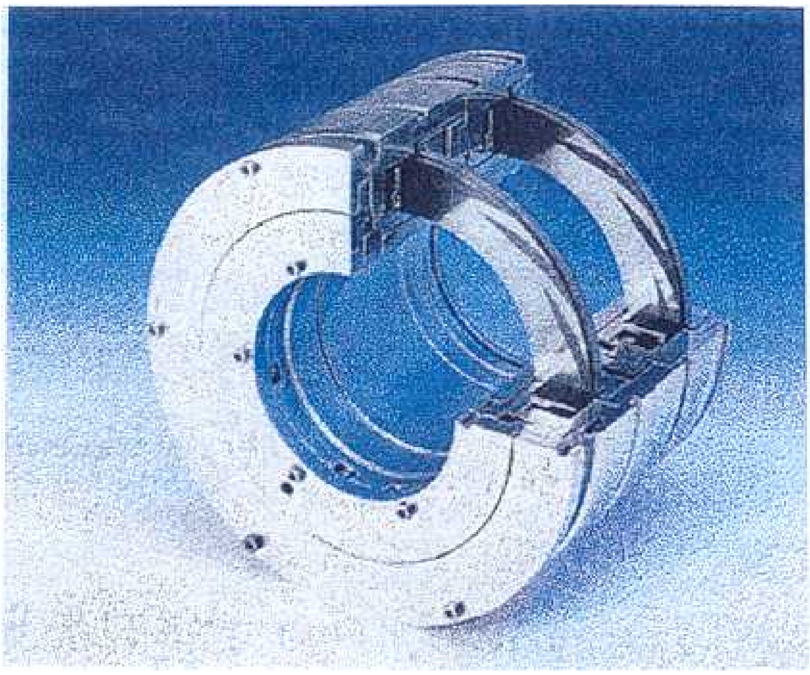
Brazing is relatively straightforward as hardmetals are readily wetted if clean, but care has to be taken to minimise thermal residual stresses because the thermal expansion coefficient is quite low, about half that of high speed steel. Welding is not possible but adhesives can be used in some circumstances if care is taken with surface preparation.

- THERMAL EXPANSION AND CONDUCTIVITY

The thermal conductivity of standard WC/Co hardmetals is about twice as high as that of high speed steel. Both conductivity and expansion can be tailored by changing the volume fraction of binder-phase and type of carbide/carbonitride hard phase.

- ELECTRICAL AND MAGNETIC PROPERTIES

Hardmetals usually have transition metal binder phases and consequently are slightly ferromagnetic, with coercive force values between 5-30 kA m^{-1}, depending on the binder-phase content. Non magnetic hardmetals can be made using Ni or alloy binder-phases as an alternative to the more usual cobalt. Electrical conductivity is good with values of resistivity in the range 15-20 nΩm. Higher values of upto 100 nΩm can be produced if cubic carbides such as TiC substitute for the WC.



Hardmetal seals (courtesy of John Crane - Engineered Sealing Systems). *Mechanical seals need hard wear resistant materials for a high performance rating. In many cases hardmetals provide the required properties.*

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