POWDER METALLURGY AND APPLICATIONS OF HARDMETALS - THE OPPORTUNITIES FOR MALAYSIAN INDUSTRIES

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ABSTRAK : *Pembangunan terhadap 'logamkeras baru' sejak beberapa tahun lalu banyak memberi tumpuan ke atas bahan-bahan bersaiz halus, sangat halus (sub-mikron), tersangat halus (ultra halus) dan struktur nano. Banyak inovasi penting telah dikenalpasti dan tumpuan kepada penggunaan 'logamkeras' bersaiz tersangat halus dan nano kini begitu menarik tumpuan dan perhatian. Tambahan pula dengan meningkatnya penggunaan bahan berprestasi tinggi, adalah amat bersesuaian untuk mengeluarkan komponen dengan sifat-sifat istimewa ini. Pembangunan ini telah membawa banyak penambahbaikan kepada hayat alat, sifat-sifat mekanikal dan pencapaian prestasi di dalam kerja-kerja yang terlibat. Keistimewaan sifat yang ada pada 'logamkeras' telah menjadikan ia bahan yang sangat penting bukan sahaja pada kerja-kerja pemotongan logam. Pengubahsuaian terhadap 'aloi logamkeras' juga telah banyak digunakan pada alat-alat perlombongan, alatan tahan haus, komponen struktural dan juga pada alat penempaan dan pembentukan.*

ABSTRACT : The development of new hardmetals during the past few years has focus strongly on fine, extra-fine (sub-micron), ultra-fine and nano-structured materials. Significant innovations have occurred and the move towards 'ultra-fine and nano-grained' hardmetals is attracting even more attention. Moreover, the increasing use of high-performance materials makes it possible to manufacture components with outstanding properties. These developments have brought about considerable improvements in tool life, mechanical properties and performance achievement in service applications. The special properties of hardmetals have made them an indispensable material not just in metal cutting. Tailored hardmetal alloys are also used in mining tools, wear parts, structural components, and in forging and forming tools.

KEYWORDS : hardmetals, ultra-fine, nano-structured, metal cutting.

INTRODUCTION

In many areas of engineering, especially aerospace and car manufacture, increasing use is being made of materials with specially tailored properties. Examples of these properties include low wear under exposure to corrosive media, high heat resistance, increased mechanical strength and low specific gravity. Materials which can be mentioned in this contexts include stainless steel and high-alloy steels, cast iron: spheroidal graphite iron, lightweight materials: metal matrix composites and carbon fibre polymer matrix composites, and titanium and nickel base alloys.

The increasing use, as described, of materials with special properties and the introduction of new machining technologies have had a decisive influence on the further development of hardmetal alloy and coatings (Van Den Berg, 2007). In the non-cutting area (dies), and in the area of highly wear-resistant structural components, numerous changes have been made to adapt properties to individual applications.

The range of applications in which hardmetals are used has also continued to grow, driven by competitor's requirements for improved performance. An impression of this range, and the range of compositions and microstructures that can be tailored for specific property requirements may be gained from Table 1. Improved mechanical properties, for example toughness, have enabled hardmetals to compete in applications previously held to be the reserve of other cutting tool materials. A vital requirement is cost effective performance: advanced tools provide longer life, or productivity gains by increasing the rate at which workpieces can be processed (Van Den Berg, 2007).

PRODUCTION OF HARDMETALS

The term hardmetal is used to describe alloys produced from metallic hard materials (primarily carbides) and tough binder metals of the iron group. In terms of microstructure, properties and performance, hardmetals can be divided into alloy types as shown in Table 1. Tungsten carbide (WC) is the main hard material used. Titanium carbide (TiC), tantalum carbide (TaC), and niobium carbide (NbC) are also important in metal cutting. Cobalt is the main binder used. The effects of the individual components on performance can be summarised as shown in Table 2.

Table 1. The range of hard materials and their applications (Brookes, 1998)

Hard Metal	Grain Size, m	Binder content, wt-%	Range of Applications
WC-Co	Ultra fine : 0.2-0.5	2-4	Wood machining and wear parts
		6-9	Microdrills and micromills for PCBs; indexable inserts for metal cutting
		10-16	Shaft tools; paper cutting knives
	Sub micron : 0.5-0.8	4-16	Indexable inserts for metal cutting; shaft tools
	Fine : 0.8-1.3	4-25	Indexable inserts for metal cutting; chipless shaping; wear parts
	Medium : 1.3-2.5	4-25	Heavy duty machining; chipless metal forming
	Coarse : 2.5-6.0	4-25	Mining tools
	Extra coarse : > 0.6	4-25	Chipless metal forming
WC-Ni, (Cr), (Co)	0.5-2.0	4-20	Chemical Engineering; components for corrosive environments; non magnetic structural parts
WC-(Ti,Ta,Nb) C-Co	0.5-2.0	4-15	Indexable inserts for steel cutting
Cerments (Ti,Ta,Nb,W,Mo) (C, N)./ (Co, Ni)	0.5-2.0	4-15	Indexable inserts for steel cutting

Table 2. The effect of the individual components on performance of hardmetals (Upadhyaya, 2001)

Element	The effect of the individual components
Co, (Ni), (Fe)	Toughness, corrosion properties
WC	Hardness, good wettability by Co
TiC, Ti(C,N)	Compared with WC higher hardness, lower thermal conductivity and lower solubility in ferrous alloys, main component in cements
(Ta, Nb) C	Improved high-temperature properties and thermal shock resistance
VC, Cr_3C_2	Grain growth inhibitor in WC-Co hardmetals
Mo_2C	Improved wettability of Ti(C. N) in cements

To produce hardmetal components, grade powders are mixed and compacted or shaped into green compact. This is subsequently sintered to obtain its final shape and properties. Grinding or final shaping, and coating may follow. Figure 1 shows how hardmetal is produced through Powder Metallurgy routes (Brookes, 1998).

Due to the great variety of shapes in which hardmetal is used, a number of shaping methods are employed. These can be divided into four groups: (i) direct shaping by uniaxial pressing (die pressing), (ii) indirect shaping of cold isostatic pressed (CIP) powder blocks, (iii) extrusion, and (iv) high and low pressure injection moulding (Baojun *et al.,* 2002; Van Den Berg, 2007). The actual shaping process used depends mainly on the geometry of the part and the quantities involved. Common to all shaping methods is the low green density about 70-75% of the as-sintered density (Selamat, 2004). The goal of sintering is to achieve full densification of the powder parts. Sintering is mainly carried out in vacuum furnaces using graphite-heating elements. Sintering is a very important step in which a large number of processes take place as shown in Table 3.

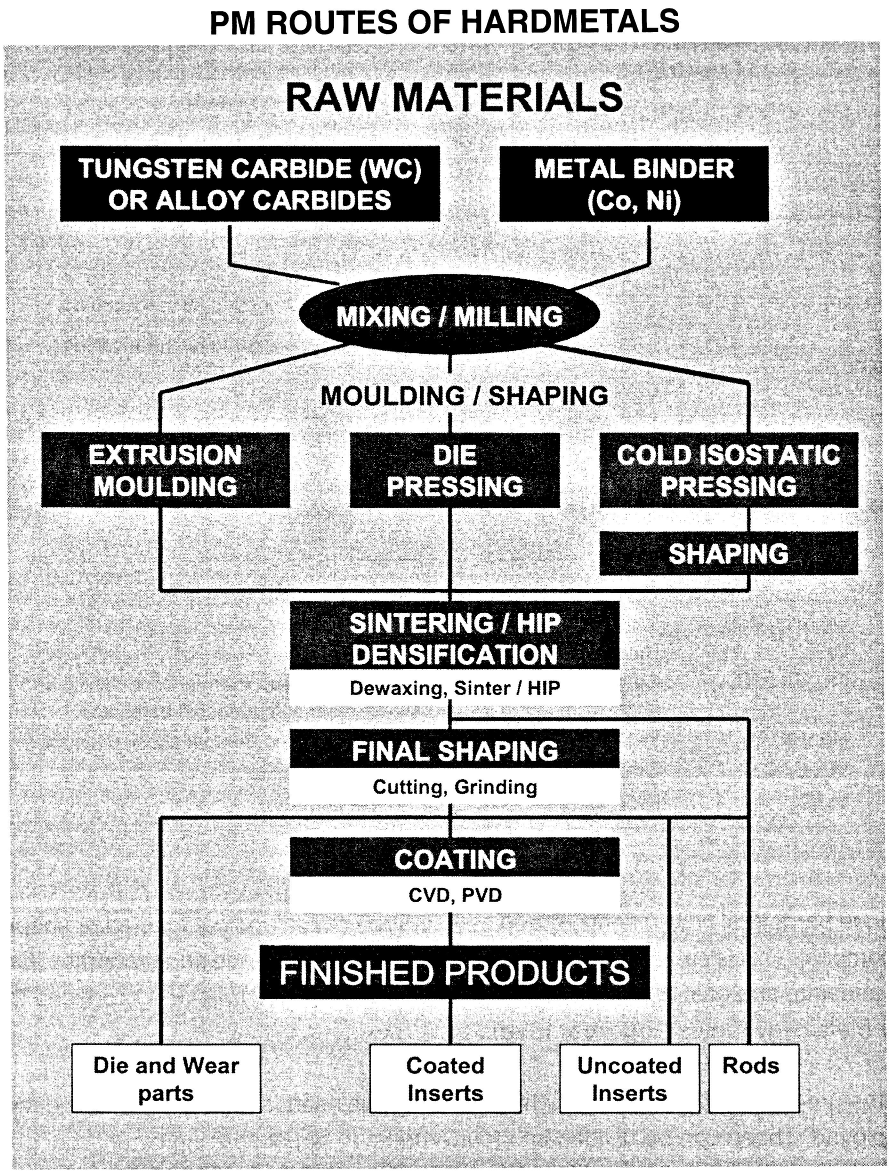

Figure 1. *Manufacturing process of hardmetals through PM routes*

Table 3. A number of processes during sintering of hardmetals (Brookes, 1998)

Process involved	Temperature involved
Melting of pressing lubricant (wax)	~60°C
Desorption of moisture	Room Temperature - 150°C
Evaporation of pressing lubricant	150 - 400°C
Reduction of Co oxides and cracking of decomposition products of lubricant	300 - 500°C
Reduction of W oxides	700 - 900°C
Reduction of mixed carbides oxides	> 1000°C
Rapid shrinkage; depends on grain size of WC particles (roughly 80% of shrinkage takes place before melting of binder)	> 1100°C
Melting of binder phase	1320 - 1400°C
Grain growth and solution repreciptation processes at sintering temperature	1400 - 1500°C

To improve quality, particularly with very fine-grained hardmetals and low in binder metal, hot isostatic pressing (HIP) is used (Sznchez *et al.,* 2005), as shown in Figure 2. In this process the hardmetal is heated close to sintering temperature and at the same time exposed to an inert gas pressure, generally argon, of around 50 to 150 MPa. Under these conditions, the low residual porosity can be completely removed. The strength increase achieved depends on; (i) the number and size of the pores in the sintered hardmetal, (ii) the carbide size distribution, and (iii) binder content. Fine-grained hardmetals achieve greater transverse rupture strength rather than coarse grades. The relative strength gain also increases with increasing binder content (Figure 3).

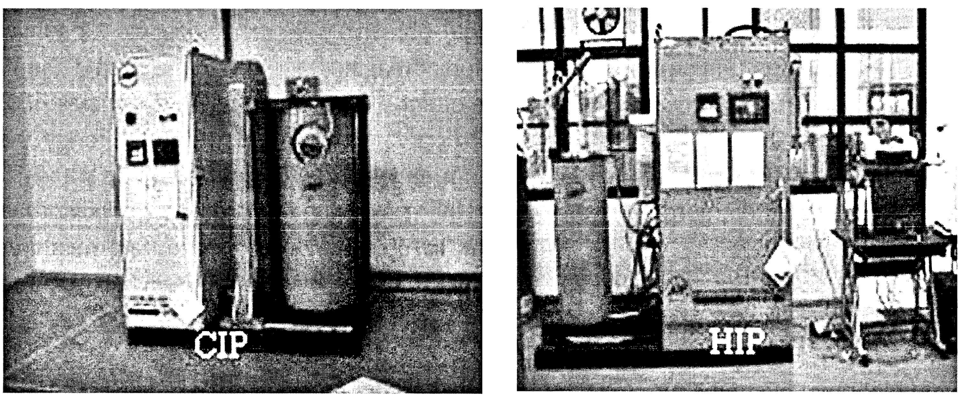

Figure 2. *Cold Isostatic Pressing (CIP) and Hot Isostatic Pressing (HIP) machines*

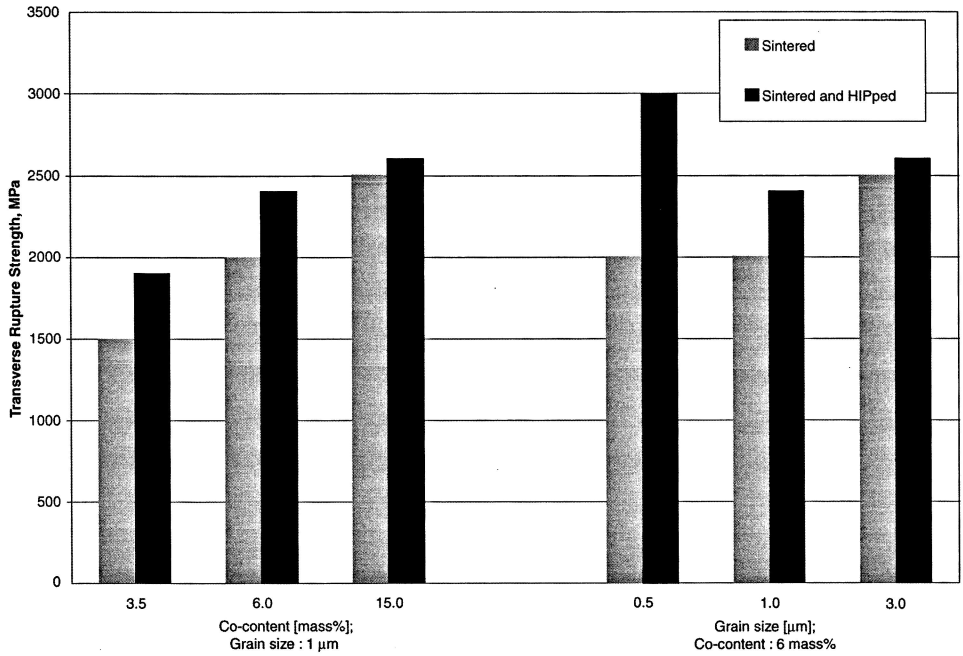

Figure 3. *Influence of HIP on transverse rupture strength as a function of Co-content and grain-size (Sznchez et al., 2005)*

ALLOY DEVELOPMENTS AND MATERIAL PROPERTIES

In resent years numerous new alloys have been developed with the aim of improving specific properties such as hardness, compressive strength, abrasive wear resistance, etc (Upadhyaya, 2001). The most important new developments for increasing hardness in the case of the WC-Co hardmetals are the submicron and ultra-fine grained alloys with the WC grain size of 0.5 - 0.8 m and 0.2 - 0.5 m, respectively and Co contents of 6 - 16 weight%. Today these hardmetals have reached a high standard of performance. Finer powders (termed 'nanosized' at <0.2 m) are also commercially available and there is now market demand for powder <0.1 m (Van Den Berg, 2007). Figure 4 shows the HV30 hardness of these hardmetals as a function of Co content. Worthy of note is the fact that with increasing grain refinement the hardness of hardmetal increases too.

The development of submicron and ultra-fine grain hardmetals has been driven by demands for solid hardmetal tools for drilling and milling printed circuit boards (PCB) in miniaturised electronic equipment (mobile phone, MP3 players, etc.) (Van Den Berg, 2007). Figure 5 shows the stages in the production of a micro drill, from blank to finished part (shank diameter: 3.2 mm, drill diameter: 0.2 mm). In 2006, a 0.1 mm diameter drill was launched for the Japanese market following the expression of strong interest in such a product.

Apart from using finer powders, control of grain growth during sintering is an important issue that will become ever more relevant as powder size is reduced, as mentioned by many researchers (Arenas *et al.,* 1999; Cha and Hong 2003). Doping of suitable additions to inhibit grain growth, for example with vanadium, chromium or tantalum carbide (VC, Cr_3C_2 or TaC) allows fine, uniform structures to be maintained during sintering (Morton *et al.,* 2005). VC is the most effective grain growth inhibitor and results in particularly high hardness and abrasion resistance.

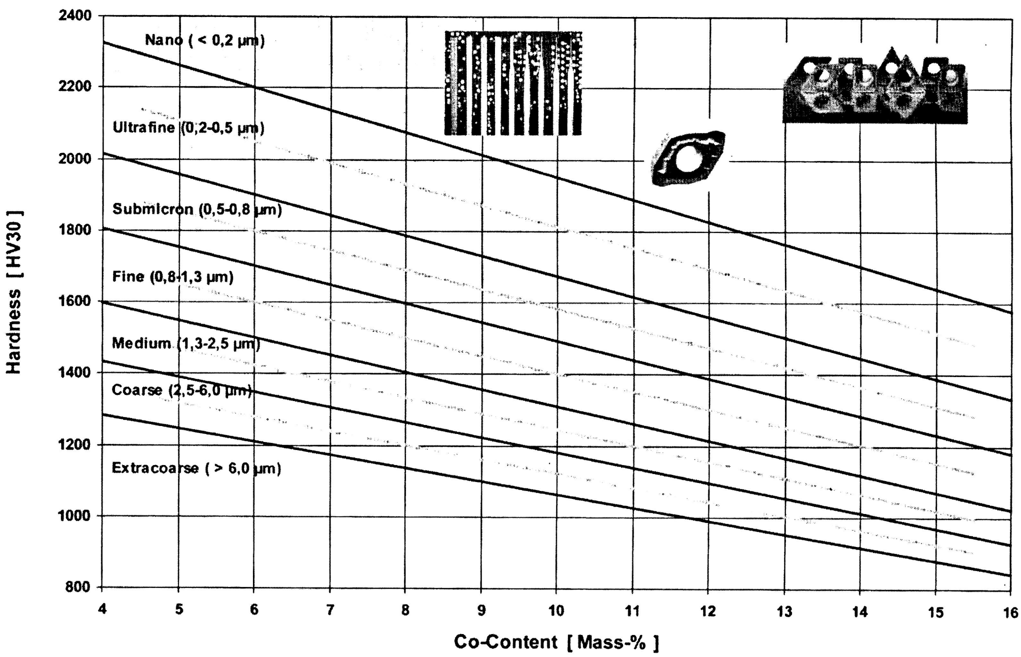

Figure 4. *Hardness of WC-Co hardmetals as function of cobalt content and WC grain size (Brookes, 1998)*

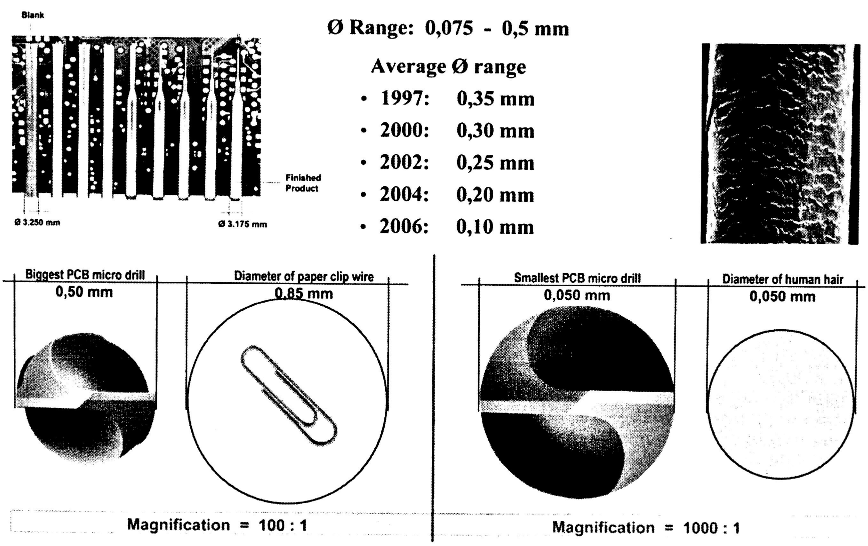

Figure 5. *Evaluation of average diameter of PCB micro drills over period 1997-2006 (Van Den Berg, 2007)*

The finer microstructures permit finer drill edges to be produced and improve wear resistance; however, drill life is generally determined by breakage (Brookes, 1998). The combination of finer WC-Co substrate with multi-layer coatings (e.g. TiN-TiNC-Al_2O_3-TiCN) can further extend the tool life and performance of drill. In tests on 4130 steel crankshafts at 130 m/min with a feed of 0.2 mm/rev, the new drills were found to be still intact after 130 m of drilling, compared with a mean life of 43 m for currently used products (Van Den Berg, 2007).

MARKET FIGURES AND OUTLOOK

The annual demand for hardmetal tools for metal cutting, mechanical seals, dies and wear protection amounted to approximately 31,179 tons ($US 7,450 millions) worldwide in 1999 (Van Den Berg, 2007). Consumption has increased steadily since the first commercial production of hardmetals in 1926, i.e. over 80 years ago. World production of hardmetals more than double over the period 1993 to 2005, from 20,000 to 50,000 tons per year (Van Den Berg, 2007). During this period, Western European production grew from 5,500 to 17,000 tons, while the Chinese production also grew from 5,000 to 16,500 tons in 2005 (Figure 6). This growth shows no sign of slowing, and in 2006 hardmetal inserts for the German market showed a 9% increase over 2005 driven by increased vehicle production, and also partly by record levels of machine tool utilisation (Baojun *el at.,* 2002). For round tool for drilling and milling PCBs for the electronic industry demand is forecast to double in the next few years.

Currently in Malaysia, foreign mechanical seal manufactures through their local sales offices or trading house satisfy almost all of Malaysia's mechanical seal demands, since none are produced locally. More than RM12 million were spent yearly (MATRADE Report; 2003-2004) to import mechanical seals from the original supplier (Europe countries or USA) and a refurbishment value of RM 4 million per year are also indicated. It also reported that global cutting tool and wear resistance of hardmetal parts demand in the world in 2005 was US $25 billion.

The modern developments in hardmetal technology are characterised by the trend to improve the uniformity and reliability of the sintered products. This was done by precise control of the starting materials in terms of composition, purity, grain size, grain shape and grain size distribution, and by close tolerances in the pressing and sintering parameters (Upadhyaya, 2001; Morton *et al.,* 2005). While, the future-oriented research and development projects for hardmetals are now geared in the area of :

- hardmetals with extremely fine grained microstructure with hard materials in the sub-micron, ultra-fine and nano-sized grain structure
- alternative binder metals and binder alloys (Ni, FeNi, FeCo, FeCoNi) to reduce and replace Co, and increase high-temperature strength and corrosion resistance
- low-binder hard material alloys (to produce binderless WC prepared by spark plasma sintering) (Cha and Hong 2003)
- alternative production technologies, i.e. precision pressing by CIP and HIPed; low-pressure injection moulding (Sznchez *et al.,* 2005), and microwave and spark plasma sintering (Cha and Hong 2003)
- thicker multi-layer and multi-component coating materials and technologies on the basis of ultra-hardmetals (Brookes, 1998)

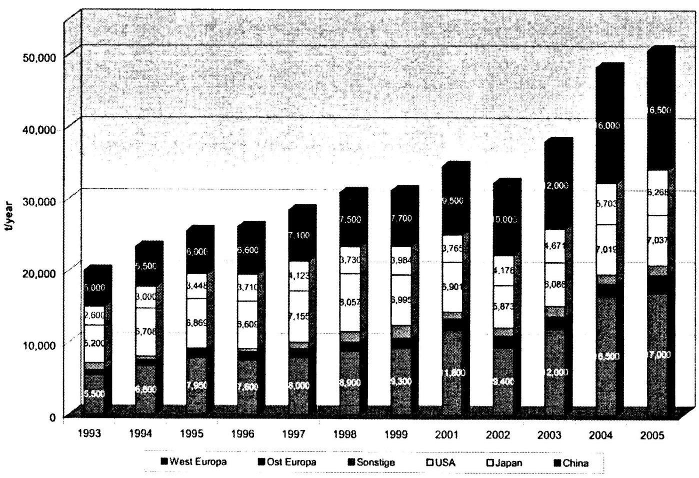

Figure 6. *Worldwide hardmetal production 1993-2005 (tons/year), broken down by region (Van Den Berg, 2007)*

CONCLUSION

Full density sintering is a commercially established method of production of high performance Powder Metallurgy hardmetal components. Some parts have already been made in large quantities and have proven very satisfactory in actual service, especially for cutting tool applications. The high hardness, strength, heat resistance and wear resistance properties of these hardmetals make them an attractive material to be developed for the purpose of Malaysian industries.

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