Archives of Materials Science and Engineering

Volume 43
Issue 2
June 2010
Pages 87-93

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

Hardness to toughness relationship on WC-Co tool gradient materials evaluated by Palmqvist method

L.A. Dobrzański*, B. Dołżańska
Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

Received 05.02.2010; published in revised form 01.06.2010

ABSTRACT

Purpose: Goal of this work was to describe the propagation characteristic of cracks produced at the corners of Vickers indent and the toughness change in functionally graded WC–Co cemented carbide with high disproportion of cobalt matrix portion between core and surface layer.

Design/methodology/approach: Investigations of toughness methods were developed during the investigations for tungsten carbide and cobalt, making it possible to obtain four materials and then their structure was determined.

Findings: A wide variation in hardness and toughness has been obtained in WC-Co composites. The propagation characteristic of cracks produced at the corners of Vickers indent and the toughness change in functionally graded WC–Co cemented carbide with dual phase structure were investigated. It is shown that cracks tend to propagate both around and across WC crystal grain. The changes of toughness with the microstructure and an integrated strengthening effect, as well as high toughness characteristic of the tool gradient material are revealed.

Practical implications: Material presented in this paper are characterized by very high hardness of the surface and relative ductility of core. The cobalt phase in obtained TGM material will changing smoothly.

Originality/value: The Palmqvist test provides a useful method of measuring fracture toughness of material characterized by very high hardness of the surface and relative ductility of core.

Keywords: Toughness; Cemented carbides; Palmqvist; Powder Metallurgy

Reference to this paper should be given in the following way:

L.A. Dobrzański, B. Dołżańska, Hardness to toughness relationship on WC-Co tool gradient materials evaluated by Palmqvist method, Archives of Materials Science and Engineering 43/2 (2010) 87-93.

PROPERTIES

1. Introduction

Tool graded materials (TGM) incorporate gradual transitions in their microstructure and composition with distance. The gradients provide means to favourably engineer their thermo mechanical properties by changing the state of residual stresses, stress concentrations, driving force for crack growth, etc. However, prior to optimizing such gradients, a clear understanding of their effect on thermo mechanical properties is necessary. Than the influence of compositional gradients on the state of thermal residual stresses in WC–Co composites.

Tool graded materials (TGM) are gradients of composition, phase distribution, porosity and related properties [1-15,17, 19-23]. These gradients are engineered, i.e., intentionally introduced in order to achieve an improvement in mechanical or other properties of the final component. Tool graded materials WC–Co hardmetal is a unique TGM material with a cobalt composition gradient were WC is expected to offer many advantages for specific applications. For example, a tough core and a hard surface would be particularly useful for cutting picks in the mining industry [23].

Developments in layered WC–Co have provided a novel methods to design WC–Co composites. They shows desirable combinations of mechanical strength and fracture toughness [3,4]. These structures contain an outer most hard layer to provide high wear resistance, and one or more underlying soft layers to provide damage resistance. Traditional laminates which promote toughness by interlayer crack deflection due to the strong interface to the weak core. Layered materials have shown promise for damage resistance in applications such as cutting tools [15-19].

However conventionally, there are few methods for measuring the fracture toughness of homogeneous WC–Co material and mainly two methods are determined to apply to the WC–Co materials [19]. One is the Palmqvist indentation test, which evaluates the surface fracture toughness of the material. The Palmqvist indentation nor SENB standard test is directly applicable for evaluating the fracture toughness of graded WC–Co materials because the fracture toughness of graded materials varies with in the material.

The Palmqvist fracture toughness can be inferred from the total length of cracks produced at opposite corners of a Vickers indent. The hardness profile measurement can directly reflect the change in the microstructure of tool gradient cemented carbide [10-23].

The aim of this work was to investigate the crack propagation characteristic in cemented carbide so as to have an in-depth know ledge about the effect of the phase and structure characteristic on its toughness.

2. Experimental materials and methods

2.1. Hardmetal compositions

Specimens of powders were prepared based on previous investigations in powder metallurgy technology [5]. The morphology of the starting materials was investigated by scanning electron microscopy (SEM-FEG) SUPRA 35 form ZEISS Company equipped with a system of chemical composition analysis EDS.

Powder of cobalt consist of aggregated particles, whose average size is about 5-6 μm (Fig. 1), while of tungsten carbide form more compact structure, with grains whose average diameter is about 5 μm (Fig. 2).

X-rays studies for the analyzed materials were carried out on X`Pert PRO system made by Panalytical. XRD resutles confirmed the presence of used powders (Fig. 3 and Fig. 4). No contaminants were observed.

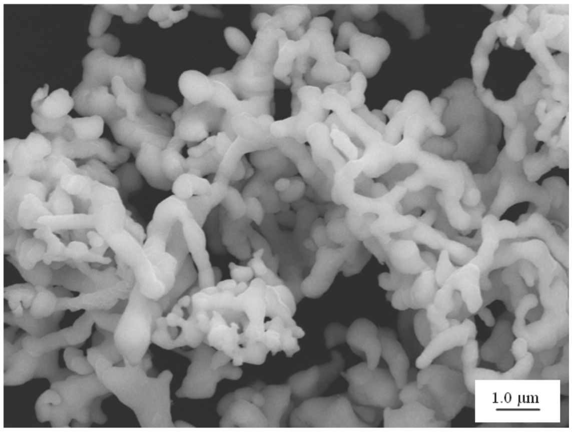


Fig. 1. Scanning electron micrographs of powder of cobalt (UMICOR & Specialty materials)

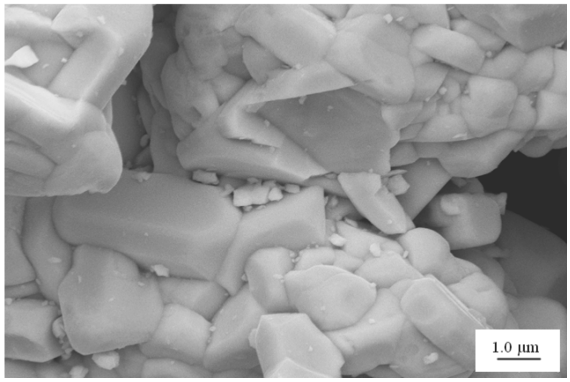


Fig. 2. Scanning electron micrographs of powder of tungsten carbide (UMICOR & Specialty materials)

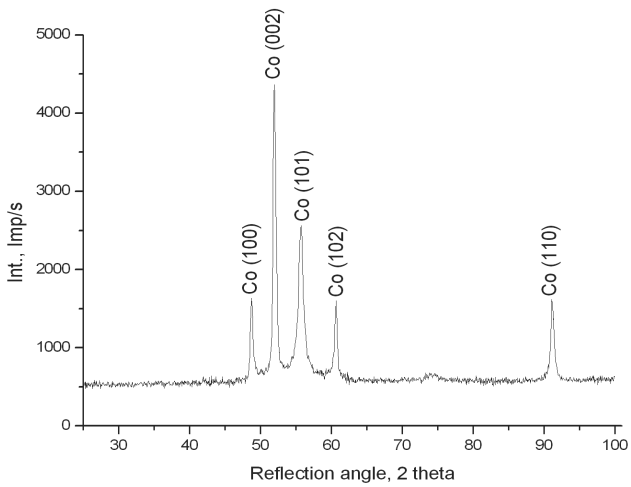


Fig. 3. X-ray diffraction pattern of Co

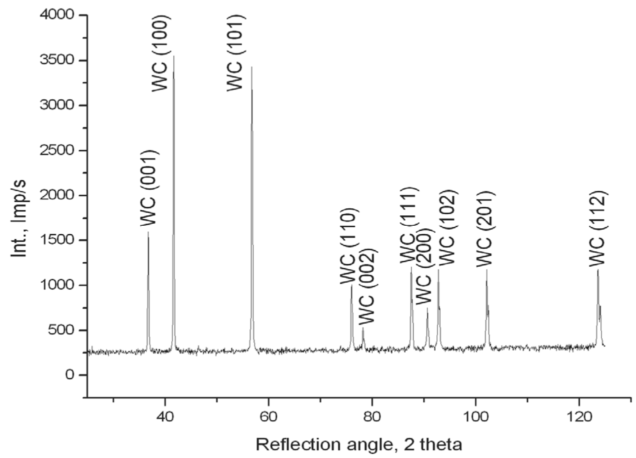


Fig. 4. X-ray diffraction pattern of WC

Two powders Co and WC were combined via mechanical agitation to form a four new chemistry compounds. Chemical properties of the powders are shown in Table 1. The complex porosity was determined and for both powders was equal 0.675 [%].

Table 1.
Chemical composition of Co and WC (%wt)

Chemical element	WC	Co
Mn	< 0.001	< 0.001
Ca	< 0.001	< 0.001
Zn	< 0.001	< 0.001
Si	< 0.002	< 0.002
Pb	< 0.002	< 0.002
Ni	< 0.002	< 0.002
S	< 0.002	< 0.002
Cu	< 0.002	< 0.002
O	0.45	0.45
Co	0.09	-
C	0.02	0.02

For powder mixes preparation the carbide ball mill was used. The mass ratio of grinding medium and powder in any case was equal 1:1, and the time of milling was 8 h. Four different powders mixes were prepared with mass fraction of cobalt 3, 5, 7 and 9% respectively. About 2% mass portion of paraffin was added to improve the formability the tungsten carbide and cobalt mixture .

Connection of layers (Fig. 5) is achieved through uniaxial and unilateral pressing under pressure about of 340MPa, for 1 min. In to such prepared powder mixes of hard phases and cobalt.

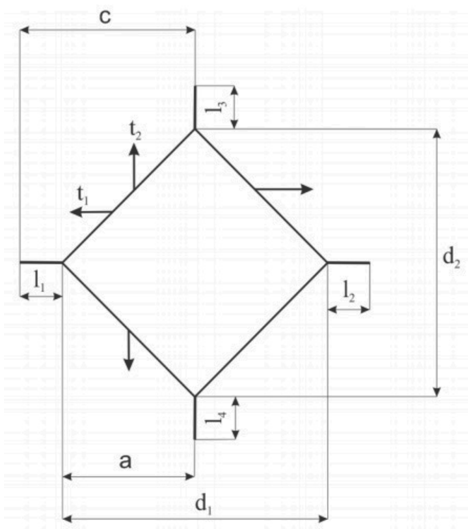
Fig. 5. Scheme of TGM sample

After cold-pressing the samples were sintered in a vacuum furnace at 1425ºC, 1460ºC and 1424ºC + HIP (Hot Isostatic Pressure). After sintering, the parts were ground to the desired layer thickness and polished using 1μm diamond paste. Hardness tests were followed by cobalt analysis using hardness tester.

2.2. Palmqvist technique

Palmqvist fracture toughness can be inferred from the total length of cracks produced at opposite corners of a Vickers indent and from the hardness of the specimen. The sum of crack lengths values into Palmqvist fracture toughness values is used.

Indentation and crack length measurement the distance from crack tip to crack tip for both diagonal directions. The total crack length is the sum of both these values minus the sum of the indentation diagonals (see Figure 6).



were: l_n (mm) is crack length at indent, t_n (mm) is tip to tip crack length, d_1 and d_2 (mm) are indention – diagonal individual value

Fig. 6. Schematic diagram of palmqvist indentation characteristics

The average value of the two diagonals, in [mm], and convert to a true value, d, in [mm], by dividing by the calibrated value for the magnification. The hard metal Vickers hardness, HV, is given by the following equation (1):

$$HV = \frac{1.854 \times P}{\left[(d_1 + d_2) \times \frac{1}{2} \right]^2} \qquad (1)$$

Two different values for toughness can be calculated. Palmqvist toughness, W_G (2), and Palmqvist fracture toughness, K_{IC} (3).

$$W_G = \frac{P}{(t_1 - d_1) + (t_2 - d_2)} \quad (2)$$

$$K_{IC} = A \times \sqrt{HV} \times \sqrt{W_G} \quad (3)$$

where HV is the hardness, MPa; W_G is the Palmqvist toughness, Nmm^{-1}; K_{IC} is the fracture toughness, $MNm^{-3/2}$; P is the indentation load is 30 [kgf], and A is the constant factor 0.0028.

Palmqvist indentations were made on a polished surface which was free from residual stresses introduced by the polishing procedure. In this work indentation crack length were observed via SEM.

After polishing, Vickers diamond indentations were made on each sample, using an indenting load of about 300 N. The total length of cracks for each indentation was then measured. The mean crack lengths and their coefficients of variation were then evaluated for each tool gradient materials.

3. Discussion and results

The hardness to toughness relationship of cobalt gradient WC-Co tool gradients materials was studied on Palmqvist indentation toughness measurements. Three lab-sintered tool gradient materials of the same composition, microstructure but the others sintered temperatures were investigated to build up a representative hardness/toughness measurement band. This band is then used to discuss the influence of the various temperature parameters on the hardness to toughness relationship of WC-Co tool gradient materials.

Typical HV30 indent image and the track at the corner in the surface zone with 97%WC+3%Co on the sample I, are shown in Fig. 7 and Fig. 8. HV30 indent image of the crack at the corners in the intermediate zone with WC + Co two-phase structure diagonal lengths are shown in Fig. 9.

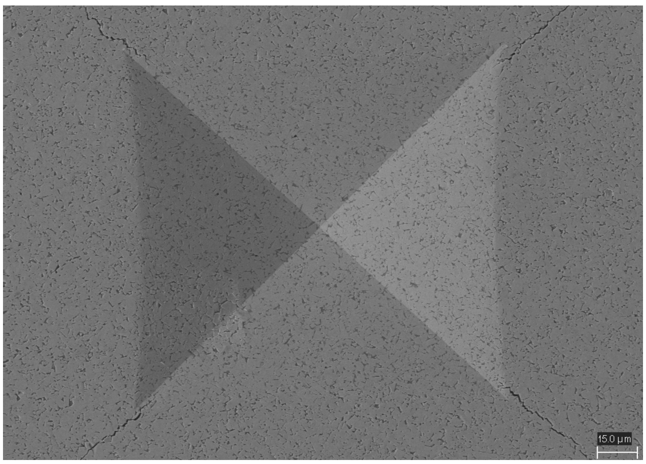


Fig. 7. Vickers indentation in the surface zone, diamond indenter, indentation load, 30kgf in WC+Co tool gradient materials

Vickers Hardness along the gradient changes regularly from high to low, corresponding to surface zone (97%WC+3%Co), intermediate zone and core zone (91%WC+9%Co).The cracks at the corners has been changed with the formation of the cobalt gradient at the samples. Its can be observed at the corner in the surface zone of sample 1421˚C+HIP with WC+ Co two-phase structure. The longest crack length observed in the surface zone.

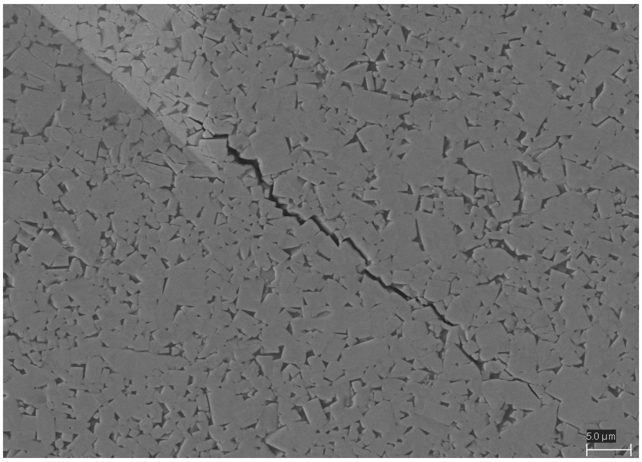


Fig. 8. Micrographs of the crack at the surface zone with WC+Co tool gradient materials

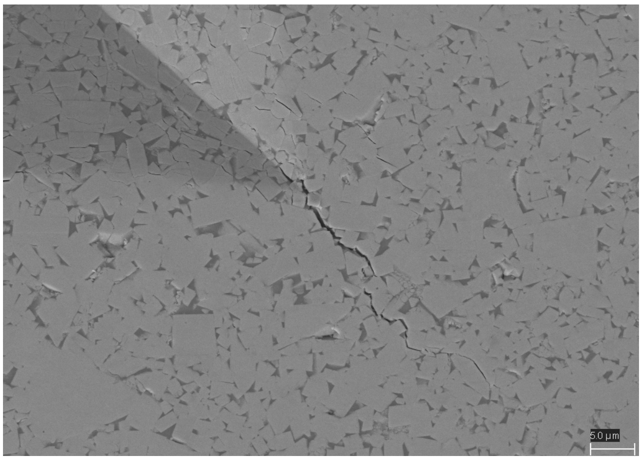


Fig. 9. Micrographs of the crack at the intermediate zone with WC+Co tool gradient materials

Typical HV30 indent image in intermediate zone of the crack at the corner are shown in Fig. 10 The measurement of diagonal lengths shown the longest crack length in surface zone than the intermediate zone.

The Vickers hardness indentations in the core zone show the length of crack is shorter than the ones in the surface zone and the intermediate zone.

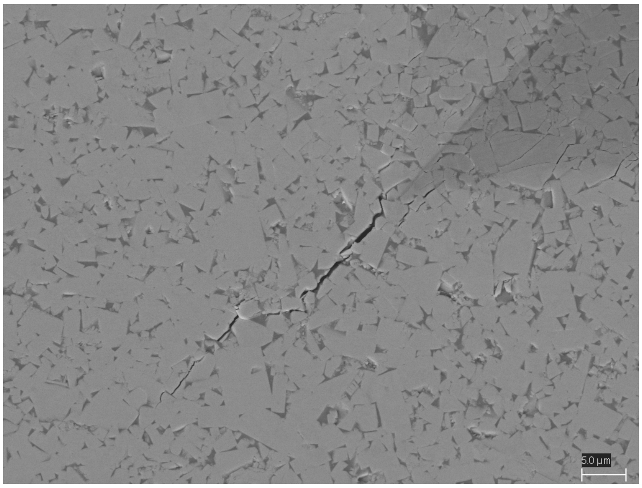


Fig. 10. Micrographs of the crack at the corner zone with WC+Co tool gradient materials

Each measurement point presented in Fig. 11, Fig. 12 and Fig. 13 is loaded with a certain measurement uncertainty, which arises from deviation errors during length measurement.

The results of the hardness and sum of crack lengths measurements are summarizes in one diagram (Fig. 11), a wide measurement band is formed. In overhead, the higher the hardness of the composites (HV30: 1333 to 1388), the longer the cracks were which formed during indention, indicating a decrease in toughness with increasing hardness.

However, at a certain hardness the crack lengths very significantly which indicate that some of the tool gradient materials obviously sample 1424˚C+HIP have better hardness or toughness combinations than others, depending on their composition and microstructure with depending on the temperature. One of the most arguments for better hardness/toughness combinations of WC-Co tool gradients materials is the higher binder (Co) content which can be tolerated in this material for a given hardness level desirable.

The toughness measurement values are presented as Palmqvist fracture toughness and K_{IC} toughness. The figure and figure presents difference changes, but the main characteristics remain the same. Tool gradient materials 1460˚C and 1424˚C+ HIP which are ranking on the upper lines and represent a clear changes in Fig. 12 and Fig. 13 represent optimal hardness/toughness.

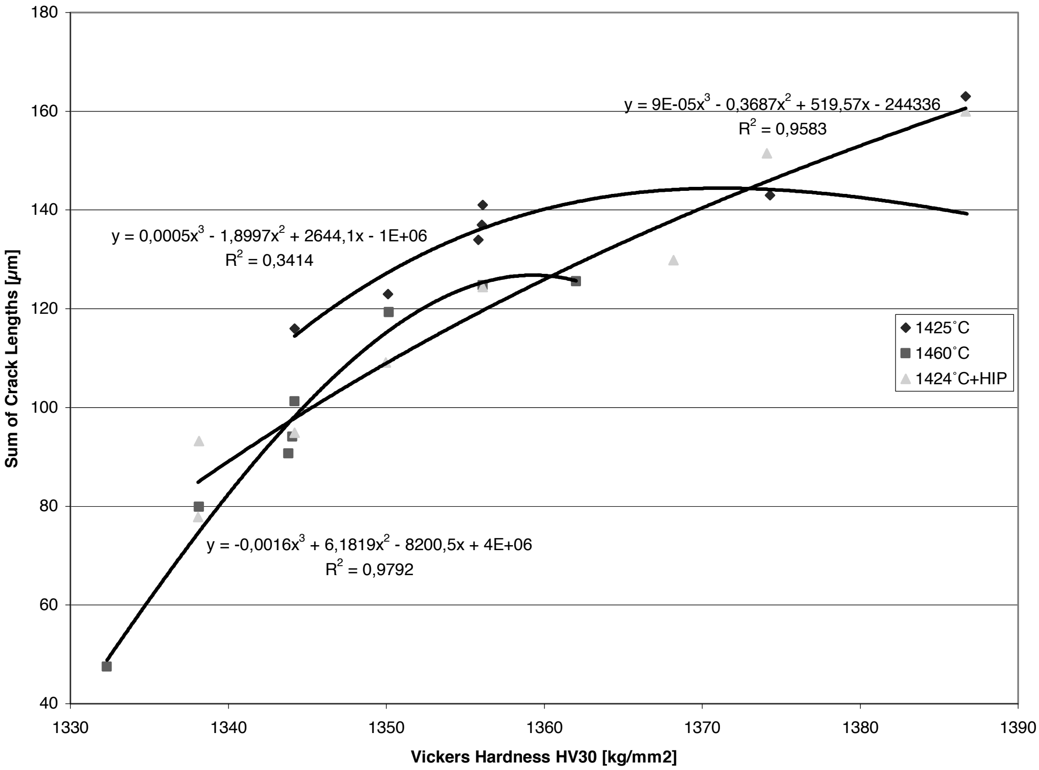


Fig. 11. Sum of crack vs hardness

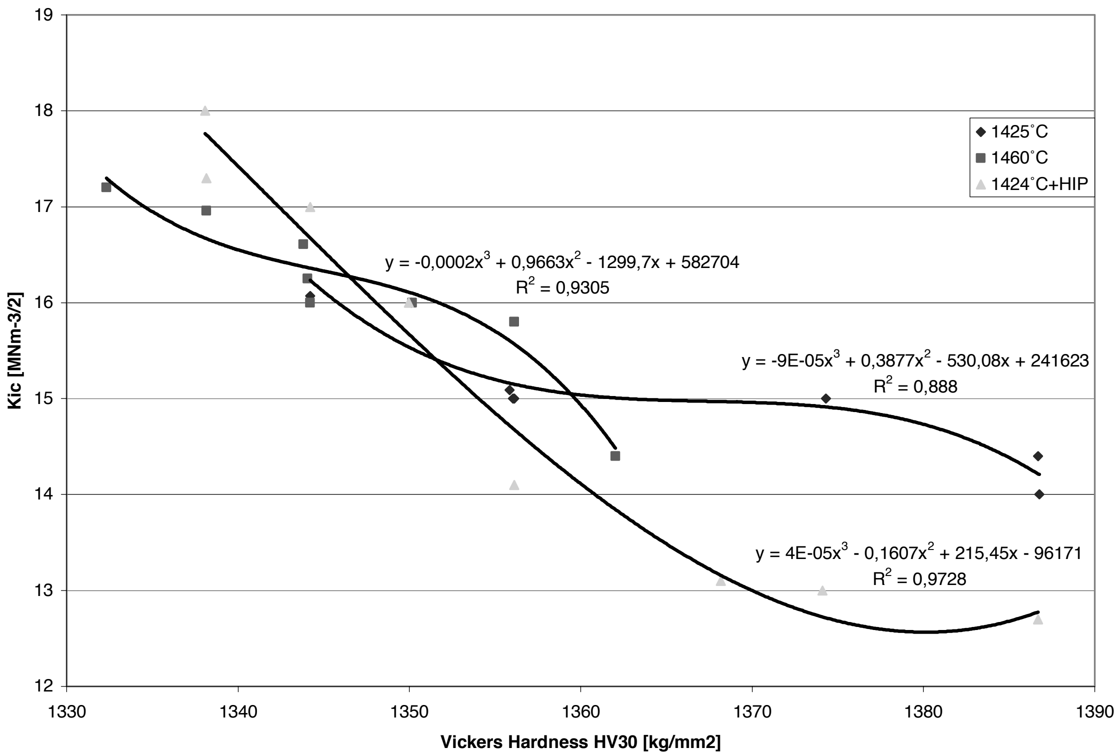


Fig. 12. K_{IC} vs hardness

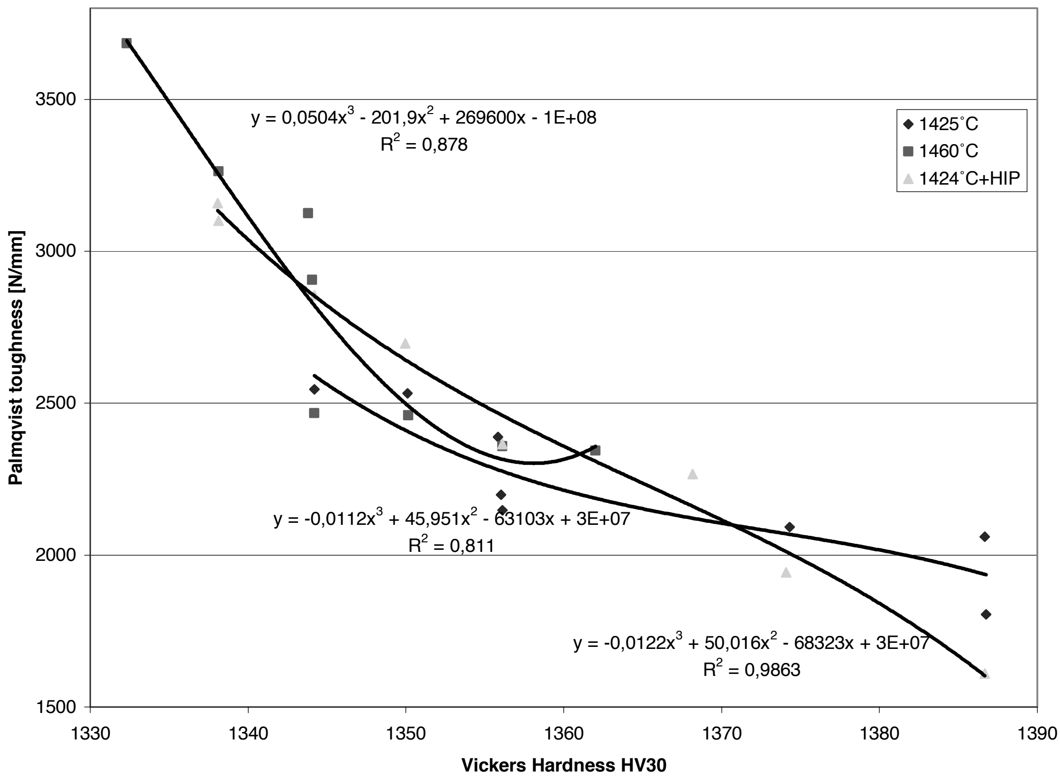


Fig. 13. K_{IC} vs hardness

4. Conclusions

- The aim of this investigation was establish a reliable experimental basis for a comparison of the hardness to toughness relationship of strength gradient WC-Co hardmetals in terms of hardness to Palmqvist and K_{IC} toughness measurements.
- The sintering conditions play an important role in determining the hardness to toughness relationship.
- Palmqvist indention toughness testing can be used to evaluate the hardness to toughness relationship of tool gradient materials. However, a proper preparation technique is very important prerequisite for reliable testing, to eliminated residual compressive stresses.
- The hardness gradient was measured across the hard layer to the soft layer. No delamination was observed along the interface using either the Vickers indentation technique.
- In WC–Co tool gradient materials, continuous and multiple cracks are observed. The cracks can propagate a cross WC crystal grain.
- The toughness in the surface zone , intermediate zone and core zone increase in sequence.
- The results of this study demonstrate that Palmqvist indentation technique is an effective method for characterizations of WC-Co tool gradients materials.
- Further studies are needed to establish the dependence of the Palmqvist dentation behaviour of graded WC–Co materials on the Layer to material properties between the layers, and the macroscopic residual stresses.

References

[1] S. Biamino, A. Antonini, M. Pavese, P. Fiano, C. Badini, $MoSi_2$ laminate processed by the tape casting: microstructure and mechanical properties investigation, Intermetallics 16 (2008) 758-768.

[2] O.O. Eso, P. Fan, Z.Z. Fang, A kinetic model for cobalt gradient formation during liquid phase sintering of functionally gradem WC-Co, International Journal of Reinfractory Metals and Hard Materials 26 (2008) 91-97.

[3] J.J. Bucki, T. Wejrzanowski, Quantitative metallography of Armico-iron with microstructure gradient, Materials Engineering 4 (2001) 237-240.

[4] G. Matula, L.A. Dobrzański, Structure and properties of FGM manufactured on the basis of HS6-5-2, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 101-104.

[5] G.S. Upadhyaya, Cemented Tungsten Carbides, Noyes Publications, 1998.

[6] G.H. Lee, S. Kang, Sintering of nano-sized WC-Co powders produced by a gas reduction-carburization process, Journal of Alloy and Compounds 419 (2006) 281-289.

[7] Y. Liu, H. Wang, Z. Long, P.K. Liaw, J. Yang, B. Huang, Microstructural evolution and mechanical behaviours of graded cemented carbides, Materials Science and Engineering A 426 (2006) 346-354.

[8] L.A. Dobrzański, B. Dołżańska, G. Matula, Influence of carbide (W, Ti) C portion on the structure and properties of TGM manufactured on cobalt matrix, Archives of Materials Science and Engineering 28/10 (2007) 617-620.

[9] W. Lengauer, K. Dreyer, Functionally Graded hardmetals, Journal of Alloys and Compounds 338 (2002) 194-212.

[10] L.A. Dobrzański, A. Kloc-Ptaszna, A. Dybowska, G. Matula, E. Gordo, J.M. Torralba, Effect of WC concentration on structure and properties of the gradient tool materials, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 91-94.

[11] J. Ma, G.E.B. Tan, Processing and characterization of metal-ceramics functionally gradient materials, Journal of Materials Processing Technology 113 (2001) 446-449.

[12] R.M. German, A-Z of Powder Metallurgy, Elsevier, 2005.

[13] J.L. Johnson, R.M. German, Liquid Phase Sintering of Functionally Graded W-Cu Composites, Proceedings of the 16th International Plansee Seminar, Vol. 2, 2005, 116-130.

[14] C. Larsson, M. Odén, X-ray diffraction determination of residual stresses in functionally graded WC–Co composites, International Journal of Refractory Metals and Hard Materials 22 (2004) 177-184.

[15] M.T. Laugier, Palmqvist toughness in WC-Co composites viewed as a ductile/brittle transition, Journal of Materials Science Letters 6 (1987) 768-770.

[16] W.D. Schubert, H. Neumeister, G. Kinger, B. Lux, Hardenss to toughness relationship of fine-grained WC-Co hardmetals, International Journal of Refractory Metals and Hard Materials 16 (1998) 133-142.

[17] Z. Li, W. Yuan-Jie, Y. Xian-Wang, Ch. Shu, X. Xiang-Jun, Crack propagation characteristic and toughness of functionally graded WC–Co cemented carbide, International Journal of Refractory Metals and Hard Materials 26 (2008) 295-300.

[18] G. Matula, L.A. Dobrzański, B. Dołżańska, Structure and properties of TGM manufactured on the basis of cobalt, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 151-154.

[19] C.T. Peters, The relation ship between Palmqvist indentation toughness and bulk fracture toughness for some WC-Co cemented carbides, Journal of Materials Science 14 (1979) 1619-1623.

[20] A. Kawasaki, R. Watanabe, Concept and P/M fabrication of functionally gradient materials, Ceramics International 23 (1997) 73-83.

[21] R. Spiegler, S. Schmadder, L.S. Sigl, Fracture toughness evaluation of WC-Co alloys by indentation testing, Journal of Hard Materials 1/3 (1990) 147-158.

[22] L.A. Dobrzański, A. Kloc, G. Matula, J.M. Torralba, Structure and properties of the gradient tool materials of unalloyed steel matrix reinforced with HS6-5-2 high-speed steel, Archives of Materials Science and Engineering 28/4 (2007) 197-202.

[23] H. Zhang, Z.Z. Fang, Q. Lu, Characterization of a bilayer WC–Co hardmetal using Hertzian indentation technique, International Journal of Refractory Metals and Hard Materials 27 (2009) 317-322.