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Functionally graded cermets

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Materials

ABSTRACT

Purpose: Cermets have very good plasticity and high hardness. Functionally graded cermets secure obtaining of cutting tools with hard wear resistance surface layer and ductile body frame. A new FGM was obtained using P/M method.
Design/methodology/approach: Materials were obtained using free sintering at vacuum and the high temperature-high pressure sintering method. Functionally graded cermets have more amount of hard phase in the surface layer and lower participation of this phase in the body frame. FGMs were prepared by the layers pressing method and the centrifugal deposition method.
Findings: Material with 55 wt.% of TiC and 45 wt.% of (Ni,Mo) was prepared. The phase's composition of this material was analysed. The ring structure of material and complex carbides formation was confirmed. The gradient of the phase composition and hardness measurement are presented. Phase composition of FGM strongly depend on conditions of centrifugal sedimentation process: duration, rotation speed, solid content, dispersive liquids. The centrifugal deposition process of powders forming guarantees gradient phase composition for materials obtaining the powder metallurgy methods. The FGM obtained by powders forming method should be sintered using pressure processes in a closed containers (or special assembly) because of materials high porosity which is a result of various chemical contents of this same material parts.
Practical implications: Due to their low chemical affinity to steel and the resistance for high temperatures oxidation, cermets have better cutting properties than carbides. Application of cermet inserts guarantees the high quality of machined surface (low roughness). Cermets could be used in "dry cutting" processes.
Originality/value: The centrifugal deposition method for powders with phases content gradient forming is original value.
Keywords: Tool materials; Functionally graded materials; Centrifugal deposition; HP sintering

1. Introduction

Cermet is an acronym derived from the words ceramic and metal, which are two major phases of this material. The ceramic phase includes the carbides, nitrides and carbonitrides of titanium, molybdenum, tungsten, tantalum, niobium, vanadium, aluminum and their solid solutions with titanium nitride as the major constituent. The metallic binder phase consists of nickel alloyed with cobalt or molybdenum and constituents of the ceramic phase, depending on their solubility [1,2,3]. The wear and corrosion-resistance properties of the carbide or nitride matrix are combined with the enhanced toughness of the metallic phase. The wear behaviour of the cermet materials is a function of both hardness and toughness [4,5,6]. Ceramics particles react with the metal bonding phase, which is in liquid solution resulting in densification of the composition through particle rearrangement by capillary forces [1,7]. The most popular method of the cermets obtaining is powder metallurgy processing techniques with free sintering or using sintering under pressure, for example HIP method [8].

Metal bonding phase guarantees the material good wettability and adhesion to the ceramic phase. Good adhesion forces between ceramics and metal bonding phase results the higher toughness due to crack propagation through the ductile binder phase. However presence of the metal phase has influence on the cermets hardness decreasing. During the cermets sintering process there is almost not grain growth process. The first cermet TiC-Mo_2C-(Ni,Mo,Cr), Titanit S was obtained by Plansee in 1930 but this material was not introduced because of their brittleness and problems with the materials brazing to the tools body. The TiC – (Ni,Mo) cermets were introduced by Ford Motor Co. in 1960 [9]. The success of cermets is based on their superior wear resistance for machining ferrous and non-ferrous metals over a wide range of cutting speeds. At higher temperatures, cermets are oxidation resistances and they have better cutting properties, very good adhesion and diffusion wear resistance comparing to the cemented carbides. Therefore, they could work without lubricants. Cermets guarantee better surface quality after machining. Cermets have some defects in compare to the cemented carbides tool materials such: lower fracture toughness (but higher than other ceramic tool materials), lower resistance for the plastic deformation, higher thermal expansion [9]. The lower temperature shock resistance of cermets limits the application of coolants in turning, grooving and threading. Costs of cermets production are lower then cemented carbides.

Functionally Graded Materials are composite materials with a continuous spatial change of properties [10,11,12]. The first industrial application of the Functionally Graded Materials (FGM) concept have emerged in production of cermets cutting tools in 1996 by Sumitomo Electric Industries, Ltd. In this material, in-situ formation of the graded structure was used. A homogenous mixture of TiCN, 40wt.% WC, 10wt.% Co and 5wt.% Ni powders was used for the green compact. They were sintered at 1670 K in vacuum and then held for one hour under a controlled nitrogen pressure. During this heat treatment, the WC in the outer layer dissolved in the molten Co-Ni and precipitated at the surface as a solid solution of (Ti,W)(C,N). The molten metal moved from the surface by controlling the atmosphere and the cooling rate. By eliminating the surface metal layer, a high to low gradation in hardness from the surface to the interior was reached [13]. The thin surface layer, which consist of almost 100% (Ti,W)(C,N) ceramic without the metal binder, has high hardness of 22 GPa. The high hardness and high compressive stress at the surface and high toughness in the interior, improve wear resistance about two times and tool life about five times compared with conventional cermet tools. Functionally graded cermets have more amount of hard phase in the surface layer and lower participation of this phase in the body frame. FGMs secure obtaining of cutting tools with hard wear resistance surface layer and the ductile body frame. The coated tools have higher wear resistance and toughness than those of the FGM tools, but sometimes delaminations of coating film occur and shorten the tool life. The in-situ formation or one-step formation of FGMs is the nearest route for economical production. Net-shape formation of complex form FGMs is costly, but useful for special applications [14]. The present work focuses on the TiC(Ni,Mo) cermet with the phases content gradient obtaining by the centrifugal deposition of powders [15].

2. Experimental procedure

The homogenous mixture of 55 wt.% TiC and 45 wt.% (55Ni,45Mo) powders was formed into discs (Φ =15mm, h =5 mm) by pressing in a steel matrix under pressure of 200 MPa. The characteristics of powders is presented in Table 1.

Table 1.
Characteristic of powders applied for cermets preparing

Powder	Average grain size, [μm]	Purity, %	Apparent density, [g/cm^3]	Producer
Mo	2	99,9	10,22	GoodFellow, UK
Ni	3	99,4	8,99	Zakłady Metalurgiczne Trzebinia, Polska
TiC	1,4	98,5	3,386	H.C.Starck

Compacts were obtained using the free sintering method in vacuum atmospheres in the GERO HTK 8/22G furnace and using the pressure sintering method. For High Temperature-High Pressure (HT-HP) method samples were heated using an assembly provided with an internal graphite heater. Compacts from the HT-HP method were obtained at pressure of 4.0±0.2 GPa and temperature about 1670 K in the high pressure Bridgman type apparatus. Samples were the HT-HP sintered for 1minut.

FGM-samples were prepared using a powder metallurgical process by the layers pressing method. Metallic and ceramic powders were mixed in several proportions. After mixing process, the mixtures were stacked layer by layer with a concentration difference in components content like in the Figure 1, using pressing method. Next, functionally graded materials (FGM) were prepared by the sedimentation method. The mixture of 55 wt.% of TiC and 45 wt.% of (55Ni,45Mo) powders was dispersed by the ultrasonic method in solution of water with organic additives. This suspension with 0.3 wt.% of solid content was introduced into special dismountable centrifugal tubes. Deposition process was carried out in ultra centrifuge UP 65M (prod. Germany) with rotational speed of 20000rpm/min for 20 and 40 minutes. The deposited materials were removed from the centrifugal tubes and directly put into graphite heaters. After that, materials were dried and put into the special assembly for the HT-HP sintering. Materials were sintered at pressure of 4.0±0.2 GPa and temperature about 1620 K, in the high pressure Bridgman type apparatus. Materials were HT-HP sintered for 1 minute.

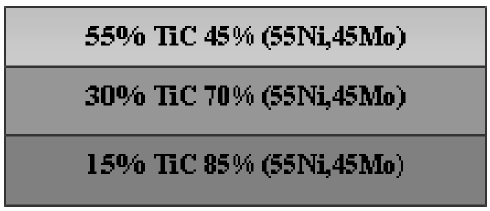


Fig. 1. Scheme of TiC – mixture (Ni, Mo) material with the phases content gradient, prepared by the layers pressing method

Sintered compacts for hardness measurement were prepared by lapping them with diamond abrasive. The Vickers indentation tests were performed on compacts, using FM-7 microhardness tester. The applied load for non graded materials was 0.9 N, for FGM materials was 0.450 N. The microstructures and chemical composition were observed using JEOL JSM 6460 LV scanning electron microscopy (TEM) with Energy Depressive Spectrometer EDS.

3. Description of achieved results of own researches

The specific feature of titanium carbide alloys is a ring structure of carbide grains, as in Figure 2. The elements concentration analysis by EDS spectra in the grain with metal contact zones, in the center of grains and in alloys, respectively to points in Figure 2 were presented in the Table 2.

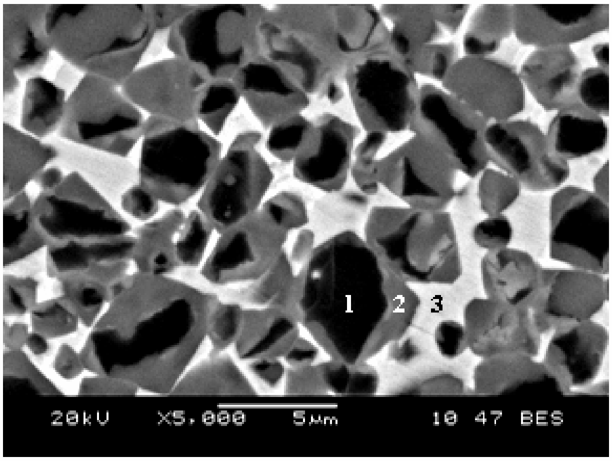


Fig. 2. Microstructures of the TiC-(Ni,Mo) cermet after sintering at vacuum atmosphere: 1) TiC grain (black colour), 2) (Ti,Mo)C ring (gray colour) and 3) Ni-Mo matrix

Table 2.
Elements concentration in three zones of the TiC-(Ni,Mo) cermet: 1- grain (black); 2 – ring (gray); 3 – matrix (light)

Element contents	Concentration in grain no 1, wt.%	Concentration in ring no 2, wt.%	Concentration in matrix no 3, wt.%
C	24.008	13.846	3.933
Ti	72.791	60.560	17.696
Mo	3.201	25.595	5.771
Ni	-	-	70.993
Others*	-	-	1.608

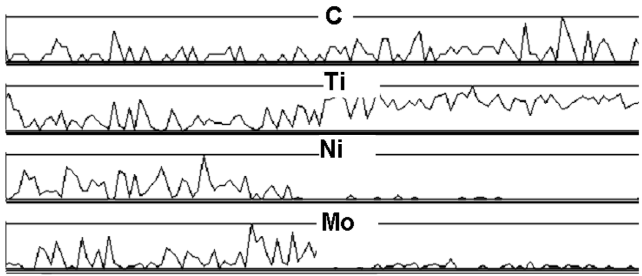
*elements from waters organic liquid

The rings microstructure of material, composed of TiC-(Ti,Mo)C-(Ni,Mo) was formed. The complex carbides (Ti,Mo)C formation was confirmed. Hardness *HV1* of non-gradient cermets with 45 wt. % of Ni and Mo mixture (55;45) from the free sintering method is 18.2± 1.0 and its density is 5.84 g/cm^3.

The functionally graded materials prepared using the layered pressing method and free sintering methods have high porosity. It is a result of various content of layers and various conditions of sintering process for each of these layers.

In the Figure 3 microstructure and elements distribution of the cermet with the phases composition gradient, obtained by the centrifugal deposition method were presented.

a)



b)

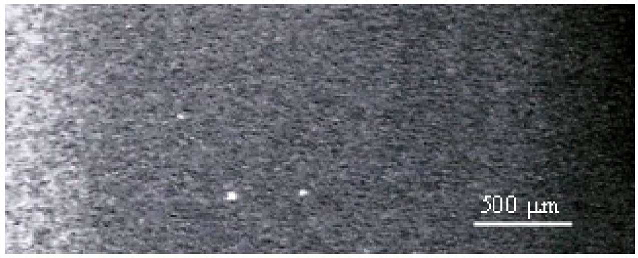


Fig. 3a). Elements: C, Ti, Ni, Mo distributions in cermet with the gradient of phases content; 3b) Microstructure of the graded cermet

The gradient of hardness measurements from the top surface to the bottom surface of sample is presented in Figure 4.

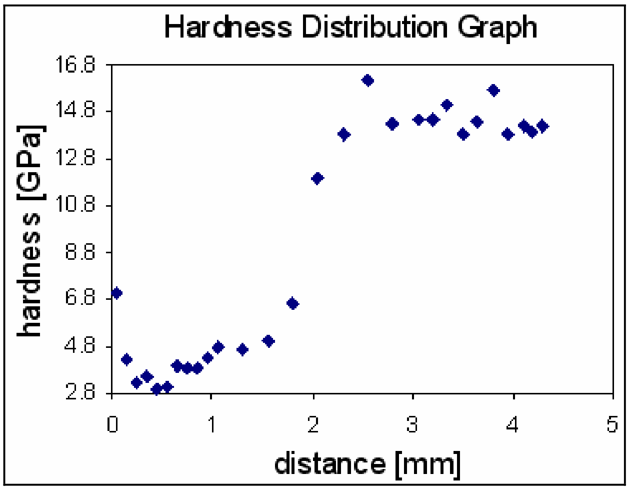


Fig. 4. The hardness *HV0.5* distribution in the cermet with graded microstructure; material was prepared by the centrifugal deposition method

4. Conclusions

- The specific feature of titanium carbide in the TiC-(Ni,Mo) cermets is a ring structure of carbide grains. The complex carbides (Ti,Mo)C formation was confirmed.
- The metal – ceramic functionally graded materials obtained by the powder forming should be sintered using pressure processing in closed containers.
- Free sintering is not suitable for the powder forming samples, because of high porosity, which is a result of various chemical contents of these same material parts and various conditions of these parts sintering.
- The centrifugal deposition process guarantees graded structures of phase compositions.
- Phase composition of functionally graded materials strongly depends on conditions of the centrifugal sedimentation process (duration, rotational speed, solid content, water organics liquid).

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