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Internal Stresses in Diffusion Bonded Joints

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Mechanical properties of “cermet-steel” joints have been studied. Chromium and titanium based cermets were joined using diffusion welding and bonding processes. Several types of interlayers and amorphous filler metals were tested. Vacuum bonded joints using amorphous filler metals have shear strength up to 260 MPa – 350 MPa. The applicability of mechanical metallization process with rotating titanium brushes to get a thin film on the cermets was tested. Electrochemically and mechanically deposited films of Ag, Ni and Ti were used to improve the wettability and strength of the joints. Internal stresses in the diffusion bonded joints depend on the type of a cermet and the interlayer used in the joining process.

Keywords: hardmetals, cermets, diffusion welding, brazing, internal stresses.

1. INTRODUCTION

Bimetallic compounds “hardmetal + steel” are mainly used for production of cutting and cold forming tools, as well as wear resistant machine parts. In many cases hardmetals or cermets based on titanium and chromium carbides with Fe-Ni, Ni-Mo and Ni binder were also used for products working in adhesion wear or corrosive environment conditions. Fair durability of bimetallic tools depends on the quality of the joint “cermet + steel”. So far bimetallic cutting tools have been most widely produced by brazing using various traditional filler metals. Shear strength from 150 MPa up to 300 MPa – 450 MPa has been obtained for WC-based hardmetals. Diffusion welding process for joining TiC and Cr_3C_2 based cermets with steel has been successfully utilised. Shear strength up 250 MPa – 350 MPa was obtained [1 – 2]. Utilization of the brazing process, using Cu and Ag based traditional filler metals (TFM) to join cermets with steel, is often restricted by the wettability problem. New amorphous filler metals (AFM) produced using rapidly solidified technology have good prospect due to their chemical composition, as well as compatibility with cermets [1]. According to literature some grades of Ti and Ni based AFM have been tested for joining cermets with steel [3 – 5], but the most prospective and available AFM of grade MBF 20 has not been tested.

The AFM have the following advantages over traditional filler metals:

- high ductility,
- good wettability,
- good flowing properties,
- lower melting temperature,
- wide range of materials suitable for brazing,
- small amount of oxides.

The disadvantages of the AFM are:

- low thermal stability (up to 600 °C),
- only one heating cycle is used for joining,
- brazing must be carried out only in protective atmosphere.

Various interlayers, in the form of foils or coatings, between the surfaces to be joined perform a number of functions, such as:

a) distribution of stresses at the interface and reduction of stress concentration,
b) accommodation of some differences in expansion and contraction during heating and cooling,
c) promotion of wetting and prevention of oxidation of the joint interface.

Some diffusion bonding interlayers have been produced by depositing thin coatings by electrochemical and vacuum methods. Another alternative is to use active brazing filler metals. Such an active element as Ti has been added to traditional Ag-Cu filler alloy in the form of powder or foil to promote wetting in brazing of ceramics [5]. However, electrochemical methods of deposition of Ti thin films are expensive and not environmentally friendly.

Mechanical metallization method for joining ceramics was developed by the Julich Research Center. The mechanical metallization was performed using a rapidly rotating (9000 rpm) titanium brush [5]. The brush wires were frictioned against a harder surface, and a thin film with the thickness up to 5 μm was deposited. The metallizing process is simple and cost effective and has not been tested for treating hardmetals and cermets. The reliability of bimetallic joints depends on the level of the residual internal stresses induced during cooling after joining dissimilar material combinations. The level of the residual stresses depends on the difference in the thermal expansion coefficients of hardmetals related to steel and the interlayers used in the joining process. Internal stresses in bimetallic joints cause deformation and cracking of hardmetal. The level of residual stresses in the cermet-steel bimetal joints after diffusion welding and vacuum brazing has not been covered sufficiently in literature. Experimental methods based on the determination of deformation bimetallic specimens or coatings have been used. Some preliminary results about internal stresses in diffusion welded joints”cermet-steel” are given in [2].

The objective of the present work was to study: the level of internal residual stresses in joints “cermet – steel”, the possibilities of utilization of mechanical metallizing

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process for coating hardmetals and cermets, the influence of thin Ag, Ni and Ti coatings on the strength of the joints.

2. EXPERIMENTAL

Titanium carbide based cermets with 30 % and 40 % of steel binder (8 % and 14 %) Ni in the binder phase (grades TiC70FeNi14 and TiC60FeNi8 respectively) were tested. Cermets with Ni binder phase TiCNi50 were also tested.

Chromium carbide based cermet with 30 % Ni-Mo binder (grade CrNi30) was in the focus of the investigation. Hardmetal on the basis of WC with 15 % Co-binder as a comparative composition, was also tested.

The specimens had the diameter 17.0 mm – 18.6 mm and the height of 10 mm were. Carbon structural steel of the grade C45 was used for counterparts.

The hardmetal and steel counterparts to be bonded were ground to the surface finish $R_a \leq 1$ µm. Ni, Ni-Fe foils with the thickness of 0.1 mm were used as the interlayers between hardmetal-steel to promote diffusion and relax internal stresses. AFM foils with the thickness of 50 µm and the designation S1311, S1201, S1204 and MB F20 were used. Copper based filler metal (grade F-Bronze), as well as Ag-based filler metal (grade Argobraze 49H) were used as traditional materials for bonding carried out in the air.

The chemical composition and melting temperatures of filler metals are given in Table 1.

Fluxes with designation T125, T300 and F100 were used. The diffusion welding and brazing processes were conducted in a special welding equipment UDS-4 in vacuum (0.1 Pa). The joints were heated by induction heating. The diffusion welding parameters were: temperature – 1100 °C, pressure – 8 MPa and time – 10 min.

Two series of specimen were joined without using interlayer foils. The foils of AFM were placed between the hardmetal-steel parts under low pressure (500 N) with the induction heating for 1 min. In some cases the brazing process was carried out in the air. Some cylindrical specimens were mechanically metallized with Ti. Specimens were clamped to the spindle of a lathe by a chuck. Rotating Ti brushes passed the end surface of cermets and coated them with the film of titanium. The mean thickness of these coatings was 5 µm and the optimal process parameters were used.

To estimate the strength of the joints, the shear strength of the respective dual specimen was determined.

As an additional characteristic of reliability, the level of residual internal stresses in hardmetals was evaluated. The Treuting-Read method (stepwise removal of rectangular material strips) was used.

Rectangular shape hardmetals with the length of 50 mm, the width of 8.3 mm and the height of 4.5 mm were joined with steel parts with the height of 20 mm. The height of the steel counterparts was machined to the value of 4.5 mm.

Due to the compressive residual stresses in the joint surface the displacement or deformation of the central part f_{tot} was measured by an indicator. Then the steel part was removed, and the displacement f_{pl} characterized the plastic deformation of the hardmetal. The elastic deformation f_{el} was calculated as the difference $f_{\mathrm{tot}} - f_{\mathrm{pl}}$.

The residual internal stresses were calculated according to the formula:

$$\sigma_S = \frac{f_{\mathrm{el}}}{l^2}\left[E_{\mathrm{hm}} + \frac{E_{\mathrm{hm}} \cdot h_{\mathrm{hm}}^3 + E_{\mathrm{st}} \cdot h_{\mathrm{st}}^3}{3h_{\mathrm{hm}}\left(h_{\mathrm{hm}} + h_{\mathrm{st}}\right)}\right], \tag{1}$$

where f_{el} is the elastic deformation, l is the length of a specimen, E_{hm} and E_{st} are the modules of elasticity of the hardmetal and steel, h_{st} and h_{hm} are the thicknesses of the steel and hardmetal parts.

3. CHARACTERIZATION OF METALLIZED SURFACE

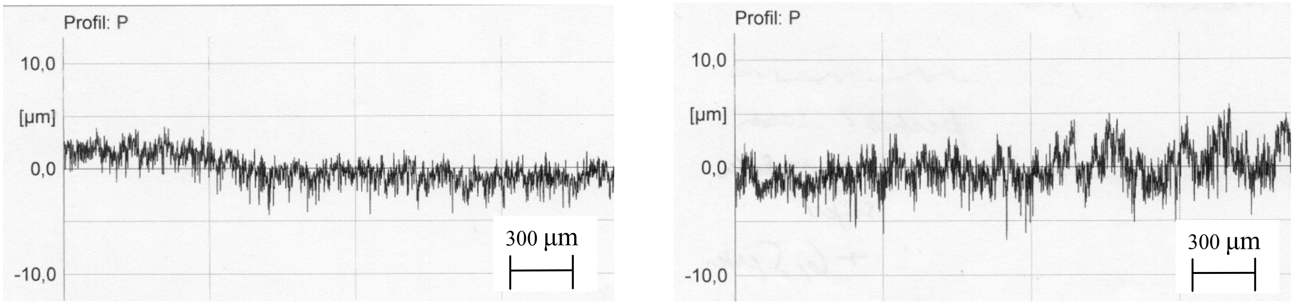
Surface roughness of the end surfaces of ground and mechanically metallized cermets was described using the authentic mean value (R_a) and the maximum roughness (R_z). Laser-based profilograph produced by company Mahr was used. The roughness measurements of one specimen were carried out in two perpendicular directions. There was no significant difference in the roughness values. The surface roughness measurements results are given in Table 2 and photograph of surface on Fig. 2. The results show that after metallization the surface roughness increased, especially for the parameters R_z and $R_{\max}$ (Fig. 1). In the process of wear, the titanium was deposited on the necks of the roughened surface. The surface roughness distribution was not uniform in the radial direction of the specimens.

Table 1. Chemical composition of AFM and TFM

Grade	Type	Composition	Melting T, °C	Brazing T, °C
S1201	AFM	52Ti-24Cu-12Zr-12Ni	820	900
S1204	AFM	72Cu-28Ti	825	900
S1311	AFM	70Ni-16Co-5Fe-4Si-4B-0,4Cr	985	1020
MBF20	AFM	82Ni-7Cr-4Si-3B-3Fe	1025	1070
F-Bronze	TFM	58Cu-38Zn-2Mn-2Co	890 – 930	1000
Argobraze 49H	TFM	49Ag-Cu-Zn-Mn-Ni	680 – 705	750

Table 2. Characteristics of metallized surface

Parameter	Cr_3C_2 cermet			TiC cermet		
	Before metallization	After metallization		Before metallization	After metallization	
		Average	In the centre of a sample		Average	In the centre of a sample
R_a, µm	0.65	1.06 – 1.28	1.40	0.68	1.2 – 1.3	1.4
R_z, µm	6.67	10.4 – 13.4	13.5	6.24	11.0 – 12.0	12.8
R_{max}, µm	7.0	12.2 – 13.2	21.6	7.33	12.6 – 16.3	18.0



a b

Fig. 1. Profilograms of surfaces in radial direction: a – before metallization, b – after metallization

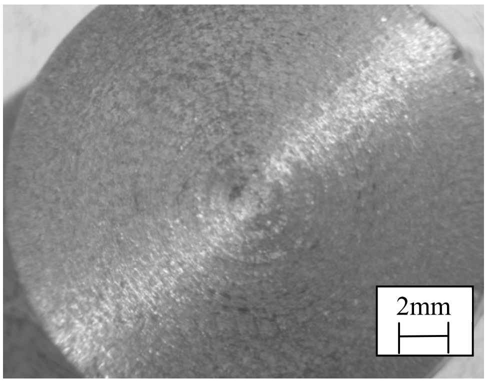


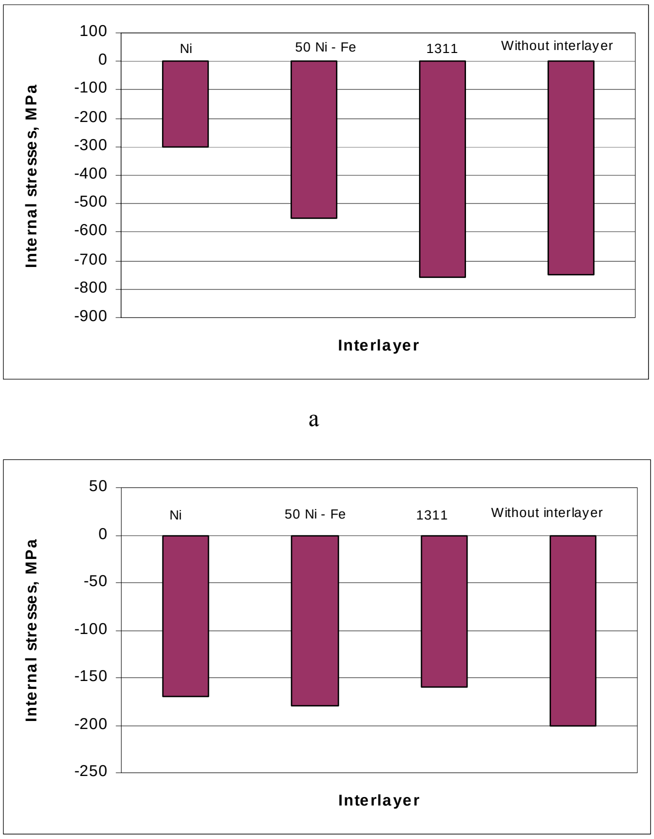
Fig. 2. Photo of metallized cermet specimen

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

The shear strength of joints brazed in vacuum and air using different AFM and TFM are given in Table 3.

The residual internal stresses in the diffusion bonded joints are given in Fig. 3. WC-based hardmetals are characterized with a high level (up to 740 MPa) residual stresses, particularly in the diffusion welded joints without interlayer metals. In TiC cermet-steel joints internal stresses are up to 5 times lower than in WC based hardmetal ones. Vacuum brazed AFM joints of TiC cermets have internal stresses practically of the same level, when Ni interlayers were used.

The shear strength of "WC-steel" joints produced by using amorphous filler foils was lower than the strength of the diffusion welded ones. The differences in the strength of the joints of TiC and Cr_3C_2 based cermets performed by vacuum brazing process and ones produced by diffusion welding are relatively small. The most prospective AFM for joining TiC based cermets are alloys of Cu-Ti (grade S1204) and Ni-Co-Fe (grade S1311) type. The chemical composition of the AFM of the grade S1204 is more compatible with the basic structure of a cermet, and the AFM of grade S1311 – with the binder composition.



a

b

Fig. 3. Internal residual stresses in jboints of WC-Co and TiC-steel hardmetals using Ni, 50Ni-Fe permalloy, AFM grade 1311 foils and without interlayer: a – hardmetal HA15, b – cermet TiC 60FeNi8

Table 3. Shear strength of joints. Brazing in the air (a) and vacuum (v)

Cermet	Filler metal	Flux	Brazing conditions	Shear strength, MPa
TiCN50	S1311	–	v	260
	S1204	–	v	300
	S1311	T125	a	190 – 210
	Argob 49H	T300	a	195
	Bronze F	–	a	200
	MBF20	–	v	170
CrNi30	S1311	–	v	200
	S1201	–	v	230 – 350
	S1311	T125	a	200
	Argob 49H	T300	a	75
	Bronze F+ +Ag coating	T300	a	190
	Argob 49H+ +Ni coating	T300	a	200
HA15	S1311	–	v	240
	S1311	F100	a	175

CONCLUSIONS

1. The internal stresses in the diffusion welded and brazed “hardmetal-steel” joints depend on the type of the hardmetal and the interlayer chemical composition. TiC based cermets joints demonstrated up to 5 times less internal stresses compared with WC based hardmetals.
2. The brazing in the air using amorphous filler metals decreases significantly the shear strength of TiC based joints.
3. Traditional Cu and Ag – based brazing filler metals may be used for joining TiC based cermets when the process is carried out in the air.
4. The shear strength of the joints from cermets on the base of Cr_3C_2 may be improved by coating the cermets with different coatings (Cu, Ni). Mechanical metallizing process with rotating brushes may be utilized for coating cermets and hardmetals with interlayer.

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