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Influence of Co and W powders on viscosity of composite solders during soldering of specially shaped diamond-abrasive tools

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Abstract. The influence of Co and W powders on the structure and the viscosity of composite solders Sn-Cu-Co-W used for the manufacture of the specially shaped diamond tools has been studied. The solders were obtained by mixing the metallic powders with an organic binder. The mixtures with and without diamonds were applied to steel rollers and shaped substrates. The sintering was carried out in a vacuum at 820 ° C with time-exposure of 40 minutes. The influence of Co and W powders on the viscosity solders was evaluated on the basis of the study of structures and according to the results of sintering specially shaped diamond tools. It was found that to provide the necessary viscosity and to obtain the uniform diamond-containing layers on the complex shaped surfaces, Sn-Cu-Co-W solder should contain 27–35 vol % of solid phase. This is achieved with a total solder content of 24–32 wt % of cobalt powder and 7 wt % of tungsten powder.

1. Introduction

The specially shaped diamond-abrasive tools are used in mechanical engineering for machining parts from hard metallic and ceramic materials as well as for dressing of grinding wheels. Use the specially shaped diamond-abrasive tools instead of the standard tools of simple shape in many cases allows one to significantly improve the accuracy and productivity of processing. Application of abrasive tools with specially shaped working surfaces is the only possible for some types of work.

The working surface of some types of diamond tools is quite complex. It consists of elements of circles and has ledges and sharp edges [1-3]. At the present time diamond-containing coatings on such surfaces are formed by electroplating or vacuum brazing. Nickel and chrome binders are used during electroplating. Nickel base alloys containing additives of metals adherent-active to diamond such as Ti, V, Mn, Si, Zr, Cr [4-6] are mainly used as binders in the case of vacuum brazing. Binders formed during electroplating and vacuum brazing do not always have the sufficient resistance to abrasive wear caused by the action of the particles of the processed material. Besides, brazing does not allow diamond-containing coatings to be obtained on the sharp edges of tools and parts and form multilayer diamond-containing coatings. Nickel soldering is carried out at high temperatures of about 1000 ° C which leads to graphitization and diamonds destruction and deterioration of diamond-containing composites properties.

The problem of obtaining diamond-containing layers on the complex shaped surfaces can be solved using composite solders which contain metal powders of a refractory filler and a low-melting matrix [7]. The presence of the low-melting matrix ensures a reduction in the sintering temperature. The refractory filler not melting at the sintering temperature increases the viscosity of the solder and prevents its draining from covered surfaces. And this makes it possible to obtain diamond-containing layers on tools and details of complex shape. The mutual diffusion of the liquid phase components and the refractory filler during sintering leads to the formation of the metallic binder which consists of hard refractory structural components. The selection of the composite solders components was submitted in the works [7, 8] from the point of view of interaction of solders with diamond and the wear resistance of the resulting diamond-containing layer. It is determined that it is effective to use the powders of tin and copper for obtaining the liquid phase of solder, and cobalt and tungsten powders are used as refractory fillers. At the same time, the influence of various factors on the viscosity of composite solders has not been studied sufficiently.

The purpose of this paper is to determine the influence of the composition and structure of Sn-Cu-Co-W composite solders on their viscosity and, on this basis, to develop the solder with a high viscosity providing obtainment of diamond-containing coatings of large thickness on the specially shaped surfaces of tools.

2. Materials and methods

The composition of researched solders is shown in Table 1. The powders of tin, copper, cobalt and tungsten of technical purity grade were used for preparation of composite solders. The powder particles were uniaxial and had the following sizes: tin of 17–30 µm, copper of 45–70 µm, cobalt of 1–2 µm, and tungsten of 6–20 µm. The content of tungsten powder in all solders was 7 wt%. The ratio of tin to copper in all solders was the same, Sn / Cu = 0.36.

The 5% aqueous solution of polyvinyl alcohol was added to the mixture as a binder in the amount of 12% from the weight of the metallic powders.

Table 1. Composition of the Sn–Cu–Co–W solder

Sample no.	Component content, wt %			
	Co	Sn	Cu	W
1	18	20	55	7
2	20	19.5	53.5	7
3	22	19	52	7
4	24	18.5	50.5	7
5	26	18	49	7
6	28	17.5	47.5	7
7	30	17	46	7
8	32	16.5	44.5	7

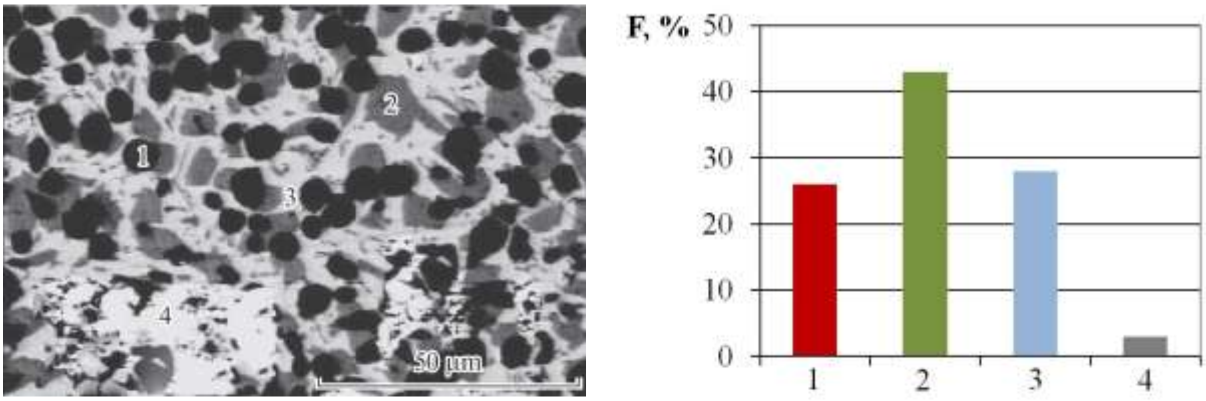
Composite solders without diamonds were inflicted to cylindrical rollers of 20 mm in diameter made from the steel St3 with the thick layer of 2.5 mm. The mixture of solder with diamonds AS150 (400/315 µm is the grain size), containing 25% of diamonds in the volume, was inflicted to the shaped rollers made of steel 45 with the maximum diameter of 85 mm, and the thick layer of 2.5 mm. The samples with the inflicted solder were dried and sintered in a vacuum at the temperature of 820 ° C with 40 minutes of time delay.

Microsections were prepared as the examples without diamonds. The phase composition of the samples was investigated by X-ray diffraction analysis using a D8 DISCOVER diffractometer produced by Bruker. The structure of alloys and the distribution of elements in them after sintering were investigated by electron microscopy using a JSM-6480LV scanning electron microscope produced by JEOL. The quantitative ratio of the structural components to the sections surface was determined using the specialized software IncaEnergy of Oxford Instruments company and AxioVision Rel.4.8 of CarlZeiss company.

3. Results and discussion

X-ray diffraction investigations showed that all obtained alloys consist of four phases: β-Co (hexagonal lattice), (Cu) solid solution based on copper (face-centered cubic lattice), intermetallic phase ε (Cu_3Sn) (hexagonal lattice) and W (primitive lattice).

Figure 1a shows the microstructure of alloy No. 5 (Table 1). F % is the part of the given component on the surface of the section shown in the column diagram (figure 1b). The results of the phase and electronprobe microanalysis of the alloy of the specified composition are presented in Table 2.



a b

Figure 1. The structure of Sn-Cu-Co-W alloy containing 26 wt% of cobalt (a), and the percentage of structural components on the microsections surface (b): 1 – cobalt particles, 2 – (Cu) solid solution based on copper, 3 –intermetallic phase ε, 4 – tungsten particles

Table 2. Results of the phase and electron probe microanalysis of the Sn-Cu-Co-W alloy containing, wt %: 20 Sn, 43 Cu, 30 Co and 7 W

Phases	Phase chemical composition, wt %			
	Sn	Cu	Co	W
β-Co	-	3	97	-
(Cu)	16	82	2	-
ε (Cu_3Sn)	34	63	3	-
W	-	-	2	98

The volume fraction of β-Co phase increases in the structure of the alloys under the increase in the cobalt content. Herewith the phase relation (Cu) and ε and the volume fraction of particles W remain unchanged.

Apparently, a solid solution and an intermetallic phase are formed during the crystallization of the liquid phase of the composite solder. Cobalt presence in the phases (Cu) and ε indicates about its dissolution in the liquid phase at the soldering temperature.

Let us note that the size of the cobalt particles in figure 1a is 2–5 µm with the initial particle size of cobalt powder of 1–2 µm. It happens due to the dissolution process of small cobalt particles by a liquid phase and its subsequent deposition on larger particles [9]. The electronprobe microanalysis showed that tungsten is not contained in β-Co, (Cu), and ε phases. Apparently, tungsten is not dissolved in the liquid phase at the temperature of 820 ° C. Figure 1 shows that cobalt and tungsten particles were separated by a liquid phase at the soldering temperature and did not form a solid frame.

Due to the fact that at the temperature of 820 ° C, the composite solder was the liquid containing disintegrated solid particles, its properties can be described on the basis of the rheology of suspensions.

The dependence of the solder viscosity on the solid particles content in it is determined by the expression [10]:

$$\eta = \eta_0 \frac{1}{1-(\varphi+\omega)} \quad (1)$$

where η_0 is the viscosity of the liquid phase without solid particles, Pa · s;

φ is the volume fraction of the solid phase;

ω is the volume fraction of added liquid phase (which moves together with the solid particles).

Let us note that the copper-tin liquid phase of the solder has high viscosity η_0, which is due to the high chemical affinity of the components and the formation of an intermetallic compound [11].

It follows from the expression (1) that the viscosity of the solder increases when the volume fraction of the solid phase increases. The value of ω increases, and accordingly the viscosity of the solder increases under the increase of the refractory filler dispersity. The irregular shape of the refractory particles contributes also to the increase in the volume fraction of the added liquid phase. In this connection, the dissolution-precipitation process, which leads to the growth of cobalt particles and gives them more rounded shape, contributes to a certain decrease in the viscosity of the solder during sintering.

The approximate values of volume fractions of β-Co and W were determined as the result of alloys microstructures analysis**,** which are shown in figure 1. Since the cobalt and tungsten particles did not melt at the sintering temperature, the sum of their volume fractions amounts value φ in expression 1.

The volume fraction of solid phase φ at the temperature of 820 ° C for solders with different cobalt contents is shown in figure 2.

If the value of ω is neglected in expression (1), then according to this expression, the solder viscosity increases 1.27 times when the volume fraction of solid phase φ equals 0.21, and at φ equals 0.35, it increases 1.54 times compared with the solder not containing the solid particles. Thus, undissolved cobalt and tungsten particles increase the viscosity of the composite solder.

The experiments on sintering a diamond-containing layer on specially shaped rollers confirmed the increase in the viscosity of the composite solder when the volume fraction of the solid phase increases. Inflows and overflows form on the surface of the rollers if the content of cobalt powder in the solder is less than 24 wt% . Obviously, such content of cobalt powder is insufficient to impart the desired viscosity to the molten composite solder. It is determined that the solder should contain 27–35 vol% of the solid phase to obtain uniform diamond-containing layers up to 3 mm thick on vertical and curved surfaces and sharp edges of specially shaped tools. It can be achieved if not less than 24–32 wt% of cobalt powder and 7 wt% tungsten powder are inputted into the solder simultaneously. A higher content of cobalt and tungsten powders is not desirable since it leads to the formation of hot cracks in the diamond-containing layers and increased porosity [8].

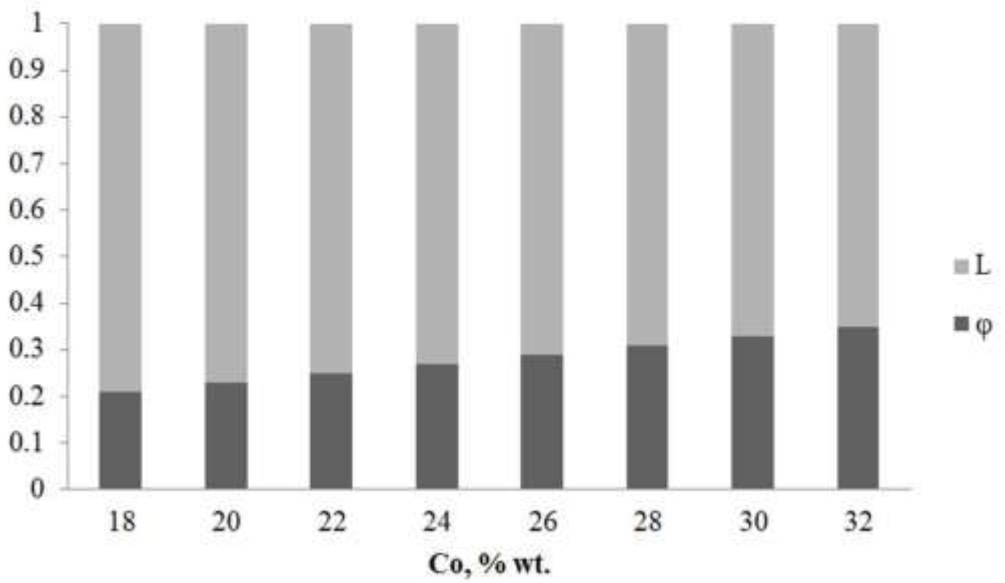


Figure 2. Volume fractions of liquid phase (*L*) and solid phase (φ) for Sn-Cu-Co-W solders with different Co contents

Figure 3 shows specially shaped diamond rollers obtained using solder No. 6 (Table 1). The uniform diamond-containing layer 2 mm thick was obtained on the rollers as well as the sharp edges were well-formed on the rollers. The hardness of the metal binder formed from the solder is 92–94 HRB on these rollers. During the sintering process, the solder containing 30 wt% of cobalt powder and 7 wt% of tungsten powder due to the high viscosity was well retained on specially shaped surfaces, including the vertical sections and sharp edges.

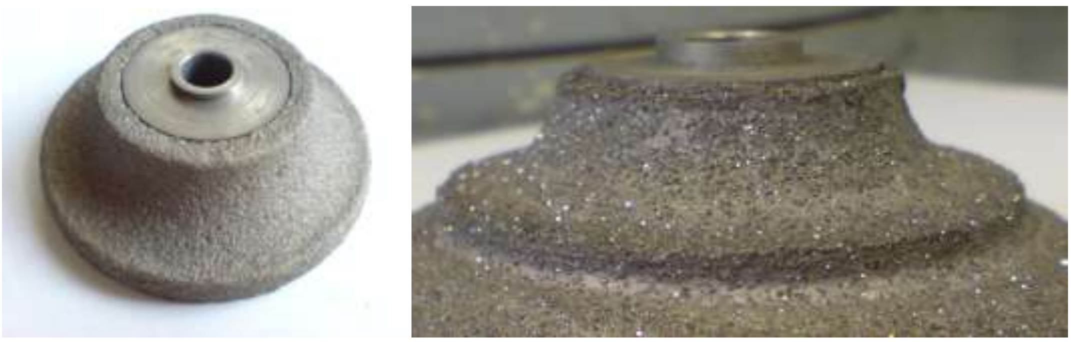


Figure3. Specially shaped rollers with the binder containing 30 wt% of Co powder and 7 wt% of W powder

4. Conclusion

1. The viscosity of Sn-Cu-Co-W composite solders at the temperature of 820 ° C depends on the content of the solid phase in them.
2. Sn-Cu-Co-W solder should contain 27–35 vol% of the solid phase to ensure the necessary viscosity and obtain uniform diamond-containing layers on complex specially shaped tool surfaces. This is achieved with a total content of 24–32 wt% of cobalt and 7 wt% of tungsten powder in the solder.

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