

# Forming of Tungsten Containing Coats on the Substrates from Aluminum and Copper by Method of Vacuum-Free Electron Beam Surfacing

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**Abstract** – The tungsten containing coats was formed on aluminum and copper substrates with using of focused electron beam extracted in atmosphere. The electron energy 1.4 MeV and beam power up to 85 kW were used. Flux addition was used for preventing of surfacing powder from atmospheric effect. Thickness of the coats was varied from 1 mm on the copper substrate up to 6 mm on aluminum substrate. The grains of not totally dissolved tungsten particles, intermetallics such as  $Al_4W$ ,  $Al_2Cu$ ,  $Al_4Cu$ , were formed in the Al or Cu matrix, however the phases containing W–Cu were not formed that can be explained by the absence of corresponding phase diagram. High volume fraction more than 80% of the tungsten containing phases was achieved in upper layer of the coatings. The coating on aluminum substrate can be applicable as target of converting the electron beam into powerful X-ray source for sterilization purposes. And both types of coatings on copper and aluminum substrates can be applicable to barrier coatings for heatsink.

## 1. Introduction

The purpose of this work was formation of relatively thick tungsten containing coating with high tungsten concentration on the non-ferrous substrates: aluminum and copper. The coating was formed with using of extracting in atmosphere powerful focused electron beam. The beam was generated by industrial electron accelerator that was produced at Budker Institute of Nuclear Physics, Novosibirsk. High coating to substrate adhesion is the advantage of applied method because of in the region of coating-substrate transition matrix of coating is made solid with substrate. Such coatings may have several applications. First purpose

of aluminum substrate coatings formation was the production of a target for powerful electron beam converting in the range of 1.5–5 MeV electron energy into  $\gamma$ -bremsstrahlung spreading, mainly, towards incident beam for treatment of medication, equipment sterilization, etc. To examine technological potentialities of target production, a multilayer coating with tungsten concentration at the upper coating zone up to 88% by weight and its surface density in a coating up to 1.9 g/cm<sup>2</sup> had been formed. Aluminum is practically to be used as a substrate, as it weakly absorbs  $\gamma$ -radiation passing through the target towards incident beam and has high thermal conductivity for target heat pick-up. Heat abstraction may be carried out through water channels built-in aluminum substrate at the opposite side of coating.

Another possible coatings' application is their use as thermo-barrier heat-resistant coatings. W–Cu alloy may be also used for production of high voltage electro-contacts breakers and other goods.

## 2. Experimental procedure

Focused electron beam with power up to 85 kW and electron energy 1.4 MeV was extracted into atmosphere. The substrate covered by powder mix layer, including surfacing material and flux, was moved under the beam. To increase the treatment area the beam scanned by means of electromagnetic scanner in crosswise direction towards travel direction of a sample [1] with scanning widths of about 5 cm. Scanning frequency was chosen enough high to provide quasi-homogeneous beam effect, as a heat source, and was equal to 20–50 Hz. Traverse speed of samples was 2–3.5 cm/s. Surfacing was produced onto aluminum and copper substrates. Five types of samples were produced as it is shown in Table 1.

Table 1. Investigating samples

Sample name	A	C-1	C-2	CC-1	CC-2
Substrate material and its grade	Al (AMc)	Cu (M1)	Cu (M1)	Cu (M1)	Cu (M1)
Number of surfacing layers	6	1	2	1	2
Composition of surfacing powder	W 85%, Al 15%	W 85%, Al 15%	W 85%, Al 15%	W 75%, Al 15%, Cu 10%	W 75%, Al 15%, Cu 10%

Cross sections of coated samples were investigated by methods of optic metallography and scanning electron microscopy (SEM). Phase structure of coatings was determined by X-ray diffraction (XRD) analysis. Elemental composition of individual structure parts were found by X-ray microanalyzer combined with SEM and by means of Auger spectroscopy. Microhardness distribution of coatings was measured by microhardness tester at 5–100 g loads. Hardness of individual phases was determined by means of nano-hardness meter “Nano Hardness Tester” company “CSEM” production at 1 g load.

### 3. Results and discussions

Total thickness of coating sample A is 5 mm. It is a bit more than substrate melt penetration after single-stage surfacing. At surfacing of second and subsequent layers, the melt penetration decreased. This conclusion was made at investigating the cross-sections of samples, obtained after single, double and triple surfacing onto aluminum substrate. At surfacing of each subsequent layer, the remelting of previously formed coating took place. The melt penetration is from 100% (second layer) up to ~40% (fifth, sixth layer). Such a nature of coating formation results in relatively smooth transition of the structure from the layers, which are meagre of W at a bottom of molten pool to the layers with high content of alloying element at the top of the sample.

Micrograph of coating is shown in Fig. 2. Phases were identified on the basis of XRD and microprobe analyses of phase chemical composition (Table 2). In intermetallic  $Al_4W$  there must be 37 weight % of Al at stoichiometry. X-ray microanalysis shows the value about 33%, that is close with equilibrium value for  $Al_4W$  phase [2].

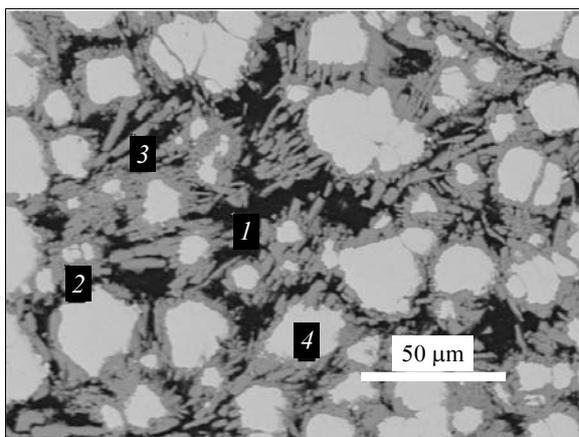


Fig. 1. Structure of sample C-1 coating at the upper of coating zone. Phase marking: 1 – aluminum matrix; 2 and 3 –  $Al_4W$  phase; 4 – incompletely dissolved grains of initial tungsten powder

XRD analysis was carried out from surface plane of the sample and from cross section. At the sample surface the following phases have been found (in de-

scending order of possible concentration), these are: Al, W and  $Al_4W$ . In cross section, the same phases were found, as well as the additional  $Al_5W$  and  $Al_{12}W$ . In accordance to phase diagram W-Al, two last phases should be formed at relatively low temperatures 697 and 870 °C, correspondingly. Evidently, as a result of quick cooling, in our case, they are formed in small quantities and are not emerged by metallography. The temperature of  $Al_4W$  phase formation from the melt is 1327 °C.

Table 2. Phases in the sample A coating

Phase	Chemical composition, atomic %	Nanohardness, GPa
W initial grains	W 100	9.7–13.0
$Al_4W$ crystals	Al 78-80, W 22-20	10.5 (adjoin to the W grains) 6.2–8.9 (separate grains)
Al matrix	Al 99.2, Mn 0.6, Fe 0.3	0.73
Al substrate	Al 98.9, Mn 0.8, Fe 0.3	0.4 ( $H_V$ at 20g load)

Phases in the C-1 sample coating, determined by XRD pattern, are shown in Table 3.

Table 3. Phases in the C-1 pattern coating

Phase	Chemical composition, atomic %	Nanohardness, GPa
W initial grains	W 100	6.9–7.6
$Al_2Cu$	Al 65.3, Cu 34.7	not measured
$Al_4W$	Al 77, W 23	9–11
Cu matrix	Al 10.6, Cu 89.4	2.4
Cu substrate	Cu 100	0.8 ( $H_V$ at 100g load)

They are performed in descending order of their evaluation bulk concentration from upper table lines to lower ones. Intermetallic  $AlCu_3$ , probably, also presents, but its peaks at XRD pattern coincide with peaks of other phases, so the presence of this intermetallic remains undecided. Phases W,  $Al_2Cu$ , and  $Al_4W$  were identified at micrographs in accordance with their chemical composition. Tungsten grains in the coating are incompletely dissolved tungsten initial particles.

Copper phase is absent in upper coating part. Closer to pool bottom the phase composition is different: original tungsten grains are immersed into matrix from Al solid solution in Cu with 4.8%, Al content that corresponds to 10.6 at %.

In the sample C-2 (Fig. 2, Table 4), at the bottom of molten pool, the same content of Al solid solution in copper, as in the sample C-1, but with higher concentration of 7.9% by weight or 16 at %, is observed.

In the middle and in the bottom of molten pool the basic phases are:  $Al_4W$ , original tungsten grains W,

arias of Al solid solution with 5.3% copper solute content, that corresponds to 2.4 at %. In accordance with phase diagram such solubility is available at eutectic temperature 548 °C only. At indoor temperature, solubility of copper in aluminum matrix is practically impossible.

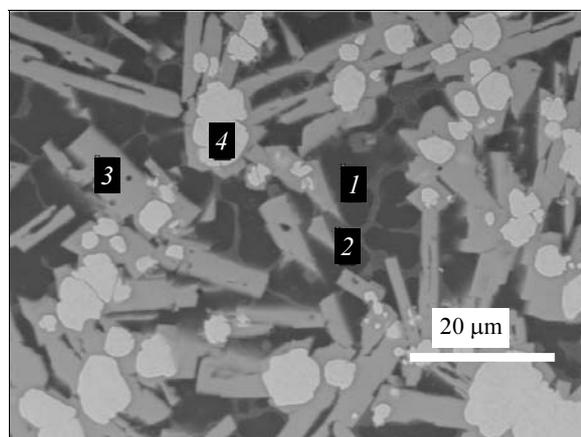


Fig. 2. Structure of coating of sample C-2 at the upper coating zone. Numerated: 1 – aluminum matrix; 2 – Al–Cu region with Al 79 at % content; 3 – Al<sub>4</sub>W phase; 4 – incompletely dissolved grains of original tungsten powder

Table 4. Phases in the C-2 coating

Phase	Chemical composition, atomic %	Nanohardness, GPa
Al <sub>4</sub> W	Al 77, W 23	7.7–9.7
W initial grains	W 100	8.4
Al	Al 97.5, Cu 2.5	3.4–3.7
Cu dawn layer	Al 17, Cu 83	3.0
Cu substrate	Cu 100	1.4 ( $H_V = 0.8$ Gpa at 100 g load)

Probably, in our case the decomposition of solid solution did not occur because of high cooling rate. Increased nanohardness of aluminum phase equal to 3.5 GPa, evidently, is explained by certain presence of copper in aluminum lattice, as well as weak shift of aluminum peaks at XRD pattern towards 2θ angles increase (Fig. 3), that, obviously, is connected with a small increase of lattice parameter due to solution in it of smaller copper atoms. Phase content of region shown in Fig. 2 as “2” was not unambiguously identified.

Coating of sample CC-1 consists of inclusions of W particles in matrix of Al solid solution in copper. Nanohardness of W phase are 7.6 and copper from 2.1 to 3.9 GPa. Concentration of Al dissolved into Cu matrix is close to extreme one – 13 at %

After second layer was added, in coating of sample CC-2 aluminum concentration increases and matrix consists of Al<sub>4</sub>Cu<sub>9</sub> and Al<sub>3.892</sub>Cu<sub>6.10808</sub> intermetallics, which are found by XRD analyses (Table 5). Matrix at lower coating layers of this sample consists of, as well as in sample CC-1, solid solution on base of copper.

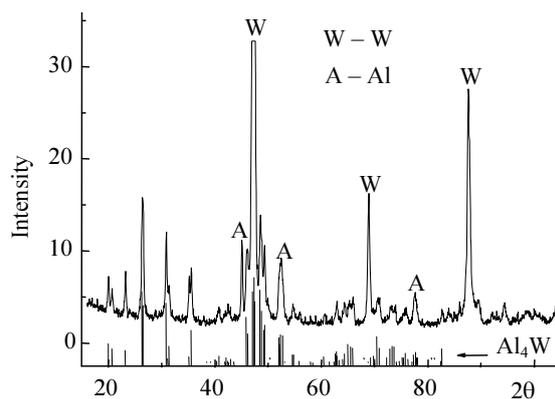


Fig. 3. XRD pattern of sample C-2 coating at the upper region of surfacing zone. At the level of X-axes the peaks of standard Al<sub>4</sub>W compound are shown

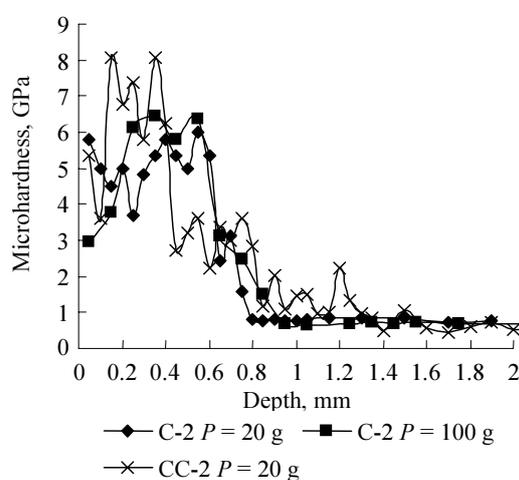


Fig. 4. Microhardness distribution of samples C-2 and CC-2

In Table 5, nanohardness of Al<sub>4</sub>Cu<sub>9</sub> and Al<sub>3.892</sub>Cu<sub>6.10808</sub> are marked by question-mark, as their position at micrograph is determined hypothetically, because microprobe analysis chemical composition data are not available.

Table 5. Phases in the CC-2 pattern coating

Phase	Chemical composition, atomic %	Nanohardness, GPa
W initial grains	W 100	7.7
Al <sub>4</sub> Cu <sub>9</sub>	not measured	(9.4–11)?
Al <sub>3.892</sub> Cu <sub>6.10808</sub>	not measured	8.8?
Cu matrix	Cu 86.4–87, Al 13–13.6	2.1–3.9
Cu substrate	Cu 100	0.8 ( $H_V$ at 100 g load)

#### 4. Summary

1. On copper or aluminum substrates the gradient multilayer coatings of thickness up to several millimeters containing thermostable W-phases at surface layer may be formed. These are metallic tungsten and intermetallic Al<sub>4</sub>W, which has 70–90% bulk concentration.

2. At certain mode of forming the coating on copper substrate they consist of intermetallic matrix of Cu–Al system, in which tungsten containing phases are immersed. This intermetallic matrix is of relatively high hardness, that, in combination with hard tungsten containing phases, provides total high-hardness of surface layer of coatings at 6–7 GPa at 0.5–0.6 mm depth.

3. The coatings obtained have to be of high level of adhesion to substrate, because the method of their forming provides smooth growth of modifying phase concentration in the direction from a substrate to the coating surface. The layer bordering upon a substrate has a “solid inclusions in substrate matter” structure.

4. The described method of production of coatings at aluminum substrate may be promising in production

of high-reliability target for converting of powerful electron beam into X-ray.

5. Due to the surface layers’ structure containing refractory phases in combination with high substrate thermal conductivity, the examined multilayer coatings have to possess thermobarrier properties, enabling remove of intensive heat flows from the coatings.

### References

- [1] I.M. Poletika, M.G. Golkovski, M.D. Borisov, R.A. Salimov, and M.V. Perovskaya, *Phys. and Chem. of Materials Treatment* **5**, 29–41 (2005).
- [2] N.P. Liakishev, O.A. Bannykh, and L.L. Rokhlin, *Dual phase diagram of metal systems: Handbook*, Vol. 1, Moscow, Mashinostroenie, 1996.