Evaluation of wear resistance of Ti-Cu coated surfaces by scratch test

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Abstract. The article reports findings on the study of microhardness and wear resistance of Ti-Cu coatings produced by a complex technology. It is established that within the temperature range under investigation (20 to 400 °C) the wear resistance of non-alloyed coatings exceeds copper wear resistance three-fold, while the wear resistance of alloyed coatings exceeds copper wear resistance eight-fold; the fact is attributed to a higher hardness of alloyed coatings.

1. Introduction
In modern metallurgical production, a considerable part of final product cost is made up of equipment repair costs.

When molten metal flows through the continuous casting mold, it results in the abrasive wear of the mold surface and an alteration of its geometry. Thus, an increase of the casting mold copper wall wear resistance is a topical task [1-5]. The problem is solved by cladding mold walls with various coatings, their hardness being their wear resistance criterion. It has been demonstrated that sufficient wear resistance is provided if the hardness of the mold wall surface exceeds 4 GPa [5-7]. If the upper hardness boundary of 8 GPa is achieved, it leads to a critical brittleness of the coating with a subsequent decrease in its efficiency.

The paper investigates the microhardness and wear resistance of Ti-Cu based coatings produced on copper substrate through a high energy pulse impact (explosive welding) followed by heat treatment as per the contact melting regime [8-10].

2. Materials and methods
Coating production on copper substrate surface included the following stages: 5 mm thick plates of copper M1 were explosively welded with those of 4 mm thick titanium BT1-0 and 0.7 mm thick titanium BT6; a heat treatment regime was applied to bimetal M1+BT1-0 to produce an unreacted titanium layer (900 °C, 10 minutes); a heat treatment regime was applied to bimetal M1+ BT6 to provide a complete solution of the titanium layer (900 °C, 30 minutes).

Coating microstructure investigation was performed with the Olympus BX61 optical microscope. Phase composition was identified by comparing data obtained both with the Versa 3D Dual Beam scanning electron microscope and the Bruker D8 ADVANCE ECO diffractometer. Coating microhardness was determined with the Nanotest 600 instrument (a triangular diamond pyramid was used); in addition, surface roughness was determined. Besides, a scratch test was performed with an indenter of Berkovitch geometry. The number of indentations in each series was not less than 10. When coating surface roughness was investigated, Ra value was calculated as roughness at an area of 700×500 µm averaged over at least 10 measurements. The scratch test parameters are as follows (Figure 1): scan length (scratch track length) equals 800 µm; a progressive load is applied; a scratch cycle consists of 5 stages: topography (1 mN) – scratch (200 mN) - topography (1 mN) – scratch (200 mN) - topography (1 mN).

A plane parallel geometry of specimens was ensured during measurements with the specimens glued to the heated substrate with high-temperature glue. Relevant applications were used to process the data obtained.

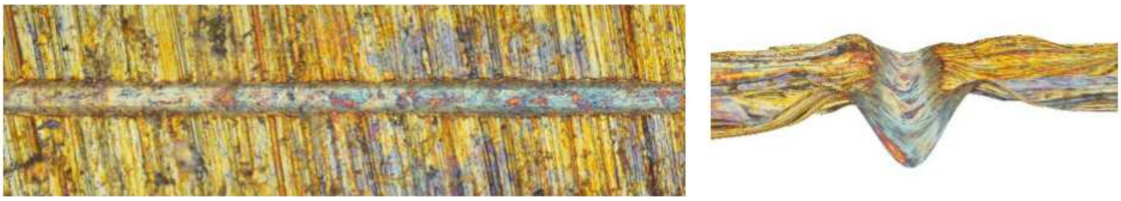

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Figure 1. A track picture after copper specimen scratching (a) and 3D track model (b)

3. Results and discussion

The metallographic study demonstrated that after the self-separation of titanium unreacted layer the thickness of the non-alloyed coating produced on the copper substrate surface was equal to 300 µm while that of the alloyed layer was equal to 1600 µm (Figure 2). The basic structural components of the non-alloyed layer are structurally free intermetallic compounds $\beta TiCu_4$ and $TiCu_2$, and intermetallic compound Ti_3Cu_4 is present on the surface. The basic structural components of the alloyed coating are structurally free intermetallic compounds $\beta TiCu_4$, $TiCu_2$ and $TiCu_2Al$. The roughness of the non-alloyed coating surface is 746±108 µm, and that of the alloyed coating is 671±90 µm.

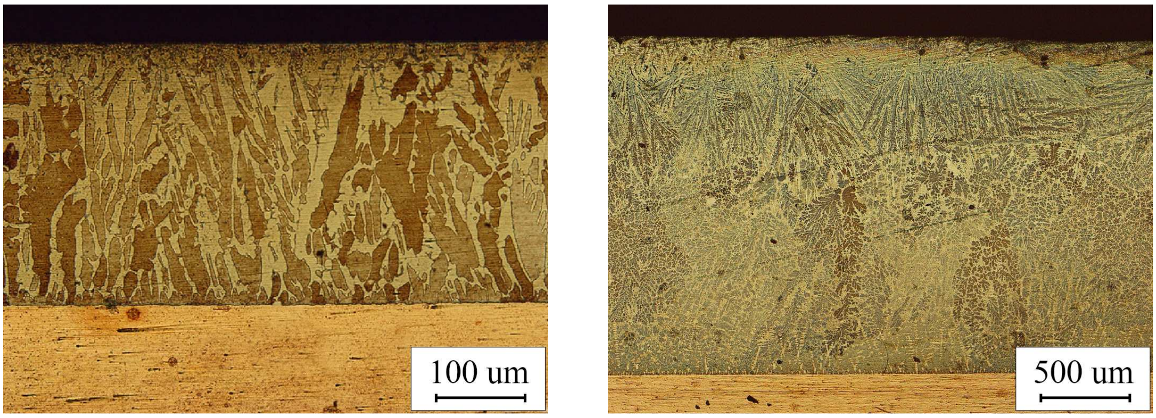

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Figure 2. The microstructure of non-alloyed (a) and alloyed (b) Ti-Cu compound coatings produced on copper substrate surface

The curve representing coating microhardness alteration against test temperature (with the thermal drift considered) is given in Figure 3. The curve demonstrates that the dependence is nonlinear for the temperature range under study. The trend is a result of the interaction of two competing processes: surface oxidation is accompanied with the formation of a harder oxide chemical compound and surface weakening occurs due to heating. It is clear that the first process prevails at temperatures up to 200 °C and results in microhardness increase.

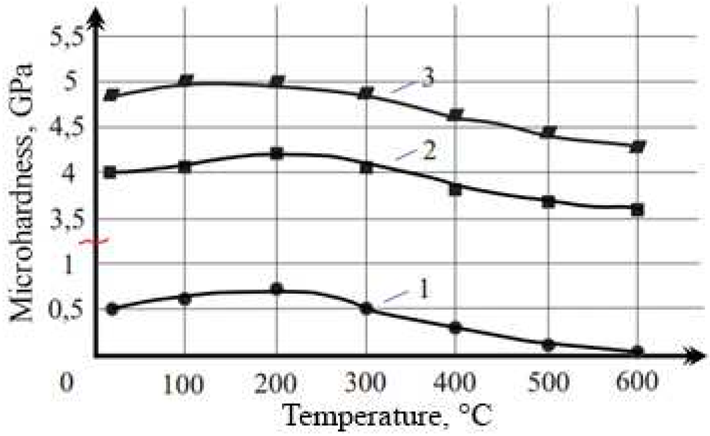
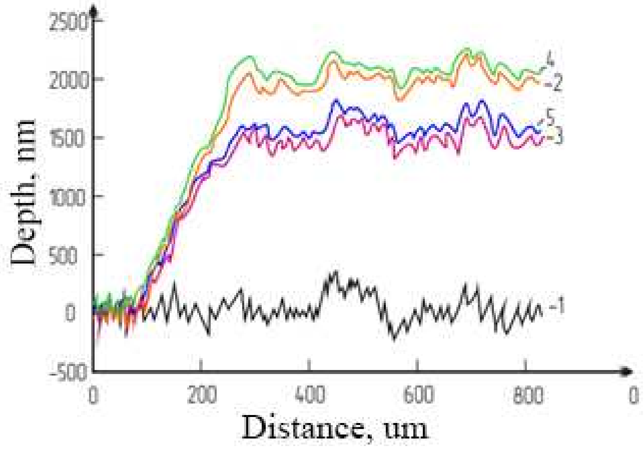


Figure 3. Temperature dependence of the microhardness of copper (1), a non-alloyed coating (2) and an alloyed coating (3)

Figure 4 shows indentation depth under multiple scratching of the surfaces of copper (a), a non-alloyed coating (b) and an alloyed coating (c) at 20 °C. The analysis of the data obtained made it possible to establish that after the first scratch (Figure 4, a, curve 2) the surface profile smoothes out (curves 3 and 4). After the second scratch (curve 4) surface macroscopic profile remains practically unchanged.

A shallower indentation depth after scratching at 200 mN (curve 2 in Figure 4) is explained by material rebound after load removal. The effect is more pronounced in copper specimens. A smaller indentation depth in the coatings (compared with copper) demonstrates that the coatings have a higher hardness and, consequently, wear resistance.



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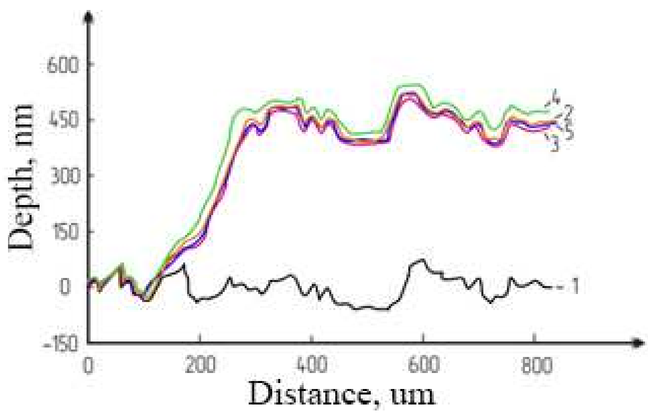

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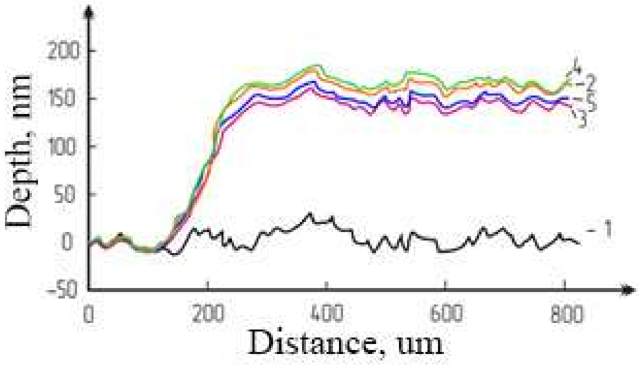

c

Figure 4. Alteration of indentation depth under multiple scratching of copper (a), a non-alloyed coating (b) and an alloyed coating (c) at 20 °C: 1, 3, 5 are surface topography at 1 mN load; 2, 4 are surface scratching at 200 mN load

Figure 5 presents an overall picture of indentation depth within the entire temperature range under study. Relative wear resistance calculated by the ratio of indentation depths in copper surface and coating surfaces was equal to 3 for non-alloyed coatings and 8 for alloyed coatings.

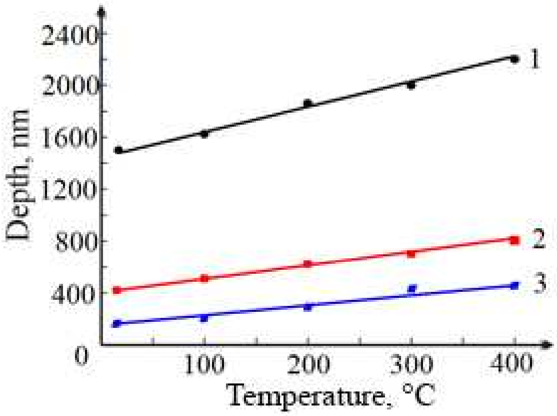

Figure 5. Temperature dependence of full indentation depth in copper surface specimens (1), non-alloyed (2) and alloyed surface specimens (3)

4. Conclusion

If the heat treatment of explosively welded bimetal compounds BT1-0+M1 and BT6+M1 is performed under the regimes which provide contact melting at the compound interlayer interface, an intermetallic non-alloyed coating is formed with the following parameters: phase composition: $\beta TiCu_4 + TiCu_2 + Ti_3Cu_4$; roughness Ra: 750±108 µm; hardness: 5GPa.

When scratched within a temperature range of 20 to 400°C, non-alloyed coating wear resistance exceeds that of copper 3-fold and that of alloyed coatings 8-fold.

Since Ti-Co compounds combine high wear resistance and hardness, it enables to use them as wear resistant coatings on the copper surface of continuous casting molds.

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