UDC 621.791.927.5
O. Ivanov[1], PhD, P. Prysyazhnyuk[2], PhD, Assoc. Prof., H. Kramar[3], PhD, Assoc. Prof., S. Marynenko[3], PhD, Assoc. Prof., I. Koval[3], PhD, Assoc. Prof., O. Huryk[3], PhD, Assoc. Prof.
[1] Professional College of Electronic Devices, Ivano-Frankivsk National Technical University of Oil and Gas, 76006, Ivano-Frankivsk, Ukraine
[2] Ivano-Frankivsk National Technical University of Oil and Gas, 76019, Ivano-Frankivsk, Ukraine
[3] Ternopil Ivan Puluj National Technical University, 46001, Ternopil, Ukraine

USING OF 3D MODELING FOR INVESTIGATION OF THE STRUCTURE OF HARDFACING MATERIALS DEVELOPED WITH FCAW USING OF POWDER ELECTRODES WITH REACTION MIXTURE FE-MO-B-C

Abstract. The main aim of the research is to investigate the structure of the hardfacing based on the perspective tungsten-free Fe-Ti-Mo-B-C system deposited with flux-cored arc welding FCAW. Investigation includes developing the methodology for the 3D modeling of the $Fe(Mo, B)_2$ grain. Obtained result in the form of 3D model show that in the hardfacing based on the Fe-Ti-Mo-B-C system main strengthening phase $Fe(Mo, B)_2$ is formed around grains of TiC, which act as a modifier.

Flux-cored arc welding (FCAW) [1] alongside with gas metal arc welding (GMAW) and Shielded Metal Arc Welding (SMAW) are widespread methods for hardfacing and, in some cases, restoring of machine parts. Wear resistance is one of the most important aspects of the durability not only of the parts but of machines itself. The advantages of the above mentioned is that the hardfacing could be provided without using of expensive equipment, at the complex geometry surface and could be used for restoring of machine parts as they could provide high volume of the deposited material. Also, using flux-cored electrodes as a material for hardfacing opens the possibility of an easy changing a ration of materials for the requirements both for mechanical properties and chemical composition of the hardfaced layer. Based on the modern trends in the material science and engineering, materials for hardfacing can be roughly divided into two groups: systems based on tungsten and tungsten-free materials. Classic tungsten-free systems are usually based on the Fe-Cr-C and Fe-Ti-C [2] and similar systems [3], but it is reasonable to point the perspective Fe-Ti-Mo-B-C system [4], using of which can increase the wear resistance of machine parts and overall durability of the machines that work under conditions of intensive abrasion wear.

Flux-cored arc welding (FCAW) was choose as a hardfacing method mainly because of the providing of the high volume of deposited material and its simplicity. As a hardfacing system the Fe-Ti-Mo-B-C system was choose.

FCAW electrodes were manufactured with placing mixture of initial components into 08 kp low carbon steel (DSTU EN 10139:2018) sheet. Width and high of cross-section of the electrode wire was 8 × 2.5 mm, electrode length – 420 mm. Chemical composition of electrode shown in Table 1.

Table 1. Chemical composition of experimental electrode.

Compositions, at.%				
Ti	Mo	B	C	Fe
8.26	8.26	22.01	5.51	bal

Welding parameters, based on the research [5] were as follows: direct current 150 A with a reverse polarity, arc-voltage 30-32 V. Cooling was carried out on an air at 20° C.

VDU-506 rectifier was used for hardfacing. Hardfacing was made in three layers in order to ensure higher amount of deposited material during structure investigation.

Microstructure was investigated with a SEM using ZeiSS EVO 40XVP electron microscope. The hardness measurement was tested by Rockwell method, scale "C". Also, PMT-3 hardness meter with a camera added to the lens was used for additional structure observing.

Blender software was used for 3D modeling and Image Pro Plus software was used for images analysis and measurements.

Microstructure (Figure 1) of the sample is characterized with presence of the large (~ 8 μm) grains of $Fe(Mo, B)_2$, surrounded with homogeneous phase alongside with eutectic-like areas. Also, small (~ 1 μm) grains of TiC that are centered in $Fe(Mo, B)_2$ can be spotted.

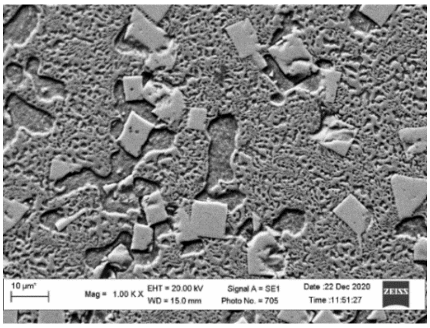


Fig. 1. SEM analysis of the microstructure of hardfaced layer

Special methodology that consist of four steps was developed and used for the 3D modeling of the grain. Blender and Image Pro Plus software as well as mathematical calculating were used for modeling of the $Fe(Mo, B)_2$ grain. Also, the research area was selected by the observation of the structure, carried out with the DCM510 camera attached to the PMT-3 hardness tester.

Such method of structure investigation has significant advantages as using of it can ensure full 3D researching of the microstructure of the material as well as the external and internal geometry of single grain.

Using the developed methodology 23 images (Figure 2) of the structure were taken with constant amount of removed material as well as the depth of material removed between taking images was calculated.

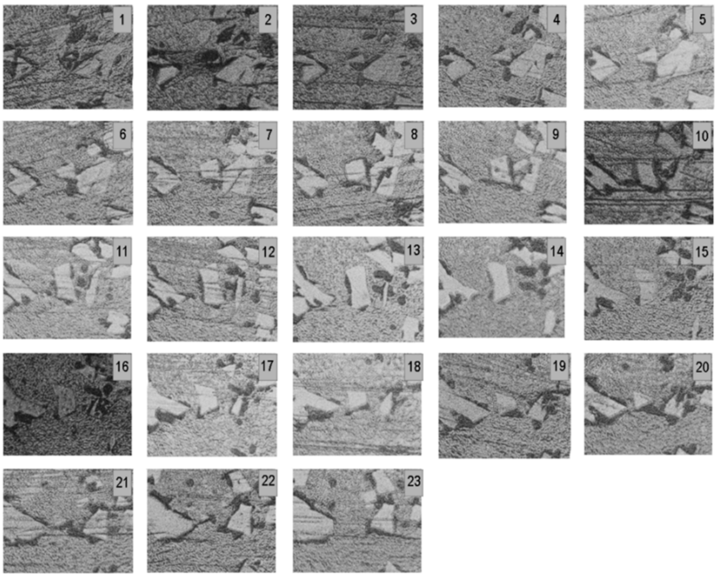
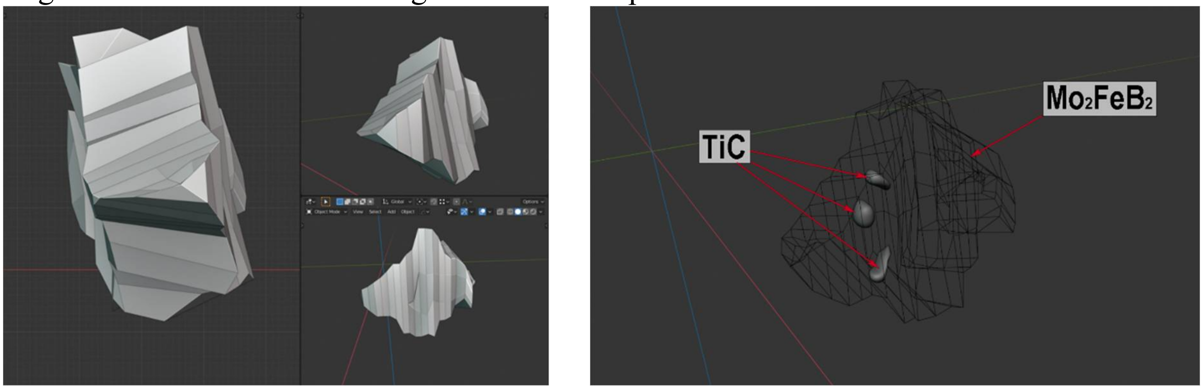


Fig. 2. Images of the sample structure, taken with a constant material removed between images

Using the 3D modeling software Blender and built-in tools of the software a particle consisting of 23 sections was modeled (Figure 3, a). Also, the internal structure of the particle, which is presented in Figure 3, b, was taken into account during modeling. The image shows that there are three grains inside the particle.



a b

Fig. 3. 3D model of a 23-section particle modeled according to the data of Figure 2 (a) and the internal structure of a particle, that confirms the presence the TiC grains inside of it

Hardfacing using FCAW with Fe-Ti-Mo-B-C as a hardfacing system shows hardness of 65 HRC in the top layer. Microstructure observation shows that the small TiC grains presented in the Fe(Mo, B)$_2$ grains. Modeled internal structure of the grain (Figure 3, b) confirms the presence of small inclusions of titanium carbide TiC, around which the main strengthening phase Fe(Mo, B)$_2$ is formed in the form of rectangular prisms, which corresponds to its tetragonal crystal system. Such results of the experimental observation and 3D modeling can be described as a confirmation that TiC grains acts as a modifier for the formation of the other phase. And the developed methodology could be used for further research of the materials to establish the geometry of the grains of different phases as well as usage of 3D models for precisely simulation of material behavior.

Literature.

1. Trembach B., Sukov M., Vynar V., Trembach I., Subbotina V., Rebrov O., Rebrova O., Zakiev V. Effect of Incomplete Replacement of Cr for Cu in the Deposited Alloy of Fe–C–Cr–B–Ti Alloying System with a Medium Boron Content (0.5% wt.) on its Corrosion Resistance. Metallofiz. Noveishie Tekhnol. 2022. 44, No. 4. https://doi.org/10.15407/mfint.44.04.0493

2. Trembach, B., Vynar, V., Trembach, I., Knyazev, S. Comparison of two-body abrasive wear resistance of high chromium boron-containing Fe–C B–13wt.%Cr Ti alloy with incomplete replacement of Cr for Cu the Fe C B 4wt.%Cr 7wt.%Cu–Ti alloy. Problems of Tribology. 2022. 27(3/105). https://doi.org/10.31891/2079-1372-2022-105-3-34-40

3. Kocaman E., Kılınç B., Şen S., Şen U. In-situ TiB2 and Fe2Ti intermetallic assisted hard coatings by Fe-Ti-B based hardfacing electrodes. Journal of Alloys and Compounds. 2022. Volume 900, 163478. https://doi.org/10.1016/j.jallcom.2021.163478

4. Bembenek M, Prysyazhnyuk P, Shihab T, Machnik R, Ivanov O, Ropyak L. Microstructure and Wear Characterization of the Fe-Mo-B-C—Based Hardfacing Alloys Deposited by Flux-Cored Arc Welding. Materials. 2022. 15(14):5074. https://doi.org/10.3390/ma15145074

5. Ivanov O., Prysyazhnyuk O., Shlapak L., Marynenko S., Bodrova L., Kramar H. Researching of the structure and properties of FCAW hardfacing based on Fe-Ti-Mo-B-C welded under low current. Procedia Structural Integrity. 2022. Volume 36. https://doi.org/10.1016/j.prostr.2022.01.028