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ZrN coatings on U8 steel obtained by electrospark alloying after a concentrated solar irradiation

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Structure, hardness, and tribological characteristics of electrospark coatings from ZrN-(Cr, Ni, Al_2O_3) on U8 steel after treatment by concentrated solar radiation (CSR) have been investigated. It is shown that the intensity of wear and factor of friction of specimens with coating after CSR are essentially less than for non-treated U8 steel. At changing of regime of CSR treatment from 785°C, 25.3 s to 530°C, 8.6 s and at decreasing of sliding speed at wear test from 10 m/s to 5 m/s the tribological characteristics improves. After treatment by CSR the strengthening of steel surface is observed – the quenching with formation of martensite and troostite take place. At treatment by concentrated solar radiation changing in phase composition of coatings observed: before treatment by CSR the main phase in coating is ZrO_2 (cubic), after treatment by CSR the main phase is ZrNi, ZrO_2 (tetragonal) is also present.

Исследованы структура, твердость, трибологические характеристики электроискровых покрытий из ZrN-(Cr, Ni, Al_2O_3) на стали У8 после обработки концентрированным солнечным излучением (КСИ). Показано, что интенсивность износа и коэффициент трения образцов с покрытием после воздействия КСИ существенно меньше, чем необработанной стали У8. При изменении режима обработки КСИ от 785°С, 25,3 с до 530°С, 8,6 с и при уменьшении скорости скольжения при испытании на трение от 10 м/с до 5 м/с трибологические характеристики улучшаются. После обработки КСИ наблюдается упрочнение поверхности стали – происходит закалка с образованием мартенсита и троостита. При обработке концентрированным солнечным излучением наблюдаются изменения в фазовом составе покрытий: до обработки КСИ основная фаза в покрытии – ZrO_2 (кубический), после обработки КСИ основная фаза ZrNi, присутствует также ZrO_2 (тетрагональный).

The requirements of high antifriction characteristics of coatings obtained by electrospark erosion requires the development of novel electrode materials. The electrospark alloying (ESA) is used to enhance the reliability and service life of machine parts [1]. The ESA using short electric pulses at a high current strength is a coating method of good prospects [2]. To enhance the surface properties of U8 steel, the use of ESA is of considerable interest. The main specific features of ESA consist in the obtaining of an alloyed layer having an enhanced adhesion to the substrate. The ESA apparatus is rather simple and easy to use. However, the formation of non-continuous and rough coatings due to the discharge pulse discreteness is among its drawbacks [2]. It is expedient to use the concentrated solar irradiation (CSI) to enhance the physical and mechanical properties of the ESA coatings [3]. The heating temperature in this work was monitored using an SGU-2 unit with help a chromel/alumel thermocou-

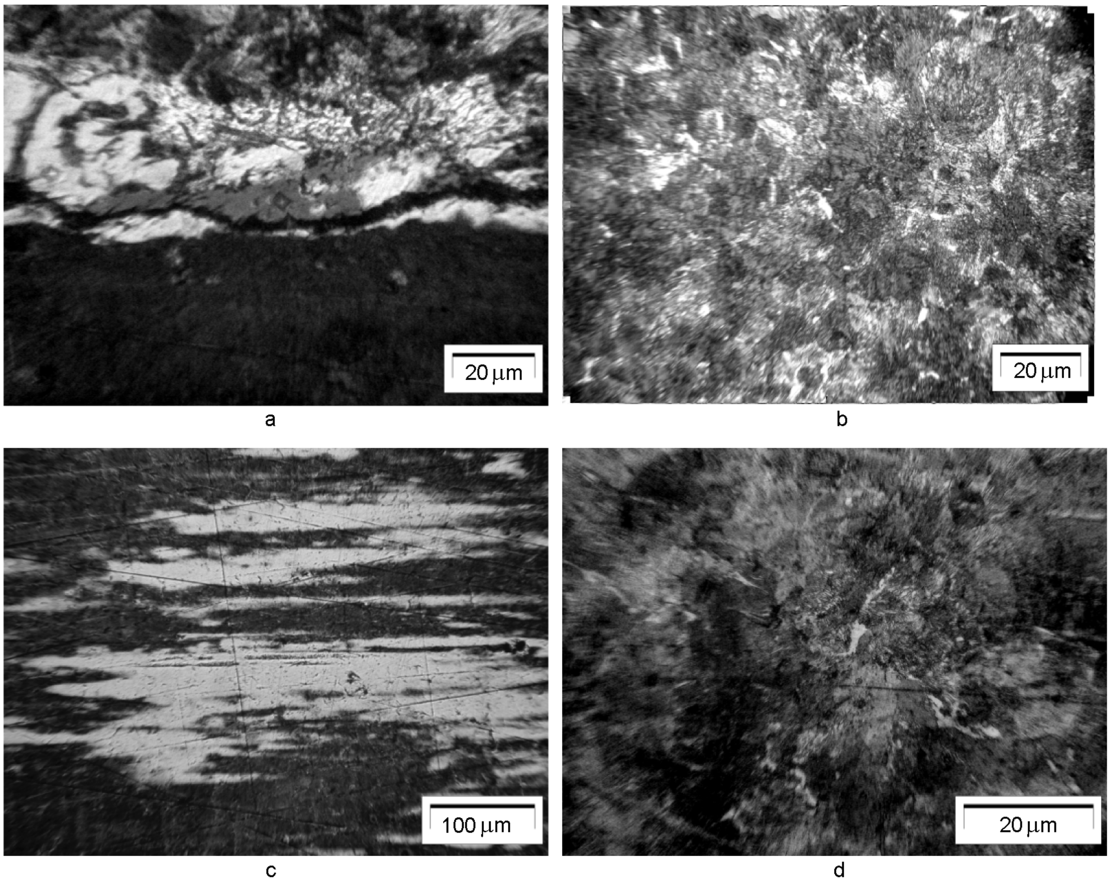

Fig. 1. Microstructure of a ZrN-(Cr, Ni, Al_2O_3) ESA coating (a) and of steel. On the heating depth: perlite (b) (initial), martensite + troostite (c), perlite (d) after CSI treatment.

ples attached to the reverse side of the sample.

The heterophase ZrN materials are of good prospects as the ESA electrodes for the manufacturing of wear-resistant coatings [4]. The alloying electrodes were prepared by compacting and sintering in a SShV furnace under argon atmosphere at 1400–1700°C.

In this work, the structure and properties of ZrN-(Cr, Ni, Al_2O_3) coatings obtained on U8 steel using the ESA have been studied. The alloying was carried out using an EFI-46A unit at $I = 1.5$ A, $C = 300$ μF. The tribotechnical characteristics were measured using a MT-68 unit [5] in the bush/shaft mode, thus allowing to hold the friction coefficient (f) and the sample wear rate (μm/km). The tribotechnical characteristics were measured in air without any lubricating material in the contact zone, the HVG steel being the friction material, at $V =$ 5 m/s, 10 m/s and pressure $P = 0.5$ MPa and 1.0 MPa. The MIM-9 microscope, PMT-3 unit and DRON-3 installation with in Kα copper emission were used to carry out the metallographic, durometric, and X-ray phase examinations, respectively. The surface treatment by CSI was carried out using a SGU-2 unit that is a mirror concentrator of solar energy provided with a Sun tracing system. The radiant energy flux was controlled using a jalousie and was of 3000 to 4000 kW/m^2.

Table 1. X-ray phase analysis data for surfaces

Material composition, %	ESA	ESA + CSI
ZrN + (Cr, Ni, Al_2O_3)	Main phase: ZrO_2 (cubic) Solid solutions: Ni(Zr), FeNi, FeCr* Oxides: FeCrO, Al_2O_3	

*traces

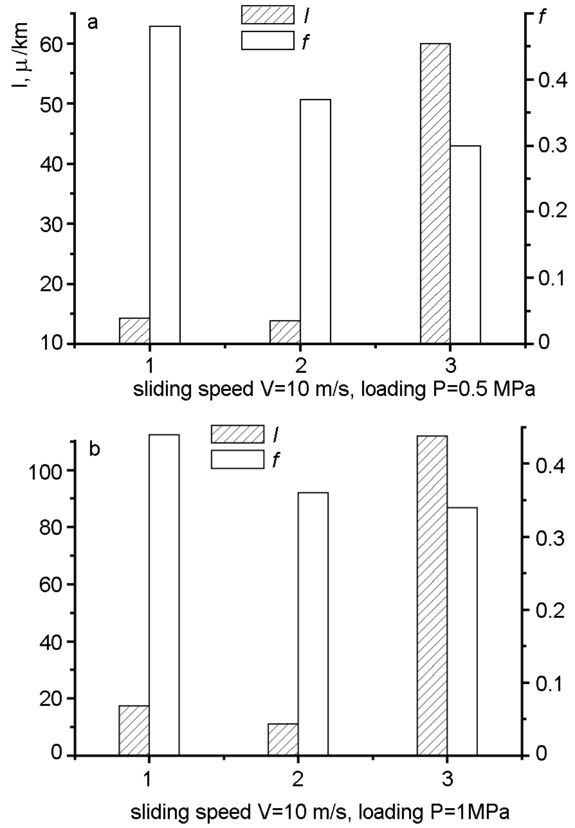

Fig. 2. *a* –Wear intensity (I) and friction coefficient (f) of ZrN-(Cr, Ni, Al_2O_3) ESA coatings as a function of the heating temperature T (°C) and the holding time τ (s): T = 785, τ = 25.3 (*1*); T = 530, τ = 8.6 (*2*); U8 steel (non-annealed) (*3*). *b* – Wear intensity (I) and friction coefficient (f) of ZrN-(Cr, Ni, Al_2O_3) ESA coatings as a function of the heating temperature T (°C) and the holding time τ (s): T = 635, τ = 15.2 (*1*); T = 460, τ = 9.8 (*2*). U8 steel (non-annealed) (*3*).

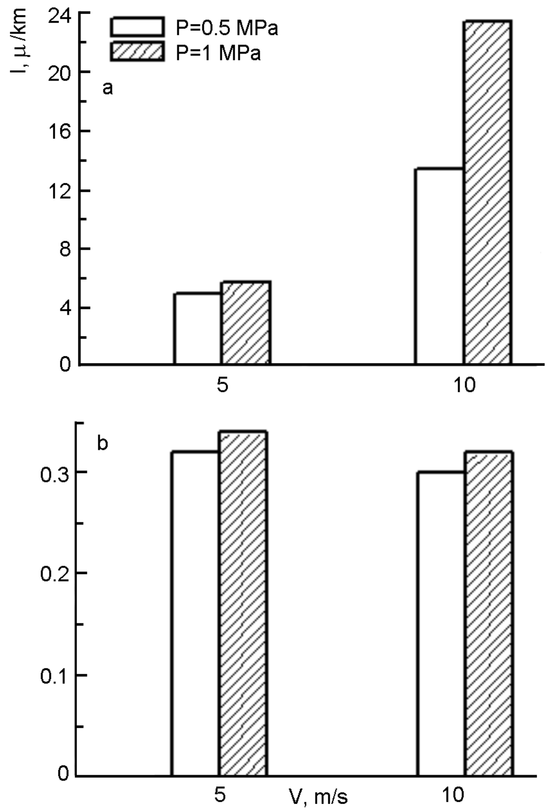

Fig. 3. Wear intensity I (a) and friction coefficient f (b) of ZrN-(Cr, Ni, Al_2O_3) ESA coatings as a function of the rotation speed under loading P.

The work is aimed at the study of the CSI treatment use to enhance the physical and mechanical properties of the ESA coatings.

The X-ray phase examination of the samples under study has been shown what follows. During the CSI treatment, the cubic ZrO_2 is transformed into the tetragonal one. Moreover, the intermetallic compounds ZrNi, FeNi, FeCr (trace amounts) are formed as well as the ternary FeCrO oxide. The main phase in the ESA coatings prior to the CSI treatment is a ZrO_2 cubic while after the CSI, the intermetallic compound ZrNi is the main phase. In both cases, the Zr solid solution in Ni, Ni(Zr), is present.

The microhardness investigations has shown that the microhardness of 50 μm thick alloyed layer is 9.5 GPa. The sample was irradiated at T = 635°C, τ = 15.2 s. Under the coating, troostite is formed with 7.8 GPa microhardness. Within the troostite structure region, 100 μm thick martensite areas are observed with 11 GPa microhardness, followed by perlite areas with 3.78 GPa microhardness (Fig. 1, a–d). The structure of the steel untreated by CSI consisting of perlite is shown in Fig. 1b.

The tribological tests have shown that the wear rate and friction coefficient increase as the heating temperature rises (Table 2, Figs. 2 and 3).

The tribological characteristics have been shown to decrease as the sliding speed drops (Table 2, Figs. 2 and 3). The tribological properties of the U8 steel (unannealed) are appreciably more as compared with those of and CSI-treated ESA coatings in both speed modes (Figs. 2–4).

Thus, as the sliding speed decreases from 10 m/s to 5 m/s and the heating temperature from 635°C to 460°C, the tribotechni-

Table 2. Tribotechnical properties of ZrN + (Cr, Ni, Al_2O_3) ESA coatings treated by CSI

No.	Heating temp. *T*, °C	Heating time, *s*	Sliding speed *V*, *m/s*	Loading *P*, MPa	Friction coefficient, *f*	Wear rate, *I*, μm/km
1	785	25.3	10	0.5	0.48	14.3
2	635	15.2	5	1.0	0.44	17.5
3	530	8.6	10	1.0	0.34	13.9
4	460	9.8	5	0.5	0.36	11.1

cal characteristics improves. After CSI treatment of ZrN-(Cr, Ni, Al_2O_3) coatings obtained on U8 steel using ESA, the steel surface is strengthened due to hardening with martensite and troostite formation.

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Электроіскрові покриття на основі ZrN на сталі У8 після обробки концентрованим сонячним випромінюванням

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Вивчено структуру, твердість, трибологічні характеристики електроіскрових покриттів з ZrN-(Cr, Ni, Al_2O_3) на сталі У8 після обробки концентрованим сонячним випромінюванням (КСВ). Показано, що інтенсивність зношування та коефіцієнт тертя зразків з покриттям після впливу КСВ суттєво менше, ніж необробленої сталі У8. При зміненні режиму обробки КСВ від 785°C, 25,3 с до 530°C, 8,6 с та при зменшенні швидкості ковзання при випробуванні на тертя від 10 м/с до 5 м/с трибологічні характеристики покращуються. Після обробки КСВ спостерігається зміцнення поверхні сталі – має місце загартування з утворенням мартенситу та трооститу. При обробці концентрованим сонячним випромінюванням спостерігаються змінення у фазовому складі покриттів: до обробки КСВ основна фаза у покритті – ZrO_2 (кубічний), після обробки КСВ основна фаза ZrNi, присутній також ZrO_2 (тетрагональний).