Formation of coating based on ferrum aluminides on surface of fechral Cr15Al5

V G Shmorgun, O V Slautin, D V Pronichev, V P Kulevich
Volgograd state technical university, 20, Lenina Ave., Volgograd, 400005, Russia
E-mail: mv@vstu.ru

Abstract. The features of solid and liquid phase interaction at the interface of the explosion-welded composite fechral Cr15Al5 – aluminum AD1 are investigated. A way of increasing the aluminum content in the surface layer of the fechral Cr15Al5 after double thermal treatment is proposed.

1. Introduction
Fechral alloys (heat-resistant Fe-Cr-Al system alloys) have found wide application in the industry as a material for electric heating and resistive elements, nuclear power structural and fuel cladding components [1-5] due to a number of advantages over the nichrome (alloy Ni-Fe-Cr system). Their main advantage is a lower price due to the absence of expensive nickel in the composition. At the same time, the main disadvantage of high-chromium fechral alloys, in comparison with nichrome, is low plasticity in the initial state (which is important in the manufacture of heating elements), as well as a significant reduction in the plasticity of the alloy during operation [3]. To ensure their good mechanical properties (particularly, high plasticity) and the absence of significant grain growth and intercrystalline fracture at elevated temperatures can either be due to complex doping by various elements (Si, Mn, Zr, Ti, Y, Ce) [6-8], or by reducing the content of chromium in the alloy and the increase in the aluminum content in the surface layer of the product (which will contribute to the formation of complex oxide films of complex composition on the surface) [9-11].

The purpose of this paper is to search for optimal saturation regimes of fechral alloy Cr15Al5 surface with aluminum under conditions of solid and liquid-phase interaction at the interface of the explosion-welded composite Cr15Al5 + AD1.

2. Materials and methods
The investigations were carried out on bimetal samples of the composition of aluminium AD1 + fechral Cr15Al5 (2.5 + 1.6 mm), obtained by explosion welding.

The alloy Cr15Al5 was chosen as the main one because it possesses good plastic properties due to low chromium content and can be cladded with aluminum AD1 by explosion welding.

The thermal treatment was carried out in a SNOL 8.2 / 1100 furnace at a temperature of 650 – 800 °C and in a LOIP LF-7/13-G1 furnace at 1000 – 1100 °C. Metallographic studies were performed on a modular metallographic microscope Olympus BX-61. The phase composition of the diffusion zone (DZ) has been evaluated by analyzing the data obtained by the scanning two-beam electron microscopy Versa 3D DualBeam system.
3. Results and discussion

In the triple Fe-Al-Cr system, as well as in binary (Fe-Al), the excess of aluminum melting temperature should lead to an intensification of the diffusion interaction due to the presence of the liquid phase.

The metallographic analysis of samples heated at 650 – 660 °C showed that the DZ is a continuous interlayer of a variable thickness with a large number of cracks (Figure 1, a), consisting of an intermetallic compound Fe$_2$Al$_5$ with a Cr dissolved in it (Figure 1, b). An increase of the heating time leads to a change in the average thickness of the diffusion zone, an increase in the variability of the thickness, and the appearance of pores.

![Figure 1](image1.png)

**Figure 1.** The structure of the diffusion zone after heating at 660 °C, 1 h (a) and the distribution of chemical elements along its thickness (b)

An increase of the heating temperature to 670 °C changes the structure the DZ due to the liquid-phase interaction (Figure 2, a). In this case, a weakly discernible boundary is visible between the regions of solid and liquid-phase interaction.

An analysis of the chemical elements distribution along the thickness of DZ shows that the region of liquid-phase interaction corresponds to a mechanical mixture of the intermetallic FeAl$_3$ with Al, and the solid-phase interaction region corresponds to the intermetallic Fe$_2$Al$_5$ (Figure 2, b). At the same time, ~ 5% at. Cr is dissolved in the intermetallic compound Fe$_2$Al$_5$, while in FeAl$_3$ – no more than 2 % at. Cr. The boundary of the diffusion zone with aluminum looks like "flame tongues" with the inclusions of the intermetallic FeAl$_3$ that is detached from the base in the aluminum matrix.

![Figure 2](image2.png)

**Figure 2.** The structure of the diffusion zone after heating to 670 °C, 1 h (a) and the distribution of chemical elements along its thickness (b)
Analysis of the obtained results made it possible to conclude that the nature of the diffusion processes in the Fe-Cr-Al system in solid-liquid-phase interaction is similar to that considered for the binary Fe-Al system [12]. This suggests that on the fechral surface, an aluminides coating can be obtained according to the technological scheme proposed in [12]. However, the mechanical action on the composite to separate the non-reacted aluminum layer from the diffusion zone led to such a breakdown that no intermetallides remained on the surface of the fechral (Figure 3).

The problem of obtaining an aluminides coating on the fechral surface was solved by reducing the thickness of the aluminum layer to 300 µm during rolling and its complete transformation during annealing at 800 °C for 1 h into the Fe$_2$Al$_5$ intermetallide (Figure 4). The resulting coating is very brittle and its transfer to a more ductile one was carried out by reheating.

The optimum transformation temperature of the coating phase composition (Fe$_2$Al$_5$ → FeAl + Fe$_3$Al) – 1000 °C has been determined experimentally. A lower temperature does not provide an acceptable duration of the phase transformation (Figure 5, a), and an increase temperature to 1100 °C leads to pore formation at the surface of the coating (Figure 5, b). The time sufficient for obtaining aluminide coating FeAl + Fe$_3$Al with inclusions FeAl$_2$ (Figure 6) was 20 hours.
4. Conclusion

The heat treatment of the bimetallic cr15al5 – aluminum ad1 at the solid-phase interaction temperature leads to the formation of a diffusion zone at the interface of the compound consisting of a layer of Fe2Al5 intermetallic with a large number of pores and cracks. After the application of mechanical loading, the composition is broken along the boundary by the diffusion zone – the fechral.

The heat treatment of the bimetallic fechral Cr15Al5 - aluminum AD1 at the temperature of the liquid-phase interaction leads to an intensification of the diffusion zone growth, the appearance in its composition of the intermetallic FeAl3, an interlayer and the two-phase (FeAl3 + Al) region. The application of a mechanical load leads to the destruction of the diffusion zone along the intermetallic Fe2Al5.

The minimization of the aluminum layer thickness on the surface of the fechral allows the intermetallic Fe2Al5 coating to be formed after the primary heat treatment (at a temperature of 800 °C), and after the secondary (at a temperature of 1000 °C) – to transform the brittle intermetallic Fe2Al5 into a multiphase coating of greater plasticity: (FeAl + FeAl3) / FeAl / Fe3Al.
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