INVESTIGATION OF HIGH-TEMPERATURE MULTI-LAYER MATERIAL BASED ON VANADIUM ALLOY AND STAINLESS STEEL

ИССЛЕДОВАНИЕ ЖАРОПРОЧНОГО МНОГОСЛОЙНОГО МАТЕРИАЛА НА ОСНОВЕ СПЛАВА ВАНАДИЯ И КОРРОЗИОННОСТОЙКОЙ СТАЛИ

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Abstract: The investigation of the interface connection area of the three-layer tube "steel / vanadium alloy / steel" after different deformation-heat treatments was performed. Furthermore, a qualitative and quantitative analysis of the structure of the three-layer material were conducted, including analysis of the contact area of the steel and the vanadium alloy and the diffusion layer between them was obtained. The analysis of the microstructure and mechanical properties (microhardness, ultimate tensile strength, yield strength and elongation) of three-layered material has been carried out.

KEYWORDS: THREE-LAYER TUBE, VANADIUM ALLOYS, STAINLESS STEEL, STRUCTURE, MECHANICAL PROPERTIES, COMPOSITE

1. Introduction

Vanadium alloys V-(5-10)%Ti-(4-6)%Cr are promising materials for the fuel claddings of fast nuclear reactors due to their high thermal conductivity, high-temperature tensile strength, high temperature creep resistance (at temperatures up to 800 °C) and radiation stability comparing to austenitic and ferrite-martensitic steels. However, oxygen and nitrogen are highly soluble in vanadium at operating temperatures up to 400 ºC and decrease corrosion resistance [1-6].

Therefore, it is required to protect vanadium surface by corrosion-resistant materials, for example, through creation of multi-layer compositions for preventing of vanadium alloys embrittlement upon interaction with oxygen and nitrogen. We propose a multi-layer structural material based on high-temperature vanadium alloy that is protected by corrosion-resistant ferritic steel from the surface. Vanadium alloy provides high long-term strength of the material, while steel provides - high corrosion resistance in various media (liquid metals, water, steam).

2. Experimental procedure

Two types of three-layer tubes based on vanadium alloy V-4Ti-4Cr and different stainless steels (ferritic-martensitic steel (Fe-0,2C-13Cr) and ferritic (Fe-0,08C-17Cr-1Ti) steel) were produced in this work by join plastic deformation. Ring samples of a three-layer tube were studied after joint hot deformation at 1100 °C (hot extrusion) and also after annealing at for 2 h at 800 and 1000 °C.

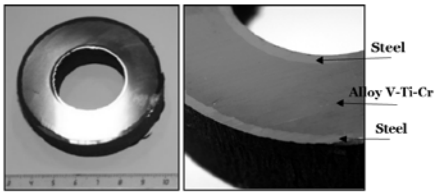


Figure 1 *- The appearance of a three-layer tube sample based on vanadium alloy (V-4Ti-4Cr) coated with an inner and outer surface by steel (0.2C-13Cr-Fe) after a hot extrusion*

In this research paper we used a metallographic analysis, an electron microprobe analysis in the contact area, microhardness measurements, mechanical testing methods.

An analysis of the microstructure of the transition zone of the three-layer material was performed by optical and scanning electron microscopes Carl Zeiss Axiovert 40 MAT and JSM-6610LV (JEOL) at magnification ×100 - 1000. In addition, we obtained concentrations maps at the vanadium alloy/steel interface and concentration profiles of chemical elements using JSM-6610LV (JEOL) scanning electron microscope with energy dispersive X-ray spectrometer (EDS). An optional EDS provides elemental analysis, that is why we used EDS for the analysis of the chemical elements redistribution in the transition area of three-layer tube steel//vanadium alloy//steel.

Tensile tests were conducted for assessing the quality and strength of the connection between vanadium alloy and steel. The miniature vanadium alloy samples and special two-layer (steel//vanadium alloy) samples were prepared for the tensile test. Tensile tests were performed in the air at room temperature by Instron 5966 with special grippers.

3. Results and discussion

Results of study of phase composition, structure and mechanical properties of three-layer material at various stages of technology are presented at fig.2 - 5.

The metallographic examination showed that the contact area steel / vanadium alloy of the three-layer tube is clean, smooth and has well-defined border connections without pores, micro-cracks or separation. Figure 2 shows structure in the transition layer of the vanadium alloy with steel after hot extrusion of the three-layer tube and subsequent annealing.

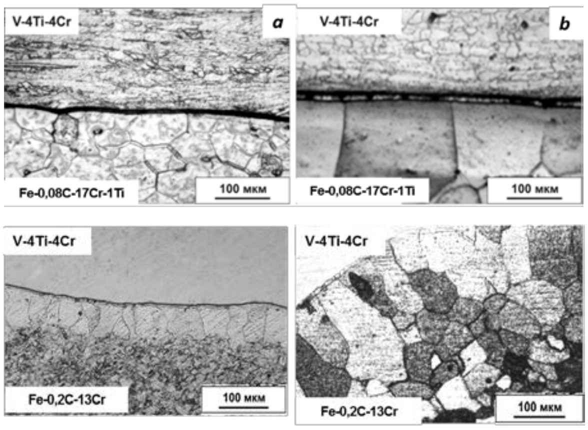
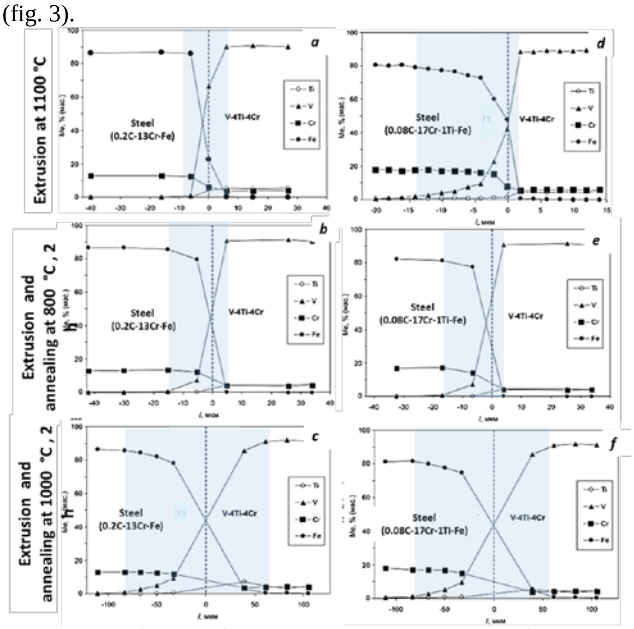


Figure 2 *- The structure of the contact area between alloy V-4Ti-4Cr and steel after annealing*

Annealing at 800 °C after hot extrusion in a transition area between the steel and vanadium alloy forms recrystallized structure with a grain size of 40 - 50 µm in steel and 5-10 µm in the vanadium alloy. Increasing the annealing temperature to 1000 °C causes the grain growth in the steel up to 60 - 70 µm.

It is shown that "transition" layer is formed in the three-layer material due to the joint hot deformation and annealing. This layer is a solid solution with monotonically changing chemical composition. The formation of the diffusion ‘transition’ layer provides durable connection between dissimilar metals (material / coating). The "transition" layer has the same thickness about (20 ± 5) µm in the three-layer tubes with both ferritic-martensitic (Fe-0,2C-13Cr) and ferritic (Fe-0,08C-17Cr-1Ti) steels. Annealing at 1000 ° C can increase its thickness up to 150 µm (fig. 3).



Me - mass fraction of chemical element; l - the distance from the interface vanadium alloy/steel

Figure 3 *- The distribution of chemical elements in the contact area of the alloy V-4Ti-4Cr with Fe-0,2C-13Cr (a - c) and Fe-0,08C-17Cr-1Ti (d - f)*

Microhardness through the wall thickness of the three-layer tube with ferritic steel (Fe-0,08C-17Cr-1Ti) is about 150 - 190 HV, but microhardness after hot extrusion and after annealing at 1000 ° C is about 450 – 500 HV in steel Fe-0,2C-13Cr (fig.4).

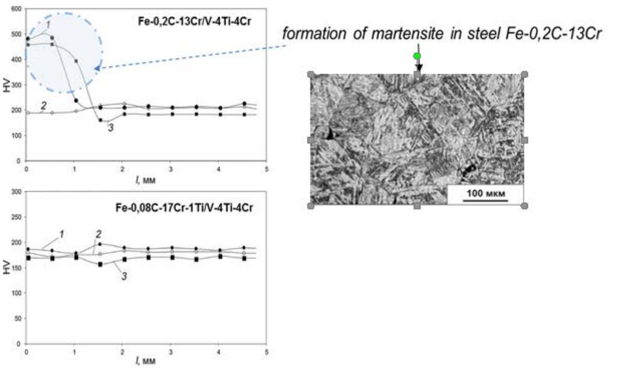


Figure 4 *- Distribution of microhardness through the wall thickness of the three-layer tube: 1 - after hot extrusion; 2 - after annealing at 800 ° C; 3 - after annealing at 1000 ° C;* l - length of the outer tube wall*

A more technologically advanced material for the protective coating of tubes from vanadium alloys is ferritic steels with 17 – 26 %Cr, because Martensite formed in steel (Fe-0,2C-13Cr) after annealing at 1000 °C and cooling in air of the three-layer tube.

Tensile test results of samples of the transition area that were cut from transition area of the three-layer tube in different condition (after hot extrusion; after hot extrusion and annealing at 1000 ^{o}C, 2 hours) are shown in Figure 5.

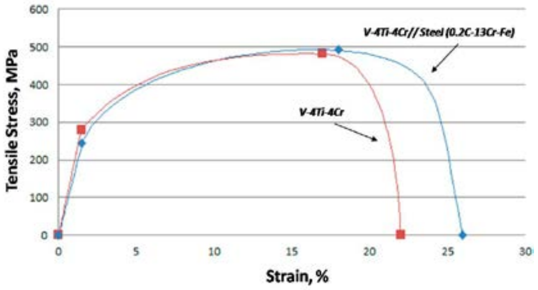


Figure 5 *- Stress – strain curves of the samples from the three-layer tube: a - after hot extrusion; b - after hot extrusion + annealing (1000* ^{o}*C, 2 hours)*

The tensile test results of the samples from the transition layer demonstrate that these samples behave as a monolithic material and are failed with necking without the formation of cracks between the vanadium alloy and the steel. Ultimate tensile strength of two-layer samples V-4Ti-4Cr//(steel Fe-13Cr-0,2C) was 515± 15 MPa, yield strength was 295 ± 35 MPa and elongation was 22 ± 2 %, that is not worse than the mechanical properties of the vanadium alloy (V-4Ti-4Cr) alone.

4. Conclusion

The studies of the structure, the chemical composition and the mechanical properties of the three-layer tubes based on a vanadium alloy with ferritic and ferritic-martensitic steels coating have shown the formation of a diffusion layer in the contact area between the vanadium alloy V-4Ti-4Cr and the steel of a three-layer material, which provides a three-layer monolithic tube material. The microstructure analysis confirmed the mutual diffusion of the chemical elements between the vanadium alloys V-4Ti-4Cr and the steels near the interface between the layers. The research has shown that the "transitional" layer is formed in a three-layer material due to the joint hot deformation and annealing, which is a solid solution with monotonically changing chemical composition. The interaction area ("transitional" layer) has the same size of about (20 ± 5) µm in the three-layer tubes with (Fe-0,2C-13Cr) and (Fe-0,08C-17Cr-1Ti) steels coating. Annealing at 1000 °C can increase the thicness of the transition layer to 150 µm. The research has also shown that the ferritic steels with 17 – 26 %Cr are a more technologically advanced material for the protective coating of tubes from vanadium alloys. Tensile test results demonstrate that two-layer sample behaves as a monolithic material.

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