

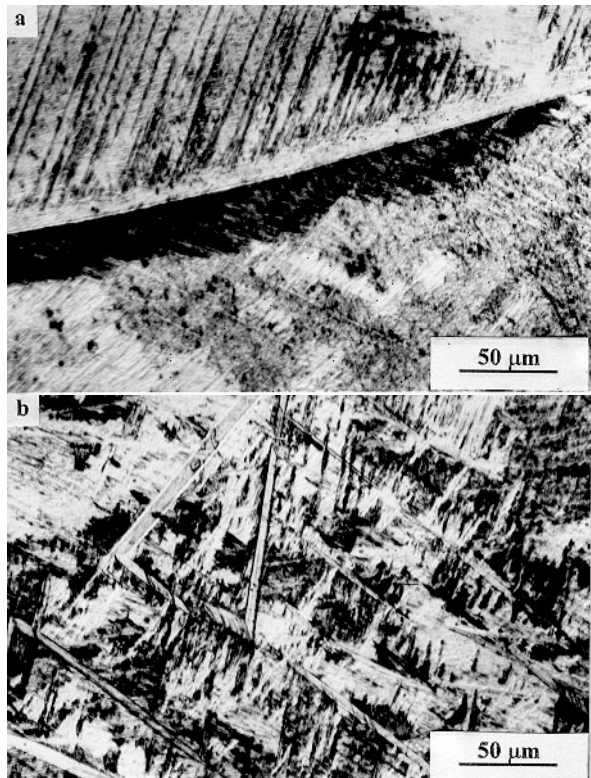


## FEATURES OF BAINITIC TRANSFORMATION IN Zr-Rh ALLOYS

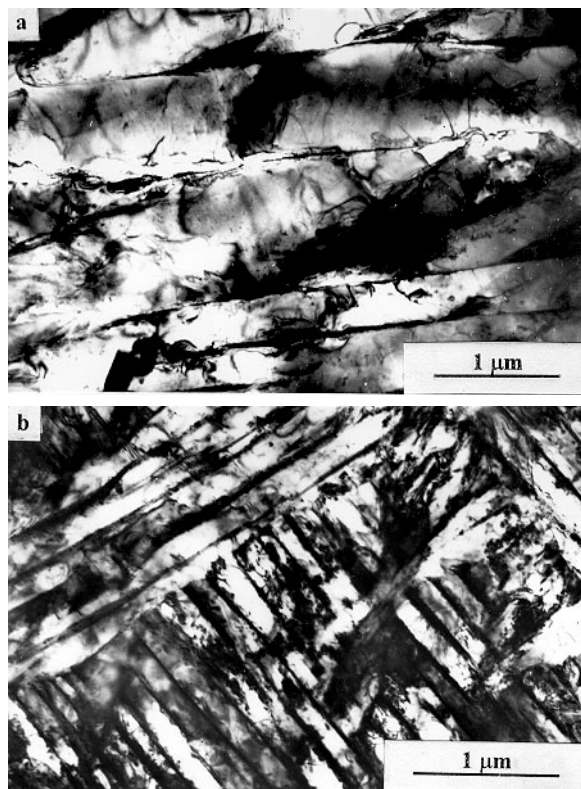
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In the zirconium alloys with  $\beta$ -stabilizing elements the martensitic or bainitic structures can be formed during quenching from  $\beta$ -phase region depending on position of the alloying metal in the Periodic Table and cooling rate. As the bainitic transformation is the result of two processes - polymorphic transformation and eutectoid decomposition, the bainitic structures differ from those formed during equilibrium eutectoid decomposition and exhibit the features characteristic of martensitic transformation. The rate of the eutectoid decomposition in the zirconium alloys increases with increasing number of group and decreases with increasing number of period of alloying metal. It has been shown in our previous works that, as a result, the martensitic transformation occurs in Zr-V, Zr-Nb, Zr-Mo, Zr-Ta, Zr-W, and Zr-Re alloys and the bainitic transformation occurs in Zr-Cr, Zr-Mn, Zr-Fe, Zr-Co, and Zr-Ni alloys during quenching in ice water. The structure of binary zirconium alloys with the metals of platinum group (group VIII, periods 5 and 6 of the Periodic Table) has been studied insufficiently at the present time. The determination of the phase transformation type in these alloys during quenching is very important for studying general regularities of the formation of zirconium alloys structure.



**Fig. 1.** Optical micrographs of quenched Zr-0.5 at.% Rh alloy: (a) near grain boundaries; (b) inside the initial  $\beta$ -phase grains



**Fig. 2.** TEM micrographs of quenched Zr-Rh alloys: (a) Zr-0.5 at.% Rh; (b) Zr-1.2 at.% Rh

In the present paper we report the results of structural studies of bainitic transformation in quenched Zr-Rh alloys. The phase diagram of the Zr-Rh system was studied in most detail in [1]. According to [1], the eutectoid decomposition of the  $\beta$ -phase occurs at 740 °C and the eutectoid composition corresponds to 5 at.% of rhodium. We studied the structure and phase state of quenched Zr-Rh alloys containing from 0.5 to 4.5 at.% of rhodium. The maximal rhodium content was sufficient for the formation of *a priori* possible nonequilibrium and metastable phases in these alloys. The alloys selected allowed us to determine the possible effect of the eutectoid decomposition on the formation of the structure during quenching.

The alloys containing 0.5, 1.2, 2.2, 2.65, 3.2, 4.0, and 4.5 at.% rhodium were prepared from iodide zirconium and rhodium of 99.9% purity. The ingots produced were homogenized in a vacuum of  $1 \times 10^{-3}$  Pa at 1000 °C for 3 h and quenched from this temperature in ice water. X-ray diffraction analysis, optical and transmission electron microscopy (TEM) were used in studying the alloys structure.

The phase state and the structure of the quenched alloys have been shown to depend on the rhodium content. The results of X-ray diffraction analysis are given in Table. In the alloys containing from 0.5 to 2.2 at.% rhodium the

hexagonal  $\alpha$ -phase and intermetallic compound  $Zr_2Rh$  are formed. While the X-ray diffraction does not indicate the presence of the  $Zr_2Rh$  intermetallic compound in the Zr-0.5 at.% Rh alloy, the smeared reflections of the  $Zr_2Rh$  intermetallic compound are present on the electron-diffraction patterns. The metastable  $\alpha$ -phase is formed at the content of rhodium in the alloy ranged from 2.65 to 4.5 at.%, with the eutectoid decomposition being suppressed.

The metallographic study reveals a noticeable change in the structure of quenched alloys, depending on the rhodium content. The Zr-0.5 at.% Rh alloy has the structure of upper bainite (Fig. 1). Clearly pronounced areas with lath morphology are observed near the initial  $\beta$ -phase grain boundaries. This structure differs from the lath martensite structure in that the laths inside packets have less clear contours. In addition, thick extended plates are inside the initial  $\beta$ -phase grains. Numerous smaller areas with lath morphology are also present between these plates. The plates disappear completely in the structure of the Zr-1.2 at.% Rh alloy; the structure undergoes refinement and the areas with lath morphology near the initial  $\beta$ -phase grain boundaries become narrower. The structure of the Zr-2.2 at.% Rh alloy becomes very fine and differs in morphological features from the structure of the alloys with less rhodium content. As rhodium content increases to 2.65 at.%, the structure changes substantially. Instead of the structure of bainitic type, a typical Widmansttten pattern is observed.

The TEM examination of the Zr-0.5 at.% Rh alloy reveals the structure of upper bainite resembling the structure of the packet-type martensite with the difference that the laths have more rounded ends, and the bands of precipitates are seen at the boundaries between the laths (Fig. 2a). In the Zr-1.2 at.% Rh alloy, the  $\alpha$ -phase laths are smaller, their distribution inside the packets is more regular, and the packets themselves often form regular geometric patterns (Fig. 2b). The precipitates of the intermetallic compound at the boundaries of the  $\alpha$ -phase laths are generally observed as a continuous network which is clearly visible both in bright-field and dark-field images (Fig. 3a). In some cases, one may see in the dark-field images that this network is broken up into isolated particles (Fig. 3b). A substantial structure refinement is observed in the Zr-2.2 at.% Rh alloy. The lath arrangement becomes less regular, and the thickness of the  $\alpha$ -phase laths decreases substantially. Although the structure contains only a little amount of distinctly visible packets, they are still observed as small isolated blocks. In addition, in the structure of this alloy, extended plates which do not contain twins are found rather often.

The obtained results show that the bainitic transformation (but not the martensitic transformation) occurs during quenching in ice water in the Zr-Rh alloys containing up to 2.2 at.% rhodium. This fact indicates that the rate of the eutectoid decomposition in this system is rather high. The occurrence of the bainitic transformation hinders the formation of the martensitic  $\alpha'$  ( $\alpha''$ )-phase in these alloys. To obtain the  $\alpha'$  ( $\alpha''$ )-phase in the Zr-Rh system, one should use substantially higher rates of quenching from the high-temperature  $\beta$ -phase region.

1. J.L. Jorda, T. Graf, L. Schellenberg, J. Muller, K. Cenzual, J.C. Gachon, J. Hertz, *J. Less Common Metals*, **136**, 2 (1988) 313-328.

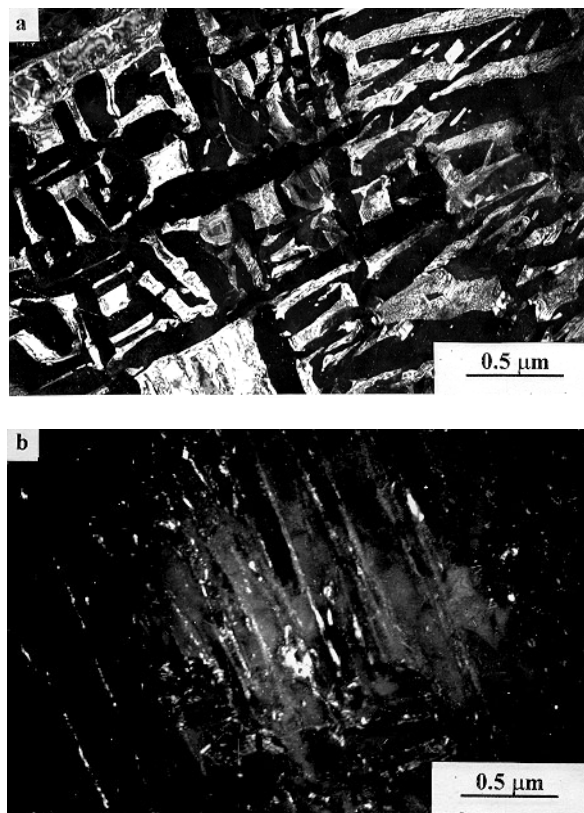


Fig. 3. TEM micrographs of quenched Zr-1.2 at.% Rh alloy: (a) and (b) dark-field image of different areas of the foil taken using reflections of the  $Zr_2Rh$  intermetallic compound

**Table.** Phase state of quenched ZrRh alloys according to X-ray diffraction analysis

Alloy composition, at.%	Phase state
Zr-0.5 % Rh	$\alpha$
Zr-1.2 % Rh	$\alpha + Zr_2Rh$
Zr-2.2 % Rh	$\alpha + Zr_2Rh$
Zr-2.65 % Rh	$\omega + (\beta) + \alpha$
Zr-3.2 % Rh	$\omega + (\beta)$
Zr-4 % Rh	$\beta + \omega$
Zr-4.5 % Rh	$\beta + \omega$