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A STUDY OF THE STRUCTURE AND PROPERTIES OF CERTAIN ALUMINIDES

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Translation of "Issledovaniye struktury i svoystv nekotorykh alyuminidov". Legkie Splavy i Metody Ikh Obrabotki, (Light Alloys and Their Preparation), Edited by M.E. Drits, Moscow, "Nauka" Press, 1968, pp. 146-150.

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16. Abstract

Experimental data are presented on the structure and heat resistance of the aluminides $ZrAl_3$, Fe_2Al_5 and Co_2Al_9, considering sp. wt., type of combination, and resistance to oxidn. at high temperatures. Co_2Al_9 possesses a relatively high heat of formation, attributed to its high heat-resistance characteristics.

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The varied and valuable complex of physico-chemical /116* properties possessed by metallic compounds has conditioned their possibility of practical application as materials having special physical properties, as well as the bases for structural heat-resistant alloys [1-7].

However, the application of such materials is for the most part inhibited due to the high brittleness of the metallides not only at room temperature, but also at elevated temperatures.

Outstanding in its properties among the metallic compounds is the class of aluminides, which are lightweight and have a relatively high melting point. Some of them are characterized by a high heat resistance and scaling resistance, and possess superconductive and other special physical properties. This class of metallides has not yet been sufficiently studied. The available data on the physical and mechanical properties are extremely limited and difficult to compare due to the differences in methods of producing and studying the compounds [8-10].

The goal of this work included the accumulation of experimental data on the structure and heat resistance of aluminides $ZrAl_3$, Fe_2Al_5, Co_2Al_9.

The available literary data on the properties of these compounds are presented below.

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* Numbers in margins indicate foreign pagination.

Properties	$ZrAl_3$	Fe_2Al_5	Co_2Al_9
Aluminum content, weight %.......	47.01	54.71	67.32
Fusion temperature, °C...........	1580	1173	946
Specific weight, g/cm^3...........	4.11	--	3.46
Crystalline structure............	Tetragonal	Monoclinic	Monoclinic
Character of compound formation..	Congruent	Congruent	By peritectic reaction
Heat of formation, kcal/mole.....	--	6.4	38.5
Electrical resistance, mkom·cm...	17	--	--
Microhardness at room temperature, kG/mm^2..........................	560	1000	735
Chemical stability..............	Resistant against oxidation	--	--
Solubility of other elements in compound.....................	--	--	High solubili of Fe, Ni, significant solubility of Si.

In selecting the indicated objects of study, consideration was also given to such characteristics as the specific weight, fusion temperature, character of compound formation, resistance to oxidation during heating and others, as well as to the practical interest which these compounds may have individually or as reinforcement phases in aluminum alloys.

The compounds $ZrAl_3$ and Fe_2Al_5 have relatively high melting points, possess congruent melting points, and their specific weight is on the order of 4 g/cm^3. The compound Co_2Al_9 with specific weight of 3.46 g/cm^3 is formed according to the peritectic reaction. As compared with most other aluminides, compound Co_2Al_9 differs in its high heat of formation, which makes it possible to rely upon its high refractory characteristics.

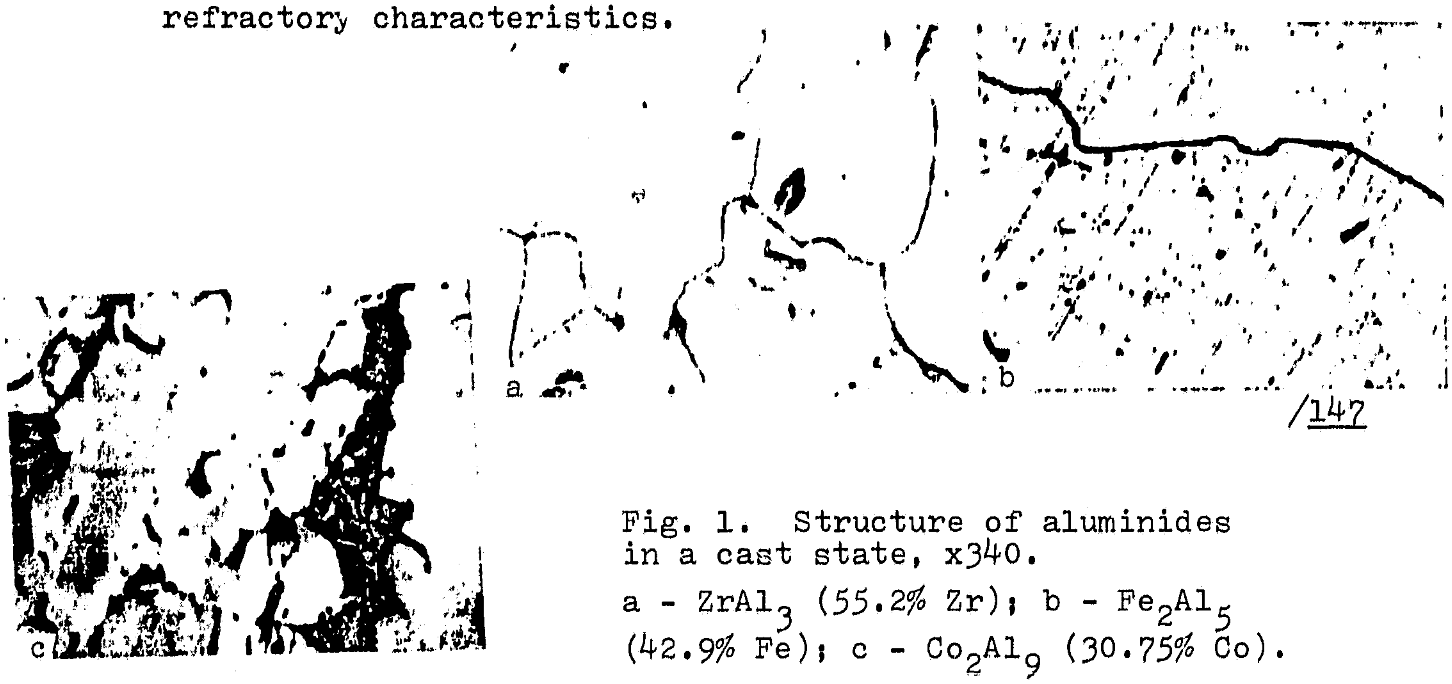

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Fig. 1. Structure of aluminides in a cast state, x340.
a - $ZrAl_3$ (55.2% Zr); b - Fe_2Al_5 (42.9% Fe); c - Co_2Al_9 (30.75% Co).

A study of the properties of the indicated metallic compounds is evidently good not only for clarifying their role as alloying elements in aluminum alloys, but also for an evaluation of their possible application as the basis for a heat-resistant alloy.

The preparation of the compounds selected for study was done by means of direct fusion of the pure components. The charge materials were: aluminum grade A99, iodide zirconium, armco-iron and cobalt grade K0. The computation of charge was conducted in accordance with the compound's stoichoimetric composition. The compounds were prepared first in an arc furnace in a helium atmosphere in the form of lumps, and then smelted in an induction furnace under an argon stream with subsequent casting into a heated steel ingot mold with graphite fitting. The results of the chemical analysis indicated values close to the computational, with a deviation from the given composition within the margins of 1 - 1.5%.

Confirmed by means of metallographic analysis was the presence of a single-phase structure for compounds $ZrAl_3$ and Fe_2Al_5 (fig. 1). In the case of compound Co_2Al_9, however, despite the similarity of its chemical composition to the given one, the structure of the ingot was heterophasal, which is evidently associated with the peritectic character of formation of this compound.

Evident in the microphotograph (fig. 1,c) are thermo-etched sections of aluminum-cobalt eutectics and two types of crystals. Located inside the light-grey crystals are crystals with a darker coloration. In accordance with the character of peritectic transformations in the system Al - Co we may consider that the light-grey crystals are the compound Co_2Al_9, while the more cobalt-rich compound Co_4Al_{13} is located in the center.

For compounds $ZrAl_3$ and Fe_2Al_5, an x-ray analysis was also conducted on a URS70 device in a RKD chamber with cobalt irradiation. The computation of the x-ray photographs to interplanar distances, the analysis of line intensities, and the comparison of the results with tabulated /148 values for pure substances showed that the crystalline structure of the studied materials corresponds to the structure of compounds $ZrAl_3$ and Fe_2Al_5.

For the purpose of eliminating defects in the cast structure and increasing the plasticity of the brittle compounds, hot deformation of the cast ingots was performed. Efforts were made by means of the deformation also to accelerate and facilitate the diffusional processes of equalization in compound Co_2Al_9 with the peritectic structure by subsequent high-temperature annealing. The deformation of the cast compounds was implemented by means of static hot jumping up on a hydraulic press of 200 t. The excess part of the ingot with concentrated piping was cut off by the electric spark method, while the healthy part of the ingot 25 mm in diameter and 40 mm in height was placed in a steel casing in the form of a cup, which was sealed at the top with a cover. The ingots in the casing were heated to 600°, after which they were upset by 50-60%. The press instrument was heated to 500°. The selected conditions made it possible to perform deformation of the indicated compounds practically without cracking and disintegration.

The changes in the microstructure after deformation were expressed in the appearance of slippage lines within the grains and the pulverization of individual grains. In the case of fusion of compound Co_2Al_9 after deformation, the traits of the cast dendritic structure are strongly retained.

An evaluation of the comparative heat resistance of the studied compounds was conducted on deformed samples by the long-time hardness method within the temperature sphere of 500 - 700°. Used for this purpose was a device with lever loading mechanism. The hardness measurement was done with a 5 mm diameter ball under a load of 150 kg and with holding the sample under load for a period of 1 hr. Testing up to 600° was conducted in a medium of molten saltpetre, and at higher temperatures -- in an air environment. At room temperature the hardness was measured on a Brinel press with a 5 mm ball under load of 250 kg on the samples which had previously been tested at elevated temperatures. The phase microhardness measurements were conducted on cast samples on an IMT-3 device at a load of 20 and 50 g.

Based on the example of compounds Fe_2Al_5 and Co_2Al_9, the effect of high-temperature annealing on their structure and hardness at increased temperatures was studied. The samples were annealed in vacuum and argon-filled quartz ampules at 1000° for 100 hrs. for compound Fe_2Al_5 and at 640° -- 10 hrs +880° -- 100 and 380 hrs. for the compound Co_2Al_9.

Presented below are the data for measurement of microhardness and hardness of the studied compounds:

Compound	$ZrAl_3$	Fe_2Al_5	Co_2Al_9
H_μ (P = 50g), kl'/mm^2	590	1100	750
H_B (P = 250 kg), kl'/mm^2	216	264	244

In a cast state, all the compounds are very brittle and are characterized by high microhardness values. After conducting the hot deformation, it was possible to perform standard hardness tests after Brinnel at a load of 250 kl'. The imprints for hardness had a regular form without any traces of cracks. The hardness value of the compounds in a hot deformed state is considerably lower as compared with the microhardness of the cast samples, which is evidently associated to a certain degree with the increased plasticity of the compounds as a result of the deformation.

The change in long-time hardness of compounds $ZrAl_3$ and Fe_2Al_5 depending on the test temperature is presented in fig. 2. In a deformed state (curves 1,2), the highest values /149 of long-time hardness within the entire range of test temperatures is exhibited by the high-melt compound $ZrAl_3$. In the temperature interval of 550 - 650° this compound suffers practically no loss of strength. Its hardness comprises around 60 - 70 kG/mm^2. Compound Fe_2Al_5 has a noticeable loss of strength with increased test temperature, and at a temperature of 600° already yields significantly by its value of long-time hardness to compound $ZrAl_3$. Annealing the compound Fe_2Al_5 leads to an increase in its long-time hardness (curve) only at 500°. At test temperatures of 550 - 600°, the long-time hardness of the compound before and after annealing is practically identical. An increase in the long-time hardness of compound Fe_2Al_5 at 500° due to annealing is evidently conditioned by the high stability of the recrystallized structure of the annealed material as compared with its deformed state (fig. 3,a).

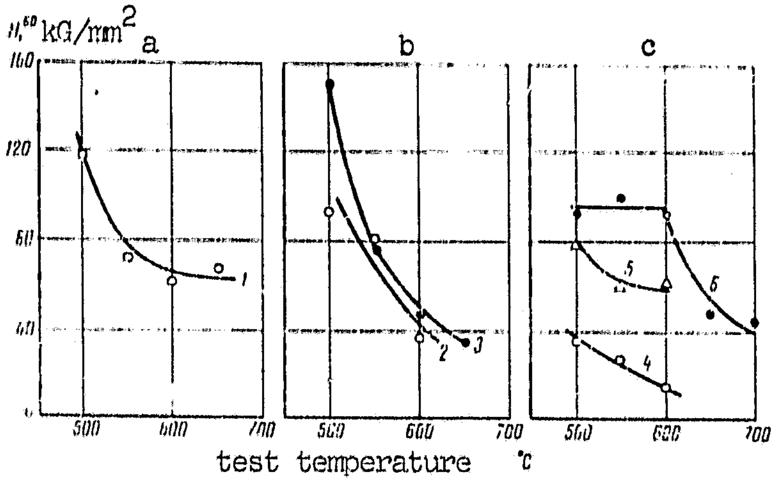

Fig. 2. Long-time hardness of aluminides at various temperatures.

a - $ZrAl_3$; b - Fe_2Al_5; c - Co_2Al_9.

1 - heat deformed; 2 - heat deformed; 3 - heat deformed and annealed at 1000° -- 100 hrs; 4 - heat deformed; 5 - heat deformed and annealed at 880° -- 100 hrs.; 6 - heat deformed and ahhealed at 880° -- 380 hrs.

The alloy corresponding in its chemical composition to compound Co_2Al_9, as indicated above, has a heterophase structure and in a non-annealed state is characterized by very low values of long-time hardness. At 500° the long-time hardness of the Al-Co alloy is equal to 40 kG/mm^2, and at 600° it drops to 17 kG/mm^2 (fig. 2, curve 4). As a result of annealing this alloy at 640° for 10 hrs., the eutectic areas disappear in its structure. Subsequent high-temperature annealing at 880° for a period of 100 hrs. still does not lead to a full homogenization in the structure of the alloy, which remains two-phased.(fig. 3,b). However, after the indicated thermal processing there is observed a noticeable increase in the long-time hardness (see fig. 2, curve 5). At a test temperature of 500°, the long-time hardness of the Al-Co alloy is approximately doubled, while at 600° it is increased by approximately 3 times and becomes close to the long-time hardness for compound $ZrAl_3$. Longer annealing at 880° for a period of 380 hours leads to full completion of the peritectic transformation and to an achievement of a single-phase, homogeneous structure of the compound Co_2Al_9 (fig. 3,c). The compound Co_2Al_9 obtained by this means is characterized by high values of long-time hardness (around 100 kG/mm^2) and suffers practically no loss of strength in the temperature interval of 500 - 600° (see fig. 2, curve 6). At a test temperature of 600°, the long-time hardness of the compound Co_2Al_9 is 50% higher than for compound $ZrAl_3$, and 170% higher than for compound Fe_2Al_5. /150

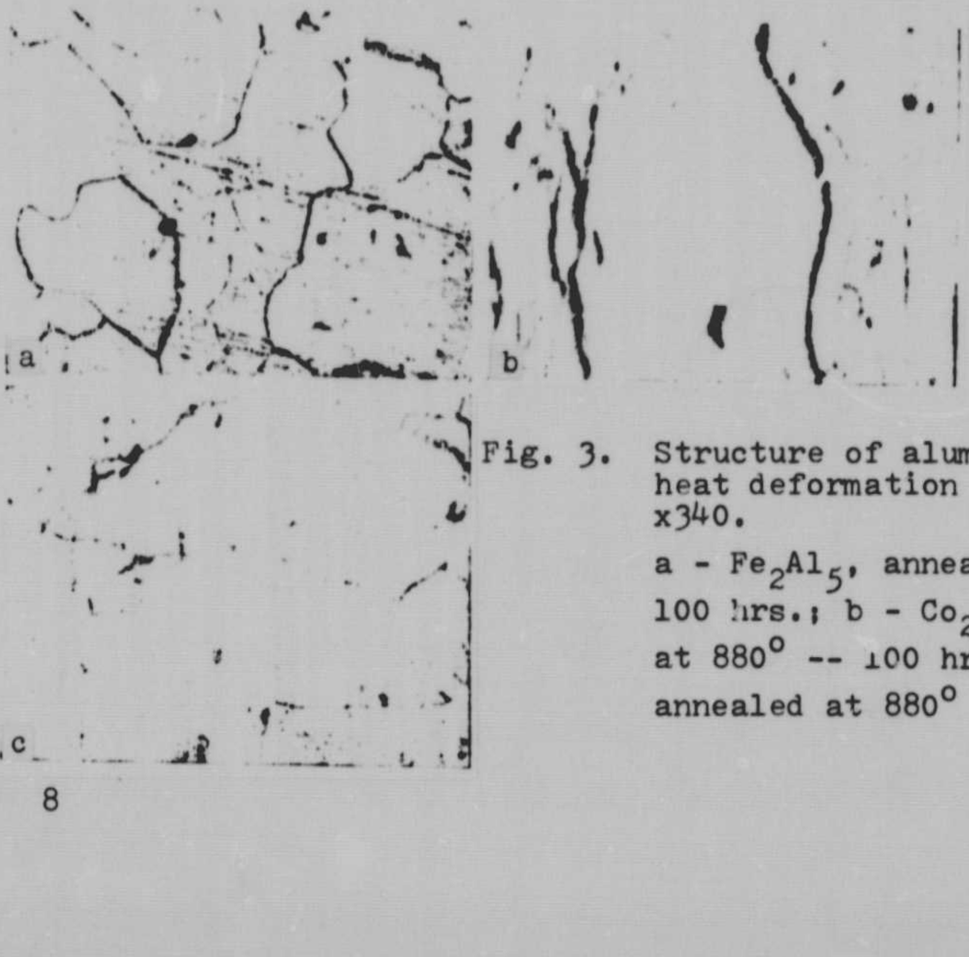

Fig. 3. Structure of aluminides after heat deformation and annealing, x340.

a - Fe_2Al_5, annealed at 1000° - 100 hrs.; b - Co_2Al_9, annealed at 880° -- 100 hrs.; c - Co_2Al_9 annealed at 880° -- 380 hrs.

As compared with a heterophasal alloy of the same composition, compound Co_2Al_9 has significantly better resistance to the action of temperature and stress, which is particularly apparent at high test temperatures. Thus, at 600° the long-time hardness of compound Co_2Al_9 is 6 times higher than that of an Al-Co alloy of the same chemical composition.

Only at temperatures above 600° is there a noticeable loss of strength in the cobalt aluminide. At test temperatures of 650 - 700°, the compound Co_2Al_9 yields in its long-time hardness to compound $ZrAl_3$, but exceeds compound Fe_2Al_5.

Thus, the comparative evaluation of heat resistant aluminides which we have conducted has shown that the highest and most stable hardness values are possessed by compound Co_2Al_9. The high absolute values of long-time hardness and the low degree of strength loss for aluminide Co_2Al_9 at increased temperatures allow us to conclude that cobalt must have a positive effect on the heat resistance of aluminum alloys.

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