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Abstract

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Change in the Microinhomogeneity of Alloys under the Influence of Heating

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It is usually accepted that holding alloys for a sufficiently long time at high temperature leads to the attainment of a more uniform distribution of components, i.e., to a decrease in the microinhomogeneity that arises during crystallization. According to these views, owing to the increased diffusional mobility of elements upon heating, concentrations in microvolumes of the solid solution are equalized, and the phases that form dissolve and coagulate, which also causes a decrease in the primary heterogeneity of the cast structure. However, the use of autoradiographic methods for studying the structure of alloys has made it possible to establish that a greater degree of homogeneity can be achieved far from for all alloys and not under all annealing conditions.

In work ([1]) the authors found that homogenizing annealing of certain nickel-base alloys leads to an intensification of nonuniformity in the distribution of some elements, i.e., in essence, to an increase in the heterogeneity of the structure of these alloys. Similar phenomena were found by us when studying the kinetics of component redistribution processes during annealing of certain light alloys based on aluminum and magnesium. Using a quantitative evaluation of the degree of microinhomogeneity of the structure, based on statistical processing of photometric data from autoradiographs, and applying the microinhomogeneity coefficients K and C^* proposed by us, we graphically expressed the change in the microinhomogeneity of the alloy structure as a function of various annealing conditions ([2]).

Figure 1 presents curves characterizing the change in the microinhomogeneity coefficients of the binary alloys Al—Fe and Al—Ca as the duration of annealing increases at a temperature lying 50° below the solidus line.

For both alloys the character of the curves is the same; only in the case of the alloy of the Al—Ca system do the changes in the course of the curves occur after a somewhat shorter heating time. As can be seen, the use of comparatively short holding times during annealing leads to a decrease in the microinhomogeneity coefficients, i.e., to an equalization of the structure of the alloys. With increasing heating time, however, either a clear increase in the degree of microinhomogeneity is observed, or a noticeable tendency toward an increase in

Figure 1 and Figure 2: graphs of the influence of annealing on alloy microinhomogeneity

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the latter.

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* The coefficient

$$K = \frac{100 - n}{100}$$

(where 100 is the total number of microvolumes in which the content of the element was measured, and n is the value of the maximum on the distribution curve) takes into account the total number of deviations of the concentration of the element from its average content in the alloy in the investigated region of the structure. The coefficient

$$C = \frac{C_{\max}}{C_{\min}}$$

determines the possible deviations of concentration in individual microvolumes of the alloy.

Let us note that both alloys investigated belong to binary systems with an almost complete absence of solubility in the solid state, i.e., in the structure of these alloys, within the given limits of alloying, there is a noticeable amount of a second phase. Accordingly, the processes of structural equalization are determined mainly by a change in the character of the distribution and in the form of the particles of secondary precipitates. Comparison of the obtained

Fig. 1. Influence of annealing time on the microinhomogeneity of alloys: **a** – alloy Al–0.19% Fe, **b** –alloy Al–0.4% Ca

Fig. 2. Influence of annealing time on the microinhomogeneity of alloys: **a** – alloy Mg–Mn–Al–Ca (0.2% Ca), **b** –alloy Mg–0.17% Ca

curves with microautoradiograms, as well as with the ordinary microstructure of alloys annealed for various times, indicates agreement between the observed changes in the structure of the alloys and the coefficients of microinhomogeneity. As we have already noted earlier ([3]), in autoradiographic investigation of aluminum alloys with iron, the heterogeneity of the cast structure of such alloys is very large and is stably retained under the action of temperature. As the annealing time increases, at first some blurring of the dendrites is observed owing to processes of redistribution of iron and calcium in the structure. This causes

Fig. 3. Microradiograms of an Al–0.4% Ca alloy; 25×. a–cast, b–annealing at 570°, 24 hours, c–annealing at 570°, 50 hours.

Figure 2: Fig. 3. Microradiograms of an Al–0.4% Ca alloy; 25×. a–cast, b–annealing at 570°, 24 hours, c–annealing at 570°, 50 hours.

Fig. 4. Microradiograms of a Mg–0.17% Ca alloy, 25×. Annealing for 24 hours. a–400°, b–500°, c–600°

Figure 3: Fig. 4. Microradiograms of a Mg–0.17% Ca alloy, 25×. Annealing for 24 hours. a–400°, b–500°, c–600°

a decrease in the degree of microinhomogeneity of the alloys (Fig. 1). A further increase in the duration of annealing causes coarsening of the dendrites and of individual accumulations of alloying components due to coagulation, which leads overall to the creation of a coarser structural inhomogeneity. The change in the character of the distribution of the alloying element with increasing annealing time is illustrated by us using the example of an aluminum alloy with calcium (Fig. 3). The dark areas of the microautoradiograms shown correspond to the places of concentration of radioactive calcium (Ca^{45}).

An increase in the microinhomogeneity of the structure of alloys under the influence of heating was also observed by us in magnesium alloys with calcium, which, within the investigated concentration range (up to 0.2% Ca), were essentially solid solutions. Inclusions of the second phase were detected only at high magnifications and in very limited quantity.

Figure 2 presents curves characterizing the change in the coefficients of microinhomogeneity with increasing annealing temperature (24 hours) for Mg–Ca and Mg–Mn–Al–Ca alloys.

In both cases heating the alloys to 500° causes a sharp decrease in microinhomogeneity in the distribution of calcium, which indicates the high intensity of the redistribution processes occurring at this temperature.

Fig. 3. Microradiograms of an Al–0.4% Ca alloy; 25×. *a*–cast, *b*–annealing at 570°, 24 hours, *c*–annealing at 570°, 50 hours.

Fig. 4. Microradiograms of a Mg–0.17% Ca alloy, 25×. Annealing for 24 hours. *a*–400°, *b*–500°, *c*–600°.

division. As is evident from the microradiogram presented (Fig. 4b), in the binary alloy of magnesium with calcium there is complete equalization of the alloy composition with respect to calcium, i.e., intradendritic segregation is not observed at all. Raising the annealing temperature to 600° noticeably increases the values of the coefficient C for both alloys studied (Fig. 2), while the coefficients K remain almost constant. Evidently, in this case a certain heterogenization of the alloy structure also takes place. At such a high annealing temperature, coagulation processes proceed very intensively, and rather large accumulations of calcium are formed in the alloy structure; these lead to the appearance of peaks on the photometric blackening curves. This is reflected especially strongly in the magnitude of the coefficient C, which determines the scale of possible concentration deviations in the investigated region of the structure, and is reflected to a lesser extent in the values of the coefficient K, which characterizes the total number of deviations from the mean composition of the alloy. The formation of concentration accumulations in the structure of the Mg–Ca alloy at a high annealing temperature is clearly visible in the microradiogram (Fig. 4c).

Thus, under certain annealing conditions, a kind of "secondary heterogenization" of the alloy structure may evidently occur, i.e., an increase in the degree of their microinhomogeneity. The development of such heterogenization will depend on the nature and interaction of the components forming the alloy, as well as on the initial microinhomogeneity of the alloy and on the ratio of the rates of the dissolution and coagulation processes under the given temperature-time conditions of heating. In alloys of the solid-solution type, heterogenization of the structure during annealing is caused by the formation of certain regions with an increased concentration of the alloying element; in alloys, however, where there is a significant amount of a second phase, the microinhomogeneity of the structure may increase owing to changes in the size and shape of the structural constituents. In one way or another, an increase in the degree of heterogenization of the structure under certain heating conditions cannot fail to affect the properties of alloys and requires further, more thorough investigation.

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Note: Figure translations are in progress. See original paper for figures.