

KINETICS OF $\beta - \alpha'$ TRANSFORMATION
IN LOW MOLYBDENUM-URANIUM ALLOYS

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Summary

The effect of the overheating degree in the δ' and β temperature regions on the kinetics of isothermal $\beta - \alpha'$ transformation was investigated in 0.45 and 0.6^{wt} % molybdenum alloys. It was found that the $\beta - \alpha'$ transformation at room temperature depends on time, which indicates that thermal activation affects the kinetics of the process. Kinetics of transformation was analysed using modified Avrami equation $x = 1 - \exp(-k\tau^n)$. It was found that a concurrence exists between the calculated value of the parameter $n=2+3$ and the experimentally established mode of growth of the martensitic phase. There are indications that the kinetics of $\beta - \alpha'$ transformation changes at the transition from the upper to the lower β solid solution region.

Introduction

The common features of the papers published so far on the $\beta - \alpha'$ martensitic transformation in uranium alloys are the examination of the crystallographic (orientation) dependence of the β and α' -phase (1,2), the determining of the TTT and CC^{wt} diagrams (3). In the literature and monographs published so far there is still lack of papers dealing in detail with the kinetic aspects of the isothermal $\beta - \alpha'$ reaction, and in applying the known equation for defining the kinetic parameters of the transformation.

^{wt}weight percent

^{cc}continuous cooling

This paper examines the kinetics of the isothermal transformation, at room temperature of the metastable β - phase to α' - martensite in uranium - 0.45 and 0.6% molybdenum alloys. The influence of overheating in the β - phase region on the course of the β - α' process was investigated also. In determining the kinetic parameters, the Avrami equation was applied which describes the isothermal transformation of the nucleation and growth type.

Materials and method

Uranium alloys with 0.45 and 0.6% molybdenum were made, with a total of 500 ppm of metal impurities. A 99.9% pure molybdenum was used for alloying. Specimens of 2 mm thickness and 8 mm diameter were annealed in vacuum for two hours at 850°C and furnace-cooled. The homogenised specimens were oil quenched from temperatures of 850°C, 700°C, 690°C, 680°C, 670°C and 660°C for alloys with a 0.45% molybdenum content, and from temperatures of 850°C, 680°C, 670°C and 660°C for 0.6% molybdenum alloy.

For metallographic investigation, the specimens were ground on N^o 600 paper and mechanically polished on diamond pastes. Electrolytic polishing was done in a chromic-acetic acid solution at a current density of about 1 A/cm². In regular time intervals, the specimens were examined and the amount (%) of α' - phase estimated.

Results

At room temperature, the metastable β - phase transforms with time to the martensitic α' - phase. The relationship between the amount of the α' - phase (%) and the overheating degree and transformation time is given in figure 1, for 0.45% Mo alloy, and in figure 2, for 0.6% Mo alloy. It has been observed that, both the incubation period and the transformation rate depend on the quenching temperature, i.e. on the overheating degree.

It can be noted that the incubation period of the formation of α' plates increases with the increased degree of overheating in the β region, i.e. going from 660°C towards 700°C the time is extended to 24, 36, 48, 64 and 72 hours. After quenching from the δ region, the induction period is increased to a considerably longer time: 380 hours.

Discussion and conclusions

In the isothermal martensite, which is formed at room temperature or below it, reliable data on the kinetics of the process are difficult to obtain because of the difficulties in conducting the experiment in such a manner as to completely suppress the athermally formed martensite (4). The examination of isothermal martensitic transformation on models of uranium alloys with elements stabilizing the β - phase is a considerably "easier" case (5). Quenching from temperatures retains only the metastable β -phase, which isothermally transforms to martensite, i.e. the system is free of the athermal phase.

The curves illustrating the β - α' transformation have the well-known sigmoidal form, characteristic of processes whose rate changes with time. The fact that the process of β - α' transformation is a function of time leads to the conclusion that, although martensite is formed by the cooperative shear of the atoms in the β - phase, thermal activation must be a factor influencing either nucleation or the growth of martensite (6). The curves shown in FIG. 1 and 2 indicate that the degree of overheating within the β -phase region affects the kinetics of transformation and that the shifting of the curves as a function of time is not monotonous. This phenomenon was commented in an earlier paper of the authors (7,8). In the case of 0.45% Mo alloy, the curves are grouped around quenching temperatures of 680°C and 700°C, and for the 0.6% Mo alloy about 670°C and 680°C.

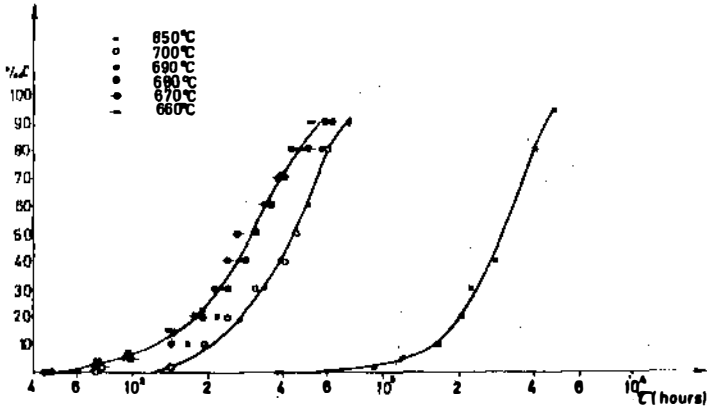


FIG. 1.
Dependence of $\beta - \alpha'$ transformation
on time for 0.45% Mo alloy

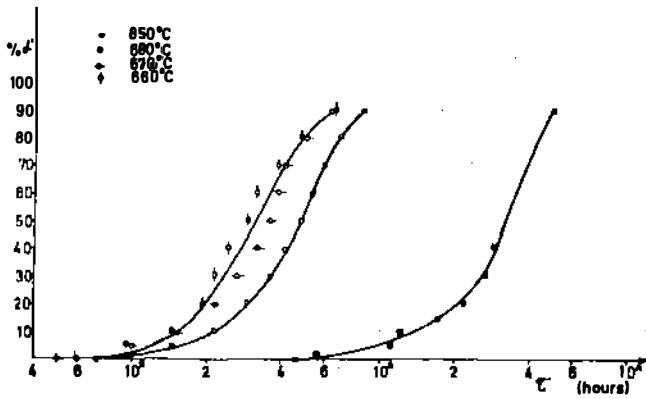


FIG. 2.
Dependence of $\beta - \alpha'$ transformation
on time for 0.6% Mo alloy

Johnson, Mehl and Avrami formulated a modified form of the general kinetic equation applicable to reactions of the nucleation and growth type, by introducing the concept of "expanded volume", which defines more closely the conditions under which the nuclei grow. The final form of the equation, known as the Avrami relation, is represented by the expression:

$$x = 1 - \exp(-k \tau^n)$$

where x is the volume fraction of the new formed phase,
 τ is time and n and k are constants.

The experimental results concerning the change of the new formed phase with time are often analysed by means of the dependence $\log \ln \frac{1}{1-x}$ versus $\log \tau$. If this equation is valid, the dependence is expressed by a straight line a slope n . In this case, the value of the parametre n provides an indication as to the type of nucleation.

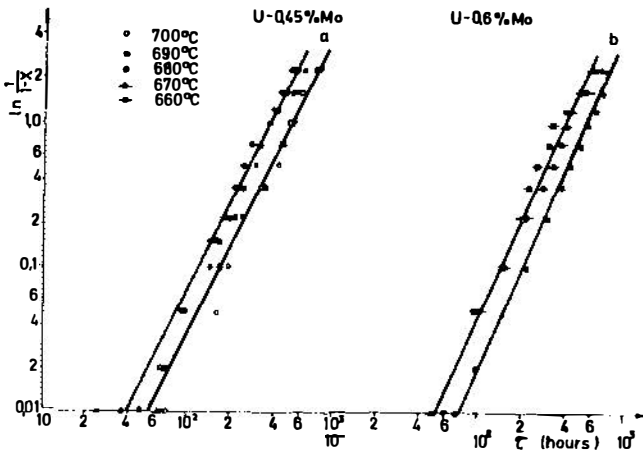


FIG. 3.

Dependence $x = 1 - \exp(-k \tau^n)$ for a) U-0.45% Mo and
 b) U-0.6 % Mo alloys

Figure 3 demonstrates the dependence between $\log \ln \frac{1}{1-x}$ and $\log \tau$ for both alloys, and the values of k and n are given in TABLE 1. In the first place, it can be noted that the kinetic data on the reaction comply with Avrami dependency,

as they give straight lines. The values of the parameter n (TABLE 1) range between 2 and 3, placing the isothermal $\beta - \alpha'$ reaction among the types of transformation where the particles grow in two directions, as postulated by Avrami for values $2 < n < 3$. This indicates that thermal activation, and not only the clear effect of β - phase atoms, play a role in the reaction. This would be in full conformance with the fact, that the plates of isothermal martensite grow both longitudinally and laterally, similar to other systems with a martensitic reaction.

The coefficient k is of the order of magnitude: 10^{-6} for 0.45 % Mo, and 10^{-7} for 0.6% Mo content, the values, however, depending on the degree of overheating. The parameter n manifests a similar dependence on molybdenum contents and on the degree of overheating.

TABLE 1

Values of k and n in the Avrami equation

Composition of alloy	Quenching temperature (t)	k	n
U- 0.45% Mo	700°C	3.30×10^{-6}	2.00
	690°C	3.30×10^{-6}	2.00
	680°C	4.40×10^{-6}	2.10
	670°C	4.40×10^{-6}	2.10
	660°C	4.40×10^{-6}	2.10
U- 0.6% Mo	680°C	3.50×10^{-7}	2.36
	670°C	0.10×10^{-7}	2.30
	660°C	0.10×10^{-7}	2.30

From the foregoing, the following conclusions could be made:

- The degree of overheating affects the kinetics of the $\beta - \alpha'$ isothermal transformation in U-Mo alloys with low contents of molybdenum. It is supposed that this phenomenon is caused by different atom arrangement in the lower and upper β - solid solution range.

- The values of parameter n in the Avrami equation, indicate that a concordance exists between the calculated

value of the parameter $n = 2$ to 3 and the experimentally established two dimensional mode of growth of the martensitic plates.

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