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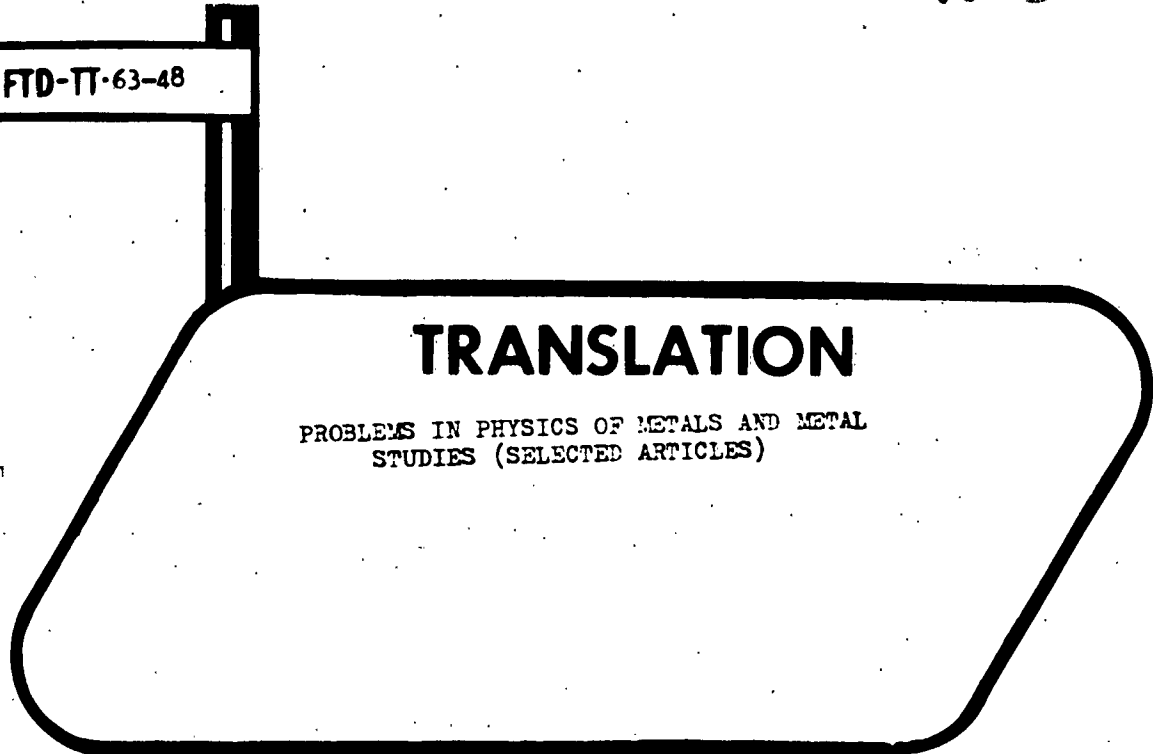
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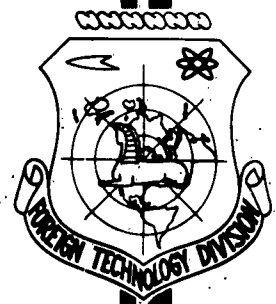
PROBLEMS IN PHYSICS OF METALS AND METAL
STUDIES (SELECTED ARTICLES)

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PROBLEMS IN PHYSICS OF METALS AND METAL STUDIES
(SELECTED ARTICLES)

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Effect of Heating Rate on the Temperature Intervals
of conversions during Electroannealing of Steel.

by

V. N. Gridnev and Yu. YA. Meshkov

It was established as result of numerous investigations that during the heating of hardened steel are observed four annealing effects, which in sequence of temperature rise their developments are called the first (50-180°), second (200-280°), third (270-400°) and fourth (over 400°) [1]. The temperature position of the annealing effects in each concrete case depends upon the composition of the steel and upon the duration of the annealing. The nature of the effects has been evaluated many times, and special literature is devoted to this problem.

In recent years greater attention has been devoted to the study of characteristics of annealing processes at rapid heatings with electric current. It was established on the basis of data of dilatometric analysis that upon an increase in the rate of heating the first and third effects of annealing steel are blended in the zone of higher temperatures [2,3]. Decomposition of residual austenite (second effect) during electro-heating according to dilatometric analysis data could not be revealed. These observations gave reason to assume, that at higher heating rates the decomposition of residual austenite is suppressed. But after rapid heating to temperatures over 400° and subsequent sharp quenching the austenite decomposes completely. Efforts were made to explain, when and at what temperature range decomposition of residual austenite takes place at electric heating. In report [4] on the basis of magnetometric analysis data at repeated heating of electroannealed samples of carbon steel it has been concluded, that the decomposition of austenite occurs either in the quenching process, or in the period of unavoidable brief isothermal exposure at the moment when heating is discontinued during electro-annealing (heating rate 1700 deg/sec).

In this way, no accurate data could be attained. It could be expected that more definite results will be obtained when observing the processes of decomposition of residual austenite directly in the period of heating the samples during electro-annealing. For this purpose in report [5] was used an AC magnetometer [6] allowing to obtain the plotting of a sample magnetization curve during electroheating at rates of up to 1000 to 1500 degrees/sec. It was shown, that when heating at a rate of the order of 300 degrees/sec the decomposition of residual austenite in carbon steel takes place in the period of heating in a range of temperatures somewhat higher than the third effect (400-550°). It is interesting to explain, what effect the rate of heating is exerting during electroannealing on the temperature of decomposition of residual austenite, determinable by data of magnetometric analysis.

For the investigation were selected chrome steels SHKH6, SHKH5 and carbon steel UL2. Samples of these steels in form of thin wires were hardened from a temperature of 1000° in water.

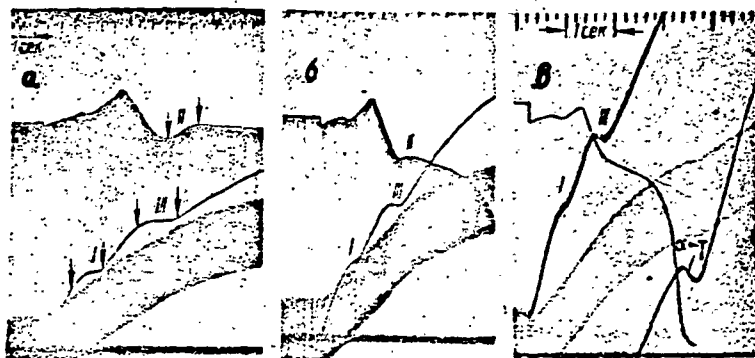


Fig.1. Oscillograms of electroheating of hardened steel SHKH5. Heating rates: a-45 deg/sec; b-80 deg/sec; c-300 deg/sec.

The content of residual austenite in all hardened samples was 20-25%. The samples were investigated on an installation for the study of rapid heatings, constructed by type [7] and supplemented with AC magnetometer [6]. On the oscillogram were simultaneously plotted temperature, elongation and magnetization curves of the sample in an intensity field of about 200 e, and time markers were made.

In fig.1 and 2 are given typical heating oscillograms obtained in this investigation. Detailed interpretation of the path of the magnetic curve in weak fields during electro heating of hardened steel was given in report [5]. As was shown, the increase in magnetization, following immediately after dilatometric compression at the third effect appears to be the result of decomposition of residual austenite [5]. Analysis of magnetograms of electro-heating of SHKH5 steel (see fig.1) shows that in ratio to the increase in heating rate the completeness of decomposition of residual austenite decreases gradually and at rates of more than 100 deg/sec its decomposition is absolutely depressed (fig.1,c). When steel SHKH6 is heated at a rate of the order of 400 deg/sec (fig.2,a) the decomposition of austenite is well noticeable, in U12 steel the decomposition of austenite takes place at rates of about 2000 deg/sec, in spite of the fact that the intensity of decomposition has noticeably decreased.

On the oscillograms were determined the temperatures of intervals of first and third effects by the dilatometric curve and second effect by the magnetic curve. Change in position of temperature intervals in ratio to the rise in heating rate is shown in fig.3-5. Attention is called to the practically linear rise in temperatures of all annealing effects in semilogarithmic coordinates. As we see, the interval of decomposition of residual austenite rises considerably faster than the intervals of the first and third effects, which practically blend parallel. Not without interest is the fact, that if we would extrapolate the obtained data to rates of the order of 10^{-2} deg/sec, then the intervals of all three conversions fall in the same range of temperatures, where they are ordinarily observed during furnace heatings. In fig.6 is given such an extrapolation for steel U12. Here are plotted the results of dilatometric determination of temperature of annealing effects according to data by [8] at various rates of furnace heating. It can be assumed, that such an extrapolation is in satisfactory conformity with data at slowheatings.

In this way, the decomposition of residual austenite can take place in a wide

range of temperatures depending upon the heating rate and under specific conditions is even covered and superimposed the interval of the third effect. In reports [2,4,5] was expressed the assumption about the accelerating effect of phase cold hardening, originating as result of the third effect, on the decomposition of residual austenite. In this case it can be expected, that upon the intersecting of decomposition temperature ranges the linear dependence of the slope of curves for the intervals of the second effect will be disrupted.

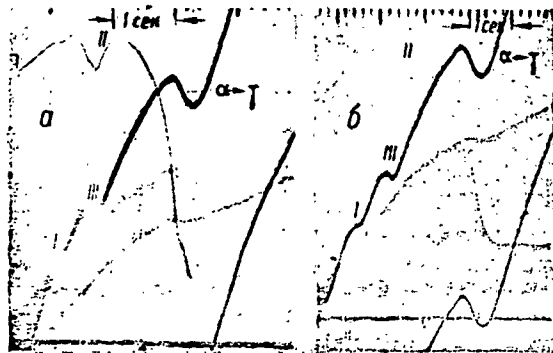


Fig.2. Oscillograms of electro heating of hardened steels: a-SHKH6, heating rate 400 deg/sec; b-UL2, heating rate 250 deg/sec.

But the obtained results do not confirm this assumption (see fig.4,5). Evidently, the volumetric effect of the third conversion and the deformation caused by it (phase cold hardening) produce no noticeable effect on the decomposition of residual austenite.

In report [9] is shown that at several hour exposures residual austenite decomposes noticeably at temperatures of 100-150°.

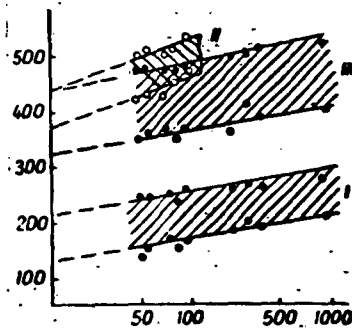


Fig.3. Dependence of temperature intervals of annealing effects upon rate of heating for SHKH15 steel.

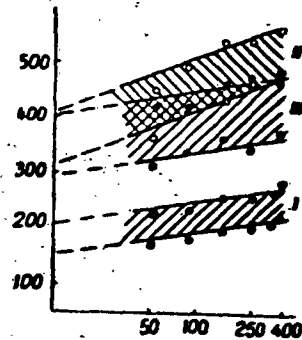


Fig.4. Dependence of temperature ranges of annealing effects upon the rate of heating of SHKH6 steel.

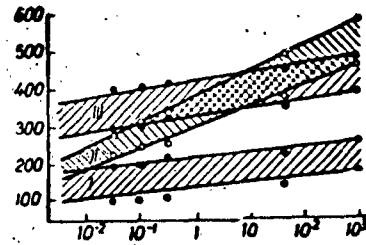
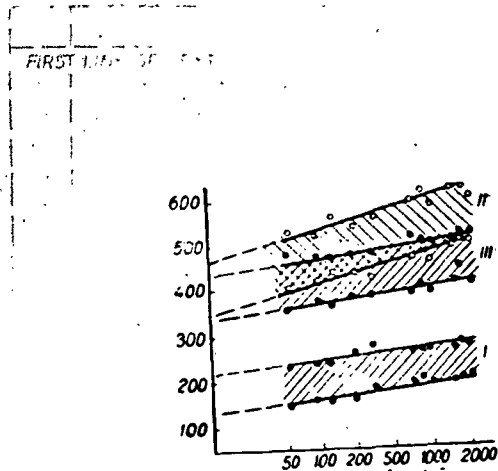


Fig. 5. Dependence of temperature ranges of annealing effects upon rate of heating of UL2 steel. Fig. 6. Extrapolation of annealing intervals of UL2 steel over the zone of slow heatings.

This result is in excellent conformity with the temperature range dependence of austenite decomposition (as shown in fig. 6) upon the rate of heating. The graph of the second effect during annealing is more steeper than of the first and third effects which, apparently, appears to be the result of reduced diffusion mobility of carbon in the austenite lattice in comparison with its mobility in α -iron. The parallel slope of the intervals of second and third effects at an increase in heating rate can in turn appear to be an indication, that at the third effect a definite role is also played by the processes, connected with diffusional distribution of carbon, since the composition of low temperature carbide, in the opinion of a majority of researchers is different from the cementite [10].

On the basis of results obtained in this investigation were made the following fundamental conclusions:

1. The temperature ranges of steel annealing in ratio to the rise in heating rate are rising continuously, whereby the range of the second effect (decomposition of residual austenite) rises considerably faster, than that of the first and third effects, as result of which the second effect during electro-heating superimposes itself over the interval of the third effect or even exceeds same.

2. The third effect during the annealing produces no noticeable effect on the process of decomposition of residual austenite in the case when their temperature ranges are in conformity.

3. In ratio to the increase in heating rate the completeness of decomposition of residual austenite decreases. The decomposition ^{of} relatively stable alloyed austenite in SHKEL5 steel can be suppressed when heated at rates of over 100 deg/sec.

4. The adopted terminology, in conformity with which conversions during the annealing of steel attained the name of the first, second and third effects, bears a conditional nature, because the second effect at low heating rates may overlap the first one and at high rates the third effect.

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On the Existence of Martensite Crystal Formation Centers
above the Point of Metastable Equilibrium

by

I. A. Arbutzova and L. G. Khandros

One of the most difficult to explain features of martensite conversions, distinguishing the latter from other phase conversions in solid state, is the cessation of conversion during the cessation of quenching. Since martensite crystals ordinarily grow at greater rate, the stoppage of conversion means a discontinuation in the formation of nuclei of the new phase.

As pointed out by Kurdyumov [1] the causes, producing this phenomenon, can be of two types. First of all, as result of formation of martensite the state of the residual martensite changes so, that the formation or growth of new nuclei in it becomes difficult. Secondly, the nucleus originates not at any given point of the volume, but only in some of its sections, where their formation is easier.

A study of iron-nickel alloys [2] showed, that at gradual quenching in ratio to the increase in the amount of martensite in the basic phase there is a considerable rise in distortion of the second type. A similar investigation, carried out on manganese steel, in addition to the formation of second type distortions, showed a considerable change in the parameter of the austenite lattice upon the appearance of the martensite phase [3,4]. In Cu-Al-Mn alloys is observed a considerable return of basic crystal fragments when the martensite phase begins forming in it.

Although the mechanism of the effect of the mentioned changes of the initial phase on the ability of its further conversion is not fully explained, apparently, these changes can lead to a discontinuation of formation and growth of new phase nuclei. But this can take place only at much later stages of conversion, when a consi-

derable amount of martensite phase has already been formed. The experiment also shows, that the mentioned rule takes place already in the very early beginning of the conversion when only several percentages of the new phase have originated.

In literature has been repeatedly expressed the idea that martensite crystals form in specific previously prepared places of the basic phase (heterogeneous nucleation). About the presence of such places and about their effect on the conversion kinetics is indicated by experiments on preliminary plastic deformation and deformation bombarded by neutrons [5]. It has been observed many times that the formation of martensite crystals took place on the grain boundaries and close to the line of shear.

In this investigation was made an effort to explain, on whether there are preferential points of nucleation in alloys, which are not subjected to preliminary treatment. For this purpose were selected alloys, in which martensite conversion is of reverse nature. It is possible to establish in repeated conversion (passage) through the martensite point, whether there are such points and whether their activity is not lost during repeated conversion cycles.

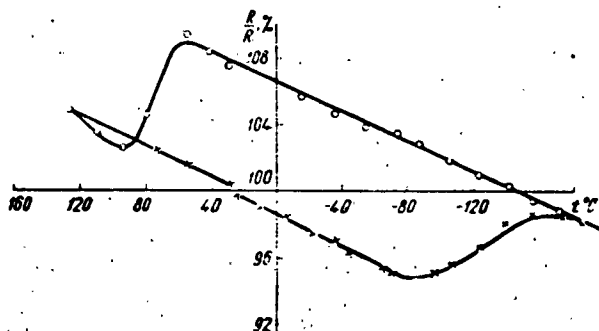


Fig. 1.

To make the experiments were selected two alloys: Cu-Sn (24.6% Sn) and Cu-Al-Ni (14.4% Al, 4.7% Ni). The first one of these alloys had considerable conversion hysteresis $\beta \rightleftharpoons \beta'$, the second one converted without hysteresis. In the first as well as in the second alloy the reverse conversion takes place exactly in the same manner, as direct conversion, as result of which the initial crystals of the β phase are fully

restored.

Samples of Cu-Sn alloys after annealing at a temperature of 700°C for a period of seven hours were hardened in cold water. The interval of direct and reverse conversions was determined by the electro-resistance change curve, and it was also controlled by x-ray and microstructural methods.

The arrangement allowed to measure electro-resistance of the sample in the range of temperatures from - 180 to + 200°. The resistance of the sample was measured with the aid of PFTN potentiometer. The sample was quenched by exposing it above the surface of liquid nitrogen or by submerging it in it. For the purpose of heating the sample was transferred into a vessel, filled with glycerin. The sample with conduits and thermocouple hooked up to it remained stationary, and the vessel with the liquid was moved toward the sample.

In fig.1 is shown the electro-resistance change curve during quenching and heating. A comparison with x-ray and microstructural data showed, that the electric resistance during quenching decreases linearly to the martensite point (-80°) after which it deviates from the linear path and grows to full conversion $\beta \rightarrow \beta'$. It then again decreases linearly at a further drop in temperature. When heated the resistance rises to a temperature of 60°, at which reverse conversion begins. Further heating leads to reverse conversion $\beta' \rightarrow \beta$, accompanied by a reduction in electric resistance. The nature of the reduction is reverse to that observed in the process of direct conversion. If the exposure in the process of experimentation at a temperature of over 120° is of no great duration and the process of decomposing does not have time to take place, then repeated quenching and heating give the very same loop as during the first cycle of quenching and heating.

It is evident from the obtained curve, that reverse conversion is fully concluded when heated up to 120°. Hysteresis in the investigated alloy equals approximately 200°, which is in good conformity with previous investigations [6].

Samples of this alloy, having the form of plane-parallel plates, 1-1.5 mm thick were hardened from a temperature of 700° in water. After polishing and buffing they were further quenched to - 180°. Here we had $\beta \rightarrow \beta''$ conversion, accompanied by the formation of an acicular relief. Martensite crystals often passed through the entire thickness of the plate, which can be noticed by the similarity of the relief on two opposite sides of the plate. The relief (contour) originating during the quenching was removed by grinding and the sample was submerged for several seconds into the bath at a temperature of + 200°. On the polished surface originated a relief, reverse of the one, which appeared during the quenching. The described cycle of direct and reverse conversion has repeated itself several times.

After each conversion cycle the picture of the relief changed, but the largest martensite crystals of the β'' -phase, forming first during the quenching, were often reproduced. Such needles could be easily distinguished from others, from the ones with much finer rounding and reliably identify the point, from where their growth began. The outer outlines of such crystals from cycle to cycle could change somewhat, but the place of origination of such a crystal was one and the same. In fig.2 are shown reliefs, formed after the first one (a), second one (b) and fifth (c) cycles of sample quenching in liquid nitrogen. It is easy to notice the appearance of one and very same crystal after various conversion cycles.

In this way, in spite of the considerable overheating of the sample (by 80° above the martensite point) the largest crystals of the martensite phase at various conversion cycles were often reproduced.

An effort was made to observe the reproducibility of crystals when heated to higher temperatures. The chart of the relief during the heating to 220°, was rarely repeated, which is, apparently, connected with partial decomposition, taking place at such a temperature.

A more suitable for similar experiments was the Cu-Al-Ni alloy. The typical

electro-resistance change curve of such an alloy is shown in report [7]. The relief in the alloy selected for the investigation originates during the quenching and disappears completely when heated to $+ 50^{\circ}$.

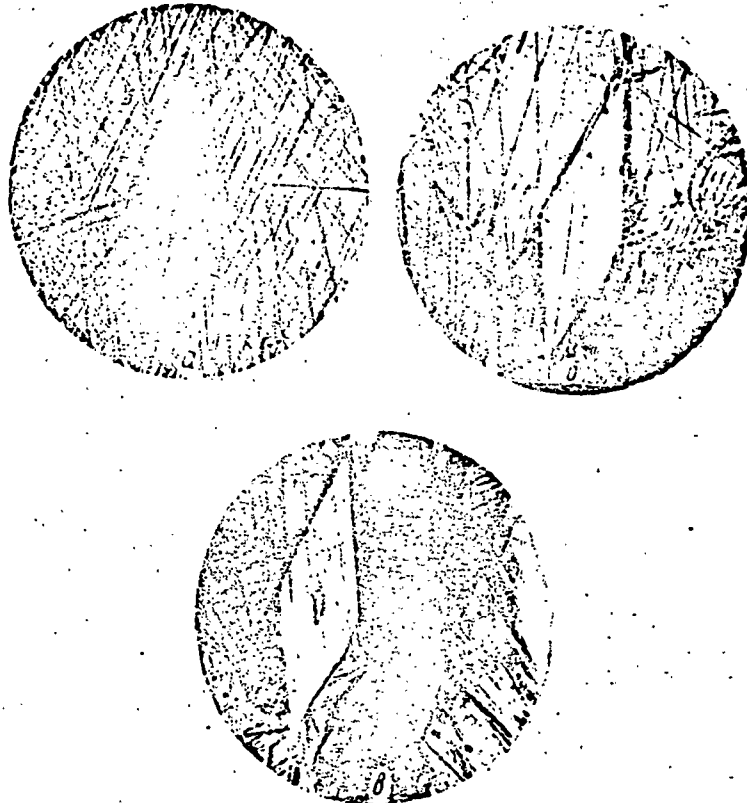


Fig. 2

The roentgenograms, taken at this temperature, showed that the sample consists entirely of β_1 - phase.

To observe the relief, originating on the surface of the slide, was employed the following method. The sample after hardening from a temperature of 900° , was polished at 70° . After quenching to room temperature on the slide was visible a small amount of martensite crystals. The sample together with holder were submerged for a certain time in boiling water, and then transferred into a vessel with alcohol, chilled to various temperatures. With the aid of a microscope through the wall of the vessel was observed the picture of the originated relief. Such experiments with one and the same

sample were repeated many times (80-100 times) Observations showed, that if no attention is paid to small crystals and only large ones are examined, it can then be noticed,

that in each β -phase grain are several places in which the largest crystals of the martensite phase are formed. From cycle to cycle may developed this or another nucleation center. The realization of one of these centers suppresses the origination of crystals in other centers. The first appearing martensite phase crystal determines

the picture of the relief in the entire grain, and quite often also in the neighboring grains. Upon the origination in the given or in the adjoining grain of another martensite crystal the entire picture of the relief changes. During many repetitions of the experiment one can see the repeating formation of large martensite crystals from the very same places, even if in intermediate cycles other crystals originated. As to fine (minute) crystals, forming in much later stages of conversion, then their origination, form and growth tendency are connected with the arrangement, form and growth tendency of previously originated crystals. The appearance of this or any other crystal nucleation center of martensite phase, apparently, should depend upon the conditions of quenching and preceding heating. But in a majority of instances were retained for some reason or other, and the picture of the relief at investigated cycles has not been reproduced.

In both investigated alloys, in spite of considerable overheating of species to above the temperature of the end of reverse conversion, is observed numerous repetition in the formation of martensite crystals in specific points. This indicates, that in the initial β - phase there is stable fixing of place, in which after quenching to below martensite point the first martensite phase crystals are formed. This conclusion is confirmed by the reproducibility of the relief picture after several conversion cycles.

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