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EFFECT OF INCREASING ELECTRICAL RESISTANCE OF ALLOYS OF VARIOUS COMPOSITIONS

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Abstract- The electrical resistance of undeformed samples hardened in water gradually increases to 300-400 °C due to the positive temperature coefficient of resistance. The progression of the curve from 400 to 700 °C indicates the development of the K-state. In the temperature range 700-925 °C, the solid solution decomposes with the formation of particles of a strengthening phase, which leads to a decrease in electrical resistance. The rise of the curve above 950 °C is associated with the dissolution of previously released particles of the second phase. The heating curve indicates the occurrence of the mentioned processes in reverse order. In deformed samples, the formation of the K-state during heating occurs in a wider temperature range (from 100 to 700 °C) and is much more intense than in undeformed samples. The course of the cooling curve is similar to the cooling curve of samples quenched in water [1]. The cooling curve in the temperature range 775-500 °C is slightly higher than the heating curve, which is associated with different degrees of formation of the K-state due to different "initial" structures [2]. After cooling, the electrical resistance of undeformed samples cooled in a furnace returns to its original value. In deformed samples it is 5% higher than before heating, which indicates a stable influence of deformation on subsequent transformations. The magnitude of the change in electrical resistance after cooling depends on the previous treatment. For samples quenched only in water, it is 3.5% higher, for samples with a reduction of 50% - by 8.7%, for samples with a reduction of 75% - by 10.5%. This increase in electrical resistance is determined by the occurrence of the K-state during cooling, and the different magnitude of the increase is associated with the influence of the deformation energy (preserved even after high heating) on the development of the process of formation of the K-state during cooling. An increase in the electrical resistance of samples cooled with the furnace from the quenching temperature is observed only up to 550 0C, regardless of whether the samples were subjected to work hardening or not, and this increase is significantly less than that of the same samples, but quenched in water [1, 3]. When cooling with the furnace from the quenching temperature, some development of the K-state already occurs in the samples, which is probably not completely destroyed even with a reduction of 50%. This determines a smaller increase in electrical resistance during subsequent heating and shifts the maximum to a temperature of 550 °C [2, 5]. In addition, a distinctive feature of the heating curves of the samples is a two-stage drop in electrical resistance in the temperature range of 550-950 °C.

Keywords: Electrical Resistance, Deformation, Temperature, Rolling, Tabulation, Plate-Wiping.

1. INTRODUCTION

Over the years, new technologies and approaches have appeared in metal science, and all this follows from the requirements of practice. In the middle of the last century, powder metallurgy was created, which is considered a new method in metal science and metal technology. This method has found wide application in the metallurgical industry. The practice requirement arises in accordance with the field of application of metal alloys obtained as a result of long-term research by metal scientists. Structural elements made of metal alloys that will be used in various environments must be pre-subjected to physical and chemical treatment. For example, in alloys requiring high hardness, a chemical composition is selected, where solid liquid additives are usually used, the resulting end result is called a state of state (K-state) in metal ology and is subjected to heat treatment for annealing. At the same time, the resistance of the metal alloy to electrical conductivity increases with the help of additives of a solid solution. As a result of increasing the resistance of electrical conductivity, the mechanical properties (hardness, toughness) of metal alloys change, and their resistance to corrosion decomposition increases. Recently, the results of electrical resistance measurements have been re-examined for indirect or direct identification of material properties. This study aims to establish a correlation between electrical resistance estimates and changes caused by high-temperature oxidation.

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In almost all cases, the change in electrical resistance of drawn samples is higher than that of rolled ones. This may be due to the fact that higher inhomogeneous micro distortions arise as a result of drawing compared to practical drawing. An increase in the electrical resistance of deformed samples is observed after holding for up to 5000 min. further exposure leads to stabilization of the electrical resistance, which indicates the simultaneous occurrence of two processes, when the drop in electrical resistance due to the decomposition of the solid solution is compensated by its increase when the K-state appears.

The electrical resistance of undeformed samples hardened in water gradually increases to 300-400 °C due to the positive temperature coefficient of resistance. The progression of the curve from 400 to 700 °C indicates the development of the K-state. In the temperature range 700-925 °C, the solid solution decomposes with the formation of particles of a strengthening phase, which leads to a decrease in electrical resistance. The rise of the curve above 950 °C is associated with the dissolution of previously released particles of the second phase. The heating curve indicates the occurrence of the mentioned processes in reverse order.

As well as at 500 °C, there is no such coincidence for deformed samples, which is explained by the intensive formation of the K-state in the first minutes of holding. The electrical resistance of the samples after heating at 600 °C for 50,000 min is lower than after the same holding at 500 °C. This is due to a higher degree of decomposition of the solid solution at 600 °C and partial stress relief. An increase in hardness during holdings up to 50,000 min is observed in undeformed samples, as well as samples deformed by 5 and 25%, cooled in water and in air.

In samples with a compression ratio of 50 and 75%, an increase in hardness is observed only up to 5,000 min, further increase in holding time does not cause a change in the hardness of samples with 50% work hardening. Some drop is noted in samples with a deformation of 75%, which is caused by partial recrystallization. The highest hardness values are obtained after aging at 600 °C.

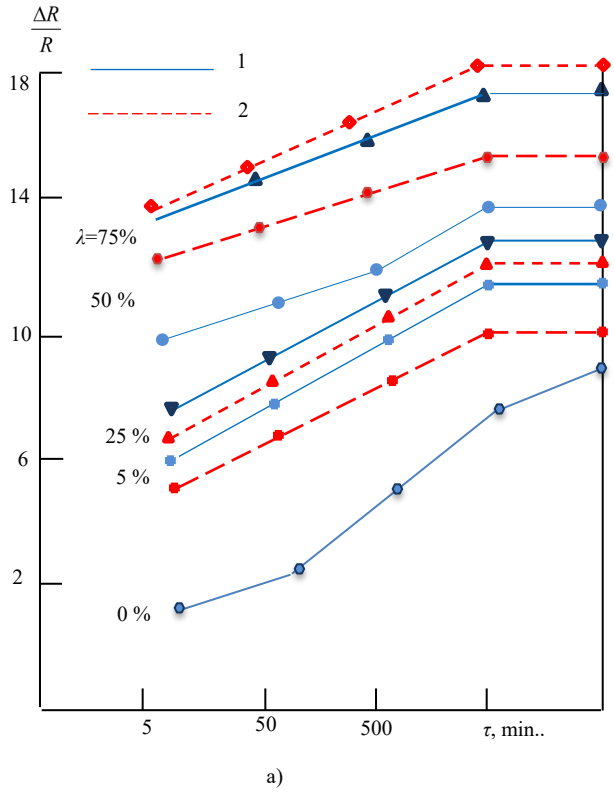
In deformed samples, the formation of the during heating occurs in a wider temperature range (from 100 to 700 °C) and is much more intense than in undeformed samples. The higher the degree of compression, the greater the increase in electrical resistance when heated. The maximum and minimum electrical resistances during heating and cooling for undeformed and also deformed samples (quenched in water) are almost the same in value, but during cooling they are shifted towards lower temperatures. The electrical resistance of samples after heating and cooling is higher than before heating.

The magnitude of the change in electrical resistance after cooling depends on the previous treatment. For samples quenched only in water, it is 3.5% higher, for samples with 50% compression - 8.7% higher, for samples with 75% compression - 10.5%. This increase in electrical resistance is determined by the occurrence of

2. PROBLEM SOLVING

Thus, preliminary cold deformation expands the temperature range and increases the intensity of the process of formation of the K-state in the solid solution of the KhN77TYUR alloy. Reducing the cooling rate during quenching reduces the intensity and narrows the temperature range of formation of the K-state, but expands the temperature limits of the decomposition of the solid solution with the release of particles of the second phase [3]. The pre-deformation scheme does not have a significant effect on the temperature ranges of structural transformations. It should only be noted that there is a slightly large increase in electrical resistance during the formation of the K-state in drawn samples (Figure 1), which may be associated with a higher level of inhomogeneous micro distortion. Figure 1 shows curves of changes in hardness and electrical resistance during isothermal exposure at 500 °C [4].

If we compare the relative change in electrical resistance measured at room temperature before and after tempering for 50,000 min at 500 °C and measured during heating at exposures of 5 and 50,000 min, we can note that for undeformed samples it is almost the same and, respectively, equal to 8 and 7.6% (cooling from tempering temperature in water, Table 1). This is not observed in deformed samples, and this difference grows with increasing degree of compression. For samples with a compression of 50%, the difference between the initial and exposures of 550000 min, it is only 6%; when hardening with a reduction of 75%, this difference is 14.5 m 2.5%, respectively (the comparison was carried out for samples hardened in water and then pierced) [5].



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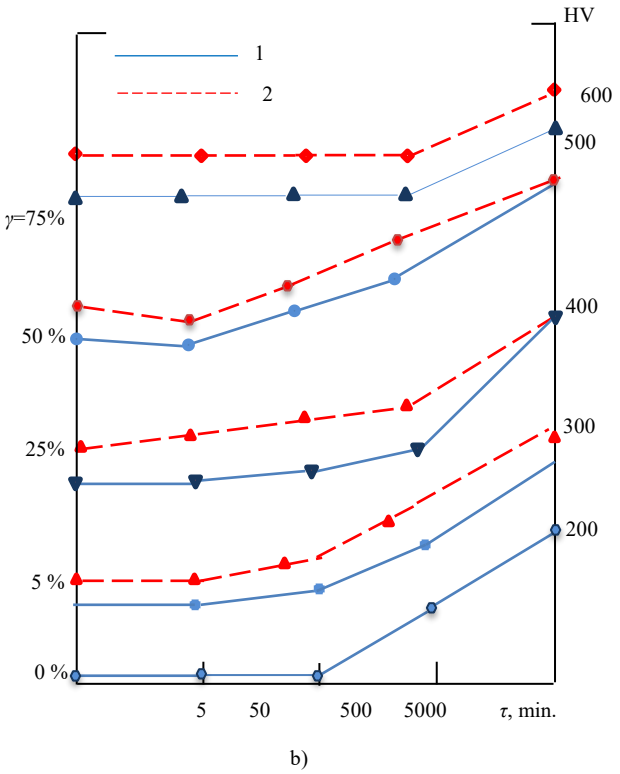

Figure 1. Change in electrical resistance and hardness of the alloy after quenching from 1080 °C in water and aging at 500 °C with different durations: 1) rolling, 2) drawing

This difference can only be due to the intensive formation of ordered atomic segregations in the solid solution (K-state) already in the first 5 minutes of exposure at 500 °C, which immediately This difference can only be due to the intensive formation of ordered atomic segregations in the solid solution already in the first 5 minutes of exposure at 500 °C, which immediately excludes the comparison of the indicated values.

Final values of electrical resistance at room temperature are 12.9%, and as a result of heating with the drop in electrical resistance with the formation of particles of the second phase, as well as partial stress relief [6]. As at 500 °C, drawing leads to greater changes in electrical resistance than rolling. If we compare the change in electrical resistance of undeformed samples at room temperature. Metallographic examination confirms the occurrence of aging during prolonged holding (5000-50000 min) in all cold-worked samples. Etch ability increases, the number of visible twins and slip lines increases, gray-green areas with sharply defined boundaries in grains appear (reduction of 50 and 75%).

The change in electrical resistance at 500 °C depends on the cooling rate during quenching and the degree of preliminary deformation to an even greater extent than hardness. Samples quenched in water have a maximum increase in electrical resistance of 7%, samples cooled in air - 4.5%; the minimum increase in electrical resistance is 2.15% and is observed in samples cooled in a furnace. This is apparently explained by the different degree of formation of the K-state during cooling from the quenching temperature. Preliminary cold deformation leads to a more intensive growth of electrical resistance in the first minutes of heating compared to what was observed in undeformed samples (Figure 2).

It is unlikely that the observed difference in the change in electrical resistance is due only to different temperature coefficients of electrical resistance due to the different composition of the solid solution of these samples. Significant deformation (50 and 75%) leads to the destruction of the K-state at room temperature, created as a result of different cooling rates from the quenching temperature; however, upon repeated heating, a very sharp increase in electrical resistance is noted, indicating an even sharper restoration of the K-state. Along with the intensifying effect of preliminary deformation on the creation of the K-state, the influence of the method of creating a given degree of deformation should be noted [7, 8].

Table 1. Relative change in electrical resistance of KhN77TYUR alloy samples at an aging temperature of 600 °C

λ, %	$\rho_{initial}$ μΩ·cm	ρ_{50000} μΩ·cm (t=20 °C)	$\frac{\rho_{initial}-\rho_{50000}}{\rho_{initial}}\times 100\%$	$\frac{\rho_{initial}-\rho_{50000}}{\rho_{initial}}\times 100\%$ (t=500 °C)
0	119.3	-	125.2	-
5	119.9	120.8	126.1	126.2
25	120.6	121.6	124.8	125.5
50	116.9	117.4	124.0	124.6
75	113.0	113.9	124.9	124.8
Air cooling				
0	121.0	-	126.2	-
5	123.8	122.5	125.6	126.2
25	124.6	124.9	125.3	125.0
50	119.8	118.5	124.5	124.8
75	113.8	113.9	124.6	124.2
Cooling with oven				
0	122.0	-	123.4	-
5	125.3	124.4	123.6	123.2
25	124.8	-	122.9	-
50	121.1	121.0	122.7	125.4
75	-	-	-	-

Aging at 600 °C reveals approximately the same patterns as at 500 °C, however, the formation of the K-state at 600 °C occurs more intensively at first, and then the process seems to slow down [9]. Stabilization of electrical resistance at 600 °C is noted after holding for 500 min, and not at 50,000 min, as was observed at 500 °C. Before and after heating for 5000 min at 600 °C with the change in electrical resistance during heating for 5 and 50,000 min, we can see a good agreement between these values (Table 1).

Holding for 50,000 min leads to a drop in the electrical resistance of deformed and undeformed samples, and in deformed samples this drop is sharper. A sharp increase in electrical resistance in the first minutes of heating cold-worked samples causes intensive formation of the K-state due to the accumulated deformation energy. The drop in electrical resistance with the formation of second-phase particles, as well as partial stress relief [10]. As at 500 °C, drawing leads to greater changes in electrical resistance

than rolled products. If we compare the change in electrical resistance of undeformed samples at room temperature before and after heating for 5000 min at 600 °C with the change in electrical resistance during heating for 5 and 50000 min, we can see good agreement between these values [11].

Long holding times (500 min and higher) cause an increase in hardness due to the formation of the K-state. The change in hardness during heating of deformed and undeformed samples depends on the cooling rate during quenching. For samples cooled with a furnace, the increase in hardness is significantly less than for samples quenched in water or air, and the increase in hardness of samples cooled with a furnace is noted with longer holding times (from 500 min). Heating at 500 °C does not equalize the hardness of samples cooled in water and air; at all holding times, quenched in air higher hardness of cooled in water, but does not reach the hardness of samples cooled with a furnace. Preliminary deformation has a significant effect on the change in hardness during repeated heating [12].

At the degree of deformation of 5 and 25% the increase in hardness during repeated heating increases in comparison with undeformed samples, high degrees of compression (50 and 75%) reduce it. The stress arising during deformation contributes to a more intensive process of formation of the K-state and decomposition of the solid solution with formation of particles of the strengthening phase, this determines a significant increase in the hardness of samples deformed by 5 and 25%. In addition, the degree of supersaturation of the solid solution also significantly affects the rate of decomposition.

Apparently, the optimal combination of all factors under the given aging conditions is in the case of quenching in water and work hardening by 25%, the hardness in this case increases from 260 to 400 HV. The decrease in the increase in hardness of samples with high degrees of compression is due to the fact that the decomposition of the solid solution has already occurred during deformation, and the greater the degree of compression. If the hardness increases of samples with 50% compression after holding for 50,000 min at 500 °S is 21%, then after compression by 75% this increase is 6%. Just as at 500 °C, there is no such coincidence for deformed samples, which is explained by the intensive formation of the K-state in the first minutes of holding. The electrical resistance of samples after heating at 600 °C for 50,000 min is lower than after the same holding at 500 °C.

This is due to a greater degree of decomposition of the solid solution at 600 °C and partial stress relief. An increase in hardness during holding up to 50,000 min is observed in undeformed samples, as well as samples deformed by 5 and 25%, cooled in water and in air. In samples with a compression degree of 50 and 75%, an increase in hardness is observed only up to 5000 min; further increase in holding time does not cause a change in the hardness of samples with a strain of 50%. Some drop is observed in samples with a deformation of 75%, which is caused by partial recrystallization. The highest values of hardness are obtained after aging at 600 °C. The time to reach the maximum value of hardness depends on the degree of preliminary cold deformation; the greater it is, the shorter the holding time should be (Table 2).

When heated to 700 °C, the change in hardness and electrical resistance is characteristic of the development of the dispersion hardening process. With an increase in the heating time to 50 min, stabilization of the electrical resistance values of undeformed samples quenched in water or air is noted, which can be explained by the superposition of the processes of formation of the K-state and decomposition of the solid solution. This indicates an intense decomposition of the solid solution with the release of second-phase particles. Partial preservation of the K-state after prolonged heating at 700 °C can be discussed only in relation to heavily deformed samples (hardened 75%), in which an increase in electrical resistance from 113.5 to 118 μΩ·cm is observed.

A significant increase in hardness at 700 °C is observed for undeformed and 5 and 25% deformed samples (quenched in water and air) only at holding times of up to 5000 min. Increasing the heating time to 50,000 min leads to a slight decrease in hardness. As the degree of compression increases to 50 and 75%, the intensity of the hardness increases decreases and the softening process occurs to a greater extent. The hardness values of deformed samples after heating at 700 °C for 50,000 min, as well as at 500 and 600 °C, remain higher than the same values for undeformed ones.

Table 2. Maximum hardness values of undeformed and rolled samples quenched in water

λ, %	Aging temperature, °C					
	500		600		700	
	Shutter speed min.	HV	Shutter speed min.	HV	Shutter speed min.	HV
0	50000	200	50000	275	5000	270
5	50000	235	50000	350	5000	315
25	50000	400	50000	425	5000	390
50	50000	435	5000	460	5000	400
75	50000	500	5000	535	500	475

Aging at 800 ^{0}C revealed intense decomposition with the release of particles of the hardening phase, coagulation of the second phase and the recrystallization process. A study of the combined effect of temperature and applied voltage on the kinetics of changes in electrical resistance was conducted on samples from serial melts of the KhN77TYUR alloy, selected in such a way that within the limits of the sample composition it would be possible to at least approximately estimate the effect of different titanium or aluminum content.

Long holding times (500 min and longer) cause an increase in hardness due to the formation of the. The change in hardness during heating of deformed and undeformed samples depends on the cooling rate during quenching. For samples cooled with a furnace, the increase in hardness is significantly less than for samples quenched in water or air, and the increase in hardness of samples cooled with a furnace is noted with longer holding times (from 500 min). Heating at 500 °C does not equalize the hardness of samples cooled in water and air; at all holding times, the hardness of samples quenched in air is higher

than the hardness of samples cooled in water, but does not reach the hardness of samples cooled with a furnace. Preliminary deformation has a significant effect on the change in hardness during repeated heating.

At the degree of deformation of 5 and 25% the increase in hardness during repeated heating increases in comparison with undeformed samples, high degrees of compression (50 and 75%) reduce it. The stress arising during deformation contributes to a more intensive process of formation of the K-state and decomposition of the solid solution with formation of particles of the strengthening phase, this determines a significant increase in the hardness of samples deformed by 5 and 25%. In addition, the degree of supersaturation of the solid solution also significantly affects the rate of decomposition.

Apparently, the optimal combination of all factors under the given aging conditions is in the case of quenching in water and work hardening by 25%, the hardness in this case increases from 260 to 400 HV. The decrease in the increase in hardness of samples with high degrees of compression is due to the fact that the decomposition of the solid solution has already occurred during deformation, and the greater the degree of compression. If the increase in hardness of samples with a compression of 50% after holding for 50,000 min at 500 °C is 21%, then after compression by 75% this increase is 6%.

On the curves of changes in electrical resistance of samples of some melts at the initial stages, a horizontal section is noted, indicating the superposition of the processes of decomposition of the solid solution and the formation of the K-state (Figure 2). In deformed samples such stabilization is hardly noticeable. In samples with 5% compression, stabilization of electrical resistance is observed only after holding for 5-50 min; further holding leads to its decrease. As the degree of deformation increases, a tendency for a decrease in electrical resistance is clearly observed, which is caused by the intensive processes of stress relief and solid solution decomposition in deformed samples. The specific electrical resistance of all samples after heating to 700 °C is significantly lower than after heating to 500 and 600 °C, and is approximately equal to 117-118 μΩ·cm.

From a comparison of the microstructures shown in Figure 3, one can see the influence of deformation, temperature and exposure on the width of the jagged boundary regions, the occurrence of which may be due to the occurrence of polygonization inside the grain, associated with a change in the angular characteristics and retraction boundaries into one grain or another. Prolonged exposures (500 min and higher) cause an increase in hardness due to the formation of the K-state. The change in hardness during heating of deformed and non-deformed samples depends on the cooling rate during quenching.

In the samples cooled with the furnace, the increase in hardness is significantly less than in the samples hardened in water or in air, and the increase in hardness of the samples cooled with the furnace is noted at longer exposures (from 500 min). Heating at 500 °C does not equalize the value of the hardness of samples cooled in water and in air, at all exposures the hardness of samples hardened in air is higher than the hardness of samples cooled in water, but it does not reach the hardness of samples cooled with an oven. Preliminary deformation has a significant effect on the change in hardness during reheating. At a degree of deformation of 5 and 25%, the increase in hardness during reheating increases compared to non-deformed samples, and large degrees of compression (50 and 75%) decrease it.

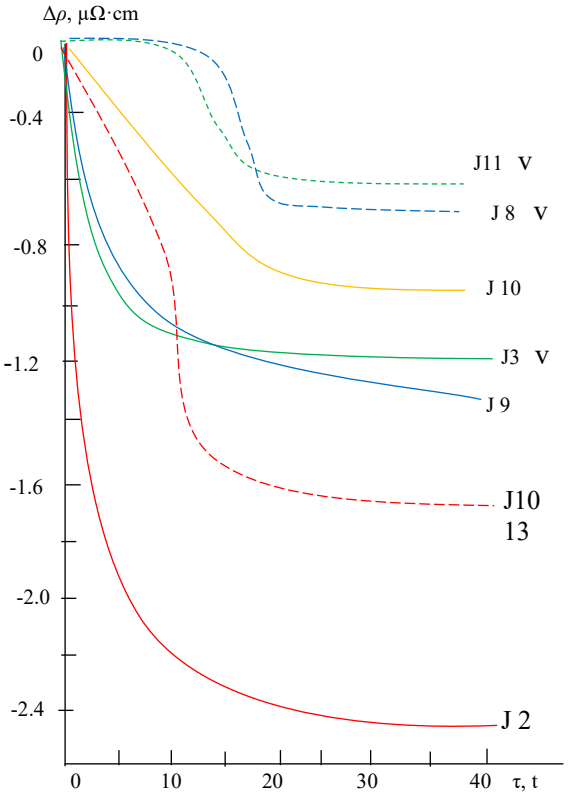

Figure 2. Change in the electrical resistance of a number of industrial melts (indices on the curves) of the KhN77TYUR alloy during isothermal exposure at 700 °C

The tension that occurs during deformation contributes to a more intensive process of the formation of the K-state and the breakdown of the solid solution with the formation of particles of the hardening phase, which determines a significant increase in the hardness of samples deformed by 5 and 25%. In addition, the degree of supersaturation of the solid solution has a significant effect on the rate of decay. Apparently, the optimal combination of all factors under these aging conditions is available in the case of quenching in water and 25% hardening, the hardness in this case increases from 260 to 400 HV. The decrease in the increase in hardness of samples with high degrees of compression is due to the fact that the dissolution of the solid solution has already occurred during deformation, and the greater the degree of compression [13]. An increase in heating time and temperature (to certain, moderate values) causes a slight increase in the size of these toothed areas; When heated to 700 and 800 °C, such structural changes along the boundaries are not observed.

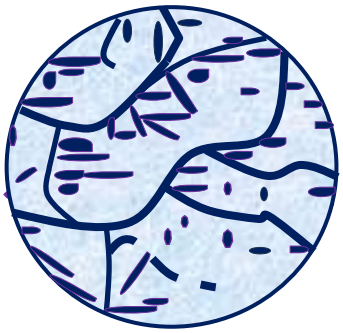

Figure 3. Microstructure of the KhN77TYUR alloy after quenching with 1080 °C water, rolling with a compression ratio of 75% and aging at 600 °C with a holding time of 500 minutes

Microhardness measurements on a Matsuzawa MMT-3X (7X) device under a load of 20 G did not allow us to establish a significant difference in the microhardness values of the jagged boundary regions and adjacent sections of grains; this confirms that the change in the shape of the boundary volumes [14] is due to the occurrence of processes in the grain itself (in this case processes such as polygonization). The direction of the teeth in the boundary regions appears to depend on the crystallographic orientation of the grains, as well as on the distribution of strain in adjacent grains.

3. CONCLUSIONS

1. It was determined that the high electrical resistance depends primarily on the composition of the alloy.
2. A model for estimating electrical resistance based on a neutron network is presented.
3. The model can predict the electrical resistance based on the chemical composition of the steel.
4. Increasing the electrical resistance of steel and alloys was achieved by the correct selection of thermal processing processes
5. It has been found that the heating environment, storage time and cooling environment are important factors for increasing the electrical resistance.
6. In the course of the research, an increase in electrical resistance was also observed in samples made from alloys with different compositions.
7. The type of cold deformation also affects the kinetics of the recrystallization process.
8. The effect of thermomechanical processing on the microstructure, electrical resistance and hardness of steels and alloys obtained by casting in an electromagnetic crystallizer was studied by computational and experimental methods.
9. It was shown that at a cooling rate of more than 1000 K/s, the amount of manganese present in the composition is dissolved in the solution.
10. After thermomechanical processing, a structure with the maximum possible number of dispersoids is formed, which results in a significant improvement in heat resistance compared to known alloys of the Al-Cu-Mn system.
11. The increase in electrical resistance of steels and alloys was achieved by the correct choice of heat treatment processes.

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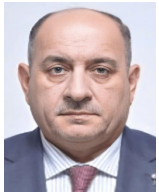

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