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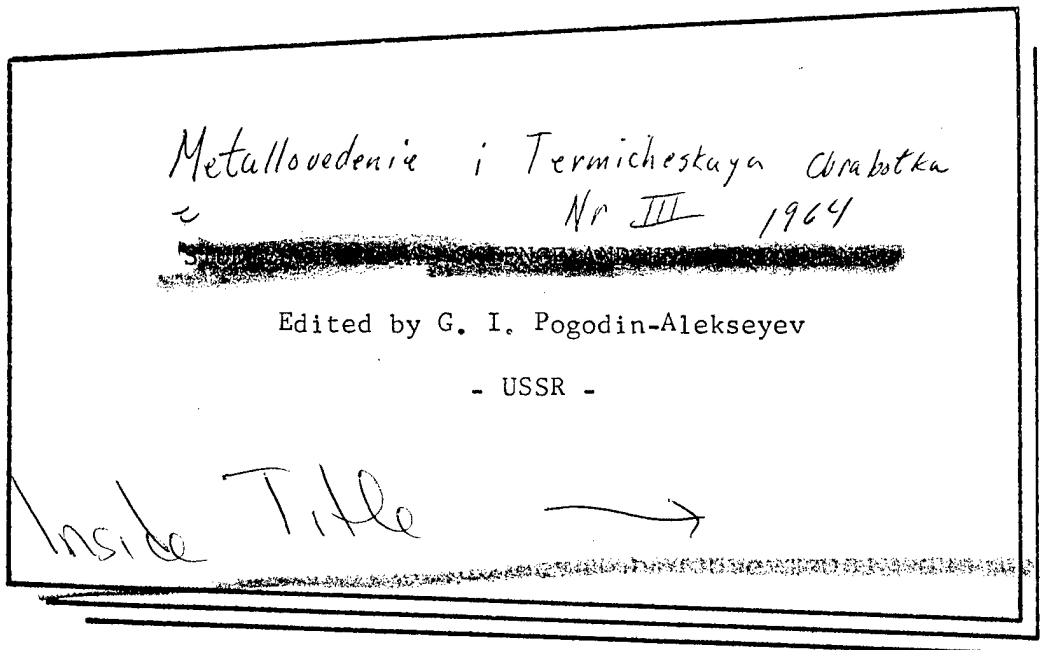
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### A STUDY OF THE PROPERTIES OF EP51 AND EP52 STEEL AT HIGH TEMPERATURES

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Pages 67-77

Some new types of steel, EP51 and EP52, which have found widespread application in industry, have been developed by the Institute of Precision Alloys TsNIICHM\* in response to the growing need for springs made of alloys, due to their durability and elastic properties at normal temperatures and during heating. These types of steel differ from the brand of steel EI702 (Ref 1) which was developed previously due to the absence of molybdenum (see Table), and this has led to an improvement in their properties, particularly during heating.

The chemical composition of austenitic dispersion-hardening alloys.

(a) Марка стали	(b) Содержание элементов в %							
	C	Si	Mn	Cr	Ni	Ti	Al	Mo
(c) ЭИ702	<0,05	<0,5	0,8-1,2	11,5-13,5	34,5-36,5	2,8-3,2	0,9-1,2	-
(d) ЭП51	<0,05	<0,5	0,8-1,2	11,5-13,5	34,5-36,5	2,8-3,2	0,9-1,2	4,5-6,0
(e) ЭП52	<0,05	<0,5	0,8-1,2	11,5-13,5	34,5-36,5	2,8-3,2	0,9-1,2	7,5-8,5

a) Type of steel; b) Content of elements in %; c) EI702;  
d) IP51; e) EP52.

It has been shown (Ref 2) that the EP51 and EP52 steels have greater durability and hardness limits than does EI702 steel after being hardened from a temperature of 1,000-

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1,100°C and after tempering at a temperature of 600-800°C. However the absolute increase of these properties after tempering is no greater than in EI702 steel, while the increase in the yield point elasticity is higher (Ref 2, 3). This can apparently be explained by the fact that in the presence of molybdenum, as can be seen from microanalysis data, disintegration of the supersaturated solid solution (obtained after hardening) takes place more uniformly in the tempering process within the body, and localization of this disintegration in the boundary zones of the grain cannot be observed.

This effect of molybdenum on the properties of steel is not connected with the formation and precipitation of a new phase containing molybdenum (Ref 2) in the tempering process. Consequently, molybdenum occurring in steel is found primarily in solid solution.

The mechanical properties of EP51 and EP52 steel have been studied sufficiently at normal temperatures but during heating - they have been studied insufficiently.

The purpose of the work described in this article was to study the properties of EP51 and EP52 steel at high temperatures. Two temperature intervals were selected: temperatures at which hot plastic deformation is carried out (in order to determine the optimum thermodeformation regime), and the operational temperatures which are possible (in order to determine the operational conditions for the springs).

#### METHOD OF STUDY

The metals to be studied were smelted according to the usual method which is used for all precision alloys, and their properties corresponded to the TU.

Samples to be used for determining the durability and plasticity properties were prepared from forged rods, and samples for determining the relaxation stability and elastic properties were prepared from a bond.

An IM-4R machine with a loading speed of 1.1mm/minutes for a sample having a diameter of 10mm was used to determine the durability and plasticity characteristics at normal and high temperatures. Calculated sample links was 50mm. The tensile strength, the yield point, the relative extension and transverse contraction and also the "hot" hardness were determined at temperatures up to 500°C. In

the range of temperatures corresponding to "hot" deformation (900-1,200°C) the same characteristics were determined with the exception of the yield point and the "hot" hardness. In order to study the hot deformation interval, a torsion test was carried out on a special apparatus (Ref 4) and a flexing test was also made. The representative displacement was determined by these tests according to the formula

$$\gamma = \frac{\pi d n}{l},$$

where D is the diameter of the sample; N is the number of rotations; L is the calculated sample link.

The maximum shear stress was determined by the formula

$$\tau = \frac{12M}{\pi d^3},$$

where M is the torque.

The torsion test velocity was 24-500rev/minutes. The samples for this test, which were 55mm long, had a ground collar with a diameter of 12mm in the middle section.

In order to evaluate the operational properties of the steel we determined: the elastic limit at normal temperatures and during heating with cyclic loading (Ref 5), changes in the elasticity modulus by the resonance method, and also the relaxation stability (Ref 6).

The alloy structures were studied with a microscope having an amplification of 400.

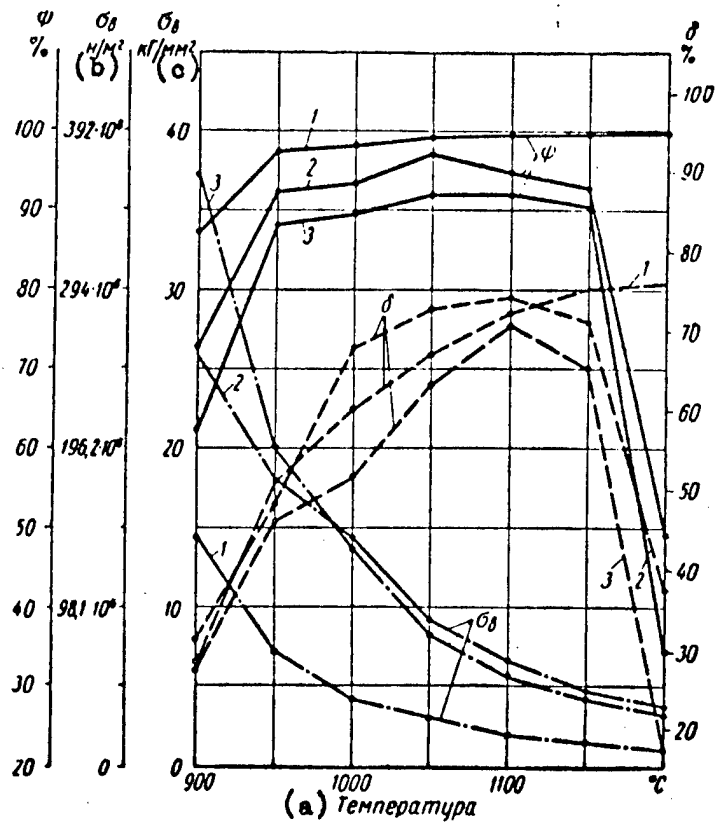


Fig 1. The dependence of the mechanical properties on the temperature for EI702 (1), EP51 (2), and EP52 (3) steel, obtained under the conditions of a brief elasticity test.  
 a) temperature; b) n/m<sup>2</sup>; c) kg/mm<sup>2</sup>.

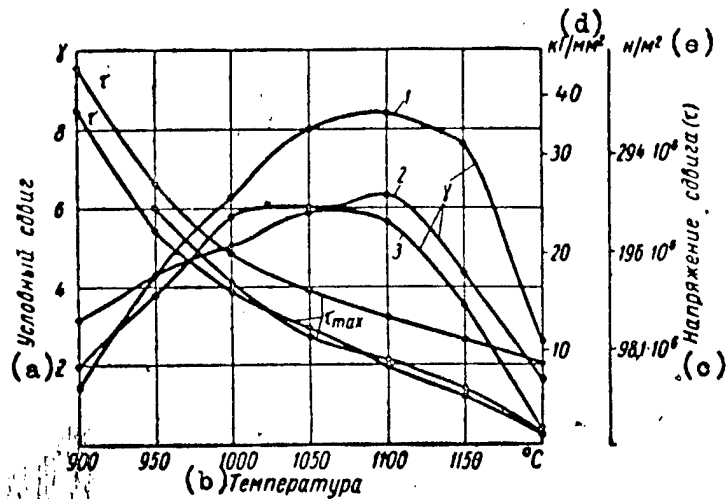


Fig 2. Mechanical properties of the function of temperature in EI702 (1), EP51 (2) and EP52 (3) steel obtained under the conditions of a torsion test.

a) representative displacement; b) temperature; c) shear stress; d) kg/mm<sup>2</sup>; e) n/m<sup>2</sup>.

#### RESULTS OF THE STUDY AND THEIR ANALYSIS

Figures 1-3 present the results obtained from determining the mechanical properties at high temperatures (900-1,200°C).

It can be seen from the data which I have presented that the introduction of molybdenum has the greatest effect on the magnitude of the temperature interval in which the characteristics of plasticity, and especially transverse contraction which makes it possible to estimate the maximum plasticity, are at a maximum. For EI702 steel, if this high plasticity interval, judging by the transverse contraction, is located within the temperature range 950-1,200°C (and

above), then for EP51 and EP52 steel it corresponds to 950-1,150°C, and for EP52 steel, 1,000-1,150°C.

In addition the absolute values for the transverse contraction for steel containing molybdenum are considerably lower. The results derived from determining the relative elongation point to high plasticity in steels containing molybdenum in a more narrow temperature interval. While lowering the plasticity of steel at high temperatures, molybdenum noticeably increases the resistance to large plastic deformations. EP52 steel with 8%Mo has a much greater resistance to plastic deformation than do EP51 or EI702 steel at a temperature below 950°C. At higher temperatures the yield strength of these steels is practically the same.

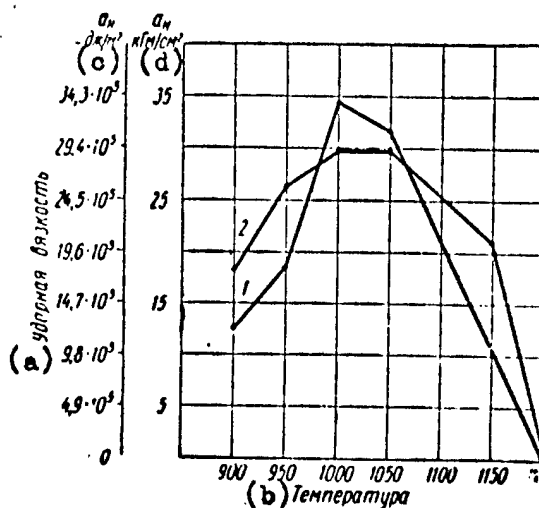


Fig 3. Dependence of the toughness of EP51 (1) and EP52 (2) steel on temperature. a) toughness; b) temperature; c) j/m²; d) kgm/cm².

Data were obtained in torsion tests which were similar to the results obtained from tests for elongation (see Fig 2). For EI702 steel, high displacement values were

obtained in the temperature interval 950-1,150°C, and for EP51 and EP52 steel in the interval 950-1,100°C. The absolute displacement values for these bands of steel within the indicated temperature interval were considerably lower than for EI702 steel. The change in the sheer stress proved to be somewhat unusual: at all temperatures it was the greatest in EI702 steel, in spite of the fact that it had less alloy.

In bending tests (see Figure 3) it was also found that EP51 and EP52 steels have a very narrow temperature interval in which they display great deformation ability. For EP51 and EP52 steels this interval is equal to 950-1,100°C.



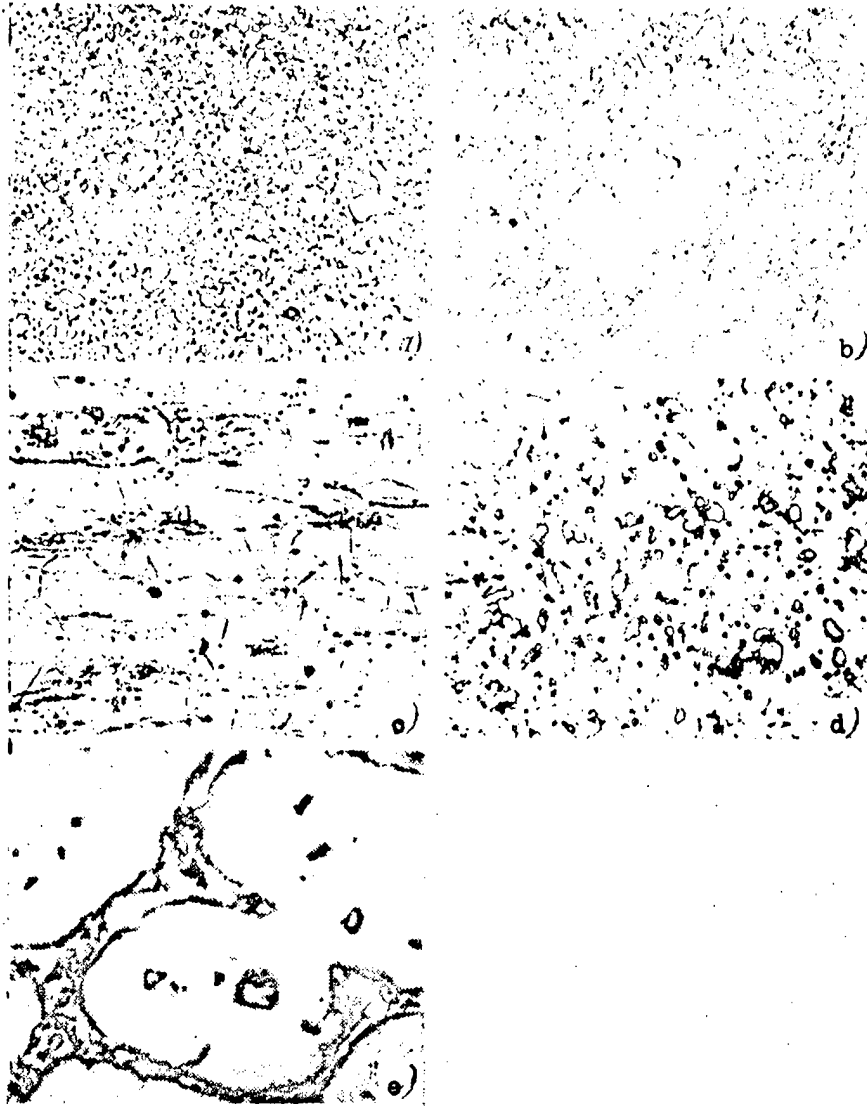


Fig 4. Microstructure of steel (X400) after torsion tests at the temperatures: a - 900°C (EP51); b - 1,000°C (EP51); c - 1,000°C (EI702); d - 1,100°C (EP51); e - 1,200°C (EP51).

In order to determine the reason for the narrowing of the temperature interval of high plasticity for EP51 and EP52 steels after molybdenum was introduced, a microstudy was made of samples which had been tested for torsion. After deformation at a temperature of 900-950°C a significant amount of type  $\gamma'$  ( $\text{Ni}_3\text{Al}$ ) phase could be seen in the structure of EP51 steel, which was evenly distributed throughout the cross section (Figure 4). In addition other much larger impurities can be seen, apparently of another phase which is not present in EI702 steel, and therefore it can be assumed that the appearance of this phase is connected with the presence of molybdenum.

Taking into account the fact that the new phase appeared in the alloys after hot deformation, it can be assumed that it is formed only under the conditions of simultaneous action and increased temperatures of plastic deformation, when a state which is close to equilibrium is reached. Under normal thermal treatment this state is not reached, and therefore a phase enriched with molybdenum is not observed in chemical phase analysis.

After heating up to a temperature of 1,000°C and after deformation EI702 steel has the structure of a mono-phased,  $\gamma$ - solid solution (see Figure 4), while in the structure of EP51 steel deposits of  $\gamma'$ -phase and impurities of a new phase located primarily along the grain boundaries are noticeable in addition to grains of  $\gamma$ - solid solution. It can thus be concluded that  $\gamma$ -solid solution in EP51 steel is very unstable, and under the effect of plastic deformation it disintegrates with the formation of an excess phase ( $\gamma'$ ) along the grain boundaries. This leads to a reduction in the plasticity and to an increase in the resistance to plastic deformation. When EP51 steel was heated up to a temperature of 1,100°C in connection with the increase in solubility of the excess  $\gamma'$ -phase in a solid solution the latter became more stable and therefore the plastic deformation did not lead to such an abundant precipitation of excess phases, as is the case with deformation at lower temperatures. Only large deposits of a new phase, mentioned above, were noticeable in the structure.

With a decrease in the amount of excess phases formed, at a high temperature plasticity of EP51 and EP52 steel increased and at a temperature of 1,100°C it reached a maximum. At a deformation temperature of 1,200°C the precipitation of a new phase as mentioned above was observed in EP51 steel along the grain boundaries. Even signs of

sweating were observed, which led to a sharp increase in fragility. Thus there is a definite connection between the tendencies of the EP51 and EP52 steel toward plastic deformation and their structure.

A STUDY OF THE PROPERTIES OF EP51 AND EP52  
AT TEMPERATURES AT WHICH THEY ARE USED AS  
SPRINGS

As has already been indicated above, in order to determine the temperature range in which EP51 and EP52 steel may be used as thermal-resistant springs, the following characteristics were determined: durability, hardness, elastic limit, elastic modulus at a temperature of up to 500°C, and also the relaxation stability. These properties were determined for purposes of comparison and were determined for EI702 steel which differs from EP51 and EP52 steel by the absence of molybdenum.

Figures 5 and 6 illustrate the manner in which the yield strength and the yield point came, and also the hardness of the steels being studied at temperatures of 20-500°C.

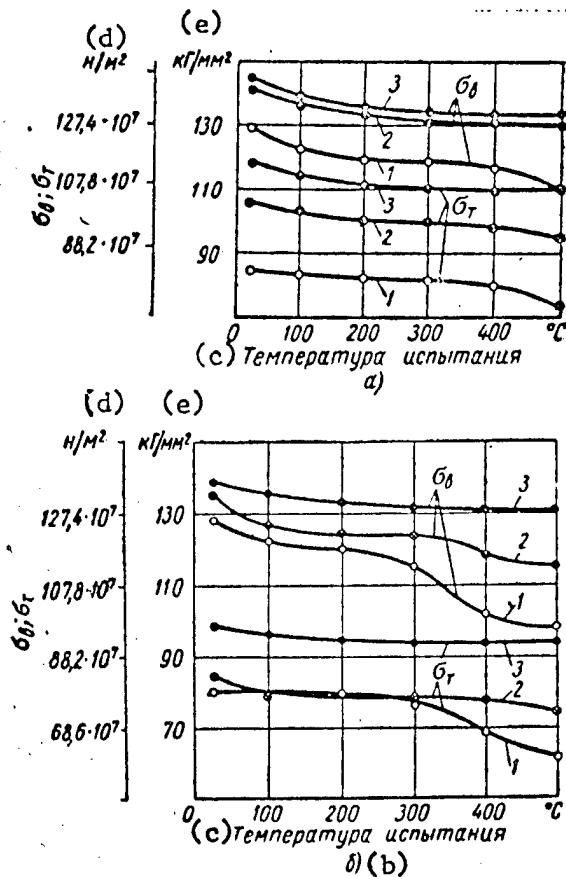


Fig 5. The mechanical properties of EI702 (1), EP51 (2) and EP52 (3), obtained from brief elongation, as a function of temperature: a) - hardening from a temperature of 950°C, tempering at a temperature of 750°C for 4 hours; b) - hardening from a temperature of 1,100°C, tempering at a temperature of 750°C for 4 hours; c) - test temperature; d) n/m<sup>2</sup>; e) kg/mm<sup>2</sup>.

As would be expected, it can be seen from the data set forth that molybdenum actually increases the temporary durability ( $\sigma_B$  and  $\sigma_T$ ) with heating thus steel containing 8%Mo (EP52) has much greater and more stable durability properties. Up to a temperature of 500°C, this steel barely becomes softened, while EI702 steel noticeably becomes

softer at a temperature above 300°C. The data given in Figures 5 and 6 also showed that after hardening from a temperature of 950°C and tempering, all of the steels studied had a greater temporary durability than after hardening from a temperature of 1,100°C with subsequent tempering. The change in the elasticity modulus as a function of temperature (Figure 7) for EI702, EP51 and EP52 steel obeys a linear law, which makes it easy to readily correct the operating properties of the elastic elements during heating.

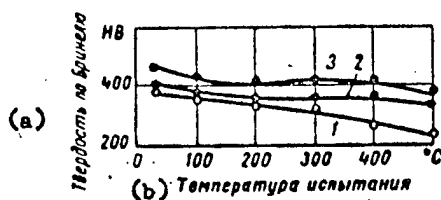


Fig 6. Hardness of EI702 (1), EP51(2) and EP52 (3) steel as a function of temperature. a) hardness according to Brinell; b) test temperature.

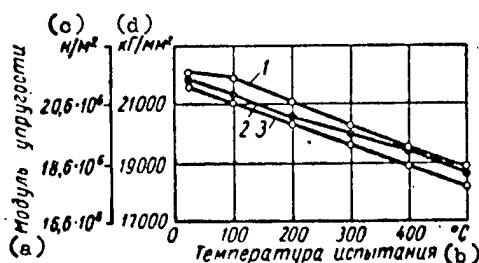


Fig 7. The normal elasticity modulus as a function of temperature: 1 - EI702 steel; 2- EP51 steel; 3- EP52 steel. a) elasticity modulus; b) test temperature; c) n/m<sup>2</sup>; d) kg/mm<sup>2</sup>.

A determination of the elastic limit as a function of temperature is of great importance for evaluating the thermal stability of steel used as springs. The elastic

limit which is a relaxation characteristic naturally depends on the loading time. This can be clearly seen in Figure 8 for EI702 and EP51 steel. With a short loading time (25 seconds), EI702 and EP51 steel have almost the same temperature dependence on the elastic limit; this dependence is similar to the change in the elasticity modulus. With a longer loading time, there is a noticeable difference between the steels. For EI702 steel, the elastic limit considerably decreases after heating up to a temperature of 200°C, and for EP51 steel only after heating above 300°C. Consequently, the increased elastic properties of steel alloyed with molybdenum are retained up to higher temperatures.

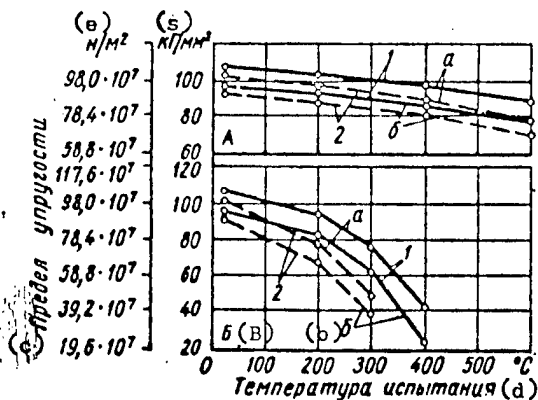


Fig 8. Elastic limit of (a) -  $\sigma$  0.01 and (b) -  $\sigma$  0.005 for EI702 (1) and EP51 (2) as a function of test temperature with loading for 25 seconds (A) and for 1 hour (B). (c) elastic limit; (d) test temperature; e)  $\text{n/m}^2$ ; f)  $\text{kg/mm}^2$ .

The greater thermal stability of EP51 and EP52 steel, as compared with EI702 steel, was revealed by carrying out relaxation tests. Figure 9 shows the change in the relaxation stress at a temperature of 400°C for a period of up to 200 hours after different thermal treatment regimes. The curves show that the greatest relaxation stability is held by EP52 steel, then EP51, and the least EI702. The largest relaxation stability in EP52 steel is obtained after hardening from a temperature of 1,150°C and tempering at

at 750°C, for 2 hours; or at a temperature of 700°C for 8 hours; and for EI702 steel - after hardening from a temperature of 950°C or 1,100°C and tempering at 700°C for 2 hours.

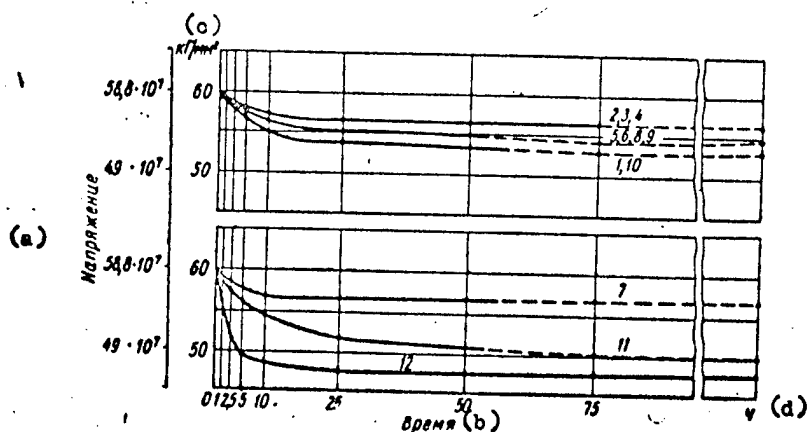


Fig 9. Stress relaxation for EI702 (12), EP51 (1-5.11) and EP52 (6-10) steel at a temperature of 400°C and  $\sigma_0 = 588 \text{ Mn/m}^2$  (60kG/mm<sup>2</sup>): 1 - hardening from a temperature of 950°C and tempering (750°C, 2 hours); 2 - hardening from a temperature of 1,050°C and tempering (750°C, 2 hours); 3 - hardening from a temperature of 1,150°C and tempering (750°C, 2 hours); 4 - hardening from a temperature of 1,150°C and tempering (700°C, 8 hours); 5 - hardening from a temperature of 1,050°C and tempering (700°C, 8 hours); 6 - hardening from a temperature of 1,150°C and tempering (700°C, 8 hours); 7 - hardening from a temperature of 1,150°C and tempering (750°C, 2 hours); 8 - hardening from a temper-

ature of 1,050°C and tempering (750°C, 2 hours); 9 - hardening from a temperature of 1,050°C and tempering (700°C, 8 hours); 10 - hardening from a temperature of 950°C and tempering (700°C, 8 hours); 11 - hardening from a temperature of 950°C and tempering (700°C, 8 hours); 12 - hardening from a temperature of 950°C and tempering (700°C, 2 hours). --- a) Stress; b) Time; c) kg/mm<sup>2</sup>; d) hours.

### CONCLUSIONS

1. The introduction of molybdenum into steel type EI702 has a great effect on the plasticity and durability properties in the "hot" deformation temperature range.

2. EP51 steel with the addition of molybdenum (5%) and EP52 (8%Mo) steel, as compared with steel without molybdenum (EI702) has less plasticity and greater resistance to plastic deformation.

3. EP51 and EP52 steel had a temperature range in which considerable plastic deformation is more likely than in EI702 steel. For EP51 and EP52 steel this temperature range is 950-1,100°C and for EI702 steel - 900-1,180°C.

4. The temperature range of "hot" deformation of the steels being studied is clearly apparent in brief tests for extension and torsion (Ref 4).

5. The lower plasticity of EP51 and EP52 steel is connected with the fact that at high temperatures excess phases located along the grain boundaries are formed during the plastic deformation process from the solid solution. At a temperature of 1,000-1,050°C, this is an excess phase  $\gamma'$ , and at a temperature of 1,150°C and above - this is a new phase rich in molybdenum. It is important to point out that the new phase is formed in EP51 steel in the high temperature regions during the simultaneous action of plastic deformation, i.e., under conditions corresponding to processes going in the direction of equilibrium. Under normal thermal treatment conditions (hardening at a temperature of 1,000-1,050°C), the velocity



of the processes leading to equilibrium is small and therefore a new phase rich in molybdenum is not formed.

6. The introduction of molybdenum into EI702 steel (EP51 and EP52 steel) increases the hardness and also the yield strength and the yield point in the temperature range 20-500°C. Thus in EP52 steel up to a temperature of 500°C the durability properties barely decrease: it can hence be concluded that molybdenum greatly increases the thermal stability of austenitic steel of the type 13-36.

7. EI702, EP51 and EP52 steels are characterized by practically the same temperature dependence on the normal elasticity modulus. This indicates that molybdenum in steel of the type 13-36 only slightly changes the energy of the bond in the crystal lattice.

8. The temporary elastic limit of EP51 and EI702 steel has practically the same dependence on temperature (25 seconds). However, the elastic limit of EI702 steel, measured under long loading ( 1 hour ), greatly decreases at a temperature above 200°C, while for EP51 steel the elastic limit decreases only above 300°C.

9. An increase in the molybdenum content in the steel decreases the stress relaxation. In EI702 steel (without molybdenum) the stress relaxation at a temperature of 400°C amounts to 20.8% for 200 hours, in steel EP51 (5%Mo) - 6.2%, and in EP52 steel (8%Mo) - 4.6%.

10. For EI702 steel the greatest relaxation stability is achieved after hardening from a temperature of 950-1,000°C degrees and tempering at 700°C, and for EP51 steel - after hardening from a temperature of 1,050-1,100°C and tempering at a temperature of 750°C for 2 hours, or at a temperature of 700°C for 8 hours - and for EP52 steel - after hardening from a temperature of 1,150°C and tempering at a temperature of 750°C for 2 hours. However for items in which not only a high relaxation stability is required but also an increased elastic limit the hardening of EI702 steel should be carried out from a temperature of 920°C, EP51 steel - from 980°C, and EP52 steel - from 1,000-1,050°C. The tempering regime is not changed.

11. For springs made from EP51 steel - 300,

and for springs made from EP52 steel - 400°C.

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