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THE EFFECT OF HEATING AND MAGNETIC ACTION ON PROCESS OF MICROPLASTIC DEFORMATION OF HIGH-NITROGEN AUSTENITE

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The effect of heating and weak pulsed magnetic field on microplastic deformation of high-nitrogen steels is studied. The methods of optic metallography, X-ray analysis, microhardness measurement and internal friction were used. As a result of experimental investigations it is stated that in high-nitrogen Cr–Mn steel at heating (low-temperature range) structure transformations take place. It is shown that at heating from 20 to 300°C the processes of interaction between nitrogen atoms and extended dislocations take place. Kinetics of processes is similar to kinetics of ageing, but with certain variations. The obtained structure is unstable and trends to recovery of the initial state during 10–100 h. The influence of TPMF has similar nature. Presumably this process is determined by the redistribution of nitrogen in solid solution–nitrogen phases–dislocation atmospheres system. The authors propose to apply heating up to 400°C during 4–8 h in order to stabilize the dislocation structure.

The formation of physical, mechanical and service properties of materials due to changes in the structure of impurity-defect complexes (IDC) as a result of influence of physical and mechanical fields is the one of central problems of physics of strength and plasticity, metal and material sciences.

Doping by nitrogen to partially replace nickel atoms in the alloyed structural steels with the austenite structure allows one to obtain new economical materials high-performance. Chemical affinity of nitrogen to atoms of chromium and manganese determines certain mechanisms of its influence on dislocation structure of high-nitrogen austenite [1]. This influence takes place especially at the initial stage of elastic deformation. The investigated steels work at different temperatures and stresses. Consequently, research of kinetics of microstructural variations of nitride austenite at microplastic deformation conditions in the case of high diffusion mobility of nitrogen atoms is important for structure control and obtaining of prescribed performance during thermomechanical treatment.

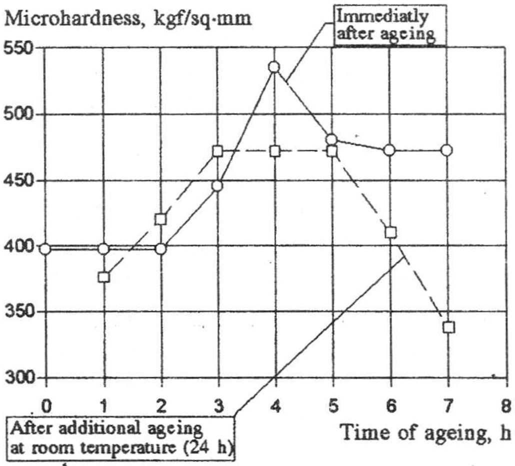
The process of isostatic and isothermal structure formation is determined by the pattern of decay of supersaturated solid solution. Hence, the investigation of structure formation kinetics is carried out by the methods indicating the changes of composition properties of solid solution in different temperatures–stresses, namely the method of internal friction, X-ray structure analysis, measuring of microhardness.

The disadvantage of steels containing nitrogen in respectively high quantities is the high tendency to embrittlement and intercrystalline corrosion. In [2] authors show the significant decreasing of impact toughness of low-alloyed steels during the experiment in the range 20–200°C and 400–600°C. It may by the result of atoms redistribution process in another order between ·the matrix, stacking faults, nitrides of VI group metals (Cr_2N and Cr_2V) and metastable nitride of VII and VII group metals (Mn_3N, Mn_4N, Fe_4N, $Fe_{16}N_2$ and others).

The experimental results

The group of steels, containing the chromium, nickel, manganese is investigated. They were the steels of Х18Г10Н16, Х19Г10АС2, Х14Г10АС quality in which the high quantity of nitrogen (from 0.06 to 0.67%) is maintained. All investigations are carried out using the samples with thermal pretreatment. The treatment includes heating up to 1100°C, exposure during 1 h and quenching (water). After the treatment all samples show the homogeneous austenite structure with nitride phase precipitation.

In order to observe the processes of formation and variations of the existing nitride phase the ageing is carried out at the following temperatures. They are: 150, 180, 250°C. The final ageing time is 9 h. The measuring of microhardness occurred at the load equaling 0.5 N with the help of microhardness tester. Thirty measurements took place at the each point. The statistical processing of obtaining results was carried out. The confidence intervals were calculated. The metallographic investigations were conducted by using of an optical microscope "Neophot-2" (magnification of ×1000). The amplitude, temperature and time dependences of internal friction in the width interval of amplitude ($\varepsilon \approx 10^{-7}$–$10^{-5}$) and also dependences of temperature T = 300–800 K and time 10–1000 min were measured. The structure of metal was studied by the X-ray method: the lattice parameter and microstresses of the second order were defined. The results of X-ray analysis of structure and the character of temperature dependences of the internal friction (Fig. 1 and Fig. 2) were matched. It is shown that precipitation of nitrogen atoms and their segregation on partial dislocations and stacking faults is one of strengthening factors at condition of microplastic deformation ($\varepsilon \approx 10^{-7}$–$10^{-5}$) in the temperature range 300–600 K [3,4].



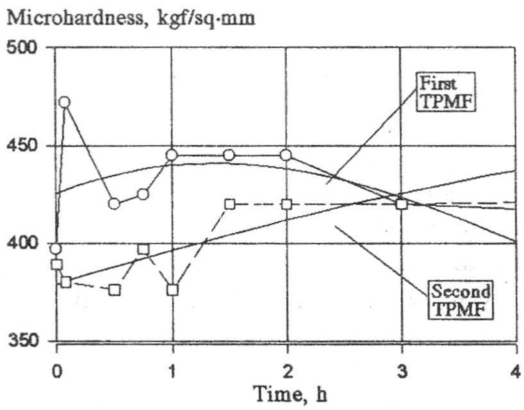


Fig. 1. Microhardness variations after ageing at 180°C

Fig. 2. The effect of repeated TIMF on process of ageing at room temperature at the early stage

At the first stage the effect of temperature on structure and properties was investigated. The specimens were subjected to ageing at different temperatures (duration 1 h). The microhardness and parameters of internal friction were measured. Some of results are shown in Fig.1, 2. Investigations of ageing in the temperature range 150–250°C have shown that in these steels the process with typical kinetics of ageing takes place. But after the additional treatment at the room temperature the difference between hardness after exposition at high temperature and the final value of hardness appears. This phenomena are very clear after the long summary expositions, therefore the unknown process occurs in this temperature range. Presumably, the nature of it deals with the redistribution of nitrogen atoms between solid solution, dislocation atmospheres and metastable nitride phases. Decreasing of hardness indicates the increasing of dislocation mobility. Measurements of internal friction show the increasing of the background level. This fact confirms the assumption about changes in the dislocation mobility.

Recently, in such countries as Ukraine, Russia, Bulgaria, USA, Japan the great interest to treatment of materials by the pulsed magnetic field (TPMF) has arisen. In this case during short-time influence of low-frequency weak pulsed magnetic field ($H < 10^6$ A/m) on magnetic and nonmagnetic materials the transformation of crystalline structure takes place. It determines the changes in physical-mechanical and service properties.

The external magnetic field changes the relative energy of different states (position) of dissolved atoms. At every temperature the equilibrium population of these states exists. Therefore, the relaxation process leading the system to the new equilibrium states takes place at switching of the external action. The relaxation time involves the diffusion factor because the transfer between states is carried out by the diffusion way.

The interstitial mechanism is the main mechanism of displacement of impurity atoms of small atomic radius forming the interstitial solid solutions in metals with the close-packed lattice.

The crystals with the face centered cubic lattice have also two kinds of the interstitial site. They are (1/2, 1/2, 1/2) octapores, which are situated in the cube center and in the middle of the rib, and (1/4, 1/4, 1/4) types tetrapores disposed on 1/4 at cube diagonal. These ones are similar to the interstitial site in the hexagonal close-packed lattice. These crystals are symmetrical and do not show the elastic aftereffect but the probability of it exists when the pairs of defects are formed. They are:

– an interstitial atom and impurity substitutional atom;

– two interstitial atoms.

The first effect (pair of an interstitial atom and impurity substitutional atom) was observed at 300°C in the austenite Cr–Mn steels and at 240°C in manganese containing steels. It is believed that effect of TPMF must take place if material is in the non-equilibrium, metastable state and contains the defects of the crystal lattice. It is stated that as a result of TPMF the transformation of IDC occurs. At first they are destroyed and after that the disintegrated elements are joined to form new IDC. Such changes were observed in the phase that is located in the monocrystalline matrix [4], and in IDC that are located on dislocations [5]. It is noted that the process of changes of properties after TPMF is similar to the process, which takes place during deformation ageing [6] but is of the different nature [5].

The effect of TIMF may by illustrated by the following data (Fig. 2). The alterations of microhardness are of the oscillation character and what's more the microhardness level was returned to the initial one after twenty-four hours of treatment. As a result of treatment the maximum changes of microhardness arrived approximately at 30%.

It is necessary to note that significant alterations of microhardness don't occur in the middle of the sample.

The delay of increase of microhardness (from 5 min after the first time of treatment to 15 h after the third one) was observed after time multiplex TPMF.

This fact may by considered as the additional evidence of resonance character of TPMF influence on given steels properties change.

The materials' investigations after radiation treatment with the help of weak pulsed magnetic field show that the alterations of materials' physics and mechanical properties take place. They have oscillation-damped character. In both cases the changes of microhardness have the nonuniform character. We see increase at the first stage and decrease with the time at the second stage. As a result of experimental investigations it is stated that in high-nitrogen Cr–Mn steel samples the structure transformations take place at heating (low-temperature range). The kinetics of it is similar to process of ageing. But there is a tendency to recover steel samples to the previous state during following ageing at room temperature during 10–100 h. TPMF causes the deviation from the stable state of material. This deviation is of the temporary nature and the system returns to the stable (equilibrium) state with time. But this process is not completely reversible, because kinetics of cover after treatment varies and the process of treatment takes more time. Detailed fixations of microstructure changes at the early stage of process show that these phenomena are of the nonuniform character and might include different local processes. The measurements of internal friction give the results similar to the previous case. The mobility of dislocations increases after TPMF.

Discussion

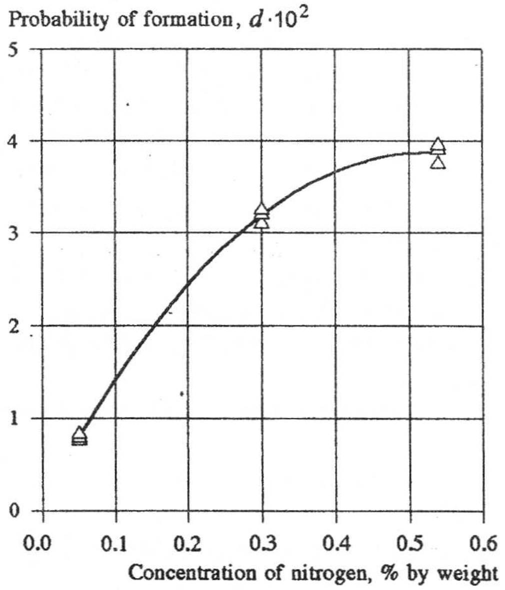
The addition of nitrogen to iron-carbon alloys was extensively applied for many years, but theoretical and practical details of how nitrogen influences structure and properties of iron alloys are not clear until now. The main reason of it is the complex nature of interaction between nitrogen, iron and impurities.

Nitrogen influences properties of steels in two different ways:

– the additions of nitrogen increase the hardness and strength;

– the additions of nitrogen stabilize the austenite in case of corrosion resistant steels. In this case nitrogen substitutes nickel. This increases the corrosion resistance of steels.

Both of these effects are of different nature. Increase of hardness is the result of formation of dislocation's atmospheres (Fig. 3), fine particles with coherent and semi-coherent boundaries, large nonmetallic inclusions and continuous layers of high-nitrogen phases. Stabilization of austenite deals with changes in thermodynamical properties of solid solution on the Fe base.



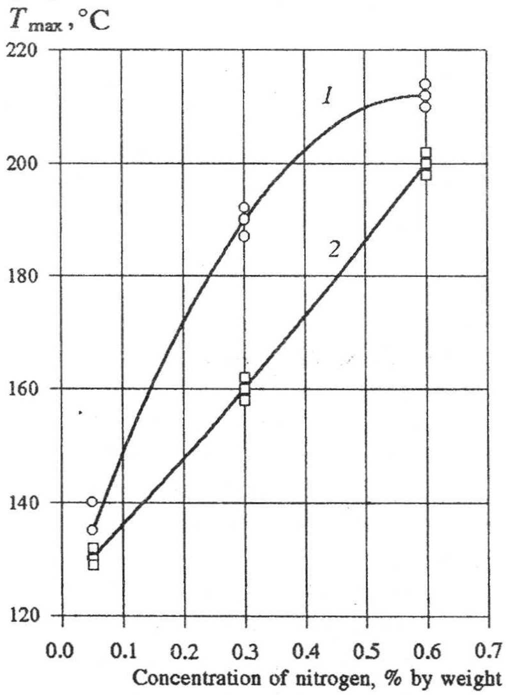


Fig. 3. The character of variations of stacking faults nucleation probability α (X-ray analysis method) depending on nitrogen concentration

Fig. 4. The dependence of maximum temperature T_{max} of non-elastic losses on nitrogen concentration for different conditions of experiment: *1* – immediately after deformation (ε ≈ 10^{-5}); *2* – after exposition (t = 90 days and nights)

But these processes are interconnected, because the formation of nitrogen-containing phases causes the changes in concentration of N in solid solution and vice-versa the stabilization of austenite changes the solubility of nitrogen in Fe and stimulates phase transformations.

It is shown in [4], that the significant decreasing of impact toughness of similar steels takes place during the treatment in the temperature range of 20–200°C and 400–600°C.

This fact allows us to suppose that the low temperature instability of these steels takes place. The early studies by these authors show (Fig. 4), that the cause of these variations of properties may be due to the processes of nitrogen atom redistribution between matrix (γ-iron), dislocations (stacking faults) and nitrides.

The complete analysis of processes in the low-temperature range is very difficult and needs more experimental data. Now we can make only preliminary assumptions. It is known from literature that steels of this type might have restricted concentrations of nitrogen in the equilibrium state (approximately 1% of Cr concentration). In these steels we have only 0.2%. Therefore, steel is supersaturated by nitrogen. On the other side, high content of Mn supports the increasing of nitrogen solubility and may prevent the formation of dislocation atmospheres. As follows from the equilibrium diagram, solubility of N in austenite decreases with the increasing of temperature. But these data are true for high temperatures. Data concerning solubility of nitrogen in high-manganese austenite at room and near-room temperatures are unavailable. Therefore during heating at ageing the formation of atmospheres may occur and microhardness increases. After cooling these atmospheres may dissolve. As follows from thermodynamical data, in the temperature range of ageing the transformation of nitride phases may occur. It follows from calculations of the Gibbs energy [7].

Conclusion

As a result of experimental investigations it is stated that in high-nitrogen Cr–Mn steel at heating (low-temperature range) the structure transformations take place. The kinetics of it is similar to process of ageing. But there is a tendency to recover the previous state during 10–100 h, at room temperature. This deviation has temporary nature and the system returns to the stable (equilibrium) state with time. But this process is not 100% reversible, kinetics of recovery after treatment is different and the process takes more time. The influence of TIMF has similar nature. Detailed fixation of microstructure changes at the early stage of process shows, that the phenomena are of the nonuniform character and it may include different processes. The whole process is determined by the redistribution of nitrogen in the system solid solution–nitrogen phases–dislocation atmospheres.

Hardness measurements after ageing at 400, 500, 600, 700, 800°C show that influence of ageing on hardness takes place at temperatures higher than 500°C. At ageing at 400°C during 1–16 h the value of hardness is practically constant. It gives the opportunity to propose to apply heating up to 400°C during 4 h for stabilizing the structure without substantial decreasing of hardness and plasticity of alloys.

1. *M.I. Goldshtein, A.V. Grin, E.E. Blyum and others*, The strengthening of structural steels by nitrides, Metallurgy, Moscow (1970) (in Russian).
2. *O.I. Datsko, E.G. Pashinskaya*, Izvestiya VUZov. Series of Ferrous Metallurgy № 8, 32 (1994).
3. *V.P. Levin, V.B. Proskurin, M.S. Stepanov*, Izvestiya Academii Nauk. Metals № 6, 107 (1993).
4. *V.N. Vrayukhin, N.N. Belousov, E.G. Pashinskaya*, FTVD **8**, № 2, 21 (1998).
5. *O.A. Bannukh, V.M. Blinov*, The dispersion-hardened non-magnetic vanadium containing steels, Nauka, Moscow (1980) (in Russian).
6. *V.A. Bogdanov, A.S. Domareva, E.G. Pashinskaya, B.M. Efros*, FTVD **8**, № 3, 104 (1998).
7. *V.N. Vrayukhin, N.N. Belousov, E.G. Pashinskaya*, FTVD 9, № 1, 12 (1999).