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Changing of the Magnetic Properties of the Ni_3Al-Base Alloys after the Deformation

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Abstract. It is shown that high temperature deformation of nickel superalloys increase the magnetic susceptibility value. Severe deformation by the shear under pressure at room temperature leads to decrease the magnetic susceptibility of Ni_3Al samples because the shear under pressure leads to the nanocrystalline structure formation and as a result by decrease of long range order. A high degree of long range order in the particle as a whole retains during the high temperature deformation of supealloys. In this case, complexes of defects of the crystal structure a locally formed. Such complexes can play a role of the ferromagnetic clusters in the paramagnet matrix. As a result, the magnetic susceptibility of the alloy increases.

INTRODUCTION

The intermetallic compounds with the transition elements may exhibit a strain-induced ferromagnetism. This phenomenon described the process when a well-ordered paramagnetic intermetallic compound comes to ferromagnetic one under plastic deformation. Super-paramagnetic state or nano scale metastable phase formation in the deformed material is observed. The phenomenon is more pronounced in case of deviation from the stoichiometric composition of the alloy. The influence of deformation on magnetic parameters of a number of intermetallic compounds, including Ni_3Al, was discussed in [1, 2].

The pure nickel is known to be ferromagnetic with the Curie temperature $T_C = 631$ K. The magnetic properties of Ni_3Al depend upon the nearest neighborhood of Ni atoms and are highly sensitive to chemical composition. Intermetallic compound $Ni_{74}Al_{26}$ is paramagnetic down to the temperature as low as 4 K, while $Ni_{75}Al_{25}$ is weakly ferromagnetic with the Curie temperature $T_C = 41$ K [3]. It was found in [2] super-paramagnetic state stoichiometric Ni_3Al after both, mechanical grinding and cold rolling up to 90%. The magnetization of Ni_3Al after grinding was about 10 times more than after cold rolling. The authors attribute the change in the magnetic properties of Ni_3Al with the interaction of nickel atoms in magnetic clusters formed after plastic deformation. After annealing the deformed samples were restored the paramagnetic properties.

Ni_3Al-based superalloys are used in the manufacture of gas turbine blades. Structure of nickel superalloy consist of nickel solid solution, strengthening γ'-phase (Ni_3Al, $L1_2$), and a small amount of carbides. At room temperature the superalloy blades are paramagnetic. The earlier studies have revealed a dramatic effect of strain on the magnetic behavior of the nickel superalloys. For example, the cyclic deformation of the nickel superalloy was shown to result in its super-paramagnetic behavior [2]. It was also observed an increase of the magnetic susceptibility of nickel superalloys after cold rolling up to 40% [4] and shock-wave loading [4].

We present the review of the experimental results of the effect of the different types of deformation on the magnetic behavior of Ni_3Al-base alloys: after high temperature deformation and after the shear under pressure at room temperature.

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TABLE 1. The chemical composition Ni-base superalloys, mass %

Alloy	Cr	Ti	Mo	W	Al	Co	Nb	C	Fe
EP-800	12.5	–	6.0	5.0	4.5	9.0	2.0	≤0.05	≤1
ChS-70V	15.4	5.0	1.5	3.6	3.5	10.6	0.25	0.10	≤1

EXPERIMENTAL

The investigation of structure and magnetic properties was carried out using samples cut out from different parts of an as-cast polycrystalline blades made from the superalloys ChS-70V and EP-800 after exploitation for 13 months with increased working temperature (from 800°C in standard to 880°C, an experimental regime). The chemical composition of the investigated Ni-base superalloys is shown in Table 1.

Magnetic tests were performed at room temperature using the original device of the magnetic susceptibility measurements for low-magnetic alloys and austenitic steels which was developed by the authors. The method has heightened sensitivity and is designed for the detection of dispersed ferromagnetic phases in austenitic alloys. Accuracy of the magnetic susceptibility measurements is $\pm 1\times 10^{-4}$. Processing of results performed using calibration samples. The vibrating magnetometer Lake Shore 7407 was also used for measurements of the magnetization of the samples for verify the results of previous measurements. The magnetization at room temperature was measured on the installation type of Faraday magnetic balance. The relative error of measurement of the external magnetic field was 0.5%; and for to measure the magnetization of 1.5%.

Polycrystalline samples of Ni_3Al alloys (75.3 at % Ni) were obtained by arc melting in an argon atmosphere in the Department of precision metallurgy of IMP UB RAS. All samples were annealed at 1100°C for 25 h. Severe plastic deformation was carried out by the shear under pressure in Bridgman anvils up to 10 rotations (P = 10 GPa) at room temperature, a speed of rotation was about 0.3 rotation/min.

The microstructure was studied using a JEM-200CX transmission electron microscope at the Testing center of nanotechnology and advance materials of IMP UB RAS.

RESULTS AND DISCUSSION

The gas turbine blades after a long-time exploitation under standard regime should stay in a paramagnetic state [1]. Usually, the working temperature of the blade made from the ChS-70V and EP-800 alloys (40% of γ'-phase) is 800°C. However, the electrical power engineering active attempts are undertaken to increase the power of gas turbines without replacement of the material for blades. As a result, the alloys have to be working under extreme conditions in terms of the temperature and the level of stresses.

The results of study of the turbine blades from alloys ChS-70V and EP-800 after exploitation on the experimental reinforced mode in an industrial environment were described in detail in [5].

After working during 13 month in an experimental regime, there was observed an increase in the magnetic susceptibility χ of blades material. An increase in the magnetic susceptibility χ was different in different parts of the blade; the maximum magnitudes were obtained for the convex part of the feather (its back), in area where stress was maximal. In the locking part of the blade, which was mainly subjected to thermal actions, the magnitudes of the magnetic susceptibility χ did not change in comparison with the initial condition before the operation. For ChS-70V samples the magnetic susceptibility changed from 2×10^{-4} in the initial state to 4×10^{-3} in the blade feather near the locking part, and to 36×10^{-3} in the feather back (Fig. 1a). The results of measurements of the field dependence of specific magnetization at room temperature for ChS-70V are shown in Fig. 1b.

For the EP-800 alloy the changes of magnetic susceptibility were considerable more: from 4×10^{-4} up to 7×10^{-2} in the convex part of the feather. The magnetic susceptibility of EP-800 alloy increased up to 14×10^{-2} in the crack area on turbine blade feather.

We did not observe the formation of any new phases in ChS-70V and EP-800 alloys after are working under extreme conditions by electron-microscopic analysis. In the samples, which were cut of the back of a blades feather, the high-resolution electron microscopy revealed a large number of defects in both the solid solution and in the particles of the γ'-phase (Fig. 2). A change in the contrast upon transition from bright-field to dark-field image of a defect (a change in the color from black to white) allows identifying them as intrinsic stacking faults.

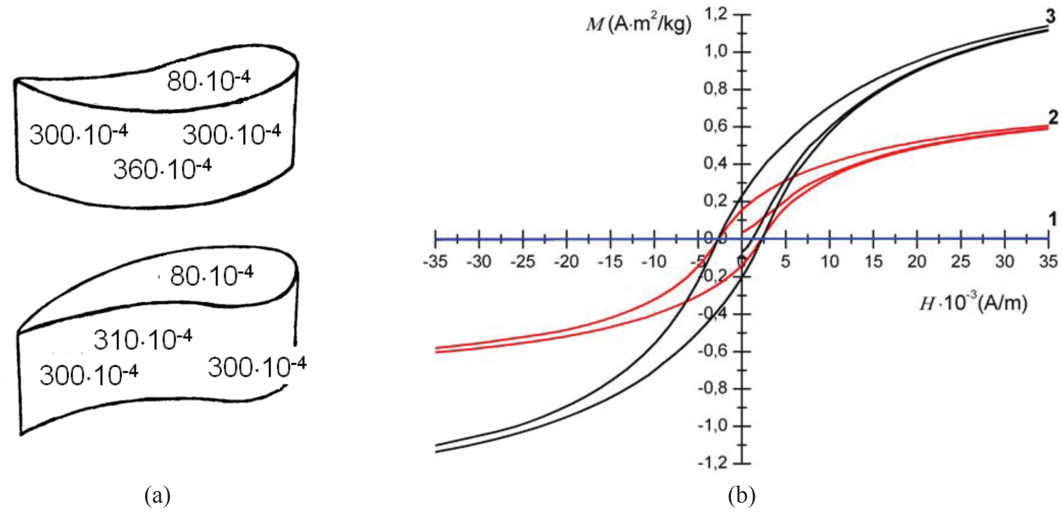

FIGURE 1. Results of the magnetic study of the ChS-70V alloy: (a) change in magnetic susceptibility χ at the part of the turbine blade feather from ChS-70V; (b) field dependence of the specific magnetization: *1*—initial state, *2*—concave part of the feather; *3*—convex part of the feather (its back)

The formation of stable faults inside the γ' phase can testify its softening. It is mean a loose of mechanical properties of the superalloy. A change in the magnetic susceptibility allows detecting such defects inside the γ' phase. So, the magnetic nondestructive testing methods can be successfully used for evaluating the working capacity of turbine blades.

Change of the magnetic properties of Ni_3Al with the decreasing of the ordering degree could be seen in the experiments using severe plastic deformation by the shear under pressure [6].

After the deformation by the shear under pressure structure of the Ni_3Al alloy was highly fragmented. The fragment size was estimated as 30 nm after 10 rotations. The lattice parameter γ'-phase calculated by X-ray data increased after deformation from 0.3565±0.0002 nm in initial state to 0.3591 nm. The long-range order of the γ′-phase (Ni_3Al) decrease with the decreasing of the fragment sizes. Figure 3 shows the decrease of specific magnetization *M* for Ni_3Al alloy with increasing of a degree of deformation.

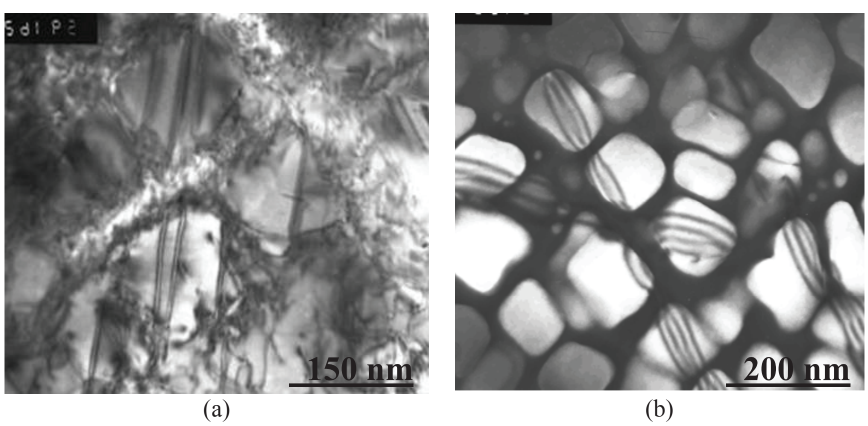

FIGURE 2. Microstructure of EP-800 superalloy after exploitation on the experimental mode: (a) bright-field imagine; (b) stacking faults on the dark-field image in superlattice γ′-phase reflex

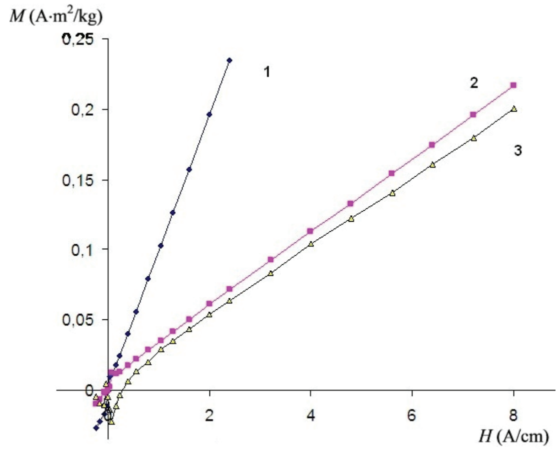

FIGURE 3. Field dependence of the specific magnetization *M* at room temperature of Ni_3Al samples: *1*—initial state; *2*—torsion under high pressure, 1 rotation; *3*—10 rotations

SUMMARY

Deformation can lead to both increase, and decrease the values of the magnetic susceptibility of Ni_3Al-base alloys. Different behavior of the magnetic susceptibility of samples of Ni_3Al depends on the type of the deformation due to the structure resulting from deformation.

The severe plastic deformation leads to the formation of nanocrystalline structure and accompanied by the formation of numerous defects inside the crystallites, a large number of borders and, accordingly, cross-border distorted volumes. The result is a significant drop in the degree of long range order in the alloy as a whole. This process accompanied by a decrease of the magnetic susceptibility of the intermetallic compound.

While in the high temperature deformation of supealloys inside of particles of the intermetallic compound locally formation of the complex defects occurs. These complexes act as ferromagnetic clusters in the paramagnetic matrix. However, the intermetallic particle as a whole retains a high degree of long range order. This process leads to the increase of the magnetic susceptibility.

The original device for the magnetic susceptibility measurements constructed in IMP UB RAS has heightened sensitivity and can be applicable to the study of low-magnetic alloys.

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REFERENCES

1. Q. Zeng and I. Baker, Intermetallics **15**, 419 (2007).
2. I. Baker and D. Wu, TMS Lett. **2**, 57 (2005).
3. Rhee Joo Yull, Y. V. Kudryavtsev, and Y. P. Lee, Phys. Rev. B **68**, 045104-1 (2003)
4. N. Kazantseva, A. Pirogov, and M. Rigmant, Long-Period Modulated Structure in Deformed Nickel Superalloys, in *Materials for Advanced in Mechanical Engineering 2006:* TMS Conference Proceedings, edited by J. Lecomte-Beckers *et al.* (Fatehgarh Sahib, Punjab, INDIA, 2006), M-1, pp. 60–65.
5. N. V. Kazantseva, A. V. Korolev, D. I. Davidov, N. N. Stepanova, N. I. Vinogradova, and M. B. Rigmant, Metallography 4, 18–24 (2013).
6. N. V. Kazantseva, N. N. Stepanova, V. P. Pilyugin, V. A. Zavalishin, and M. B. Rigmant, Lett. Mater. **3**(1), 16–19 (2013).