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Abstract

Fine atomic structure of Fe-Ni-C alloys containing of 30-36 wt. % Ni and 0.1-1.0 wt. % C have been analysed by means of a nuclear γ-resonance method. The alloys under investigation were in austenite phase. The study shows that the effective hyperfine magnetic field H_{eff} on the ^{57}Fe nuclei is affected by the presence of C atoms in Fe-Ni alloys and the mean value of H_{eff} fields increase with increasing of C element content in these alloys.

It has been detected that increase in carbon content in Fe-Ni alloys leads to a broadening of Mössbauer absorption lines. On the base of analysis of the distribution function of effective hyperfine magnetic field P (H) on the ^{57}Fe nuclei of Fe-Ni-C alloys, magnitudes of the most probable H_{eff} fields have been calculated. The calculated magnitude of these fields for a number of heat treatments regime of Fe-33wt. % Ni-0.7wt. % C alloy are H_{eff} = 320, 290, 260, 240 and 220 kOe. The presence of these fields were attributed to the formation of the local configurations in the alloy for which Fe atoms have a different number of Ni and C nearest neighbour atoms in the first coordination sphere. Hyperfine magnetic fields H_{eff} of 290 and 320 kOe corresponded to configurations of Fe atoms for which there is an increasing number of Ni atoms within nearest neighbour distances, and the number of C atoms within such configurations are very low. Other H_{eff} fields could be associated with the configurations for which Fe atoms are surrounded mainly by C atoms. It is further found that the most active processes of atomic redistribution in Fe-Ni-C alloys are taking place within the temperature range 450-600°C.

Key Words: Fe-Ni-C alloys; Fine atomic structure; Mössbauer-effect spectroscopy

1. Introduction

Mössbauer-effect spectroscopy is widely used in the investigations of the Fe-Ni invar alloys, providing important information concerning the atomic magnetic moments and the magnetic structure of the alloys. It is with this method that the internal magnetic field of ^{57}Fe nuclei have been analysed in many invar alloy studies [1-6]. In disordered alloys the internal field on the nucleus of certain atoms depends on the magnetic moments of these atoms and on the character of its local surroundings [1]. A specific characteristic of invar alloys is that the magnetic moment of Fe atoms in these alloys depends solely on its local surroundings . There are broad continuous distributions of effective hyperfine magnetic field on the ^{57}Fe nuclei depending on the local configurations of Fe atoms in the Fe-Ni invar alloys [1].

It was shown in a number of studies [2-6] that a carbon element has a significant effect on the thermophysical properties of Fe-Ni invar alloys. For example, if the Ni element concentration in the alloy is less than 34 wt.%, the presence of carbon element in the Fe-Ni alloys would decrease the thermal coefficient of linear expansion (TCLE) of these alloys. At the same time, if the Ni concentration is over a 35 wt.%, addition of carbon to Fe-Ni alloy would be increase the TCLE of these alloys [3,6]. It has been further found that addition of carbon element to Fe-Ni alloy results in the broadening of the temperature range for the low TCLE values and has a hardening effect on the austenite phase of these alloys [6].

2. Experimental Results and Discussion

2.1. Effect of Carbon Content

Mössbauer-effect measurements have been performed with an IGRS-4M constant-acceleration driving unit in combination with a multichannel analyser. The Mössbauer source was a 60 mCi of ^{57}Co isotope diffused in chromium.

The NGR (nuclear γ-resonance) spectra of Fe-30Ni-C alloys with different compositions of C element atoms within this alloy are shown in Fig. 1. It is evident from Fig. 1 that the NGR spectra of Fe-30Ni-C alloys with C concentration up to 0.75 wt. % consists of a single line. However, the NGR spectra of Fe-30Ni-1C alloy have a low-resolved or non-splitting Zeeman sextets form. It is seen from Fig. 1 that the widths of single lines increases with increase of carbon concentration in Fe-30Ni-C alloys.

The distribution function of effective hyperfine magnetic field P(H), on ^{57}Fe nuclei have been calculated by using computer programs based on the Window method [7] in order to analyse of the absorption spectra of Fe-Ni-C alloys. The calculated P(H) functions for NGR spectra shown in Fig. 1 are presented in Fig. 2. The magnitudes of P(H) in regions of low H_{eff} sharply decreases with increasing carbon content in the alloy, whilst the magnitudes of this function slightly increases in regions of high H_{eff} (Fig. 2). The magnitude of the effective hyperfine magnetic fields H_{eff} on the ^{57}Fe nuclei in the Fe-30Ni-C alloys increases from $H_{eff} = 60$ kOe to 137 kOe, as carbon concentration vary

from zero to 0.75 wt.% (Fig. 3), respectively. An increase in the magnitude of H_{eff} can be explained by assuming that each carbon atom in the alloy adds their four electrons to the common s-d band of Fe-30Ni-C alloy. Under this circumstance, the concentration of electrons in the s-d band increases leading to an increase in the mean magnetic moment of Fe atoms and, subsequently, the magnitude of H_{eff} fields in the Fe-30Ni-C alloys are also increase.

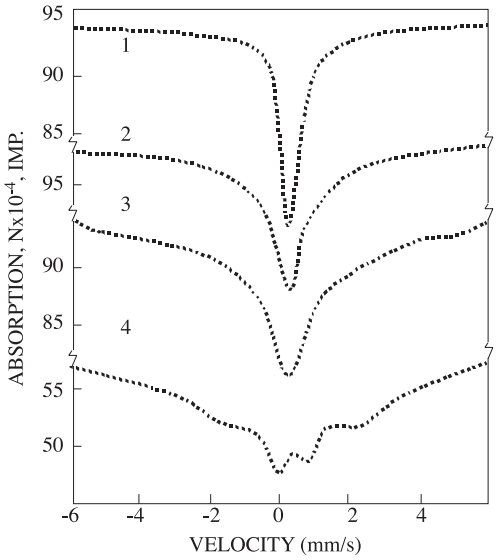

Figure 1. Mössbauer absorption spectra of Fe-30wt.% Ni-C alloys: 0.0 wt.% C (1); 0.4 wt.% C (2); 0.75 wt.% C (3); 1.0 wt.% C (4).

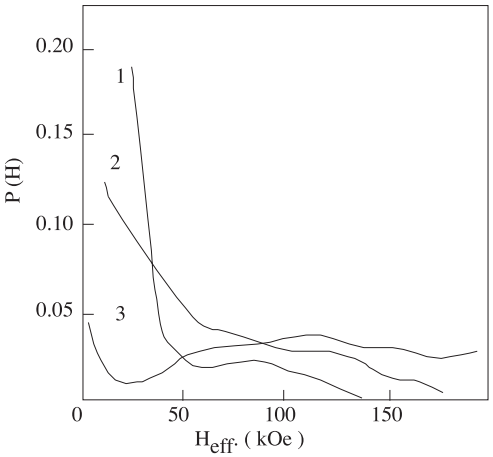

Figure 2. The distribution function of effective hyperfine magnetic field P(H) on the ^{57}Fe nuclei of Fe-30 wt.% Ni-C alloys: 0.0 wt.% C (1); 0.4 wt.% C (2); 1.0 wt.% C (3).

According to [8-11], the NGR spectra of Fe-Ni invar alloys with high content of Fe element atoms can be considered as consisting of two sections. If one of them is represented as a single line, then the other one consist of six lines of Zeeman sextets. The single line is associated with the Fe atoms that are paramagnetic inclusions in the ferromagnetic matrix of Fe-Ni invar alloys. However, Zeeman sextets correspond to the Fe atoms in the ferromagnetic matrix. The broadening of NGR absorption spectra with the increase of carbon concentration in the Fe-30 Ni-C invar alloys, detected in the present study (Fig. 1), can be explained by the transformations of paramagnetic Fe inclusions to the ferromagnetic state. A low-resolved Zeeman sextet observed for the Fe-30Ni-1C alloy confirms our explanations. It is worth noting that in the Fe-30Ni-C invar alloys with C concentration less than 1.0 wt. %, the relative fraction of Fe atoms at the ferromagnetic state are very low and therefore, the splitting of the spectra to the Zeeman sextet was not observed for these alloys.

It has been reported that the hardened Fe-Ni invar alloys have a heterogeneous magnetic structure that appears as a low-resolved or non-splitted sextet in the Mössbauer spectra of these alloys [12,13]. According to [12,13], the heterogeneous magnetic structure of Fe-Ni alloys below the critical Curie temperature T_C, has a ferromagnetic structure with FCC crystal lattice structure. Within this structure each Fe atom is surrounded by 12 atoms of the same Fe type within the first coordination sphere. Therefore, below T_C the submicro regions which are enriched by Fe atoms have a FCC crystal structure and these regions can be considered as a γ-matrix with ferromagnetic structure. At temperatures above T_C, the ferromagnetic γ-matrix is transformed to paramagnetic structure. It is evident from Fig. 1 that the relative fraction of these paramagnetic submicro areas shows a decrease with increasing carbon concentration in Fe-30Ni-C alloys.

2.2. Effect of Heat Treatments

In the present study the effect of temperature and different heat treatments regime on the NGR spectra of the hardened Fe-Ni and Fe-Ni-C invar alloys are also investigated. The NGR spectra of Fe-36Ni and Fe-33Ni-0.7C alloys after heating at 1150°C temperature and then quenching in water are shown in Fig. 4. It is well known that these two alloys have almost the same magnitude of thermal coefficient of linear expansion (TCLE). It is evident from Fig. 4 that the NGR spectra have a well-resolved Zeeman sextet form with broaden lines. The broadening of the lines can be caused by fluctuations in the magnitude of hyperfine magnetic fields around their mean values.

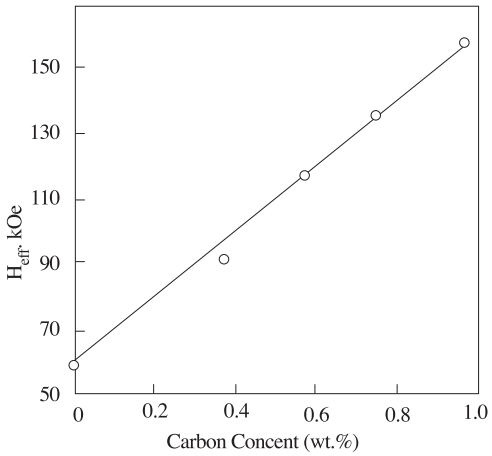

Figure 3. Variation of effective hyperfine magnetic fields H_{eff} on the ^{57}Fe nuclei as a function of carbon concentration in the Fe-30wt.% Ni-C alloys.

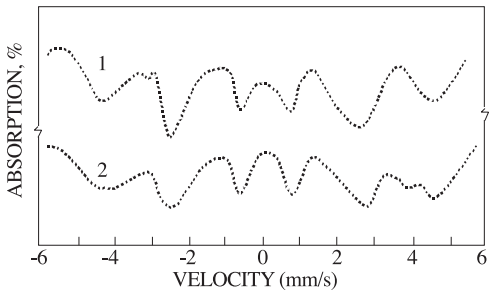

Figure 4. Mössbauer absorption spectra of Fe-36wt.% Ni (1) and Fe-33wt.% Ni-0.7wt.% C (2) alloys after heating at 1150°C temperature and then quenching in water.

The distribution function of effective hyperfine magnetic field, P(H), on the ^{57}Fe

nuclei for the hardened at 1150°C temperature of Fe-36Ni alloy is given in Fig. 5. The P(H) function for hardening at 1150°C temperature and subsequently heated at 400, 500, 600 and 700°C temperatures of Fe-33Ni-0.7C alloy are presented in Fig. 6. The P(H) curves for both alloys in the hardened state has a similar form, but they differ in the magnitude of the effective hyperfine magnetic field H_{eff}, on the ^{57}Fe nuclei of these alloys. The magnitude of the H_{eff} field in the Fe-36Ni alloy is equal to 290 kOe (Fig. 5). More detailed analysis of the P(H) curves for Fe-33Ni-0.7C alloys (Fig. 6) indicate that the magnitude of H_{eff} fields is affected by heating. As determined from P(H) curves, magnitudes of H_{eff} fields are: 320 (1), 290 (2), 260 (3), 240 (4) and 220 kOe (5) for samples hardened at 1150°C (1) and subsequently heated at 400 (2), 500 (3), 600 (4) and 700°C (5) temperatures, respectively. These H_{eff} fields can be interpreted with the formations of local configurations of Fe atoms with different number of Ni and C atoms within nearest neighbour distances (short-range order) surrounding them in the submicro volumes of these alloys. The magnetic moments of Fe atoms within these local subatomic structures would be different.

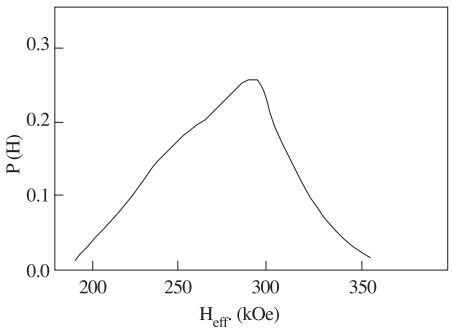

Figure 5. The distribution function of effective hyperfine magnetic field P(H) on the ^{57}Fe nuclei of Fe-36 wt.% Ni alloy after heating at 1150°C temperature and then quenching in water.

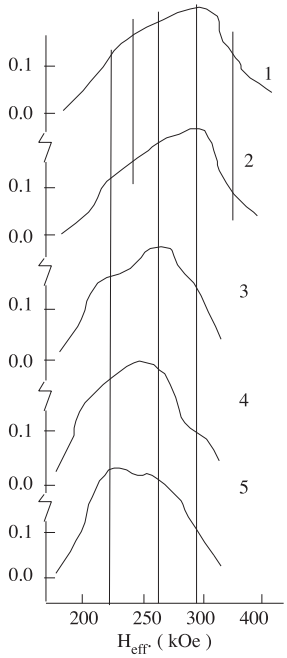

Figure 6. The distribution function of effective hyperfine magnetic field P(H) on the ^{57}Fe nuclei of Fe-33wt.% Ni-0.7wt.% C alloy after hardening at 1150°C (1) temperature and then subsequent heating at 400°C (2), 500°C (3), 600°C (4) and 700°C (5) temperatures

The configurations with H_{eff} = 210-220 kOe field are obviously associated with Fe in the Fe_3C cementite phase. It is known that the magnitude of H_{eff} field for cementite phase is equal to 210 kOe [6] and, the presence of Ni atoms in the first coordination sphere of Fe atoms can vary up to 220 kOe. At the same time configurations with H_{eff} = 260 kOe field can be associated with Fe atoms which are surrounded mainly by Ni and do not have any C atoms in the first coordination sphere. It correlates well with the fact that the magnitude of hyperfine magnetic field for Fe-33Ni binary alloy is H_{eff} = 260 kOe [6]. Finally, the configurations for which the H_{eff} = 290 and 320 kOe can be associated with Fe atoms which have a different number of both Ni and C atoms in the first coordination sphere.

It is evident from Fig. 6 also that the fraction of Fe atoms at the local configurations with the magnitude of hyperfine magnetic fields equal to H_{eff} = 320-290 kOe decreases with increasing temperature from 400 up to 700°C. Therefore, the fraction of Fe atoms in configurations with H_{eff} = 260-220 kOe increases due to redistribution of atoms in the submicro volumes of Fe-33Ni-0.7C alloy. The processes of atomic redistribution start at 450°C and complete within 600-700°C.

3. Conclusions

The effects of carbon element atoms and temperature on the fine atomic structure of Fe-Ni-C alloys containing of 30-36 wt.% Ni and 0.1-1.0 wt.% C have been analysed on the base of NGR (nuclear γ-resonance) method. The results of the current study can be summarised as follows:

1. The NGR spectra consists of a single line for Fe-30Ni-C alloys with carbon content up to 0.75 wt.% and a low-resolved or non-splitted Zeeman sextet for Fe-30Ni-1C alloy. If single lines are associated with the Fe atoms at the paramagnetic state, then Zeeman sextets are corresponded to the Fe atoms in the ferromagnetic state.

2. The NGR spectra of Fe-30Ni-C alloys with carbon content up to 0.75 wt.% show a broadening effect, which increases with increasing of carbon concentration.

3. The effective hyperfine magnetic fields H_{eff} on the ^{57}Fe nuclei are affected by the presence of C element atoms in the Fe-Ni alloys. The magnitude of the H_{eff} fields on the ^{57}Fe nuclei in the Fe-30Ni-C alloys increase from H_{eff} = 60 kOe to 137 kOe, as carbon content varies from zero to 0.75 wt.%, respectively.

4. The NGR spectra of Fe-36wt.% Ni and Fe-33wt.% Ni-0.7wt.% C alloys, after heating at 1150°C temperature then quenching in water, have a well-resolved Zeeman sextet form with broaden lines. The broadening of the lines can be caused by fluctuations in the magnitudes of hyperfine magnetic fields around its mean values.

5. The magnitude of the H_{eff} field on the ^{57}Fe nuclei in the heated at 1150°C temperature and then quenched in water of Fe-36wt.% Ni alloy is equal to 290 kOe.

6. The magnitude of H_{eff} fields in the Fe-33wt. % Ni-0.7wt. % C alloys are affected by

heating. The magnitudes of H_{eff} fields of these alloys are equal to 320 (1), 290 (2), 260 (3), 240 (4) and 220 kOe (5) for the hardened at 1150°C (1) and subsequently heated at 400 (2), 500 (3), 600 (4) and 700°C (5) temperatures, respectively. These H_{eff} fields can be interpreted with the formations of local configurations of Fe atoms in the submicro volumes of these alloys which have a different number of Ni and C atoms within nearest neighbour distances (short-range order) surrounding them.

References

[1] F. Mezzetti and L. Passari, Internal Friction and Ultrasonic Attenuation in Solids, 6-th Inter. Conf. Proc., (University of Tokyo Press, Tokyo, Japan, 1977) p. 436

[2] S. Kawarazaki, M. Shiga and Y. Nakamura, *Phys. Stat. Sol.* **B, 50** (1972) 359

[3] M. Shiga and Y. Nakamura, *J. Phys. Soc. Japan,* **26** (1969) 24

[4] M. Shiga, *J. Phys. Soc. Japan,* **22** (1967) 539

[5] Y. Nakamura, M. Shiga and Y. Takeda, *J. Phys. Soc. Japan,* **27** (1969) 1470

[6] A.O. Mekhrabov, T.A. Shukyurov, K.G. Binnatov, V.A. Aliev, Yu.L. Rodionov and I.I. Ali-zade, *Metallofizika,* **13(7)** (1991) 111

[7] B. Window, *J. Phys. E: Sci. Instrum.,* **4** (1971) 401

[8] V.M. Kalinin and V.P. Beskachenko, *Fiz. Metal. Metalloved.,* **36** (1973) 73-78.

[9] G.F. Bollig, A. Arrot and R.H. Richman, *Phys. Stat. Sol.,* **26** (1968) 743

[10] V.N. Bugaev, V.G. Gavrilyuk, V.M. Nadutov and V.A. Tatarenko, *Fiz. Metal. Metalloved.,* **68** (1989) 931-940.

[11] M.C. Cadeville and E.P. Wohlfarth, *Phys. Stat. Sol.* **(a), 26** (1974) K 157.

[12] I.B. Kekalo and B.G. Lifshits, Internal Friction in Metallic Materials (Nauka, Moscow, USSR, 1970) p.182

[13] Yu.L. Rodionov, G.G. Isfandiyarov and O.S. Sarsenbin, *Fiz. Metal. Metalloved.,* **48** (1979) 979