MOSSBAUER STUDY OF STRUCTURE CHANGES IN Fe-Co-Cr ALLOYS UPON THEIR ALLOYING WITH Ga AND W

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WHY TO STUDY?

The aim of the research was to improve mechanical properties of the well-known magnetic alloys of the Fe-Co-Cr system, which possess magnetic properties appropriate for using them as materials for high-speed hysteresis engines. As a way of modifying their structure and properties, alloying with W and Ga was used together with working-out the regimes of heat and mechanical treatments. As a result of such trials, some advantageous combinations of strength, plasticity, and coercive force were gained [1]. To control and forward these advances, interconnection of these parameters with the structure changes must be ascertained. Morphological methods such as X ray and electron microscopy present low information on the phase compositions and fine structure peculiarities of the objects under study. To this end, Mossbauer spectroscopy was successfully employed.

WHAT TO STUDY AND HOW

The Mossbauer spectra were taken in the mode of constant accelerations with a 57Co source in the chromium matrix at 300K. The spectra were processed using an MSTOOLS program package [2] which allows both directly modeling the experimental results and constructing multi-core distributions of the probability density of the hyperfine fields P(H) if there are grounds to assume that different parts of a structure present different linearity in the relationships of at least two of the main Mossbauer parameters. We examined alloys which contained 20-24 wt.%Cr, 12-17 wt.%Co, 7-9 wt.%W, and 0-4 wt.% Ga after quenching from 1300ºC, cold deformation to 60% and heat treatment at 630ºC. As a reference, spectra of the ternary composition Fe-22Cr-15Co were recorded to serve as a starting point for the series to be investigated first and to be then compared with some other compositions.

1.AFTER QUENCHING

Figure 1 shows spectra and distribution functions for three compositions after quenching.
It is seen that all the three distributions have the form featuring in the main a solid solution, though heterogeneous. In the case of the ternary alloy the effects of short-range order are pronounced to a greater extent, (even with the formation of nonmagnetic regions) whereas introduction of both W and Ga results in smoothening the distribution shifted towards lower fields. If annealing for optimal properties is performed immediately after quenching, a common modulated structure is realized, which does not meet the requirements on strength and plasticity. An intermediate cold deformation is necessary, which might serve as a means of affecting the mechanism of phase transformations.

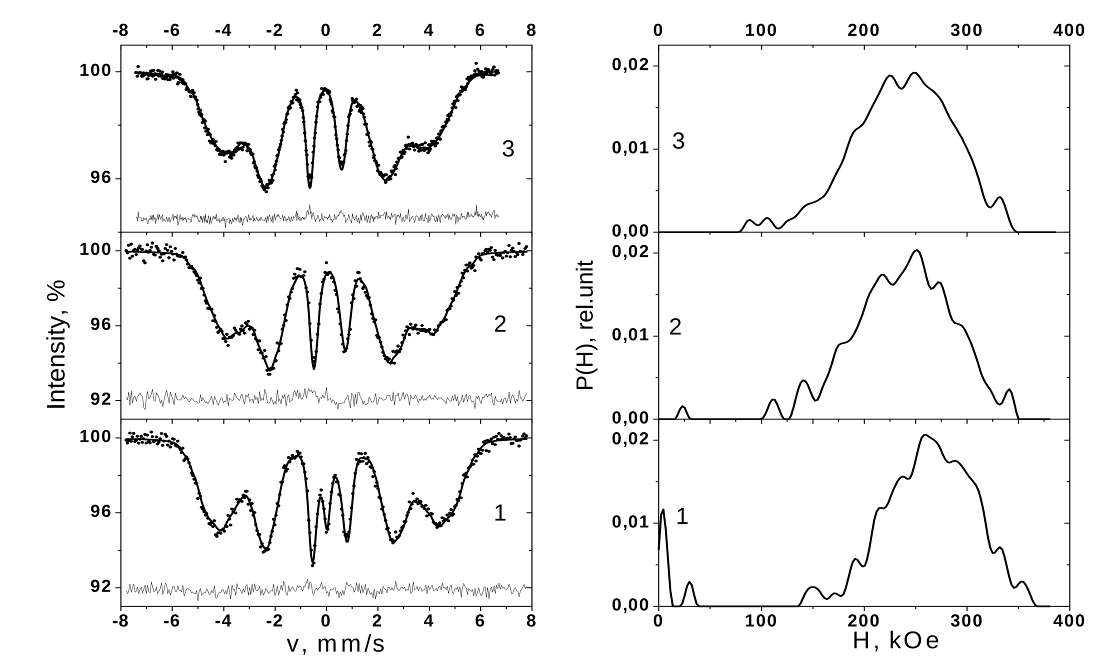

Fig.1 Spectra and P(H) of the samples after quenching:
1 - Fe-22Cr-15Co, 2 - Fe-22Cr-15Co-9W, 3 - Fe-22Cr-15Co-9W-3Ga

2.THREE STAGES OF TREATMENT

Changes in the alloy structure after rolling, common for the studied compositions, are exemplified by the spectrum and distribution 2. Structure is seen to become more homogeneous. The most remarkable difference is displayed in the relative intensities of the outer and middle peaks in the spectra, which characterizes different magnetic textures in these states. The ratio I(1,6) /I(2,5) changes from 0.77 after quenching to 0.4 after rolling. After annealing for the optimal state P(H) represents a continuous set of coordinations of Fe atoms, including those in the low-to-zero filed. To separate contributions from the structure regions with different compositions an attempt was made to construct two-core distributions.

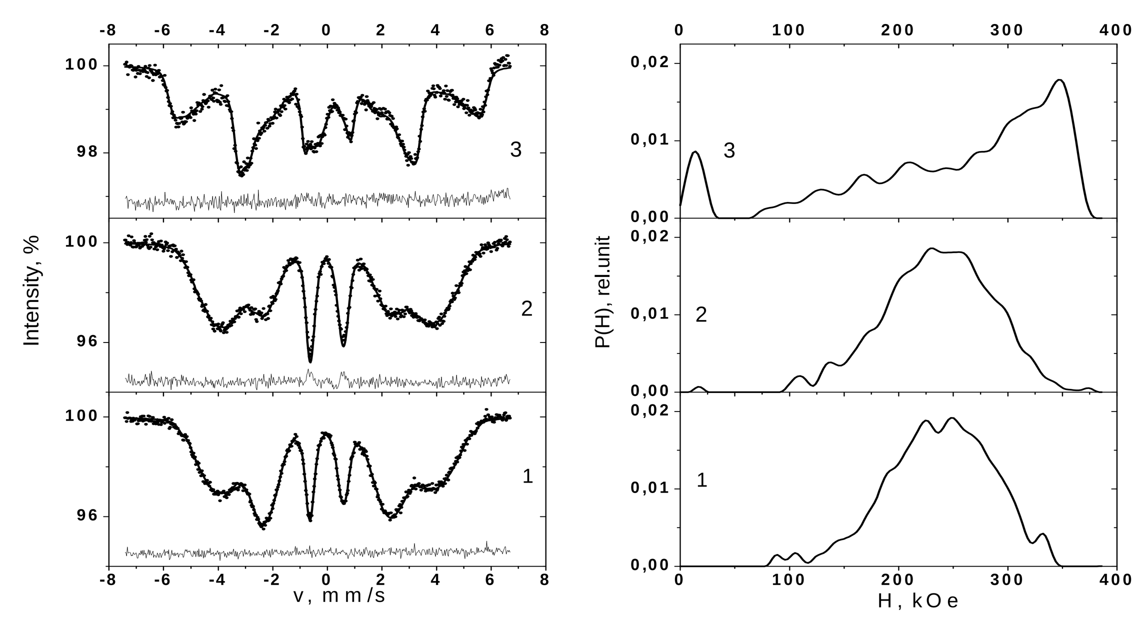

Fig.2 Spectra and P(H) for the sample Fe-22Cr-15Co-9W-3Ga after
1 - quenching, 2 - rolling, 3 - annealing

3.AFTER OPTIMAL TREATMENT

Knowing that a common ternary alloy after annealing represents a modulated structure consisting of two Fe-Cr- and Fe-Co-based phases, we suggest two P(H) functions with different correlations of isomeric shift and hyperfine fields and trace the changes in these spectral contributions versus composition. Already after addition of W the regions representing the next-to-zero field peak are formed, while the form of the high-field distribution becomes more distinct testifying to a more profound phase separation at least in chromium. Addition of Ga results in increasing intensities in the field range 200-300 kOe.

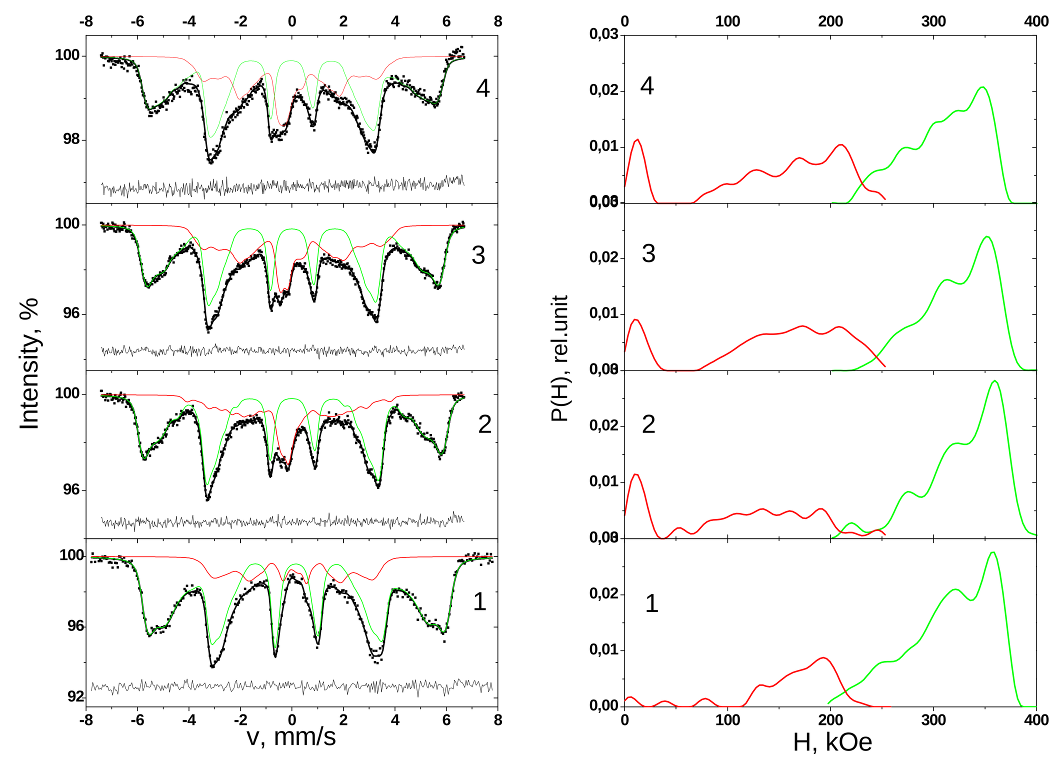

Fig. 3 Spectra and double-core P(H) for the samples after optimal treatment
1 - Fe-22Cr-15Co,
2 - Fe-22Cr-15Co-9W,
3 - Fe-22Cr-15Co-9W-1Ga,
4 - Fe-22Cr-15Co-9W-3Ga

4. DIRECT MODELING

Based on the qualitative information about structure components taken from the P(H) shape for the sample without Ga, we performed fitting of the spectra with three sextets related to the high-field contribution, one sextet from the low-field contribution, and nonmagnetic part (Fig.4). Then, we subtracted low-field and nonmagnetic subspectra and the remainder spectra were again analyzed using the P(H) apparatus. The results are shown in Fig.5a. The changes in the structure of these regions are clearly seen. With increasing Ga content, they become more inhomogeneous in concentration of impurity atoms. The intensity of the highest-field peak related to the 0-impurity-atoms configuration in the first coordination shell of iron atoms decreases, with its position being shifted toward lower fields. The similar changes in the samples of different compositions after optimal treatment are exemplified by the P(H) distributions in Fig. 5b.

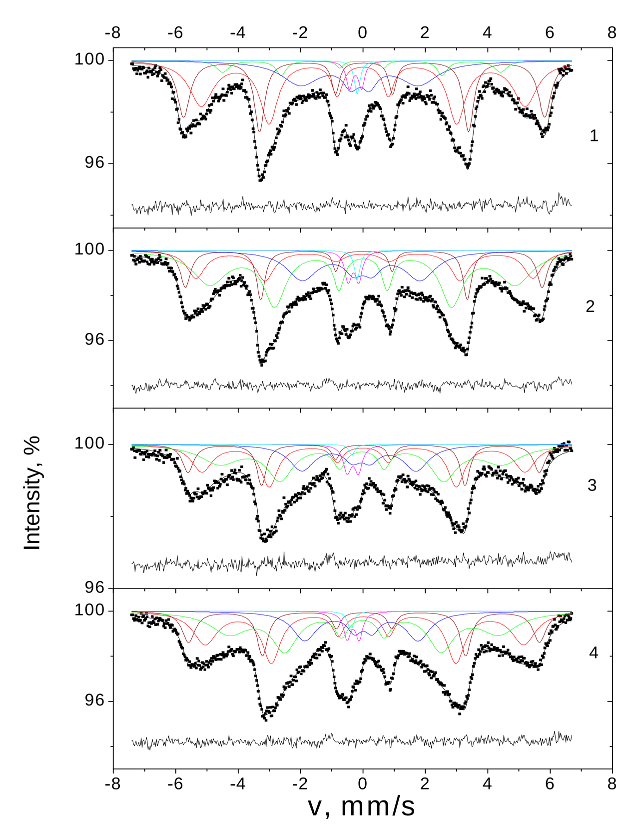

Fig. 4 Spectra and fitting subspectra for the samples after optimal treatment
1 - Fe-22Cr-15Co-9W
2 - Fe-22Cr-15Co-9W-1Ga
3 - Fe-22Cr-15Co-9W-3Ga
4 - Fe-22Cr-15Co-9W-4Ga

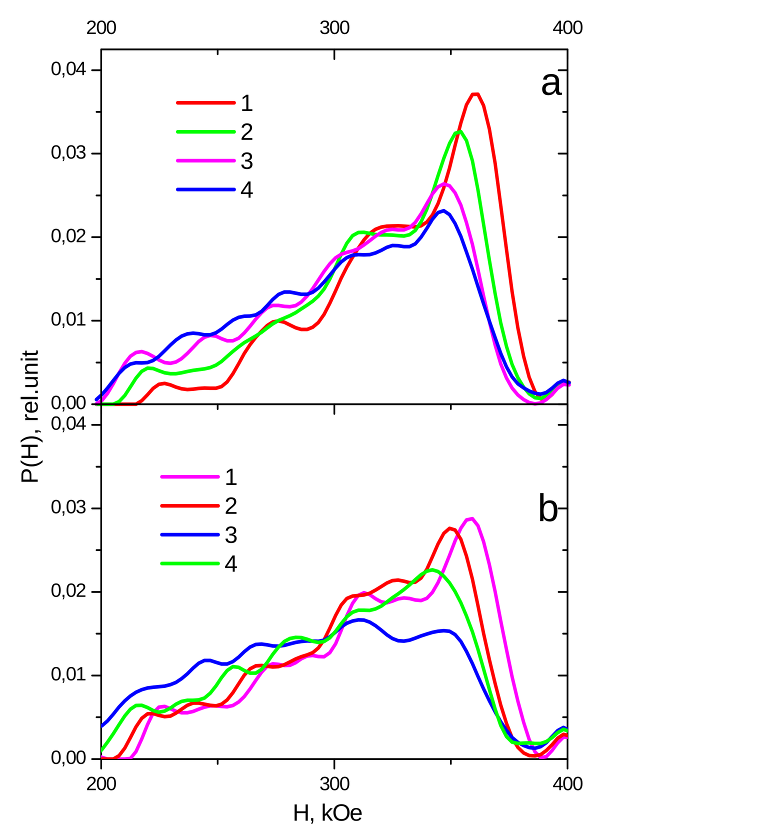

Fig. 5 P(H) function of the high-field contribution
a - series Fe-22Cr-15Co-9W: 1-OGa, 2-1Ga, 3-3Ga, 4-4Ga
b - samples of different compositions:
1 - Fe-23Cr-16Co-0.5Ga,
2 - Fe22Cr-15Co-7W,
3 - Fe-24Cr-12Co-3Ga,
4 - Fe20Cr-17Co-2Ga

5.Table.

Concentrations of elements, relative intensities of subspectra *S* and average hyperfine fields *H* of spectral contributions for the paramagnetic (p), low-field (l), and high-field portions of P(H) functions, Cr concentration in the structure components *C* and magnetic and mechanical properties..

Composition, wt.% /at.%					Relative areas, % ± 0.5			Hyperfine field (kOe) ± 0.5		Cr content, % ± 0.5		$\sigma_{0.2}$ [MPa	δ [%]	H_c [A/cm]
Fe	Cr	Co	W	Ga	Sp	S_l	S_h	H_l	H_h	C_l	C_h			
63	22/25	15/15	0	0		19	81	162	316	46	10			
54/57.1	22/25	15/15	9/2.9	0	4.4	20.2	75.4	117	326	56.5	8	1450	1-1.5	158
53/56.2	22/25	15/15	9/2.9	1/0.85	3.8	19.2	77	117	312	56.5	11	1400	2.7	110
51/54.3	22/25	15/15	9/2.9	3/2.5	4.5	16.5	79	114	299	57	14	1300	2.0	100
50/53.7	22/25	15/15	9/2.9	4/3.4	4	15	81	113	295	57	15	1250	0.3	60

To quantitatively follow the structure evolution we estimated the relative iron content and average hyperfine field separately for the paramagnetic peak, low-field and high-field subspectra (see Table), which allowed us, using the literature data on the H versus Cr concentration dependence and isomeric shifts for the binary compositions [3, 4] to determine the phase compositions as follows: paramagnetic phase is close to Fe_3W_2, low-field areas contain up to 57%Cr (including possibly W), whereas high-field areas change in concentration of (Cr, Ga). The changes in the parameters after introduction of W supports the conclusion on a more pronounced phase separation with the formation of W-enriched regions of a new kind. After addition of Ga, the average parameters of spectral contributions change, though less remarkably than the position and intensities of partial lines which constitute the P(H) functions shown in Fig. 5a,b. If to analyze these distributions by fitting them with a set of the Gaussian lines of equal width, one can conclude that not only the very parameters of already existing coordinations are changed by introduction of Ga, but some new ones appear with increasing its concentration, which purports the formation of new configurations of impurity atoms around iron atoms and growth of inhomogeneity of elemental content over precipitates. We can suggest a model of influence of Ga on the structure and properties of the magnetic precipitates under which in a small amount (up to 1%) Ga resides in their peripheral regions, decorating them (to improve the elastic properties), and does not prevent Cr from leaving. With increasing concentration of Ga, it possibly segregates and retain more Cr in these regions, which deteriorates both plasticity and magnetic properties.

6.CONCLUSIONS

1. Effect of Intermediate plastic deformation on the process of structure formation after optimal treatment manifests itself independently of the initial alloy composition.
2. Introduction of W results in the appearance of a new type of regions enriched in W with a next to zero field, whose amount is almost indifferent to the additional alloying with Ga.
3. Changes in the parameters of the P(H) distributions for the quaternary alloys in the optimal state allows one to conclude that Ga localizes itself in an intermediate region between the chromium-rich and cobalt-rich structure constituents and affects redistribution of Cr through a kind of interface through possibly changing the size and form of Ga-containing part of structure.

REFERENCES

[1] E.V. Beloserov, M.A. Uimin, A.E. Ermakov, V.V. Serikov, N.M. Kleinerman and G.V. Ivanova, Phys. Met.Metallogr. 106, N5, 2009, pp.472-480.
[2] V.S. Rusakov Mossbauer Spectroscopy of Locally inhomogeneous Systems (Almaty 2000), pp.438.
[3] P.L. Grusin, Yu.L. Rodionov, Yu.A. Lu. Phyz. Met. Metallov., 40, N5, 1975, pp.1046-1052.
[4] A. Blachowski, K. Ruebenbauer, J. Zukrowski, and J. Przewoznik. Journal of Alloys and Compounds 455, 2008, 47-51.