MÖSSBAUER ANALYSIS OF RETAINED AUSTENITE

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We propose a method for the quantitative analysis of the retained austenite produced by heat straining in welded low-alloy steels. Mössbauer spectra show that the amount of retained austenite varies with the heat-straining temperature and that the austenite breaks down under impressed mechanical forces. Quantitative analysis of austenite by nuclear gamma resonance can thus be used to optimize the welding parameters.

Practical experience with metal constructions and mining machinery in the North has shown that low temperature coupled with other adverse factors can lead to brittle fracture in welded members [1]. Fracturing is due to inadequate technical cohesive strength and cold shortness of the metal in and around the weld seam. The technical cohesive strength is further reduced by cold cracks. The development of cold cracks in weld joints is dependent upon [2]:

– the kinetics of phase transitions of the metal in and around the weld seam, which are determined by the chemical composition of the base metal and weld materials and by the heat-straining cycle; and

– high residual stresses and the presence of stress concentrators in the joint.

The weakest area in a weld joint is around the seam, primarily because of austenite growth and lowered boundary properties resulting from the segregation of impurities and some alloying elements at high temperatures. This process occurs in the metal around the seam mainly in the region of highest welding temperatures associated with rapid grain growth and heat straining.

We accordingly analyzed the kinetics of formation and breakdown of retained austenite in low-alloy steel, using nuclear gamma resonance spectroscopy which reliably identifies the austenite and martensite phases in iron-based alloys [3]. The technique is well suited to the analysis of the phase transitions produced in such alloys by external mechanical stresses and heat, since it requires no aftertreatment (e.g., polishing) of samples with retained austenite and residual thermomechanical stresses.

We choose for analysis KhVG low-alloy steel; its chemical composition and transition characteristics are: 0.9-1.05 C, 0.15-0.35 Si, 0.8-1.1 Mn, 0.9-1.2 Cr, 1.2-1.6 W, S, P $\leq$ 0.03, Cu $\leq$ 0.3, martensitic critical points M_n = 210°C and M_c = –50°C, austenitic critical points A_{c1} = 750°C and A_{c3} = 940°C.

The heat straining cycle was simulated by cutting the samples on a lathe in the form of thin chips (~60-80 μm) at different cutting speeds. In this way the cuttings could be heated to temperatures in the range A_{c1}-A_{c3}, strained, and hardened at different rates.

The Mössbauer spectra were measured on a constant-acceleration setup linear to within 1%. The gamma emission was detected with a 0.8 mm NaJ(Tl) scintillation crystal. The Mössbauer spectrum was recorded on an LP/4000 multichannel analyzer whose time was synchronized with the velocity cycle. The gamma source was a ^{57}Co isotope diffused into Pd. The spectrometer was calibrated by means of a Fe_2O_3 standard absorber.

The obtained Mössbauer spectra 1-5 (Fig. 1) show that in the KhVG steel samples cut at different speeds (0, 50, 100, 150, and 200 rpm) the spectra separate into two distinct phases: (a) austenite produced by heating, straining, and hardening – marked by a central peak, and (b) the original (ferromagnetic bcc) structure of the KhVG steel as supplied, represented by a well resolved sextet. The spectra clearly display the amount of retained austenite at the cutting speeds corresponding to different heat-straining cycles and kinetics of austenite formation. In Figs. 1-3, the abscissas indicate the channel numbers and the ordinates denote the relative intensities.

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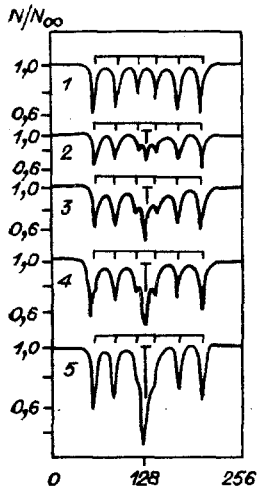

Fig. 1

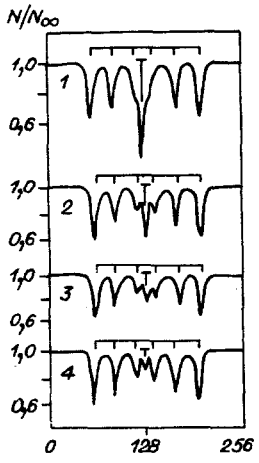

Fig. 2

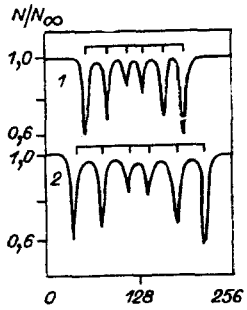

Fig. 3

The kinetics of austenite breakdown under impressed mechanical forces are simulated by gridning the metal chip. The Mössbauer spectra of the ground chips (Fig. 2) show that the degree of breakdown varies with the particle size, viz., the finer the grind the smaller the amount of retained austenite; the particle sizes in 1-4 are 4.5, 2, 1, and 0.5 mm.

The Mössbauer spectra of fully annealed samples (Fig. 3) demonstrate the formation of a single-phase ferromagnetic structure whose effective magnetic field depends on the cutting speed (H_{eff} = 270 and 356 kOe for 50 and 200 rpm – spectra 1 and 2), i.e., on the heat-straining cycle.

Since the Mössbauer-spectrum components of the different phases of KhVG low-alloy steel are separate and proportional to their content, it is possible to analyze quantitatively the retained austenite produced by hardening at A_{c1}-A_{c3}. According to [3], the fractional area of the experimental spectrum which belongs to i-th phase is defined in a thin-absorber approximation by

$$S_i = n_i f_i' \Big/ \sum_{j=1}^{k} n_j f_j',$$

where k is the number of phases in the sample, and f_i' is the probability of gamma absorption by resonance nuclei of the i-th phase. The number of resonance nuclei in the i-th phase of a multiphase alloy is given by

$$n_i = \lambda_0 N_A Q q_i t_i / G_e.$$

Here λ_0 is the fraction of resonance atoms in a natural isotope mixture of the Mössbauer element (λ_0 = 0.0219 for ^{57}Fe); N_A is Avogadro's number; Q is the mass of a 1 cm^2 sample; q_i is the relative fraction of the i-th phase $\left(\sum_{i=1}^{k} q_i = 1\right)$; G_e is the mass of one gram-atom of the Mössbauer element; $t_i = g_i/G_i$; g_i and G_i are the mass of Mössbauer atoms in a gram-molecule and the mass of gram-molecule of the i-th phase. The true mass fraction of each phase in the sample is then given by [3]

$$q_i = \left(S_i \prod_{j \neq i}^{k} t_j f_j'\right) \Big/ \sum_{\rho=1}^{k} S_\rho \prod_{j \neq \rho}^{k} t_j f_j,$$

where S_i are calculated from the experimental spectrum by the method in [4], and f_j' is derived theoretically in a Debye approximation [3]. Since austenite nucleation occurs during welding at the ferrite–cementite interfaces, the relative fraction of Mössbauer atoms in the j-th phase is t_j = 0.93311 [3].

The results of the above quantitative phase analysis of retained austenite are plotted in Fig. 4; curve 1 describes the kinetics of austenite production in different heat-straining cycles, and curve 2 represents the kinetics of austenite breakdown under impressed mechanical

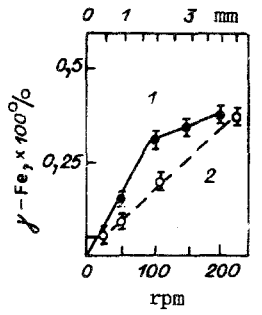

Fig. 4

forces. During welding the near-seam and thermal-effect zones are subjected to different heat straining, and as a result they contain different amounts of retained austenite. Under the effect of mechanical forces the metastable retained austenite breaks down into α and ε martensite [5] and alters the physical and mechanical properties of the weld joint. The varying amount of austenite retained at increasing distances from the seam in the $\gamma \rightarrow \alpha$ transition may also be the cause of cold cracks which affect the technical cohesive strength of the joint. Since the heat-straining cycle depends on the welding rate, the energy per unit length, and other welding parameters, these may be used to control the kinetics of austenite formation.

Our method for the quantitative determination of metastable austenite in specific steels thus provides the means of optimizing the technical welding parameters in order to improve the performance of the joint, and of evaluating the phase composition of the near-seam and thermal-effect zones under different welding conditions.

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