Analysis of patterns in the formation of phase composition during thermal and thermocyclic treatment of maraging steel

Malokhat Juraeva¹, Anna Voroshilova², Shokhrukh Yarashov³, Toyir Juraev⁴, and Sadir Shodiev⁴

¹Bukhara Engineering-Technological Institute, Bukhara, Uzbekistan
²Siberian Federal University, Krasnoyarsk, Russia
³Navoi state university mining and technologies, Navoi, Uzbekistan
⁴Bukhara Institute of Natural Resources Management of the National Research University of “TIIAME”, Bukhara, Uzbekistan

Abstract. The paper studies changes in the phase composition of typical maraging steel. The analysis performed made it possible to determine the amount of retained austenite depending on the modes of thermal and thermocyclic treatment with heating in the temperature range of α-γ transformation. The processes occurring during heating in the region of α-γ transformation are divided into two temperature regions. As a result, it is noted that the identified patterns in the formation of the phase composition during thermal and thermocyclic treatment with the temperature range of α-γ transformation make it possible to both control changes in the phase composition and properties of steel and predict these changes.

1 Introduction

Due to a specific strengthening mechanism, high strength and manufacturability [1-5], maraging steels (MS) are the most promising materials for creating modern products operating at various temperatures, high pressures and in aggressive environments.

Recently, extensive information has been accumulated on MSS, both in the main classical version (alloying high-nickel steels with molybdenum and cobalt), and economically alloyed steels with a minimum content of expensive and scarce elements. However, due to the lack of sufficient experimental and practical data on the possibility of changing the phase composition and properties of MS by preliminary thermal (TT) and thermocyclic treatment (TCT), in some cases their use in combination with other materials is limited.

Currently, corrosion-resistant austenitic-ferritic steels are widely used in various structures operating in aggressive environments [6]. Obtaining MS in a two-phase state with high strength and resistance to stress corrosion failure (SCF) in aggressive environments would make it possible to expand their common area of application.

Systematic study and obtaining practical data on the possibility of changing the phase composition and properties of MS through preliminary TT will provide an opportunity to

* Corresponding author: abrorov1975@mail.ru
develop design and technological solutions to expand the scope of their application in combination with other materials and increase the dimensional accuracy of parts and one-piece structures.

This article presents the results of work on the analysis of patterns of changes in the phase composition, which affects the mechanical properties and resistance to SCF, for economically alloyed steels, for example, 03X11H10M2T-VD, etc. Figure 1 shows the chemical composition of steel 13X11H2B2-MF. All operational characteristics, as well as the chemical composition of this material, are regulated by GOST 5632-72 standards. In particular, this grade of steel is flake-sensitive, meaning it has a tendency to develop short and intermittent internal cracks. They arise under the influence of internal and external stresses during the operation of the part.

This work is devoted to the analysis of the patterns of changes in the phase composition depending on various modes of preliminary TT of steel grade 03X11H10M2T-VD.

Fig. 1. Chemical composition of steel 13X11H2B2-MF (source: https://stalmaximum.ru/).

2 Materials and methods

The relative change in austenite content was determined using a diffractometer on Fe, Kα radiation using a standard-free method based on the reflection of integral intense lines of the (111)γ and (110)α phases upon heating in the α-γ transformation range in a high-temperature attachment from one sample setup and measurements at different temperatures.

Dilatometric analysis of changes in linear expansion coefficient (LEC) and sample sizes was carried out on a Chevenard system instrument with recording of differential curves with a reference sample. Additionally, the change in the length of the 70x70x10 mm samples was determined with a micrometer before and after different TT modes.

A comparative assessment of resistance to SCF was carried out by the accelerated method of alternating polarization according to the method described in [7].

The change in coercive force was assessed using a special device using the demagnetization current Ip, proportional to the coercive force Hc.

The analysis of the change in the phase of the third harmonic was carried out by the method of higher harmonics [8] using the angle φ3 on a phase and amplitude analyzer.
3 Results and discussion

The results of changes in phase composition and dimensions during heating in the temperature range of $\alpha$-$\gamma$ transformation and changes in phase composition depending on the heating temperature and subsequent cooling showed that during heating of 03X11H10M2T-VD steel in the range of 535..800°C (or 750°C, 1 hour) a complete polymorphic $\alpha$-$\gamma$ transformation occurs with a simultaneous relative decrease in sample size by 0.360%.

When samples cut from sheets 10 mm thick, pre-hardened at 1000°C for 1 hour, are heated to different temperatures in the $\alpha$-$\gamma$ transformation region and subsequent cooling, the phase composition of the steel changes with the formation of retained austenite. Thus, with an increase in temperature from 535 to $\sim$625°C, a relative increase in retained austenite occurs up to 45%, and the austenite formed when heated as a result of the $\alpha$-$\gamma$ transformation is stable and does not undergo a reverse transformation upon cooling.

An increase in temperature leads to further formation of austenite, but at the same time the formation of retained austenite after cooling decreases from 45 to 3% when heated to 750°C, 1 hour.

In this regard, the processes occurring during heating in the region of $\alpha$-$\gamma$ transformation can be divided into two temperature regions:

- Low-temperature region: up to $\sim$625°C $\alpha$-$\gamma$ transformation, where processes occur that stabilize the structure of austenite, which does not undergo a reverse $\gamma$-$\alpha$ transformation upon subsequent cooling.
- High-temperature region: $\sim$625..800°C, where processes of formation of austenite with an unstable structure occur, which undergoes a reverse transformation during the cooling process. At the same time, destabilization of the previously formed austenite occurs in the low-temperature region. The process of austenite destabilization intensifies with increasing heating temperature and at 800°C it ends completely.

Changes in the phase composition and structure of steel 03X11H10H2T-VD, depending on the heating temperature and subsequent cooling, affect the change in coercive force and angle $\phi_3$ of the third harmonic phase. Thus, with a change in the amount of retained austenite, a proportional change in the demagnetization current $I_p$ occurs, i.e. With an increase in the amount of retained austenite, the demagnetization current $I_p$ increases. This dependence can be used to assess the phase composition of steel using a non-destructive control method based on the coercive force $H_c$.

An increase in the amount of stable austenite formed with an increase in heating temperature in the low-temperature region and subsequent cooling leads to a decrease in the angle $\phi_3$ of the third harmonic phase, and with an increase in temperature in a narrow temperature range, a reverse increase in the angle $\phi_3$ occurs.

When a product is magnetized by an alternating field, nonlinearity appears in the change in the spectral composition of the response - the secondary EMF with the appearance of higher harmonic components in it. As is known [8], the nonlinearity characteristics of magnetic alloys, in particular, hysteresis loops, are closely related to the structure of the ferromagnet. The resulting change obviously characterizes a change in the steel structure itself and requires a more in-depth study.

The relative change in the phase composition during thermal cycling from heating temperatures in the high-temperature region of the $\alpha$-$\gamma$ transformation was carried out according to the regime: heating to a given temperature, holding for 1 hour and subsequent cooling in air.

The results of changes in the phase composition at room temperature during TCT from 650°C, 1 hour and 750°C, 1 hour showed that during TCT from a temperature of 750°C, 1 hour, the total amount of retained austenite increases from 4 to 21% and after 6 cycles no noticeable change is observed. Reducing the temperature to 650°C for 1 hour leads to an...
increase in the amount of retained austenite from 20 to 55%. At the same time, the proportion of the stable α-phase increases at a temperature of 650°C, 1 hour - from 10 to 30%.

A change in the phase composition of MS leads to a change in LEC in proportion to the content of retained austenite. Electron microscopic analysis showed that at TCT with 650°C, 1 hour after the first cycle, the separation of finely dispersed phases is observed with the identification of “plate-like” subgrains of α- and γ-phases unidirectional within the grain. Five-fold TCT increases the contrast of uneven etching of “plate-like” subgrains and increases the size of fine phases.

At TCT from 750°C, 1 h, the thickness of the “plates” of subgrains of α- and γ-phases increases and at the same time the contrast of the etchability of their boundaries decreases.

The patterns obtained for the formation of the phase composition of steel 03X11H10M2T-VD can obviously be explained as follows. The original martensite has a high dislocation density [9], which promotes diffusion processes during heating and facilitates the redistribution of alloying elements, i.e. redistribution of alloying elements between phases is possible [10-13]. Redistribution of alloying elements, high thermodynamic stimulus, thermal fluctuation, thermoelastic equilibrium in individual microvolumes, inhomogeneity of microstresses, stress “peaks” favorable to shear planes already at a temperature of ~ 535°C contribute to the formation of austenite, apparently by the martensitic mechanism (formation of “plate-like” subgrains).

4 Conclusion

An increase in temperature promotes the dissolution of intermetallic phases and the redistribution of Ni, Cr, Mo, Ti, changes the concentration heterogeneity and leads to further formation of centers and growth of austenite. An increase in temperature close to ~625°C leads to preparation for the α-γ transformation of a large volume of steel. The formation of stable austenite in the low-temperature region of the α-γ transformation can be explained primarily by phase hardening and redistribution of alloying elements that have a chemical reaction to austenite and the formation of a stable substructure.

In the high-temperature region, the leading role obviously belongs to diffusion processes, the rearrangement of dislocations, and the removal of phase hardening of austenite formed in the low-temperature region. This can be confirmed by the results of the study with TT and TCT.

Thus, the identified patterns in the formation of the phase composition in the TT and TCT processes with the temperature range of α-γ transformation make it possible to control changes in the phase composition and properties of steel and predict these changes.

References