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THE INFLUENCE OF RETAINED AUSTENITE ON PRECIPITATION HARDENING OF MARAGING STEEL

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The investigation of the influence of multiple solution-annealing on kinetics of structural transformation of maraging steels has shown that procedures of solution annealing are not totally reversible. Recurrent solution annealing results in the increase of the retained austenite share in maraging steel structure. In this paper the influence of retained austenite on precipitation hardening of maraging steels X2NiCoMo18-9-5 was determined. The laboratory experimental tests have shown that the growth of retained austenite share in the maraging steel structure decreases the hardness after aging.

Key words: *maraging steel, solution annealing, aging, retained austenite*

Utjecaj zaostalog austenita na precipitacijsko čvršćavanje maraging čelika. Istražujući utjecaj višestrukog rastvornog žarenja na kinetiku strukturnih pretvorbi maraging čelika uočeno je da postupci rastvornog žarenja nisu u potpunosti reverzibilni. Ponavljanje postupka rastvornog žarenja uzrokuje povećanje udjela zaostalog austenita u strukturi maraging čelika. U radu je istraživan utjecaj zaostalog austenita na precipitacijsko očvrsnuće maraging čelika X2NiCoMo18-9-5. Laboratorijska eksperimentalna ispitivanja su pokazala da prirast udjela zaostalog austenita u strukturi maraging čelika rezultira padom tvrdoće nakon starenja.

Ključne riječi: *maraging čelik, rastvorno žarenje, starenje, zaostali austenit*

INTRODUCTION

The increased demand for high tensile strength of materials used in mechanical engineering was the reason for the vigorous development of ultra strong steels resulting in production of maraging steel in the sixties of the XX century [1, 2].

Superior properties, such as: high ductility, high yield stress, good hardenability, good weldability, simple heat treatment without deformations, have led to a widespread application of maraging steels, not only in the manufacturing of diverse construction components, but also in the manufacturing of molds (i.e. for processing of polymers, for pressure casting, etc.).

Maraging steels are delivered in solution annealed and, for this reason, the low hardness and ductility make them suitable for work treatment. They steel are strengthened with a simple annealing procedure (ageing), which almost doubles their hardness and tensile strength compared to solution annealed state. Their heat treatment yields some advantages also that is; machining to final measure before aging, no danger of decarburizing ($C < 0,05$ %) and oxidation [1, 2].

The investigation of the kinetics of structural transformation of maraging steel during heat treatment has the purpose to determine the conditions for development of microstructures with good impact on properties. Current dilatometric studies of solution annealing have shown that the maraging of steel does not fulfill the rule of M_s interdependence on temperature and length of austenitizing as in the case of carbon and alloyed steels. Procedures of solution annealing of maraging steel are not totally reversible, i.e. they do not result in the same structural condition of material, but lead to visible phase changes that is the increase of the content of retained austenite [3].

The main intention of this paper was to investigate the influence of retained austenite on precipitation hardening of maraging the steel X2NiCoMo18-9-5.

EXPERIMENTAL WORK

The experiments were carried out on four samples ϕ 6 × 18 mm. The samples were multiple solution annealed and aged in Netzsch electronic dilatometer 402 EP (Table 1.). The use of dilatometer enabled to observe dilatometric

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changes by controlled annealing parameters (temperature and time).

Table 1. **Plan of experiments**
Tablica 1. **Plan pokusa**

Samples	Number of thermal cycles	
	Solution annealing ϑ_{SA} = 820 °C t_{SA} = 30 min	Aging ϑ_A = 500 °C t_A = 240 min
A	1	1
B	3	1
C	5	1
D	7	1

Experiments were planned and performed in two directions:

I. Solution annealing with determination of the temperatures of martensite-austenite transformation (A_s), of austenite-martensite transformation (M_s) and values of total dilatation $\Delta l_{R\check{Z}}$ from dilatogram, and calculation of the average coefficients of dilatation ($\bar{\alpha}$) for the range of heating (ϑ_1 = 20 °C … ϑ_2 = 525 °C) and quenching (ϑ_3 = 700 °C … ϑ_4 = 300 °C). The content of retained austenite based on average dilatation coefficients was also calculated. After heat treatment the samples were tested for Vickers hardness *HV*1.

II. Heat treatment experiment of aging after multiple solution annealing.
After ageing the Vickers hardness *HV*1 was measured.

Multiple solution annealing

In Figure 1. the aggregate of dilatograms of multiple solution annealing with the points of structural transformations (A_s and M_s), measured values of contractions ($\Delta l_{R\check{Z}}$) for each sample and the calculated average coefficients of dilatation during heating (between ϑ_1 = 20 °C and ϑ_2 = 525 °C) and contraction during quenching (between ϑ_3 = 300 °C and ϑ_4 = 700 °C) are shown.

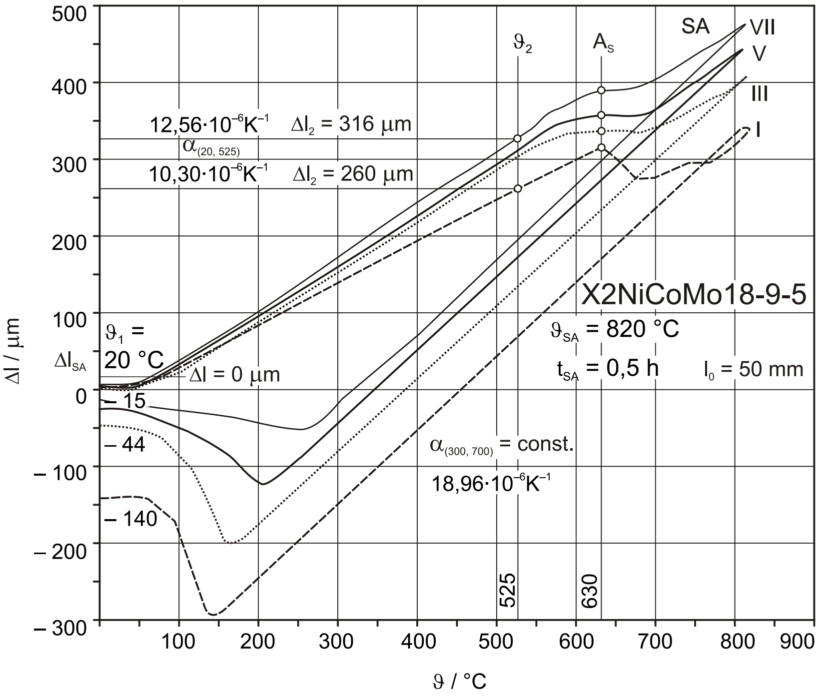

Figure 1. **Aggregate of dilatograms of multiple solution annealings**
Slika 1. **Skupni dijagram dilatograma višestrukih rastvornih žarenja**

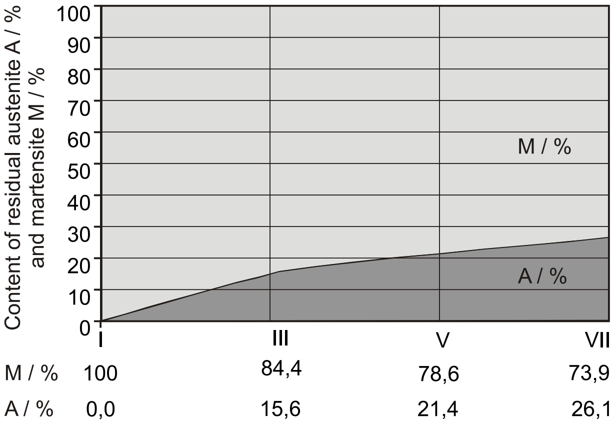

Figure 2. **Content of retained austenite after every multiple solution annealing**
Slika 2. **Udio zaostalog austenita nakon svakog višestrukog žarenja**

The growth of the average dilatation coefficient (during heating) with every repeated solution annealing indicates the increment of the content of retained austenite. Based on the calculated dilatation coefficients at heating and quenching a mathematical relation for the determination of increment of retained austenite content after every repeated solution annealings was established [3, 4].

$$\%A = \frac{\bar{\alpha}_Z - \bar{\alpha}_M}{\bar{\alpha}_A - \bar{\alpha}_M}\cdot 100 = \frac{\bar{\alpha}_Z - 10{,}30\cdot 10^{-6}}{8{,}66\cdot 10^{-6}}\cdot 100 \ / \ \%, \tag{1}$$

where:

$\%A$ - content of residual austenite / %,
$\bar{\alpha}_M$ - average dilatation coefficient of martensite (sample A) / K^{-1} (10,30 × 10^{-6} K^{-1}),
$\bar{\alpha}_A$ - average dilatation coefficient of austenite (sample A) / K^{-1} (18,96 × 10^{-6} K^{-1}),
$\bar{\alpha}_Z$ - average dilatation coefficient during heating (samples B, C and D) (20 °C to 525 °C) / K^{-1}.

Figure 2. shows the increment of retained austenite content after every repeated solution annealing.

Before and after the multiple solution annealing each sample was tested for the hardness value Vickers *HV*1 with load of 9,81 N, and the average value was determined from five measurements (Table 2.).

Table 2. **Hardness HV1 before and after the multiple solution annealing**

Tablica 2. **Vrijednosti izmjerenih tvrdoća HV1 prije i nakon višestrukih rastvornih žarenja**

Samples	Untreated $HV1_{av}$	Solution annealing $HV1_{av}$
A	322	322
B	322	322
C	322	320
D	322	320

Aging of multiple solution annealed maraging steel

The heat treatment of aging (ϑ_a = 500 °C, t_a = 240 min) has been carried out on each sample after multiple solution annealings. After aging of maraging steel X2NiCoMo18-9-5 each sample was tested for hardness value by Vickers *HV*1 method (Table 3.).

Table 3. **Measured hardness values HV1 after aging**

Tablica 3. **Vrijednosti izmjerenih tvrdoća HV1 nakon starenja**

Samples	HV1	$HV1_{av}$
A	581, 571, 581, 581, 581	579
B	551, 542, 551, 551, 551	549
C	507, 507, 505, 507, 508	507
D	490, 490, 490, 482, 490	488

Figure 3. shows changes in hardness values after solution annealing and after aging in dependence of the content of retained austenite.

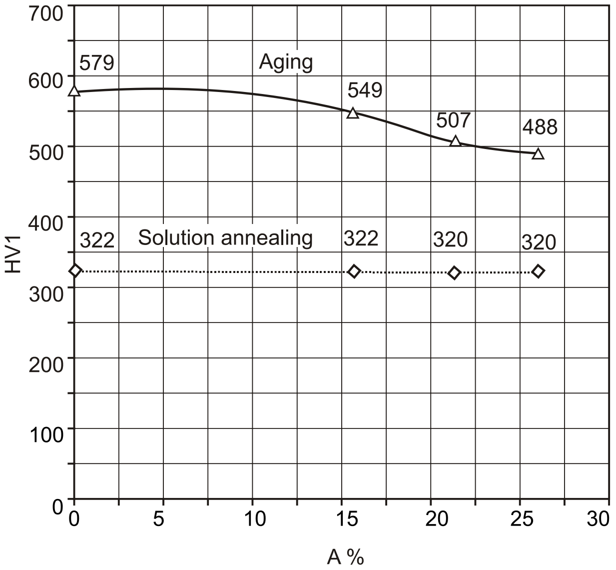

Figure 3. **The influence of retained austenite content on hardness after solution annealing and after aging for the steel X2NiCoMo18-9-5**

Slika 3. **Utjecaj zaostalog austenita na tvrdoću nakon rastvornog žarenja i nakon starenja čelika X2NiCoMo18-9-5**

CONCLUSION

In the investigation of the influence of retained austenite on precipitation hardening of the maraging steel X2NiCoMo18-9-5 the following was observed:

- after every repeated solution annealing results the content of retained austenite was increased;
- the retained austenite has no influence on hardness in solution annealed state. The explanation could be a high hardness of austenite in the high alloyed steel;
- the increase of retained austenite content results in decrease of hardness value after aging.

Based on knowledge of the mechanism of maraging steel precipitation hardening (increase of hardness value after aging is result of precipitation very hard intermetalic compounds from martensite matrix) and considering the above mentioned, it can be concluded that the retained austenite retards the precipitation process or that there is no precipitation of intermetalic compounds from retained austenite.

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List of symbols and abbreviation

ϑ_{SA} - solution annealing temperature / °C
ϑ_A - aging temperature / °C
t_{SA} - solution annealing time / min
t_A - aging time / min
A_s - temperature of martensite-austenite transformation / °C
M_s - temperature of austenite-martensite transformation / °C
*HV*1 - hardness value by Vickers method with load of 9,81 N
$\Delta l_{RŽ}$ - contraction after solution annealing / μm
$\bar{\alpha}$ - average coefficients of dilatation / K^{-1}
$\bar{\alpha}_M$ - average dilatation coefficient of martensite / K^{-1}
$\bar{\alpha}_A$ - average dilatation coefficient of austenite / K^{-1}
$\bar{\alpha}_Z$ - average dilatation coefficient during heating / K^{-1}
%A - content of residual austenite / %
%M - content of martensite / %
l_0 - original sample length / mm