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INTENSIFICATION OF THE TRANSITION OF RETAINED AUSTENITE TO MARTENSITE EFFECTED BY CHANGING THE STRESS STATE IN TRIP STEEL WIRES

INTENSYFIKACJA PRZEMIANY AUSTENITU SZCZĄTKOWEGO W MARTENZYT POD WPŁYWEM ZMIANY STANU NAPRĘŻENIA W DRUTACH ZE STALI TYPU TRIP

Change in the stress state is one of the factors that determined the transition of retained austenite to martensite. It has been proved that in products made from wires of a TRIP structure, which is characterized by a high retained austenite content, loading them with varying in sign cyclic stresses of magnitudes lower than yield strength ($R_{0.2}$) results in intensive transition of the retained austenite to martensite. The paper presents a comparative analysis of investigation results concerning the determination of the quantity of retained austenite in the structure of wire for two TRIP steel grades with varying carbon content after they have been loaded with varying in sing cyclic stresses of a magnitude smaller than $R_{0.2}$ under rotating bending conditions. The investigation carried out has determined whether and, if so, to what extent the loading of wire with cyclic external stresses of magnitudes lower than $R_{0.2}$ may influence the quantity of transformed retained austenite and thus the mechanical properties of the products.

Keywords: TRIP steel, wire drawing, retained austenite

Zmiana stanu naprężenia jest jednym z czynników determinujących przemianę austenitu szczątkowego w martenzyt. Udowodniono, że w wyrobach z drutów o strukturze typu TRIP charakteryzującej się dużą zawartością austenitu szczątkowego, w wyniku obciążenia ich cyklicznymi, zmiennymi co do znaku naprężeniami o wartościach niższych od granicy plastyczności ($R_{0.2}$), obserwujemy intensywną przemianę austenitu szczątkowego w martenzyt. W pracy przedstawiono analizę porównawczą wyników badań dotyczących określenia ilości przemienionego austenitu szczątkowego w strukturze drutów, dla dwóch gatunków stali typu TRIP o różnej zawartości węgla, po obciążeniu ich cyklicznym zmiennym co do znaku naprężeniem o wartości mniejszej niż $R_{0.2}$ w warunkach zginania obrotowego. Przeprowadzone badania pozwoliły na stwierdzenie, czy i w jakim stopniu obciążenie drutów cyklicznymi naprężeniami zewnętrznymi o wartościach mniejszych od $R_{0.2}$ może wpływać na ilość przemienionego austenitu szczątkowego i tym samym na własności mechaniczne wyrobów.

1. Introduction

A factor determining the favourable properties of TRIP steel is the retained austenite contained in its structure, which undergoes transition to martensite, this phenomenon being referred to as the TRIP (Transformation Induced Plasticity) effect [1, 2].

The stability of retained austenite in TRIP steels depends on many factors, which include the carbon content, the austenite grain size, temperature, as well as the stress state. The specificity of retained austenite transition to martensite is dependent on three temperatures that are characteristic of TRIP steels. Below the temperature Ms, the martensite transition occurs in a spontaneous manner (a factor inducing the phase transition is exclusively the temperature drop). In the temperature range of M_s - M_s^σ, the martensite transition is caused by the stress increase, while between the temperatures M_s^σ and M_d, the phase transition of retained austenite to martensite is induced by plastic deformation. Predominant deformation mechanisms for different temperature ranges are represented schematically in Fig. 1.
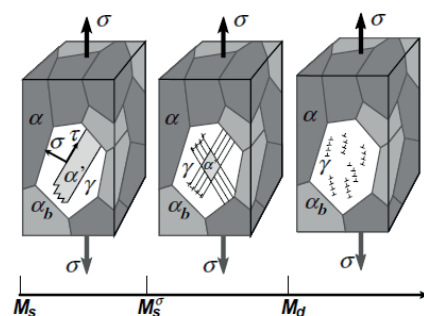

Fig. 1. Schematic of martensite transformation induced by stress, strain and temperature [3]

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The thermomechanical driving force for martensite transformation is the change in the free energy of the system, Fig. 2. At the temperature of equilibrium between the two phases, (T_0), the value of free energy change is $\Delta G^{P \to M}=0$. The formation of martensite nuclei requires a considerable amount of energy to overcome the elastic resistance of the parent phase, which must be supplied by the free energy associated with the volumetric change. For this reason, the martensite transition starting temperature, M_s, is lower than the temperature T_0. Part of the energy can be supplied by externally applied stresses, as a result of which the transition temperature shifts towards T_0 and then the transition of the retained austenite to martensite follows.
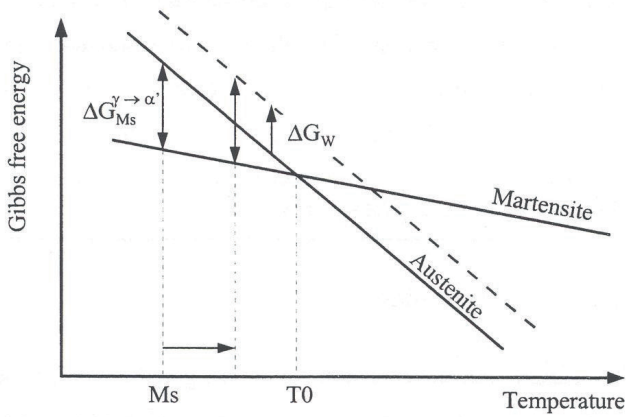

Fig. 2. Change of the free energy of austenite and martensite as a function of temperature [4]

The paper discusses investigations undertaken to determine of the quantity of retained austenite in the structure of TRIP steel wires after they have been loaded with varying in sing cyclic stresses of a magnitude smaller than $R_{0.2}$ under rotating bending conditions. A comparative analysis was made in the study for wires of TRIP steel with varying retained austenite content after two-stage heat treatment carried out with the aim of obtaining a TRIP structure.

2. Experimental

Material used for investigation

Tests were carried out for steel with chemical composition as shown in Table 1.

TABLE 1

Chemical composition of the investigated steel, weight %

C	Mn	Si	Ni	Cr	Al
0.431	1.470	1.363	0.129	0.100	0.050

For the tests, 2.60 mm-diameter wire was used, which had been subjected to heat treatment in order to obtain a maximum amount (approx. 28% volume fraction) of retained austenite in the structure, according to the parameters described in study [5]. The structure of the wire after the heat treatment is shown in Fig. 3.

Fig. 3. Structure of wire of steel with a carbon content of 0.43% after two-stage heat treatment

Then, the mechanical properties of the wires were determined on a ZWICK/Z100 testing machine to determine the bending stress value (Table 2).

TABLE 2

Mechanical test results for 2.60 mm-diameter wires after two-stage heat treatment

Tensile strength	Yield strength	Elongation	Reduction of area at fracture
(R_m)	($R_{0.2}$)	(A)	(Z)
MPa	MPa	%	%
1220	500	45.3%	44%

In order to prove the effect of the stress state change on the quantity of transformed retained austenite in TRIP steels, a comparative analysis of the results obtained from the tests on the 0.43% carbon content steel with the results for 0.29% carbon content steel, taken from study [6], was made.

3. Research

The tests were performed on a testing machine built in the Institute for the Modelling and Automation of Plastic Working Processes at the Czestochowa University of Technology, following the design of the PUL DRABI SCHENCK fatigue testing machine [6]. Schematic construction of the machine is shown in Fig. 4.
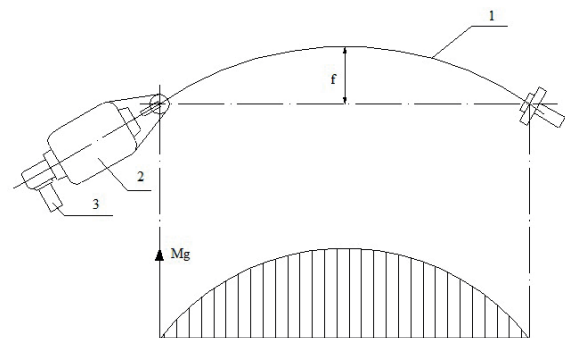

Fig. 4. Schematic construction of the fatigue testing machine: Mg – distribution of bending moments, 1 – wire, 2 – engine, 3 – counter, f – deflection.

The tests were conducted under rotary bending conditions, since the testing machine enables an oscillatory, symmetrical fatigue cycle to be obtained (Fig. 5). The variable-sign maximum bending stress in the outer wire layers was calculated from equation (1), while substituting in the formula actual Young's modulus value as determined from a tensile test performed on the testing machine.
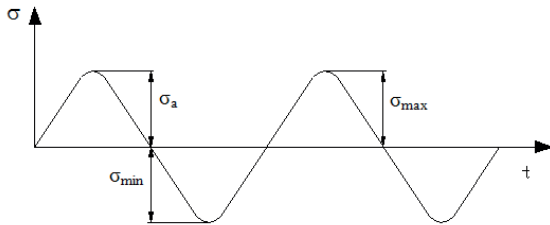

Fig. 5. Variation of stress in the wire surface layer during rotary bending

$$\sigma_{max} = \pm \frac{6 \cdot f \cdot d \cdot E}{l^2} \qquad (1)$$

where:
f – deflection [mm],
d – wire diameter [mm],
E – Young's modulus [N/mm²],
l – test piece length [mm].

During the test, the wire did not undergo deformation; only the state of stress in the material changed. To eliminate the influence of temperature on the transformation of retained austenite into martensite, the wire was water-jet cooled throughout the testing cycle.

After substituting the value of maximum bending stress σ_{max}, assumed to be the 2/3 $R_{0.2}$ of the material tested, in equation (1), the value of the deflection (f) was established. For thus established deflection value, a test was conducted for four fatigue cycle levels: 10000, 20000, 30000 and 40000.

After attaining the specified number of cycles, the test was discontinued, a sample was taken from the largest deflection location, and a section was prepared. Then the percentage retained austenite fraction of the structure was determined. The results are summarized in Table 3 and shown in Figure 6.

TABLE 3

Volumetric fraction of retained austenite of the structure of wires subjected to variable bending stresses with a varying number of fatigue cycles

Number of fatigue cycles	Quantity of retained austenite, %	
	0.293% C [6]	0.431% C
0	21	28
10 000	12.95	12.4
20 000	11.47	10.2
30 000	9.82	9.3
40 000	9.47	8.6

Fig. 6. Variation in the volumetric retained austenite fraction of the structure of wires subjected to variable bending stresses with a varying number of fatigue cycles

4. Summary

Change in the stress state causes intensive transition of retained austenite to martensite in the range of fatigue cycles from 0 to 10 000, for both steel grades.

Increasing the number of cycles by another 10 000 changed the retained austenite quantity by approx. 1.5% for both steel grades.

This relationship held until the end of the testing cycle. The next increase in the number of fatigue cycles resulted in a small decrease of the retained austenite quantity in the tested wire structure.

It can be presumed that the increase in the number of fatigue cycles does not effect of increasing the thermodynamic driving force for the martensite transformation.

The results of the investigation described herein indicate that in wire products with a TRIP structure and a high retained austenite content, transition of retained austenite to martensite takes place as a result of loading them with external stress of magnitudes smaller than $R_{0.2}$.

The transition of retained austenite to martensite enhances the mechanical properties of the material, therefore the use of such types of steel for the production of fasteners may have an effect on their properties during service.

The investigation results have a practical dimension, because e.g. a screw made of TRIP steel, exposed to variable stresses in service, may undergo additional strain hardening to a varying extent, which will affect its mechanical properties, service life and operation safety.

The knowledge acquired from the investigations will constitute a novelty in this aspect of applications and will be useful from the point of view of both the manufacturer and the user.

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