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THE ANALYSIS OF “HOT” DRAWING PROCESS OF TRIP STEEL WIRES AT DIFFERENT INITIAL TEMPERATURES

In the work the results of preliminary research of the „hot” drawing process of TRIP steel wires at different initial temperatures has been shown.

The study is expected to find whether the „hot” drawing process, and so the increase in the temperature of the material being drawn, will block the transformation of retained austenite into martensite and, as a consequence, influence the properties of drawn wire.

Keywords: TRIP steel, “hot” drawing process, wires

1. Introduction

Multiphase TRIP steels contain a soft ferritic matrix with bainitic-austenitic islets in their structure [1]. The increase in the mechanical properties of TRIP steel is caused by an increase in dislocation density in the ferritic matrix, which results from the formation of a hard martensitic phase that is responsible for the degree of strain hardening and directly influences the strength and ductility of the material [2].

Each of the structural components of multiphase TRIP steels plays an important role and influences the whole set of material properties; however, the key element of this phase mixture, which determines the degree of the martensite transformation, is the retained austenite.

The occurrence of the TRIP effect in steel is significantly influenced by the quantity and stability of retained austenite. If the stability of the phase component is too low, its transformation will occur very early, even at very small deformations, during the forming process. At too high retained austenite stability, on the other hand, no transformation of the retained austenite will take place during deformation. Therefore, an optimal degree of the stability of this phase component is required in order to obtain a wide range of the plastic deformability of the material.

During the process of cold drawing of TRIP steel wire, as a result of deformation, the transformation of retained austenite into martensite occurs until the exhaustion of the latter at large deformation degrees. In this connection, as a result of the cold drawing process, at its final stages, the TRIP effect is leveled due to depletion of the retained austenite in the structure, which transforms into martensite, thus causing additional considerable strain hardening of the material [3÷7]

As suggested by the literature [8÷11], the increase in material temperature above the temperature Md may result in the inhibition of retained austenite transition to martensite. Accordingly, it has been assumed that the application of the warm drawing process and, consequently, the increase in worked material temperature, will result in such a phenomenon, which should cause the material strain hardening process to be more intensive in terms of these factors: material deformation at elevated temperature; the presence of a greater amount of retained austenite in the structure, compared to the drawing process at the same drawing intensity but at ambient temperature, so a smaller amount of martensite causing the structure hardening.

Thus performed drawing process should allow final wire to be obtained, which, despite the considerable strain hardening, will have a significant quantity of retained austenite in its structure, which will enable the TRIP effect to be utilized in the finished product.

At the same time, this would make it possible to obtain thin wires with the TRIP effect directly from the wire rod, without having to use an additional heat treatment process to recover the TRIP structure.

2. Original investigation

Tests were carried out for φ2.58 mm-diameter wire from a steel of chemical composition, as shown in Table 1. The wire had been subjected to heat treatment in order to obtain a maximum amount (approx. 23%) of retained austenite in the structure, according to the parameters determined in previous tests [12].

TABLE 1

The chemical composition of medium carbon steel, wt.-%

C	Mn	Si	Ni	Cr	Al	S
0.293	1.430	1.320	0.122	0.100	0.045	0.011

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In order to carry out the research task, a warm drawing test stand was set up using the equipment and apparatus existing in the Institute of Metal Forming and Safety Engineering, Czestochowa University of Technology.

The drawing process was conducted using conventional drawing dies with an angle of 2α=12º on a ZWICK/Z100 testing machine at a drawing speed of v1=0.05 m/s. The wire was resistance heated using a stabilized DC power supply (Fig. 1). The temperature measurement was realized with use of thermocouple type K.

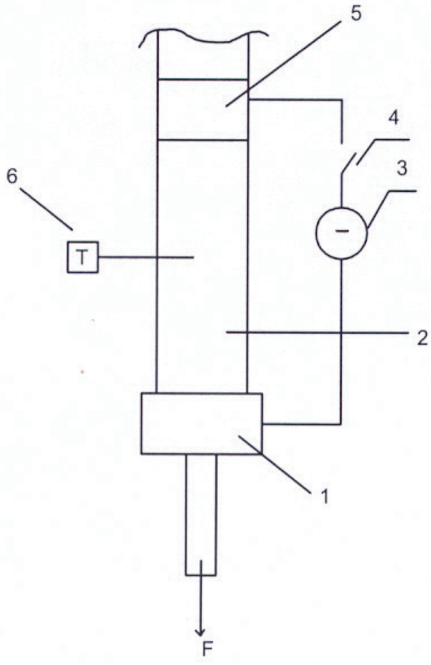

Fig. 1. A schematic diagram of the wire heating stand: 1- drawing die, 2- wire, 3- DC power supply, 4 – switch, 5 - electrode, 6- thermocouple

The application of a high heating temperature of up to 450°C considerably limited the use of carrier coatings resistant to such conditions. As normally used phosphate coatings are resistant to a temperature of up to 200°C, above which their partial decomposition follows. Therefore, a layer of electrolytic copper was applied, because its use is especially advantageous in the case of resistance heating owing to the good electrical conductivity of copper.

As the drawing lubricant, a special compound made up of a so-called carrier and a high-temperature resistant lubricating substance was used. As the lubricating agent, tungsten disulphide (WS_2) was used, as it does not get oxidized until a temperature of 600°C.

Wire, which had been previously treated to obtain a TRIP structure with a high retained austenite content (approx. 23%), was subjected to the process of drawing from the initial diameter equal to 2.56 mm to a final diameter of φ2.23 mm with a unit reduction of 24.71%. The wire was drawn at a temperature of, respectively: 20, 100, 200, 300, 400 and 450°C.

The amount of retained austenite in wires structure was determined based on structural analysis including the quantitative analysis of retained austenite in the structure of the heat treated steel using light microscopy. An Axiovert 25 optical microscope was used for the examinations.

The quantitative analysis were performed using three examination methods: the method employing the Met-Ilo software application, the point-by-point method, the secant method and the averaging of the examination results. The volume fraction of retained austenite for wires drawn at different temperatures is in table 2.

Figure 2 shows the variation in the volumetric retained austenite fraction of the structure of wires after "hot" drawing process at different temperatures. The examples of microstructures of drawn wires are shown on Fig.3.

TABLE 2
The volume fraction of retained austenite for wires drawn at different temperatures

Temperature, ºC	Volume fraction of retained austenite, %
20	6.7
100	7.9
200	8.6
300	10.
400	11.8
450	12.0

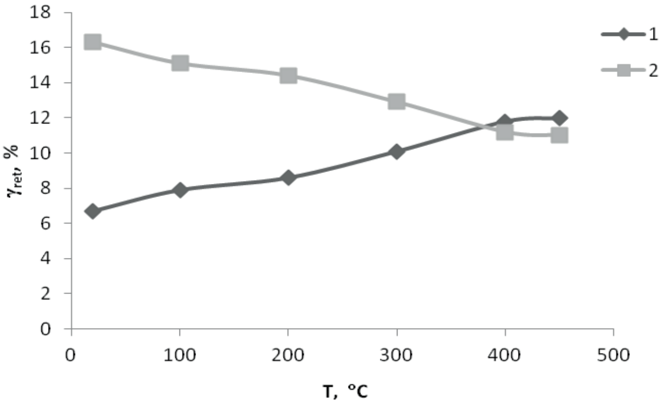

Fig. 2. The variation in the volumetric retained austenite fraction of the structure of wires drawn at different temperatures; 1 - the amount of remaining retained austenite in the structure of drawn wires; 2 – the amount of transformed retained austenite in the structure of drawn wires

As a result of the investigation carried out, a curve describing the retained austenite content of the drawn wire structure as a function of the applied drawing process temperature was obtained.

The investigation found that the increase in drawing temperature up to a level of 450°C caused the blocking of retained austenite transition into martensite. In wires drawn with the same degree of deformation at room temperature, the retained austenite content is about 30%, compared to the initial content of 23%, whereas wires drawn at a temperature of 450°C contain approx. 12% retained austenite in the their structure, that is about 50% of the initial value.

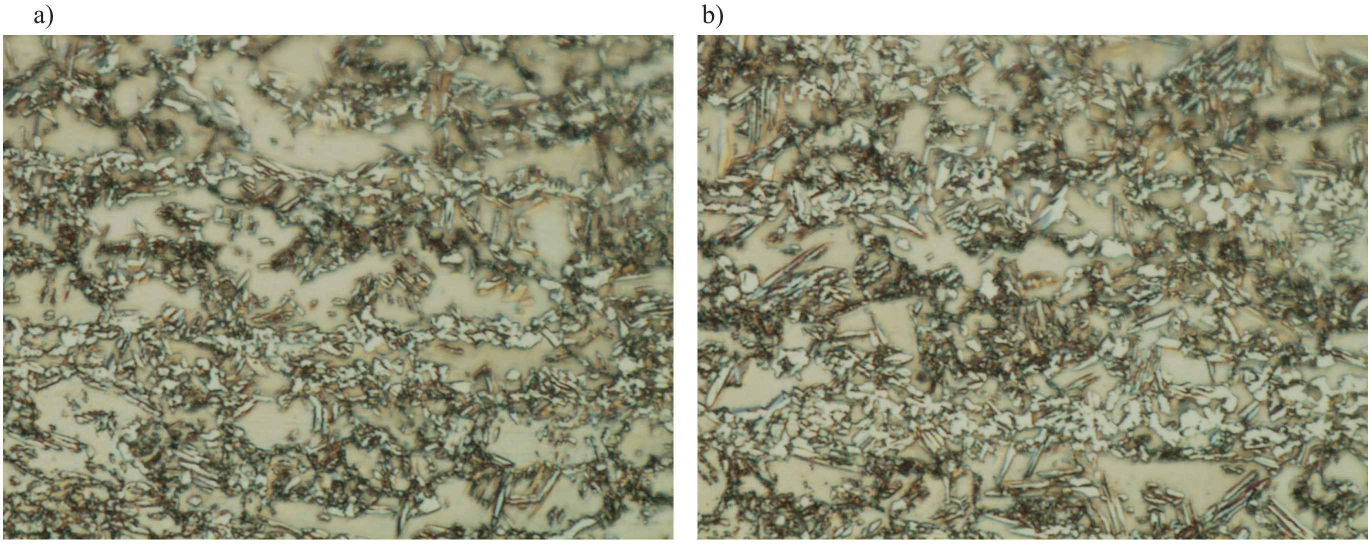

Fig. 3. Microstructure of wires after “hot” drawing process at temperatures: a). 400ºC ; b). 450ºC.; (magn. 1000 x)

The subsequent investigation stage involved the assessment of the mechanical properties of wires drawn at different temperatures (table 2). Figure 4 illustrates the variation in ultimate tensile strength (Rm), the yield strength (R0,2) for wires drawn with the identical partial reduction at different temperatures.

TABLE 3

The mechanical properties of drawn wires at different temperatures

Temperature, ºC	Rm, MPa	R0,2, MPa	R0,2/Rm
20	1159	1064	0.91
100	1061	1029	0.96
200	1058	977	0.92
300	1047	888	0.84
400	1056	790	0.71
450	1052	748	0.71

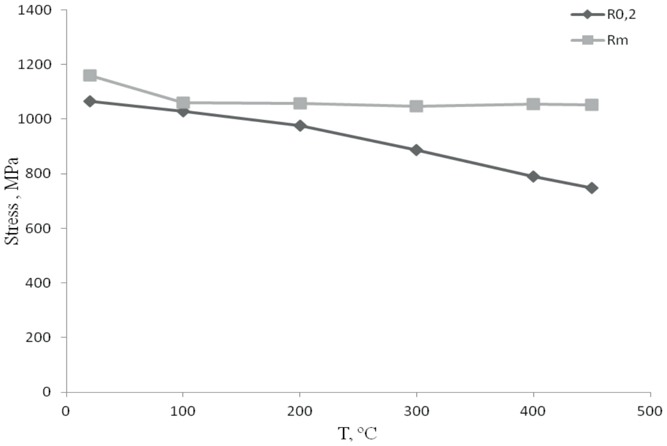

Fig. 4. The variation in ultimate tensile strength and in offset yield strength for wires drawn with the identical partial reduction at different temperatures

The analysis of the results has found that with the increase in temperature we do not observe any increase in tensile strength level, but in contrast, a significant decrease in offset yield strength is noticeable. The value of offset yield strength for wire drawn at a temperature of 20°C was higher by about 30% compared to wires drawn at temperatures of about 450ºC.

As a result of warm drawing tests carried out, the temperature at which the inhibition of retained austenite transition is observed has been determined to be 450ºC. However, this process does not occur completely, since a change in the quantity of retained austenite can be noticed as the deformation progresses, but the intensity of the transition decreases.

In order to establish the susceptibility of the drawn wires to plastic deformations, the R0.2/Rm ratio, which defines the so called “plasticity reserve” of material being deformed, was analyzed (Fig.5).

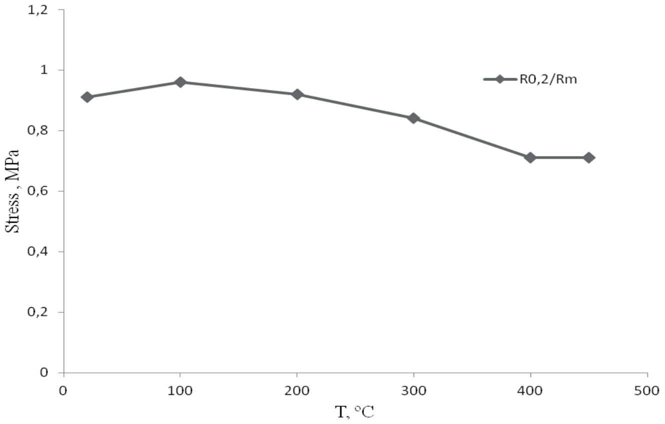

Fig.5. Variation in the $R_{0.2}/R_m$ ratio for TRIP steel wires drawn wires drawn with the identical partial reduction at different temperatures

The TRIP-structure wire warm drawing tests presented above were limited in that testing phase to the maximum wire drawing pre-heating temperature of 450ºC. This was to make sure that the AC1 temperature was not exceeded in the material being deformed, as the temperature increase due to friction and plastic deformation during the drawing process for the steel grade under consideration may be as high as 250ºC.

3. Summary

From the results of the investigation carried out, the following conclusions can be drawn:

1. Drawing of TRIP-structure wire at elevated temperatures (of up to 450ºC) allows a higher retained austenite content of their structure (up to 80%) to be preserved, compared to wire drawn at ambient temperature.
2. The quantity of preserved retained austenite is proportional to its preheating temperature.
3. The mechanical properties of TRIP wires drawn at elevated temperatures depend both on the drawing temperature and on the quantity of retained austenite preserved in those wires. While the change in Rm as a function of temperature is insignificant (a slight decrease in the range of 20÷100ºC), in the range of 20÷450ºC, a considerable $R_{0.2}$ decrease of more than 30% takes place.
4. The drawn wire "plasticity reserve", as defined by the $R_{0,2}/R_m$ ratio, which grows with temperature, indicates:
   - the possibility of obtaining thin wires with a certain quantity of retained austenite, that is with an "unexhausted" TRIP effect, upon warm drawing;
   - the possibility of further plastic working of this type of wires at higher deformation intensity, compared to cold drawn wires.
5. The presented investigation have demonstrated the ability to "control" the mechanical properties of final wires (drawn with the identical total reduction) by the appropriate selection of drawing temperature, which means the possibility of producing finished wires intended for various products and applications.

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