The Experimental and Numerical Analysis of Trip Steel Wire Drawing Processes Drawn with Different Partial Reductions

Sylwia Wiewiorowska, Zbigniew Muskalski

***Abstract*—**The strain intensity and redundant strains, dependent in multistage TRIP wire drawing processes from values used single partial reductions, should influence on the intensity of transformation the retained austenite into martensite and thereby on mechanical properties of drawn wires. The numerical analysis of drawing processes with use of Drawing 2D programme, for steel wires made from TRIP steel with 0,29% has been shown in the work. The change of strain intensity ε_c and the values of redundant strain ε_{xy}, has been determined for particular draws in dependence of used single partial reductions.

***Keywords*—**Steel wire, TRIP steel, drawing processes, fem modelling.

I. Introduction

TRIP or TWIP steel are an example of multiphase steel with TRIP effect contains in their structure retained austenite which during plastic deformation is transformed into martnesite and influences on mechanical properties of deformed material. The transformation of retained austenite into martensite (effect TRIP) to large degree depends from strain intensity and stress state [1]-[6].

Large inhomogeneity of deformation during drawing processes is caused by shape of die deformation zone and by friction between material and tool. Occurred after process the redundant strain, dependent from the values of use partial single reduction, can influences on transformation retained austenite into martnesite and thus on mechanical properties of drawn wires [7], [8].

The numerical analysis the change of strain intensity and redundant strain carried out with the use of computer program Drawing 2D, should allow to determine the effect of multistage drawing process parameters on TRIP effect and on mechanical properties of drawn wires. With a constant value of the total strain, the properties of drawn wire can be influenced by the shape of the die approach portion, amongst other factors. Using convex and concave dies, as compared to standard conical dies, is expected to contribute to enhancing the uniformity of strain, and thus the magnitude of redundant strain, which should be reflected in the quantity of retained austenite transformed into martensite and the mechanical properties of the drawn wire. The results presented herein should provide a basis for predicting both the structure and properties of TRIP steel wires drawn in shaped dies.

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II. Results

Tests were carried out for wires made from carbon steel with 0,29% of carbon content and increased levels of silicon and manganese, which influence on retained austenite stabilization obtained after two-stage heat treatment process (Table I).

TABLE I
CHEMICAL COMPOSITION OF THE STEEL TESTED /WT %

C	Si	Mn	Al	Ni	Cr
0.29	1.32	1.43	0.04	0.12	0.10

Volumetric phase fraction of the structure for wire rod after rolling process and after two-stage heat treatment process according optimal variant ensuring TRIP effect was shown in Table II and Figs. 1, 2.

TABLE II
VOLUMETRIC PHASE FRACTION OF THE STRUCTURE OF THE STEEL TASTER

Material state	Volumetric phase fraction /%			
	Ferrite /%	Pearlite /%	Bainie+ Marten. /%	Retained austenite /%
After rolling process	77,4	22,6	-	-
After heat treatment	62,4	-	13,65	23,95

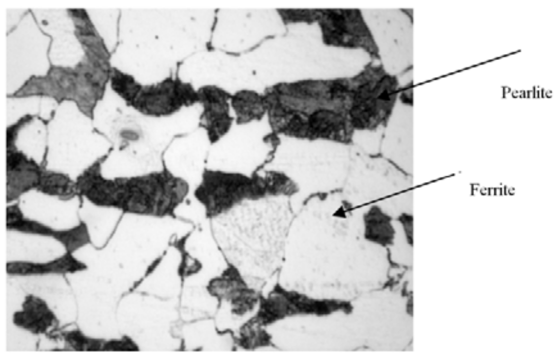

Fig. 1 The steel structure after rolling process, magn 1500 x

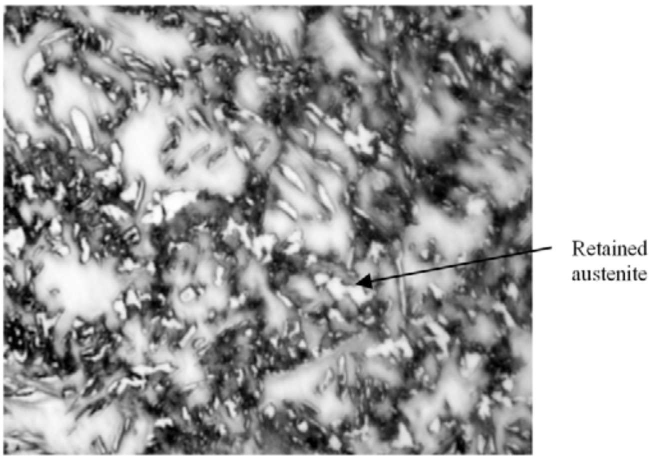

Fig. 2 The steel structure after two-stage heat treatment process, magn 1500 x

A. Modelling of Wire Drawing Process

The rheology of investigated steel has been implemented into computer program Drawing 2D and used for simulation of multistage wire drawing processes [9].

The simulation of wire drawing has been carried out for initial diameter 6,25 mm to final diameter 2,60 mm with use of two variants of drawing process: with small single reductions (about 10 – 15 %) in 6 draws and with large single reductions (about 23 – 28 %) in 12 draws.

The strain intensity and maximal redundant strain for surface layer have been determined by reading values of particular parameters from nodes of finite elements mesh, for all draws and for two variants of drawing process (Fig. 3).

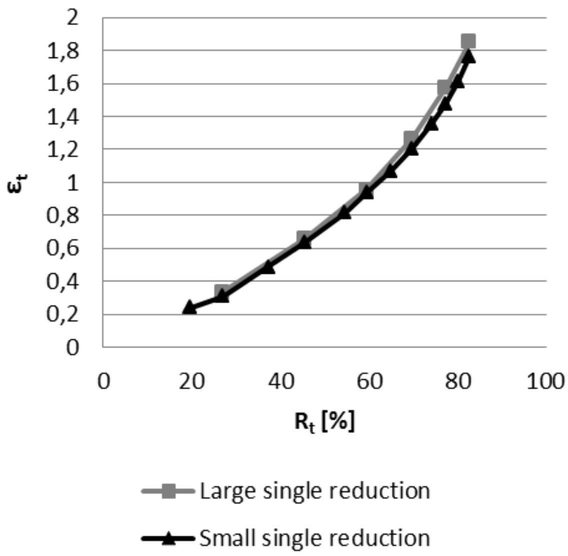

Fig. 3 Variation in strain intensity ε_t steel wires drawn with small and large partial reductions as a function of the total reduction in area (R_t)

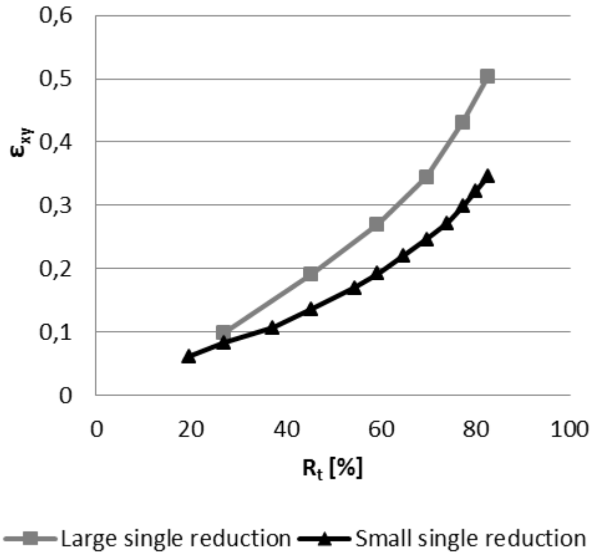

Fig. 4 Variation in redundant strain ε_{xy} steel wires drawn with small and large partial reductions as a function of the total reduction in area (R_t)

After analysis of obtained results on Figs. 3, 4 can be stated that:

- Strain intensity ε_t for surface layer of drawn wires depends from partial single reductions. The final wires with diameter mm drawn with large single reductions have the higher value of ε_t caused by the higher redundant strain ε_{xy}.
- We can by the selection drawing process parameters influence on strain intensity, at the same time, the amount of the martensite that has formed upon the retained austenite transformation significantly influences the strain hardening of the material, and consequently the mechanical properties of the wires.

B. The Analysis Influence of Drawing Process Parameters on Transformation Retained Austenite into Martensite

The retained austenite volumetric fraction of wires drawn with small and large partial reductions is shown in Table III.

TABLE III
THE RETAINED AUSTENITE VOLUMETRIC FRACTION OF WIRES DRAWN WITH SMALL (VARIANT 1) AND LARGE (VARIANT 2) PARTIAL REDUCTIONS ON THE SURFACE ($V_{\Gamma S}$) AND IN THE AXIS ($V_{\Gamma A}$) OF THE WIRES AS A FUNCTION OF TOTAL REDUCTION R_T

R_t/%	0	18.41	29.65	40.06	48.25
$v_{\gamma s}$	23.95	10.31	7.50	6.15	5.31
	23.95	-	6.65	-	4.94
$v_{\gamma a}$	23.95	12.82	10.12	8.14	5.54
	23.95	-	9.14	-	5.06

After analysis of obtained results, it can be stated that for surface layer the transformation of reatained austenite into martnesite proceeds faster. The differences for each variants are in the range 1,4÷2,5%. Such situation is caused by redundant strain which has maximal values for surface layer. On the change of retained austenite volumetric fraction in wires structure influences used in the process value of partial reduction.

C. The Investigation of Mechanical Properties

The results of research are shown in Figs. 5-6.

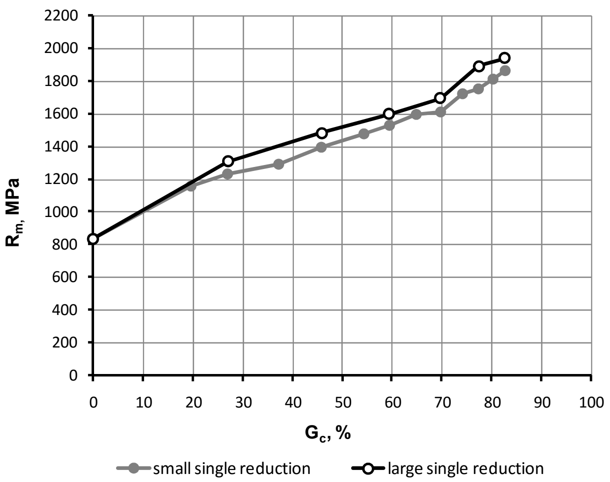

Fig. 5 Variation in the tensile strength R_m of TRIP steel wires drawn with small and large partial reductions as a function of the total reduction in area

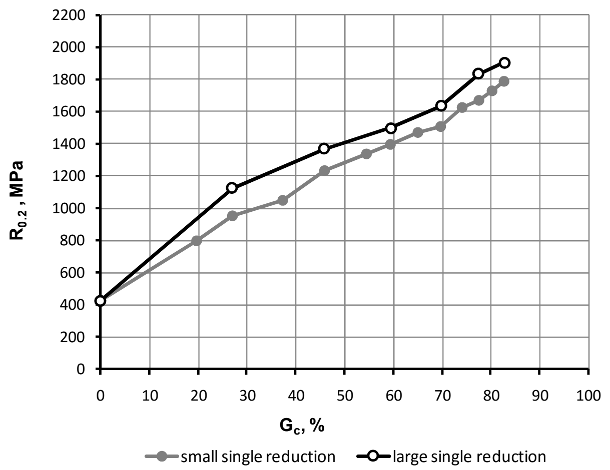

Fig. 6 Variation in the yield strength $R_{0,2}$ of TRIP steel wires drawn with small and large partial reductions as a function of the total reduction in area

We can observe the increase of Rm value after each deformation degree at about 6 % and higher at about 5÷15% values of the yield strength R0,2.

D. Examination of the Effect of the Die Approach Portion Shape on the Quantity of Retained Austenite after the Drawing Process

TRIP-structure wire rod was subjected to drawing process conducted in two draws from the diameter 5.34 mm to the diameter 4.40 mm, according to 3 variants. In Variant 1, conventional conical drawing dies with an angle of α=6º; in Variant 2, convex dies; while in Variant 3, concave dies, were used.

The effect of the shape of the die approach portion on the amount of retained austenite transformed into martensite in the drawing process was determined on material structure photographs taken on an optical microscope using three quantitative methods. The results are shown in Figs. 7, 8.

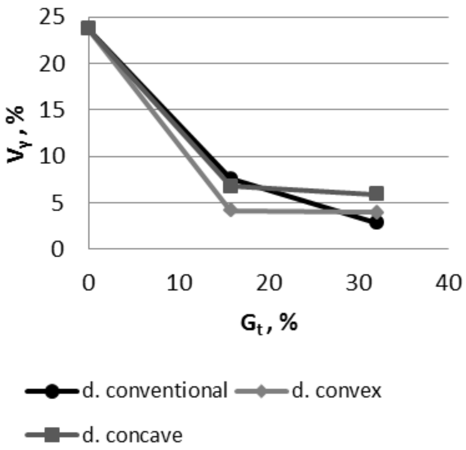

Fig. 7 The amount of retained austenite (vγ,%) on the surface of wire rod and wires drawn using conventional, convex and concave dies, as a function of the total reduction in area [10]

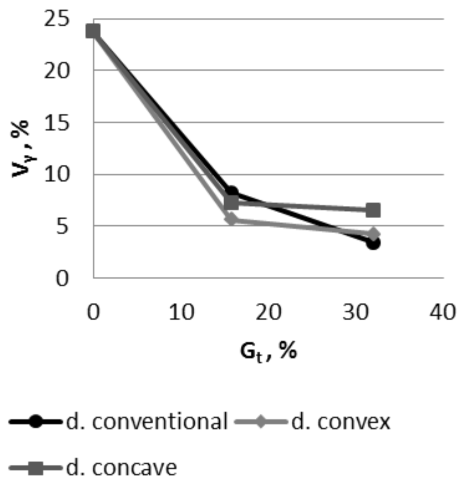

Fig. 8 The amount of retained austenite (vγ,%) in the axis of wire rod and wires drawn using conventional, convex and concave dies, as a function of the total reduction in area [10]

The investigation has shown that redundant strain (being maximum on the wire surface) causes a greater transformation of retained austenite into martensite in the surface layer of the wire compared to its axis, for each drawing variant. At the same time, it has been found that the quantity of untransformed retained austenite left after the second draw in wires drawn in concave dies is larger than for the other drawing variants, namely by as much as approx.100% compared to conventional die drawn wires and by over 45% compared to wires drawn in convex dies.

III. Summary

Used for theoretical analysis of multistage drawing process the Drawing 2D programme allowed to determination the change of strain intensity and redundant strain depending from value of partial reduction.

By the selection of drawing process parameters, we can influence on strain intensity and consequently on the mechanical properties of the wires made from TRIP steel.

The increase the redundant strain for wires drawn with large partial reductions causes a decrease in the amount of retained austenite in relative to wires drawn with small partial reductions. Such difference are in the range from 1,4 to 2,5 %.

The investigation has been found that using drawing dies with a working portion shape other than conical enhances both the mechanical properties of the wire and the homogeneity of strain on its cross-section, as indicated by the differences in the quantity of untransformed retained austenite. The investigation results presented herein can provide a basis for predicting both the structure and properties of TRIP steel wires drawn in shaped dies [10].

Acknowledgments

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