

## Evaluation of the retained austenite mechanical stability in the medium-carbon TRIP steel

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### Properties

#### ABSTRACT

**Purpose:** The aim of this study was to evaluate the inclination to mechanical destabilization of retained austenite in the microstructure of the TRIP steel containing 0.4% C, 1.5% Mn and 1.2% Si.

**Design/methodology/approach:** The new, simple method for evaluating the mechanical stability of retained austenite was proposed, which is based on the bending test and the measurement of volume fraction of retained austenite by X-ray quantitative phase analysis. The relationship between stress and local strain as well as local volume fraction of this phase in selected locations on the surface of the bending sample were revealed.

**Findings:** The applied heat treatment, modified with respect to the classic one, allowed remain approximately 25 vol.% of the retained austenite in the microstructure of the investigated TRIP steel. It was pointed that retained austenite has high mechanical stability if stress is low. Under influence of the higher stress a partial destabilization this phase occurred. It was found that in the examined steel such mechanical destabilization of retained austenite has two - or three-stage nature.

**Research limitations/implications:** Results of this study indicate a significant stability of retained austenite in the investigated TRIP steel. It is advisable to check how will change the stability of this phase when the stress or strain will be higher than those that occurred in this research.

**Practical implications:** The new method of the evaluation of the retained austenite mechanical stability provides the possibility of an easy and effective estimation of this phase tendency to mechanical destabilisation and to martensite transformation in the steel. In addition, this method allows analysing the influence of the stress as well as the strain on changes in this phase volume fraction, which occur during three-point bending.

**Originality/value:** The proposed method may be used for evaluation of susceptibility of retained austenite on transformation under load. Moreover, developed relationships between volume fraction of retained austenite-stress as well as volume fraction of retained austenite-strain, can be used for interpretation and analyze of mechanical properties changes of heat-treated steels.

**Keywords:** Working properties of materials and products; TRIP-effect; Retained austenite; Mechanical stability

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## 1. Introduction

A modern automotive industry forces car producers to search and implement better and more reliable materials. Amongst such modern materials stand out particularly: ferritic-martensitic DP (Dual Phase) steels [1-3] and TRIP (Transformation Induced Plasticity) steels of the microstructure consisting of ferrite, bainite and retained austenite [2-10].

The second, mentioned above, steel group (TRIP steels) seems especially interesting due to the presence of the retained austenite in its microstructure. This austenite can undergo transformation into martensite during plastic deformations. Thus, this phase contributes on the one hand to increasing a uniform deformation and on the second to a material strengthening [11-14].

To obtain the proper structure and required mechanical properties of the TRIP steel, apart from the relevant chemical composition (the most often app. 0.1-0.4% C, 1-2% Mn, 0.5-1.5% Si, and 0-1.5% Al), the suitable heat treatment is necessary. It should consist in a short steel annealing - in a range of critical temperatures - fast cooling to the temperature range between  $M_s$  and  $B_s$  and isothermal holding within bainitic transformation. After such treatment it is possible to leave in the TRIP steel microstructure 50-60 vol. % of ferrite, 25-40 vol. % of bainite and 5-20 vol. % of retained austenite [13-16].

The mechanical stability of retained austenite has a direct influence on its inclination to transformation into martensite [17]. At a high stability, regardless of the imposed stresses, austenite remains not transformed and can undergo strain hardening. However retained austenite of a low stability under an influence of the same stresses will be transformed into martensite in the TRIP effect [18].

Along with the progress of research concerning multiphase steels with the retained austenite, the mechanical stability of this phase has become so important issue that in literature on this subject occurred articles concerning research results of the austenite inclination to transformation into martensite under an influence of an imposed stress [19-21].

One of the methods is based on the controlled tensile. The change in the austenite volume fraction, which occurs, after applying external tensile stresses causing 2% plastic strain of the investigated steel, was assumed the measure of mechanical stability [19].

Different way of estimating the retained austenite mechanical stability was proposed in papers [20,21]. This stability was evaluated in the sample surface layer on the bases of the static 3-point bending test performed from the side of the tensile stresses operations. The retained austenite fraction ratio, which remains in the sample surface layer of the investigated steel in the place of maximum stress operations (close to e.g. 95% value of bending strength) with respect to its initial fraction - was assumed as the mechanical stability measure.

A new way of estimating, based on the modification of the second method is proposed in the present paper. This method should allow an easy and fast evaluation of the retained austenite mechanical stability. It is also expected that it will be possible to determine, by means of the proposed method, an influence of deformations as well as stresses on changes of this phase fraction in the investigated steel.

## 2. Material for investigations and a heat treatment

Steel for research was melted in the form of an ingot of a mass of app. 50 kg. This ingot was rolled into sheet, 14 mm thick, and then normalised.

The microstructure of the investigated steel obtained after these operations is presented in Fig. 1. As can be seen, it consists of pearlite and a small amount of ferrite, which fraction was estimated as 10-15 vol. %.

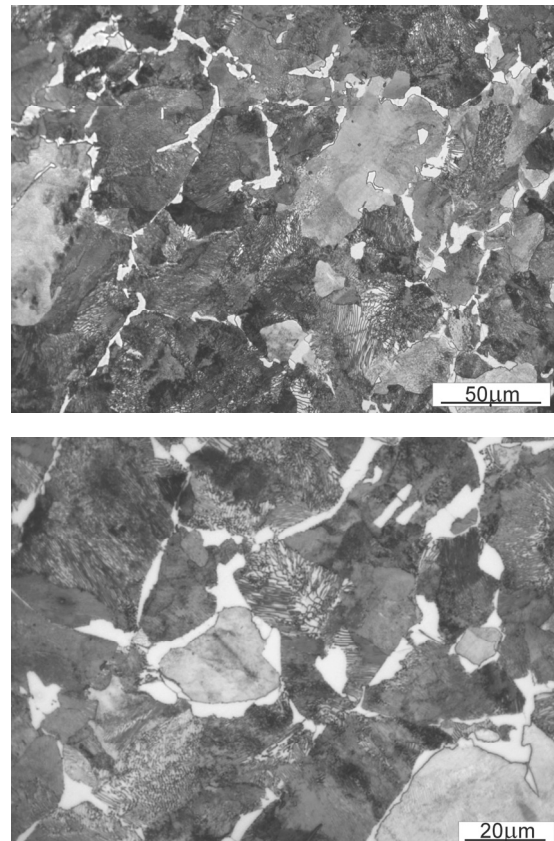


Fig. 1. Initial microstructure of the investigated steel (etching: 2% nital)

Chemical composition of the investigated steel is shown in Table 1.

Table 1.  
Chemical composition of the investigated steel

Chemical composition, mass %										
C	Mn	Si	S	P	Cr	Ni	Cu	Al	N	O
0.41	1.52	1.22	0.015	0.015	0.02	0.02	0.05	0.019	0.004	0.003

A sample of dimensions 6x11x100 mm was cut out. This sample was exposed to the heat treatment, which is schematically presented in Fig. 2.

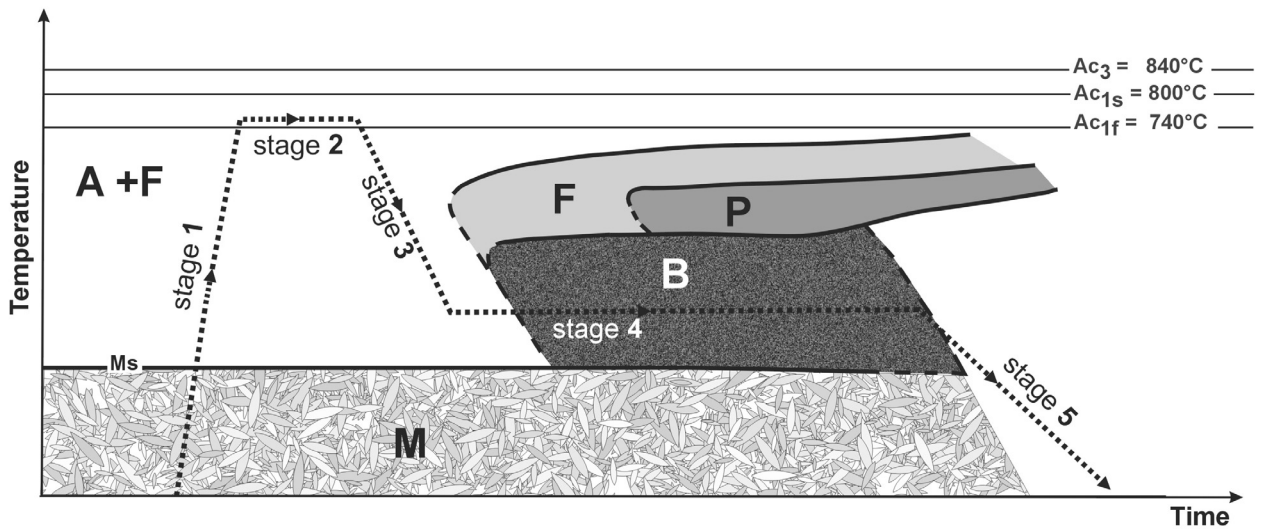


Fig. 2. Schematic presentation of the applied heat treatment at the background of the CCT diagram of the investigated TRIP steel

As it can be seen the applied variant of the heat treatment consisted of 5 stages:

1. Heating to 750°C with a rate of app. 50°C/s,
2. Annealing at 750°C for 30 minutes,
3. Fast cooling to 430°C in a metal bath,
4. Isothermal holding at 430°C in a metal bath for 10 minutes,
5. Slow air-cooling to the ambient temperature.

The temperature of annealing (stage 2) as well as and isothermal holding (stage 4) were selected on the bases of dilatometric tests of the investigated steel, described in papers [22,23]. An attention can be drawn to a very low - as for the TRIP type steel - annealing temperature (750°C). It was expected that during such annealing of the investigated steel the austenite being formed would be strongly enriched with carbon. A consequence of this process will be an increased fraction of the retained austenite in the microstructure of the investigated steel.

### 3. Methodology of investigations

After the heat treatment the sample was regrind for dimensions: 5x10x100 mm. A preliminary grinding was performed by means of the mechanical grinding machine and then on abrasive papers of grades increasing from 100 to 600. Since, it was planned - in the further part of the experiments - to perform X-ray investigations of the retained austenite fraction on one of the sample surfaces, this surface was additionally electrolytically polished. Thereby a possibility of inaccuracy of the X-ray results, by a negative influence of stresses, which can occur in the surface layer during grinding, was limited. As the final preparation of the sample - on the electrolytically polished surface - the places were marked close to which the measurements of the retained austenite fraction were to be performed.

Additionally on the same surface - every 5 mm - the markers, which were to allow an evaluation of the local deformation after the finished experiment, were deposited. Schematic presentation of the sample prepared for tests is shown in Fig. 3.

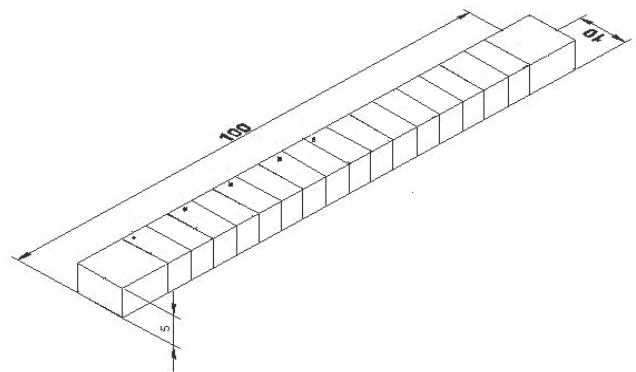


Fig. 3. Schematic presentation of the sample prepared for experiment with the markers and places for measuring the retained austenite fraction

During the main part of the experiment the surface layer of the investigated sample (in which the evaluation of the retained austenite mechanical stability was to be performed) was deformed in the static 3-point bending test [24]. The sample was bended on the universal testing machine bend fixture, allowing its supporting in places being 80 mm apart - at a opposite side of the extreme markers shown in Fig. 3. During such bending, the polished surface (on which measurements of the retained austenite were to be made) was deformed (elastically and plastically) due to tensile stresses. These stresses values were changing from 0 in the point of support, to the maximum value in the applied load point, it means in the middle of the sample (Fig. 4).

The X-ray quantitative phase analysis (method of a direct comparison of reflections intensity) described in paper [25] was applied for the evaluation of the retained austenite fraction. The cobalt lamp radiation was used in experiments and reflections from planes 111<sub>γ</sub> and 110<sub>α</sub> were recorded.

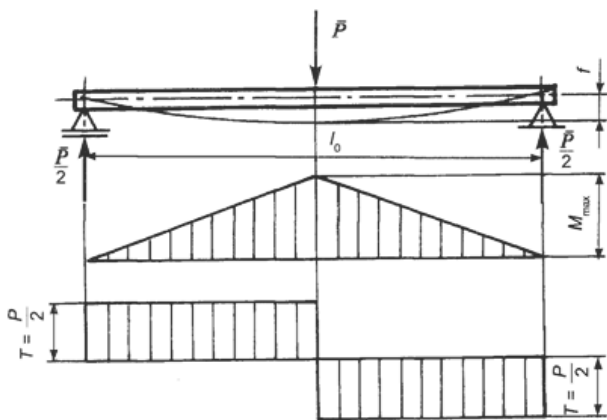


Fig. 4. Method of loading, bending moment  $M$  and distribution of transverse forces  $T$  in the 3-point bending sample loaded in the middle with the concentrated force  $P$  (acc. [24])

After determining the initial volume fraction of the retained austenite on the tested sample surface it was bended in such a way as to cause its permanent deformation. Then, next measurements of the retained austenite fraction were made in places shown in Fig. 3.

On the same surface of the sample, deformed due to bending, distances between markers were measured and the local plastic deformations were calculated. Stress values acting during bending were also estimated in the same points, in which the retained austenite fraction was measured. The following equation was applied:

$$\sigma = Mg/Wg \quad (1)$$

where:

- $\sigma$  - maximum stress on the surface of the bended sample,
- $Mg$  - bending moment,
- $Wg$  - coefficient of bending strength.

as well as changes of the bending moment from 0 Nm in the point of support to maximum value in the middle of the bended sample (Fig. 4).

As soon as the bending test, X-ray measurements and all necessary calculations were finished, the dependencies allowing the evaluation of the mechanical stability of the retained austenite were developed.

#### 4. The obtained results and their discussion

The microstructure of the investigated steel after the applied heat treatment is shown in Fig. 5. Apart from small, bright ferrite areas and darker pearlite a new, etched in grey, structural component areas are seen in photographs (see also Fig. 1). Moreover, in the part of pearlite areas a distinct change in the morphology of this component - a coagulation of cementite precipitates - can be noticed.

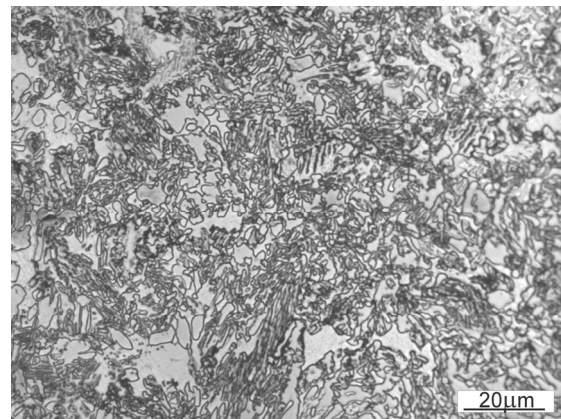
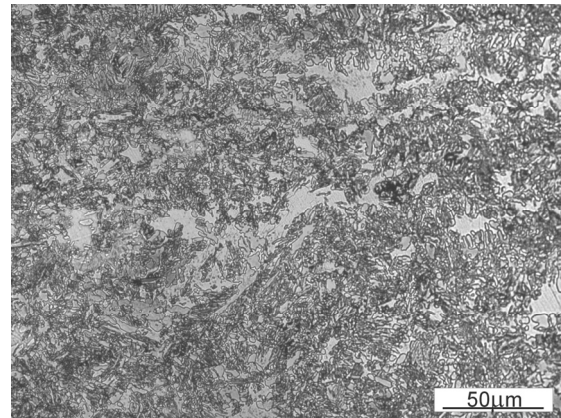


Fig. 5. Microstructure of the investigated TRIP steel after the heat treatment (etching - 2% nital)

The comparison of the microstructures before (Fig. 1) and after the heat treatment (Fig. 5) allows noticing that areas taken by ferrite and pearlite significantly decreased for a new, etched in grey, structural component. The most probably this component constitutes products of austenite transformations which were formed during annealing at 750°C. Since at such low annealing temperature the austenite was formed mainly from pearlite, it could be significantly enriched in carbon, which in turn could contribute to the chemical stability of this phase. It can be assumed, that during an isothermal holding at 430°C (Fig. 2 - stage 4) only a part of the carbon-rich austenite could transform itself into bainite, while the rest of this phase could remain not transformed in the microstructure of the investigated steel - as the retained austenite.

A significant fraction of this etched in grey component, the most probably a mixture of bainite and the retained austenite, is seen in Fig. 5. This can indicate that during the annealing at 750°C, the pearlite transformation into austenite was already highly advanced. Such advancement of the transformation pearlite  $\rightarrow$  austenite at a temperature of only 10°C higher than  $Ac_{1s}$  (temperature of austenite formation start) can indicate its isothermal course.

In order to verify the above-mentioned observations and discussion, the fractions of retained austenite were estimated by means of the X-ray quantitative phase analysis. One of recorded

diffraction patterns is shown in Fig. 6, while the all obtained results are given in Table 2.

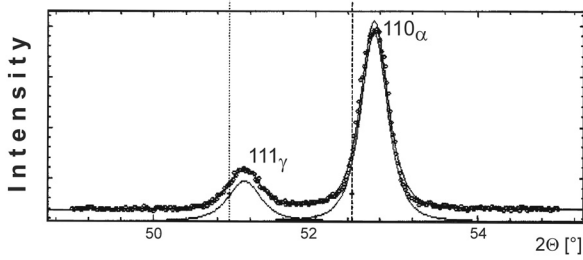


Fig. 6. Diffraction pattern of the X-ray quantitative phase analysis, obtained during measurement No 5 (see Table 2)

Table 2.

Results of the retained austenite fraction on the electrolytically polished surface of a sample of the investigated TRIP type steel, before the bending test

Measurement Number	Retained Austenite Volume Fraction vol. %	Mean vol. %	Scatters vol. %
Point of support			
1	24.4	24.5	- 0.1
2	24.8		+ 0.3
3	24.3		- 0.2
4	24.6		+ 0.1
Middle of the sample			
5	25.0	24.7	+ 0.3
6	23.8		- 0.9
7	25.4		+ 0.7
<b>Mean</b>		<b>24.6 vol. %</b>	

The measurement results listed in Table 2 proved that the applied heat treatment allowed to leave in the microstructure of the steel a significant retained austenite fraction, being in the range: 23.3-25.4 vol.%. Since the obtained results were repeatable and of a small scatter, the arithmetic mean was calculated as 24.6 vol.%. This value of the austenite fraction was assumed as the initial one for the mechanical stability evaluation.

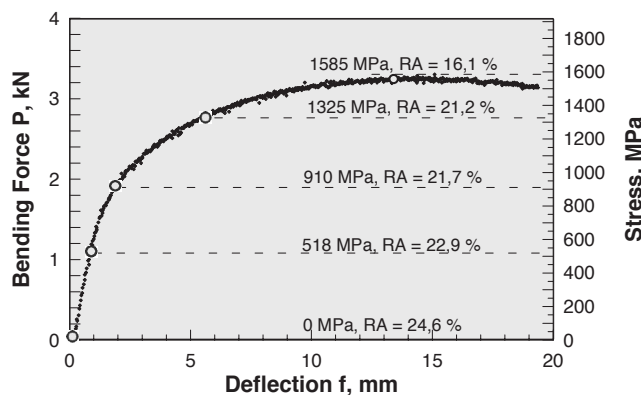


Fig. 7. Chart of bending of the investigated TRIP type steel with marked values of the retained austenite volume fraction, measured after bending in points shown in Fig. 3

The dependence of the bending force (P), recorded during the sample bending (as well as the stress corresponding to such force on the surface stretched during bending) on the deflection (f) - is presented in Fig. 7. The measurements results of the volume fraction of retained austenite as well as the stress values acting during bending in the same points, in which this phase volume fraction was measured (Figure 3) are also shown in this chart.

A direct dependence of the retained austenite fraction and such stresses is presented in Fig. 8.

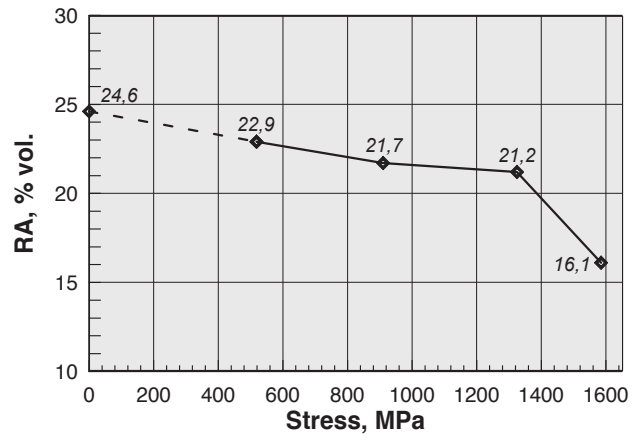


Fig. 8. Influence of stresses on the retained austenite fraction in the sample surface layer

It's easy to notice that the retained austenite fraction, which was left in the surface layer of the bended sample, was the smallest in the place subjected to the highest tensile stresses during bending. It is also worth noticing that the decrease of the retained austenite fraction under an influence of stresses applied during bending (mechanical destabilising) occurs in two stages. In the first one, under an influence of stresses increasing from 0 to 1325 MPa, the retained austenite fraction was moderately decreasing from 24.6 to 21.2 vol. %, it means approximately 0.26 vol. % for each successive 100 MPa. Only at stresses higher than 1325 MPa a more intensive austenite decrease was observed: to 16.1 vol. % at 1550 MPa, which means a decrease by 1.82 vol. %/100 MPa.

Such character of changes of the retained austenite fraction, being the effect of tensile stresses, suggests that the mechanical stability of this phase is not a constant value and also depends on stress values. At stresses not exceeding app. 1300 MPa the retained austenite was mechanically stable and had a small tendency for transformations. However, with increased stresses this mechanical stability was decreasing enabling easier transformation of this phase into martensite.

It is worth to notice that the stress of 1325 MPa corresponds to a small deflection (f), which probably also means a small deformation in the surface layer of the tested sample (Fig. 7). Thus, the observed small decrease of the retained austenite fraction - at stresses lower than 1325 MPa - could be a result of its transformation occurring mainly under an influence of stresses which were too small to cause a significant permanent deformation of this phase. However, at higher stresses and at a deflection higher than 6 mm, a yield point left in the retained

austenite microstructure could be exceeded and an intensive plastic deformation could start. It could contribute to the stability of this phase and its easy transformation into martensite.

Such influence of stresses, depended on the yield point of the remained austenite, could explain a two-stage character of the mechanical destabilising of the retained austenite. The observed changes in the retained austenite fraction in the investigated steel are also in agreement with Olson and Cohen's [26] observations, concerning formation of two kinds of martensite depending on stress values (Figs. 9 and 10).

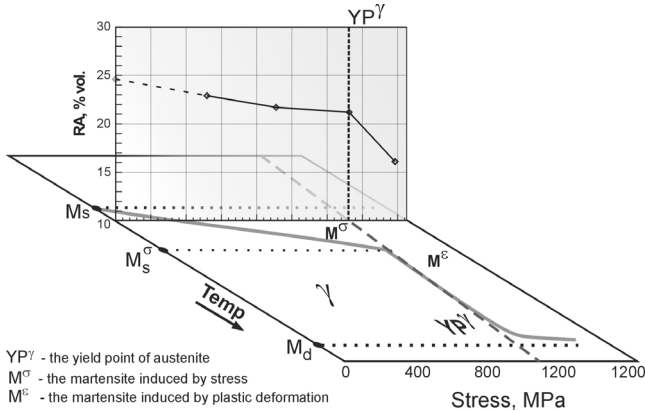


Fig. 9. Mechanical destabilisation of the retained austenite in the investigated steel at the background of the formation scheme of „stress martensite” ( $M^{\sigma}$ ) and „deformation martensite” ( $M^{\epsilon}$ ), acc. Olson and Cohen [26]

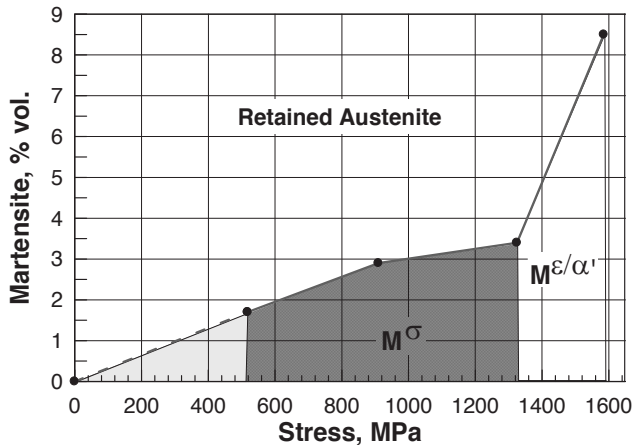


Fig. 10. Possible influence of stresses on the kind of formed martensite in the investigated steel (compare Fig. 9)

However, it is characteristic in the presented above evaluation of the retained austenite stability that - even at the maximum stresses - approximately 16 vol. % of this phase still remains not transformed. This can suggest that even in the middle of the sample, it means in the area which is subjected to the highest tensile stress, the degree of a permanent plastic deformation occurs too small for the total destabilising of the remained austenite.

Value of local deformations, calculated as a quotient of increasing distances between markers on the sample after and before bending (Fig. 2) determined on the surface of the bended sample are presented in Figure 10. Places between markers, in which after bending the measurements of the retained austenite fraction were performed, are marked in Fig. 11 by „X” symbol.

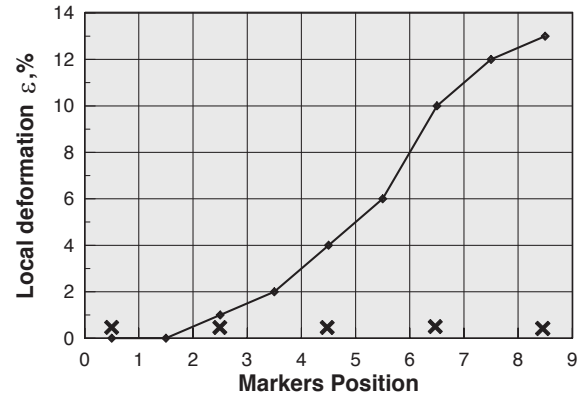


Fig. 11. Local deformation  $\epsilon$ , between markers on the bended sample surface and X-marked places in which the retained austenite measurements were made (compare Fig. 3)

The dependence of the local deformation ( $\epsilon$ ) on the retained austenite fraction (RA), which remained after bending in the X-marked places (Fig. 11), is presented in Fig. 12.

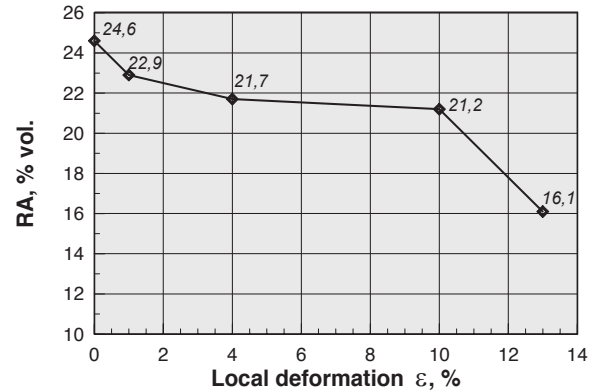


Fig. 12. Influence of deformations on the retained austenite fraction in the surface layer of the investigated TRIP steel sample

This dependence (Fig. 12) confirms observations of a multistage course of the mechanical destabilisation of the retained austenite, formulated when discussing results shown in Figs. 8 and 10. Simultaneously, on the basis of the analysis of Fig. 12, it can be stated that a decrease of the retained austenite fraction observed during the first destabilizing stage (Fig. 7) occurs mainly at the beginning of this stage, it means at stresses causing elastic strain. However, it is seen admittedly in Fig. 12 that a slightly smaller retained austenite fraction is also observed in these areas of the sample surface, for which permanent

deformations occurred (not exceeding 10%), but it should be remembered that the calculated deformation is 'a resultant' of deformations of each of structural components, including soft ferrite (Fig. 4).

However, it cannot be excluded that even such deformation could contribute to defects formations in the crystal lattice of the remained austenite. These defects could cause a decrease of the austenite mechanical stability and initiate its transformation into martensite [27]. Such speculation seems to confirm a significant decrease of the austenite fraction - observed in Fig. 12 - in this area of the bended sample in which the deformation was the highest.

## 5. Conclusions

1. The proposed method of the evaluation of the retained austenite mechanical stability provides the possibility of an easy and effective estimation of this phase tendency to mechanical destabilisation and to martensite transformation in the microstructure of the investigated steel. In addition, this method allows analysing the influence of the stress as well as the deformation on changes in this phase volume fraction, which occur during bending.
2. The applied heat treatment, modified with respect to the classic one, allows leaving approximately 25 vol.% of the retained austenite in the microstructure of the investigated TRIP type steel (0.41% C, 1.52% Mn, 1.22% Si). It was found, on the bases of the performed investigations, that this austenite is characterized by a high mechanical stability even when stresses close to 1300 MPa operate in its microstructure and its permanent deformation is equal app. 10%.
3. The reason for stated stability of the retained austenite in the investigated steel can be significant enrichment in carbon of austenite which is formed at 750°C. The presence of this element could effectively stabilize such austenite and hamper its transformation both during the heat treatment - by a strong decreasing of Ms, as well as during bending - by its solid solution hardening and an increase of its yield strength.
4. A significant decrease of the austenite fraction remaining in the microstructure was found in the surface layer of the sample, which during bending was influenced by the highest stresses (close to 1600 MPa). The most probably - this was caused by the austenite transformation into martensite. However, it should be noticed that regardless of a high stress and permanent deformation of this area (by app. 13%), only 1/3 of the initial retained austenite underwent a mechanical destabilization and transformation into martensite. All these facts indicate a significant stability of this phase and provide the possibility of applying steels with so highly stabilized austenite for elements undergoing deformations exceeding 13%.

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