# Positron Annihilation in Steel Samples Deformed by Uniaxial Tension

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Angular distributions of the positron annihilation quanta were measured for steel ST2 SAL samples deformed by uniaxial tension up to different deformation degrees. The dependences of the $S$ parameter on the relative elongation of the samples are presented. The positron annihilation data for steel are compared with the results obtained previously for polycrystalline iron samples deformed by uniaxial tension up to different deformation degrees in the proportionality and limited proportionality regions.

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## 1. Introduction

In recent years, positrons have proved to be very sensitive probes for the investigation of the structure and dynamics of lattice defects in metals and alloys [1, 2]. Uniaxial tension and plastic deformation of metals and alloys generates mainly dislocations and vacancies. In polycrystalline samples the deformations become more complex due to the various interactions between dislocations and the grain boundaries [3].

Existing quality testing methods of deformed steels are basically limited to such methods as radiography [4] and method of acoustic emission [5]. The method of electron–positron annihilation (PA) is sensitive with respect to defects (dislocations and vacancies) at an initial stage of defectiveness development in material submitted to plastic and uniaxial tension deformation.

It is generally known that metal and steel samples are deformed under the influence of increasing external forces, first elastically and after exceeding the elasticity limit, the deformation starts to be plastic. The first stage is connected with generation of relatively simple defects (monovacancies and edge dislocations), the second stage — with formation of complex vacancy-like defects and dislocations, and the third with origination of micro-pores and micro-cracks. As it was shown

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in the previous works [4–6], in the first stage of elastic deformation the parameter $(S)$ of the angular correlation of annihilation radiation (ACAR) curves linearly depends on the relative elongation $(\varepsilon)$ of metal samples.

In the present work we apply the ACAR method to investigation of changes in the annihilation parameters during deformation (by uniaxial tension) of the ST2 SAL steel samples.

## 2. Experimental

Samples of the ST2 SAL steel, made as sheet in steel rolling process technology, with dimensions $10 \times 20 \times 1$ mm$^3$, were used in the experiment. The composition (atomic %) of this steel is as follows: C 0.08%, Mg 0.77%, P 0.013%, Si 0.03%, S 0.015%, Cr 0.03%, Ni 0.02%, Cu 0.06%, Al 0.036%.

The measurements were carried out using the samples cut from the sheet, submitted to tempering at 170°C or 800°C for four hours and slowly cooled to room temperature. After that one of the samples was placed in a specially prepared setup, by means of which the sample was elongated to different relative elongations. For each elongation of the sample, the ACAR curve was measured using the standard correlation spectrometer with a long slit geometry. The positron source $^{22}$Na with activity of about 10 mCi was used. All the measurements were performed at room temperature under normal pressure.

## 3. Results and discussion

It is known that tensile toughness and the elasticity limit of steels depend, among others, on the content of fragile cementite, which in turn depends on the thermal history of investigated sample. In this context it was suitable to investigate the dependences of $S$ parameter value on the relative elongation of steel samples cut from the same sheet and tempered at different temperatures before the PA measurements, performed in the same geometry as in our previous studies on pure metals [1–3].

The experimentally determined dependences of the $S$ parameter value on the relative elongation of steel samples tempered at temperatures of 800°C and 170°C are presented in Fig. 1.

It has been found that in the interval of elongations ranging from 0 to 1.5% the course of the $S(\varepsilon)$ dependences is very similar to that observed previously for pure iron [1, 2], being the main component of investigated steel samples. That most convincing symptom of this similarity is the occurrence of a sharp minimum on the $S(\varepsilon)$ curves at $\varepsilon_{\min} < 0.50$. The greatest value of $\varepsilon_{\min}(0.44\%)$ was observed for pure iron [2], the smallest (0.17%) for steel tempered at 800°C, while for steel samples tempered at 170°C, $\varepsilon = 0.25\%$.

The difference in the values of $\varepsilon_{\min}$ for steel samples tempered at different temperatures can be explained by the effect of the thermal treatment on the phase composition and microstructure of steel. According to the phase diagram [4] the
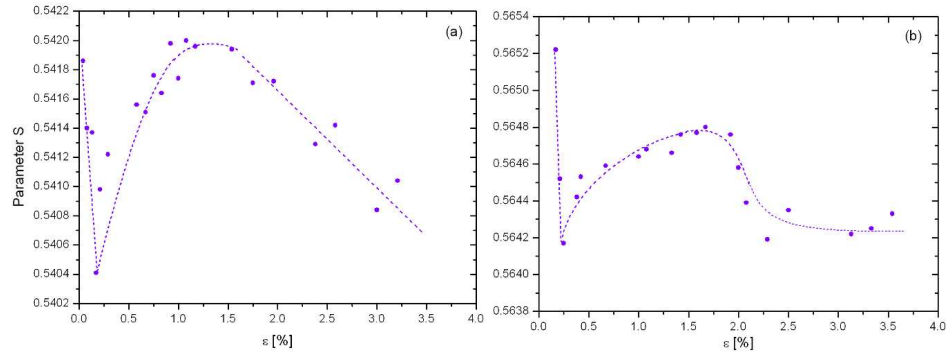
Fig. 1.   The dependence of the $S$ parameter on the relative elongation of the sample annealed in the temperature (a) 800°C, (b) 170°C.

structure of the steel sample tempered at 170°C consists of alternately stacked ferrite and pearlite platelets. Tempering at 800°C followed by slow cooling to the room temperature causes the partial transformation of ferrite to the cementite $Fe_3C$, which precipitates at the boundaries of ferrite grains [4, 5]. The precipitation of cementite changes the phase composition as well as the defect structure of investigated material, especially in the grain boundary regions. Cementite is the most fragile component of the steel samples, and therefore the $\varepsilon_{min}$ value for sample tempered at 800°C is smaller than that for sample tempered at 170°C. The difference between the $\varepsilon_{min}$ values for pure iron and investigated steel samples is, most probably, caused by the presence (in steel) of alloying elements with the positron affinity differing from that of Fe [6], or/and by the interaction of admixture atoms with dislocations, resulting from mutual attraction of stresses of opposite sign [4]. Similarly as in the case of pure metals [7, 8], the lowering of the $S$ parameter value in the initial stage of sample elongation ($0 < \varepsilon < \varepsilon_{min}$) corresponds to the interval of elastic deformation. In the intervals $0.25 < \varepsilon < 2\%$ and $0.17 < \varepsilon < 1.5$ for samples tempered at 170°C and 800°C, respectively, the changes in the $S$ parameter value coincide with the interval of elasto-plastic deformations. Further changes in the $S$ parameter value should be ascribed to the plastic deformation of steel samples, mainly by slip on the primary and secondary slip planes. In this range the $S$ parameter value for samples tempered at 800°C linearly decreases with increasing the elongation force. This means that the positron trapping is dominated by the same type of defects, only their concentration is changing. However, for the sample tempered at 170°C the staircase changes of the $S$ parameter are observed near $\varepsilon \approx 2\%$, and no substantial changes in the $S$ parameter value are observed with further increase in relative elongation. The probable reason for such behaviour is the anchoring of dislocations at the grain boundaries leading to the saturation of positron annihilation in defects.

## 4. Conclusion

From the results of the present study it follows that measurements of the angular correlation of positron annihilation quanta can be applied as a method supplementing the static tensile tests by making possible to follow the kinetics of generation of defects with conjecture to the particular ranges of the strain–stress curve. Changes in the positron annihilation parameters caused by uniaxial static elongation permit to reveal and to describe the changes in the microstructure of steel.

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