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THERMOELASTIC EFFECT IN AUSTENITIC STEEL REFERRED TO ITS HARDENING

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The effects of thermomechanical coupling occurring in metal during consecutive tensile tests, were examined. The temperature, stress and strain characteristics were found both in elastic and plastic ranges. The change of the character of the sample temperature was employed as a criterion for the limit between the elastic and plastic regimes. The thermomechanical coupling effects were interpreted in terms of the material microstructure evolution and referred to its strain hardening degree. A quite precise evaluation of the thermal effects concomitant with the thermoelastic unloading seems to be particularly valuable.

Key words: thermoelastic effect, polycrystaline metal, consecutive deformation

1. Introduction

In most commonly used materials the definite irreversible plastic deformation is preceded by the reversible elastic one. It is easy to present a lot of simple experiments, ilustrating the thermoplastic effects, but it is still difficult to describe them in analytical terms. On the other hand, the thermoelastic effect which illustrates the coupling between elastic deformation and thermal energy can be described using precise analytical terms, but it is not so simple to demonstrate it. The temperature changes accompanying the pure, volumetric elastic deformation are not too big; and in most cases do not exceed 0.2 K. Furthermore, it is difficult to carry out the investigations in adiabatic conditions. Nevertheless, in some situations the value of thermoelastic effect can be much higher, which is related to material hardening that is accomodating the microstructure of material to transferring the increased loading. The exploitation of the thermoelastic effect behaviour referred to metal initial and further, strain hardening is a subject of the article.

2. Experimental procedure

Specialy designed austenitic steel specified according to polish standards by symbol 00H19N17Pr was investigated. This steel maintains a stable structure, e.g. no phase transformations occur during the deformation. Furthermore, the low amount of carbon protecting the material structure from carbonate creation, which could disturb the homogeneity of the deformation. The grain size obtained due to thermal treatment was about $50\mu m$.

The chemical composition of the steel is given in Table 1, and the values of material coefficients, influenced the measured effects, are given in Table 2.

Table 1

Element	C	Mn	St	P	S	Cr
Contents [%]	0.05	1.35	1.0	0.016	0.008	18.58
Element	Ni	W	Mo	Cu	V	Ti
Contents [%]	17.3	0.025	0.02	0.04	0.03	0.013

Table 2

Density $[kG/m^3]$	Specific heat $[kJ/(kG^\circ K]$	Coeff. of lin. expansion $\alpha \cdot 10^6$ [1/K]	Melting point [°C]	Coeff. of steel emissivity	Coeff. of carbon emissivity
7900	0.50	16	1400	$0.1 \div 0.2$	0.95

The sheet samples were made from cold-rolled steel strips of 25 mm × 4 mm cross-section and annealed at 1050 K for 40 minutes. The shape and dimensions of the specimen were detailed by Pieczyska (1996).

Two kinds of samples of the same material were investigated: one of them after full annealing and the other after 50% of rolling. The first, initial state of material contains low density of dislocations, while in another quite pronounced texture and high evolved dislocation structures prior to testing were observed (Fig.1 and Fig.9).

The samples were subjected to elongation by means of a testing machine with a constant rate of loading and unloading, equal to $2 \cdot 10^{-3}\,s^{-1}$, according to the following procedure:

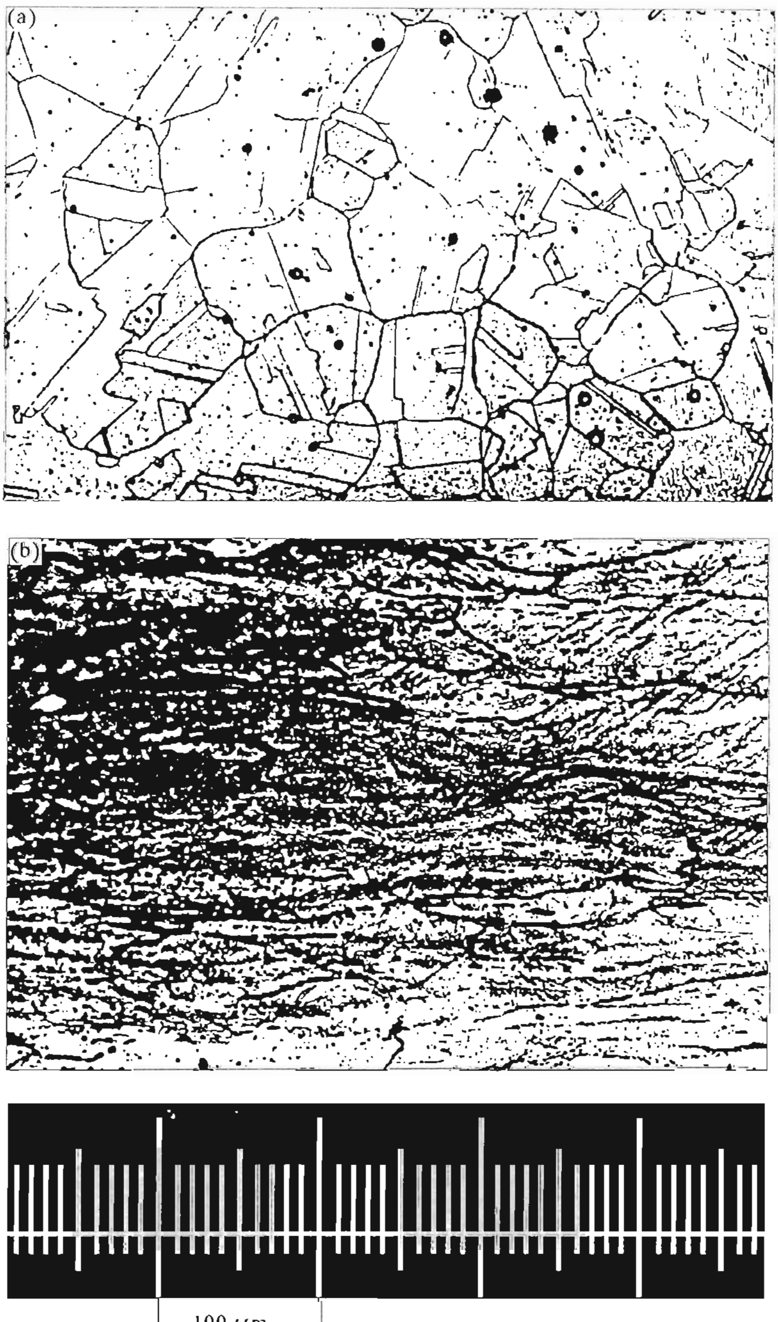

Fig. 1. Optical micrograph of samples of stainless steel surface before straining: (a) – after heating, (b) – after rolling

- straining to $\varepsilon = 4\%$ (beyond the yield point),
- unloading,
- cooling in an ambient temperature,
- straining to 1 mm again.

In this way five such cycles (loading and unloading) for each sample were performed.

A diagram of the experimental set-up is given in Fig.2. The gauge length was 25 ± 5 mm.

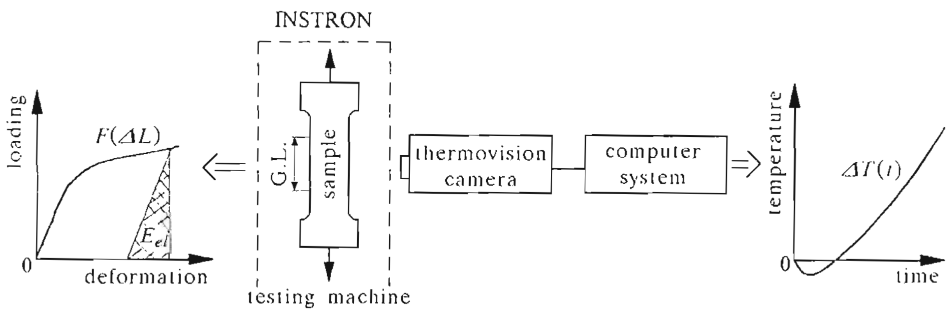

Fig. 2. Scheme of the experimental set-up

A proper choice of the rate of straining, due to the short time of temperature measurement, stabilisation of the experimental conditions (minimalisation of air fluctuation), and measurement of the temparature at the central area of the sample, made the process partially isentropic and adiabatic.

The stress vs. strain, the stress and the strain vs. time were continuously recorded during the deformation. Moreover, a distribution of the infrared radiation emitted by the sample surface was registered using the thermovision camera AGA-680 interconnected with a computer system. The infrared radiation distribution, registered by the thermovision equipment, allows us to obtain the temperature evolution of the sample with a quite high precision, up to 0.02 K (Gadaj et al., 1996a,b). The temperature was measured as an average from the measurement area of about $2\,\mathrm{cm}^2$. In order to ensure higher and more homogeneous emissivity, the sample surface was blackened with the carbon powder.

In each cycle of straining the thermoelastic effects, i.e. the decrease in temperature in the initial stage of elongation and the increase in temperature during the thermoelastic unloading were investigated.

The onset of plastic deformation evolving in the subsequent cycles of loading is examined using the temperature changes vs. stress as the basis.

The change of specimen temperature subjected to the adiabatic uniaxial elastic deformation ΔT_{el} can be described as follows (Kelvin, 1853)

$$\Delta T_{el} = -\frac{\alpha T \Delta\sigma_s}{c_p \rho} \tag{2.1}$$

where

α	–	coefficient of thermal expansion
T	–	absolute temperature
$\Delta\sigma_s$	–	isentropic change in stress
c_p	–	specific heat per unit volume at constant pressure
ρ	–	material density.

Since usually $\alpha > 0$, the temperature decreases during the elastic extension and increases during compression (Bever et al., 1973).

Assuming that the material coefficients used in Eq (2.1) are constant, the elastic deformation is described by the linear dependence between the temperature and stress change (Pieczyska, 1996)

$$\Delta T_{el} = -k\Delta\sigma_s \tag{2.2}$$

where k is the coefficient.

The departure of the temperature characteristic from the straight line indicates a change of the character of the process; it goes from the elastic deformation to elasto-plastic.

3. Thermoelastic and thermoplastic effects in austenitic steel samples after annealing

The mechanical characteristics and distributions of the intensity of infrared radiation allow us to obtain the stress-strain relations (Fig.3) and the temperature evolution of the specimen subjected to the consecutive loading cycles (Fig.4).

Looking at the mechanical characteristics (Fig.3) one can observe:

- a smooth, parabolic transition from elastic to the plastic deformation in the first cycle,
- a clearly seen yield point, that appears in the second cycle and becomes more pronounced in the subsequent cycles,

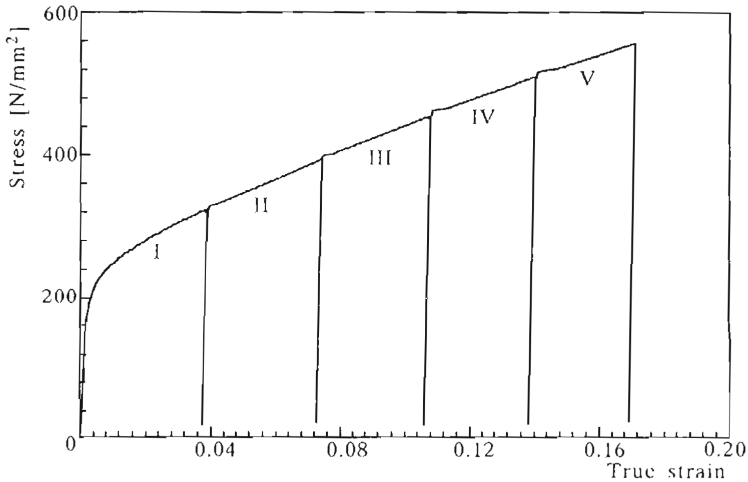

Fig. 3. Stress vs. strain during consecutive cycles of loading and unloading of the specimen of stainless steel; I,...,V – cycles of straining

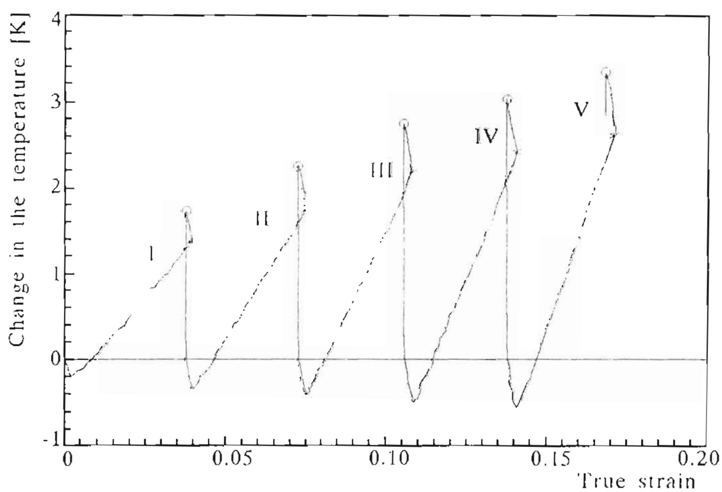

Fig. 4. Temperature changes vs. deformation during successive cycles of the loading and unloading of specimen of stainless steel; × – onset of unloading (OU), ∘ – end of unloading (EU)

- strain hardenning of the sample material, however, the hardenning rate decreases for the subsequent cycles of straining.

At the beginning of each cycle, at the elastic stage of elongation, a temperature decrease is observed (thermoelastic effect), followed by temperature increase typical for the plastic deformation (Fig.4). The middle parts of the characteristics describing the plastic straining are almost straight lines with both the length and the slopes of inclination increasing in the subsequent cycles of straining. This indicates more intensive heat emission related to a more advanced state of plastic deformation.

The process of unloading is accompanied by a rapid increase in temperature again. This seemingly strange result can be explained on the basis of analysis of the process of the thermoelastic unloading, which will be made in Section 3.2.

3.1. Temperature changes during elasto-plastic transformation

The initial changes in temperature of the specimen subjected to the successive cycles of loading and described as a function of stress are shown in Fig.5.

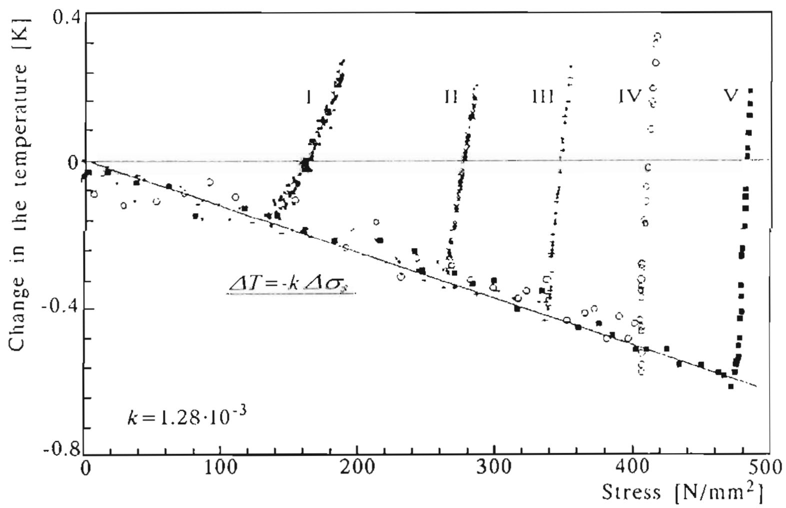

Fig. 5. Changes in temperature of a specimen of stainless steel vs. stress during initial stage of successive cycles of loading

A temperature drop at the initial stage of elongation is observed in each cycle of loading. The decrements of the measured temperature were larger and larger in the subsequent tensile tests changing from the value of $\Delta T \approx -0.18\,\mathrm{K}$ for the first cycle to the value of $\Delta T \approx -0.60\,\mathrm{K}$ for the fifth cycle.

From the figure it is seen, that the initial parts of deformation, found for each cycle, are situated on the same straight line, that describes the elastic deformation of the specimen and characterizes its material.

The point of the departure of the straight line $\Delta T = -k\Delta\sigma$ that is describing the elastic deformation, from the plot of measured temperature of the specimen, indicates the beginning of plastic deformation. Stress value corresponding to this point $\sigma_{pl\,T}$ is usually lower than $\sigma_{0.2}$ obtained as the elastic limit on the basis of $\sigma(\varepsilon)$ curve (Table 3). The value of the slope k, obtained from Fig.5, is equal to $1.28 \times 10^{-3}\,\mathrm{K\,mm^2/N}$. The value of the coefficient k, calculated for the specimen material using its handbook values, on the basis of Thomson formula, Eq (2.1), is equal to $1.25 \times 10^{-3}\,\mathrm{K\,mm^2/N}$. Hence, a good agreement between the values of k obtained from the experiment and from the calculations is observed.

The comparison of the values for the beginning of plastic deformation determined for the consecutive cycles of loading is given in Table 3; $\sigma_{0.2}$ was indicated using $\sigma(\varepsilon)$ curve as the basis, $\sigma_{pl\,T}$ was found on the basis of $\Delta T(\sigma)$ relation (Fig.5). Both values increase in the course of strain hardening in the subsequent cycles.

Table 3

Cycle	1	2	3	4	5
$\sigma_{0.2}$ [N/mm^2]	195	313	390	454	516
$\sigma_{pl\,T}$ [N/mm^2]	183	303	389	449	513

The departure from the straight line, manifesting the onset of the plastic deformation (Fig.5), becomes more abrupt in the following cycles, which can be attributed to material hardening in the previous cycles of straining.

3.2. Temperature effects of thermoelastic unloading

At the moment of unloading onset, the loading direction changes (Fig.6). Then a negative increment of stress occurs in the material still being subject to tension. Such negative stress increments induce positive increments in temperature, called the thermoelastic effect as during elastic compression. The increase in temperature is observed within the whole range of the thermoelastic unloading.

The temperature evolution of the sample obtained during five complete cycles of loading and unloading plotted vs. stress is shown in Fig.7.

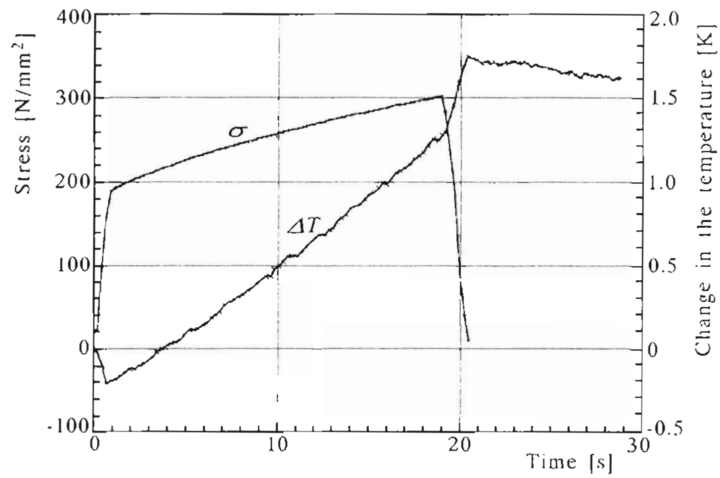

Fig. 6. Stress σ and temperature changes ΔT during a complete cycle of loading and unloading of stainless steel

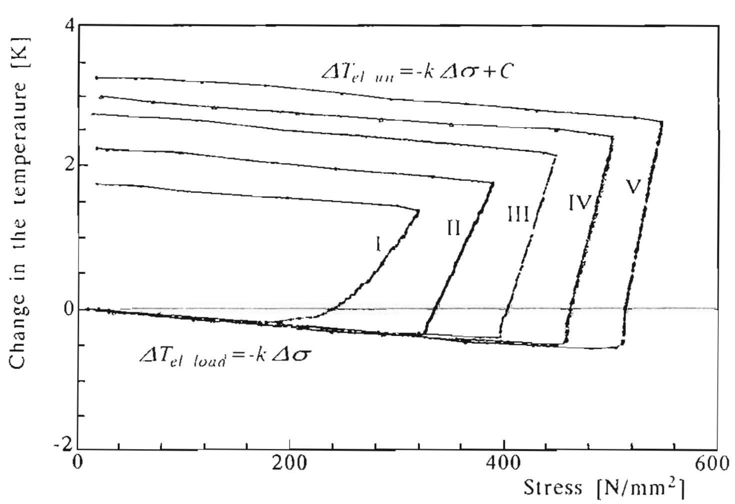

Fig. 7. Temperature changes of a stainless steel sample subjected to successive cycles of loading $\Delta\sigma > 0 \Rightarrow \Delta T < 0$ and unloading $\Delta\sigma < 0 \Rightarrow \Delta T > 0$ plotted as a function of stress

For each cycle of deformation, the initial elastic part of straining is described by a linear dependence $\Delta T_{el} = -k\Delta\sigma$ irrespective of the number of cycles.

The plastic deformation is featured by the following increasing part of the characteristics. The rate of this increase depends on the extent of the plastic deformation and it is higher in the subsequent cycles. Furthermore, some inflection points appear on the plastic parts of the characteristics, which can be attributed to the "overstresses", observed on $\sigma(\varepsilon)$ curves in the consecutive cycles obtained for more advanced state of the material strain hardening (Fig.3).

During the thermoelastic unloading, temperature rise is observed again. Moreover, the curves of $\Delta T_{el\,un}$ (unloading) vs. stress relations obtained for various cycles, are parallel to one another; they can be described by $\Delta T_{el\,un} = -k\Delta\sigma + C$ relations, where $\Delta\sigma < 0$, C – proper constant; and remain almost parallel to the straight line describing the initial elastic deformation of the material: $\Delta T_{el\,load} = -k\Delta\sigma$, where $\Delta\sigma > 0$.

The temperature changes registered for all five cycles of loading and unloading show that the temperature increments observed during the process of unloading become higher in the consecutive cycles of straining changing from $\Delta T \approx 0.45\,\mathrm{K}$ for the first cycle to $\Delta T \approx 0.76\,\mathrm{K}$ for the last cycle. The effects are behaving in a similar way to the thermoelastic effects registered during the initial stage of loading.

The first characteristic found for the initial state of material which is showing smooth transition from the elastic to plastic deformation (Fig.3 and Fig.7), is different from the other characteristics. During a significant part of the plastic deformation, it is still demonstrating a smooth parabolic dependence between the changes in temperature and stress related to a high rate of material hardening in this range of straining. Such a temperature characteristics behaviour is a manifestation of the mechanisms of plastic deformation, e.g. generation, motion, and annihilation of the defects, mainly dislocations. The defects supplying by growing strain lead to slip in individual grains, and then to coarse slip, operating in several slip systems.

The process of elasto-plastic transition and further plastic deformation in other cycles qualitatively proceeded in a similar way; it was caused by the development of secondary slip systems that were initiated at the end of the first cycle of straining.

The increase in temperature concomitant with the thermoelastic unloading results from the thermoelastic effect related to the compression test, since the material of the sample behaves like under compression. However, the internal structure of this material is a long way from the initial state. On the other hand, such a tangled dislocation structure, that developed at the end of the previous cycle of straining, is difficult to activate during the change of the loading direction. Nevertheless, one can expect that an insignificant number of mobile or faintly fixed dislocations can be set in motion and thus can effect slightly the temperature registered during unloading. Namely

$$W_{un} = W_{th\ un} + W_{pl}$$

where

W_{un}	–	energy dissipated during unloading
$W_{th\ un}$	–	energy related to purely thermoelastic unloading
W_{pl}	–	energy related to plastic deformation.

It is evident that the temperature increments found from $\Delta T(\sigma)$ characteristics (ΔT_{un}) during the unloading should be slightly higher than the temperature changes calculated on the basis of Eq (2.1) (ΔT_{th}). The comparison of these values is shown in Table 4. The obtained data confirms this presumption.

Table 4

Cycle	1	2	3	4	5
ΔT_{un} [K]	0.45	0.52	0.60	0.72	0.76
ΔT_{th} [K]	0.41	0.49	0.56	0.63	0.67

The temperature changes of stainless steel sample subjected to successive cycles of loading and unloading and described as a function of plastic deformation (Fig.8) confirm a thermoelastic nature of the initial and the final parts of the characteristics.

3.3. Microstructure and temperature evolution of stainless steel during its tensile deformation

The microstructure that develops as a result of plastic deformation creates a pattern of dislocations, which systematically accommodates the material to transferring the increasing loading. This accommodation entails the creation of new dislocations and the interaction of dislocations with grain boundaries, vacancies, foreign atoms etc. Dislocation mechanisms occur initially in proper (weaker) points of favorable oriented grains and lead to activation of "easy" dislocation sources in the primary slip system.

In the fully annealed austenitic steel that has been tested (FCC structure), the easy dislocation sources are as follows: carbide precipitates, general boundaries and steps in twin boundaries. The dislocation density is relatively low,

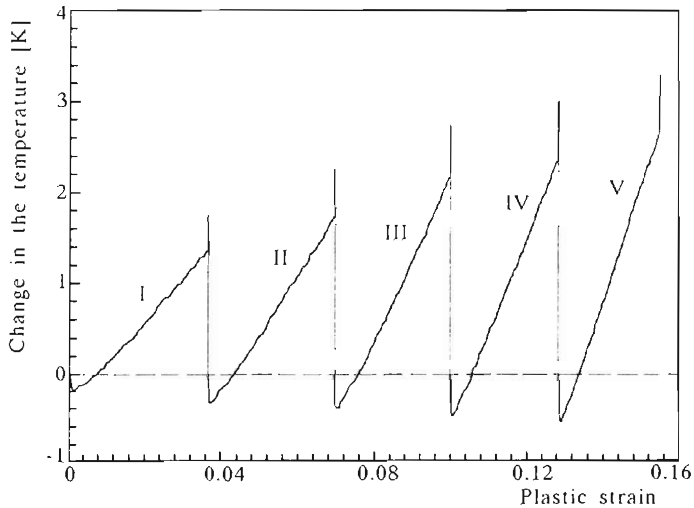

Fig. 8. Temperature changes vs. plastic deformation during successive cycles of loading and unloading of stainless steel sample

the dislocations are randomly distributed in the matrix and in the grain boundaries; no dislocation arrangements were observed prior to straining (Hirsh, 1975; Oliferuk et al., 1995). (Material of the sample subjected to investigations by Oliferuk et al. (1995, 1996, 1997) and by Pieczyska (1998) were derived from the same ingot and subjected to similar heat treatment).

During the initial stage of plastic deformation, pile-ups of dislocations (high energy dislocation structures) are the only possible configurations that can act in the primary slip system in this kind of steel (Bay et al., 1992). This was confirmed by Oliferuk et al. (1995, 1997) by the observations carried out by means of an electron microscope. The dominating sources of heat emission are the mechanisms related to the movement of dislocations: overcoming the Peierls barriers and phonon drag.

The grains, which have random orientation in relation to the applied stress before straining have to conform their shape to the shape and state of the sample. It proceeds by occurrence and development of elastic forces between grains leading to slip in some of them. These effects can be perceived during macroscopic observations of the samples surface, which was observed by Korbel (cf Oliferuk et al., 1996). The conformation necessary to preserve material continuity, was called the elastic accommodation and it is related to material kinematics hardening.

As the strain increases, extensive dislocation pile-ups occur on random boundaries. The density of dislocations becomes various in particular grains; in general it is higher in the vicinity of the grain boundaries than in the grain centers, which results in the concentration of stress on the grain boundaries.

At the upper stress and strain level the dislocation density in the grain interior and in its vicinity eventually become similar; finally coherent motion of dislocation trains along the specific slip system sets in. This stage of deformation can be related to the origin and initiation of low energy dislocation structures, according to the general principle of free energy minimization (Bay et al., 1992; Oliferuk et al., 1995) It manifests itself by the increase in energy dissipation in subsequent cycles of straining (Fig.4).

As a result of the processes that proceeded during the initial cycle of deformation, the material subjected to the second cycle of straining was more defected and, moreover, it had been accommodated to the direction of loading. Besides, some processes of recovery likely occurred while the sample was subjected to unloading and cooling. These processes of recovery resulted in the increase in critical shear stress value, so a higher stress is required to "move" the material into the process of plastic deformation. It allows the sample to deform elastically to a larger extent. After reaching the level of the actual critical shear stress, an abrupt coherent motion of dislocation trains along the specific slip system sets in. The internal elastic stresses are then partially relaxed, and the temperature of the sample suddenly begins to increase. It corresponds to the appearance of the yield point on $\sigma(\varepsilon)$ curves (Fig.3). The inflection points, noticeable on the plastic part of $\Delta T(\sigma)$ (Fig.7) characteristics is probably an attribute of the final points of the influence of the overstresses on the stress-strain curve. It would confirm the dislocation nature of the overstresses.

The same character of $\Delta T(\sigma)$ and $\sigma(\varepsilon)$ characteristics obtained for $2 \div 5$ cycles of straining indicates that the processes of elasto-plastic transition and further plastic deformation occur during these cycles in a similar way. It is caused by the development of secondary slip systems: cross slip, tangles of dislocations and annihilation of dislocations resulting in the progressive dislocation entanglement. It makes the dislocation motion progressively more difficult and leads to the observed increase in the yield stress more pronounced in the following cycles. That is why the transition from the elastic to the plastic deformation becomes more abrupt in the subsequent cycles of straining and the temperature rise corresponding thereto becomes higher and higher.

The more advanced plastic deformation and the lower rate of strain hardening in the last cycles is concomitant with the large heat emission and high temperature rise. It is probably caused by the fact that after the barriers of dislocations were interrupted, larger number of dislocations were released.

4. Thermoelastic and thermoplastic effects in austenitic steel samples after rolling

The austenitic steel samples after 50% of rolling revealed different features than the samples after annealing. They have been strongly plastically deformed during the machining, which was confirmed by the structure and microstructure investigations. Coarse slip bands, overcoming the neighbour grains were observed in the material prior to the straining (Fig.9). This was the reason, why the full experimental programm, e.g. five cycles of straining could not be realized – the samples have broken during the first, second, third or fourth cycle of straining.

The stress-strain characteristics, obtained during consecutive deformation of one of the samples after rolling, is shown in Fig.10. The sample had broken during the fourth cycle of straining. The curve is an estimation of $\sigma(\varepsilon)$ characteristics, since the actual cross section was not taken here into account because of the localisation.

The temperature distributions, registered during the test indicate, that the deformation was homogeneous within the initial, elastic range of straining. This homogeneity was sustained in the following cycles, which allows us to investigate the evolution of thermoelastic effect during subsequent cycles of straining.

Fig.11 shows that the value of the thermoelastic effect measured in the first cycle of straining for the steel after rolling, is five times higher than obtained for the same material after full annealing (Fig.5). The increase in temperature measured in the initial range of deformation changes from $\Delta T = -1.05\,\mathrm{K}$ for first, to $\Delta T = -1.20\,\mathrm{K}$ for second, $\Delta T = -1.26\,\mathrm{K}$ for third, and $\Delta T = -1.16\,\mathrm{K}$ for the fourth cycles of straining, respectively. Such a high temperature decrease in the elastic range of deformation is a result of previous material hardenning caused by rolling. The resolved shear stress is higher in the material after rolling, which was the reason for the material to increase in the range of elastic deformation.

Simillarly to the samples after full annealing, the initial parts of characteristics $\Delta T(\sigma)$ can be described by one straight line $\Delta T = -k\Delta\sigma_s$, where the value of k is equal to $1.60 \cdot 10^{-3}\,\mathrm{K\,mm^2/N}$. The value of k found for the samples after rolling is about 30% higher than the value of k obtained from $\Delta T(\sigma)$ for the steel after full annealing $(1.28 \cdot 10^{-3}\,\mathrm{K\,mm^2/N}$; Fig.5) and from theory $(1.25 \cdot 10^{-3}\,\mathrm{K\,mm^2/N})$. Therefore, it can be concluded, that the initial hardenning by rolling, changes the properties of steel also in the elastic range of deformation. It can be derived from Thomson formula, that

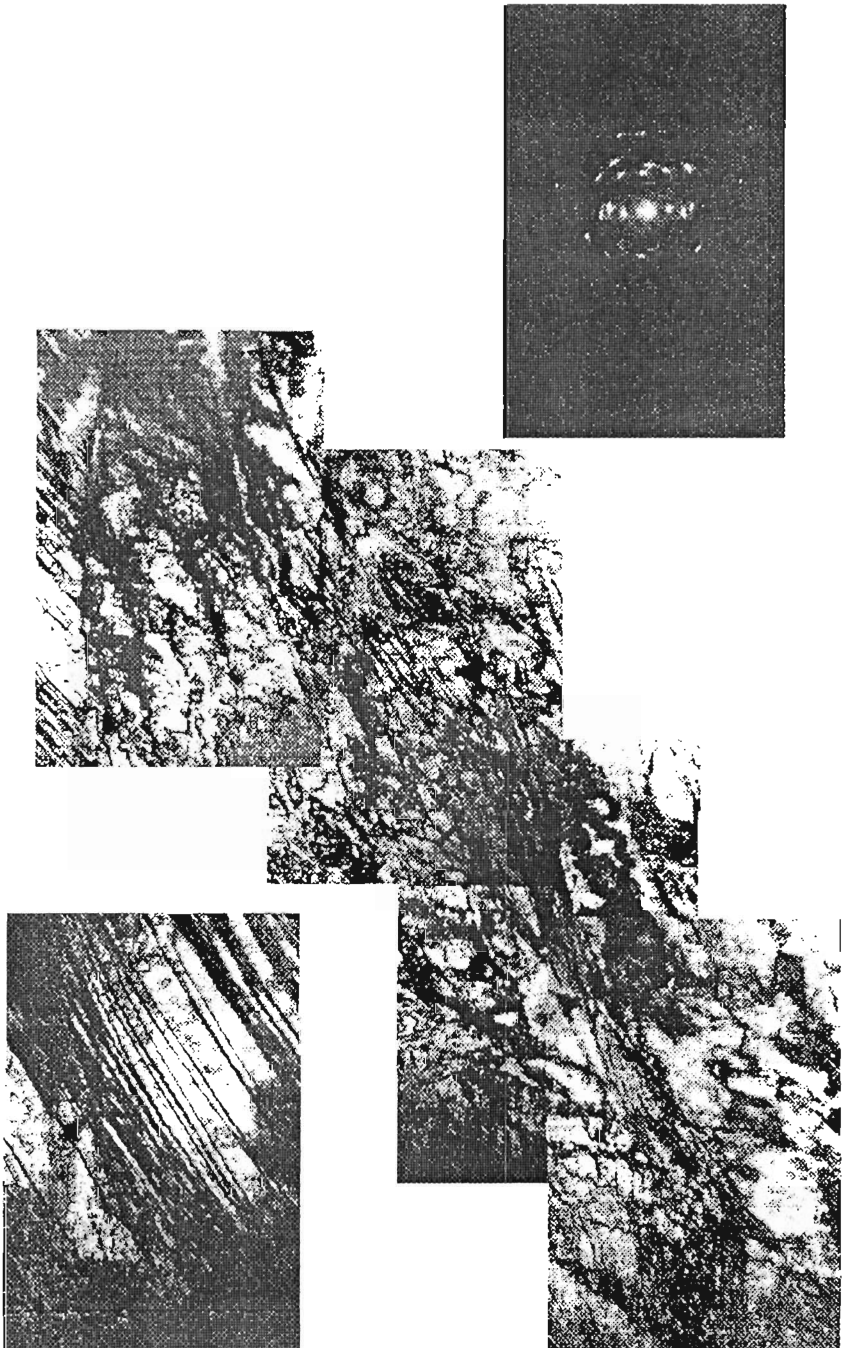

Fig. 9. Transmisson electron microstructure samples after 50% of rolling in the initial state

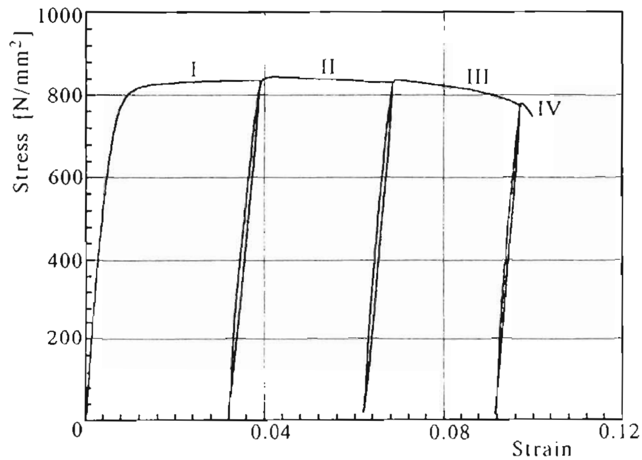

Fig. 10. Dependence of stress vs. strain during consecutive cycles of loading and unloading of specimen of stainless steel after rolling

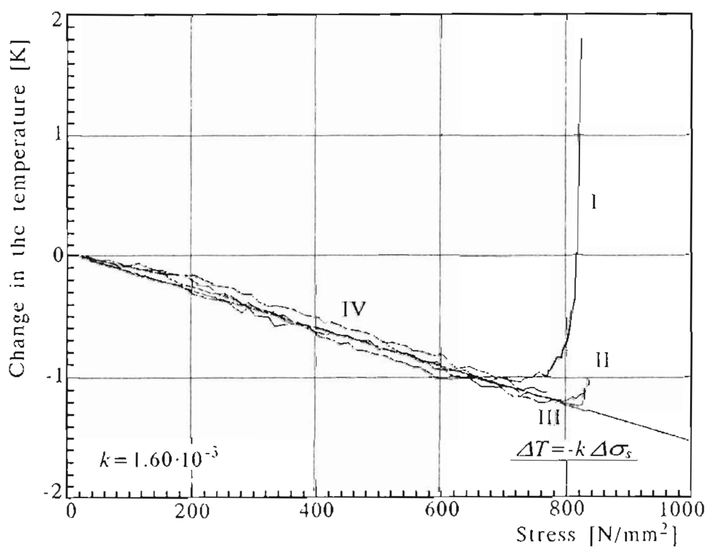

Fig. 11. Changes of temperature of a specimen of stainless steel after rolling vs. stress during initial stage of successive cycles of loading

$k = -\alpha T/(c_p \rho)$. Since all the investigations were carried out at the same temperature (295 K) and we know that the material density ρ decreases slightly, the value of ratio α/c_p should decrease by $\approx 30\%$ as a result of rolling.

Comparison between the yield limit stresses obtained for the steel after rolling using $\sigma(\varepsilon)$ curve $(\sigma_{0.2})$, and on the basis of characteristics $\Delta T(\sigma)$ $(\sigma_{pl\,T})$ is given in Table 5.

Table 5

Cycle	1	2	3	4	5
$\sigma_{0.2}$ [N/mm^2]	185	282	370	440	485
$\sigma_{pl\,T}$ [N/mm^2]	173	273	360	435	480

The everage yield limit stress is found to be much higher than that for steel after annealing (Table 3).

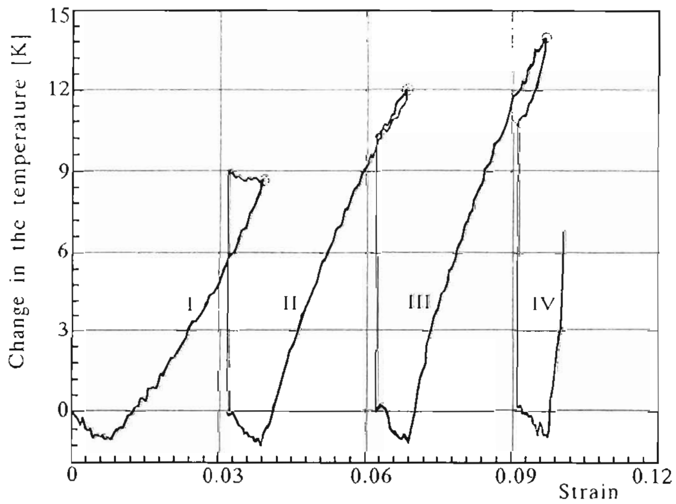

Fig. 12. Temperature changes vs. deformation in localisation area during successive cycles of loading and unloading of the sample of stainless steel after rolling

Analysis of thermograms (the temperature distributions registered during the test) indicate, that in the material after rolling just after crossing the range of elastic deformation, a localisation of plastic deformation takes place. Such a localisation is developing in the subsequent cycles of straining. It was confirmed by heterogeneous temperature distributions on the sample surface and significantly higher temperature increase in the area of localisation. The temperature changes found for the sample after rolling in localisation area for subsequent cycles and described as a function of deformation are shown in Fig.12. More detailed description of evolution of the localisation of plastic deformation in the samples after rolling was presented by Pieczyska (1998).

Looking at Fig.12 and Fig.4 one can observe, that both thermoelastic and thermoplastic effects are higher in the samples after rolling. However, within the elastic range of straining the temperature changes in the sample after rolling (Fig.12) are not such significantly decreasing in subsequent cycles as for the material not previously deformed (Fig.4). Furthermore, in the material after rolling, no effects of thermoelastic unloading due to localisation were registered.

5. Summary and conclusions

- Experimental results of the effects of thermomechanical coupling occurring during loading and unloading of an austenitic steel subjected to uniaxial tensile deformation were presented. Both mechanical and thermal characteristics registered during elongation test depend on the initial state of material and, moreover, their run evolves in the course of the metal hardening in the subsequent cycles of straining.

- In each cycle of straining the thermoelastic effects, i.e. the decrease of temperature in the initial stage of elongation and the increase of temperature during the thermoelastic unloading were observed. For all cycles the temperature changes vs. stress in elastic range of deformation are described by the same linear dependence $\Delta T_{el} = -k\Delta\sigma$, where the coefficient k can characterise the material of the sample. The parts of characteristics $\Delta T(\sigma)$ related to the thermoelastic unloading are parallel to each other and remain almost parallel to the straight line, describing the initial, elastic deformation.

- The values of thermoelastic effects found for the steel after rolling are greater than those obtained for the material after full annealing.

- Qualitative change of the nature of sample temperature behavior, in elastic and plastic ranges, allows for indication of the beginning of plastic deformation, since the macroscopic irreversible plastic deformation begins when the adiabatic dependence $\Delta T(\sigma)$ ceases to be a straight line.

- Only the first characteristic obtained for the initial undeformed state of material shows a smooth parabolic transition from the elastic to the plastic deformation, observable both in mechanical $\sigma(\varepsilon)$ and in thermal $\Delta T(\sigma)$ characteristics. The process of elasto-plastic transition and further plastic deformation in the following subsequent cycles is occurring similarly; it was caused by the development of secondary slip systems, that have been initiated at the end of the first cycle of straining.

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Wpływ umocnienia materiału na efekt termosprężysty stali austenitycznej

Streszczenie

W pracy wykazano w sposób doświadczalny, że ze wzrostem umocnienia, co wiąże się ze zwiększeniem ilości i ewolucją defektów w materiale, wzrasta efekt termosprężysty oraz efekt termosprężystego odciążania. Umocnienie realizowano drogą kolejnych cyklicznych obciążeń, jak również odpowiednią wstępną obróbką materiału.

Badaniom poddano próbki takiej samej stali austenitycznej o dwóch różnych stanach wyjściowych: po wygrzewaniu ujednoradniającym oraz po 50% umocnieniu w wyniku walcowania na zimno.

Badania przeprowadzono na maszynie wytrzymałościowej, rejestrując jednocześnie zmiany temperatury przy wykorzystaniu zestawu termowizyjnego z komputerową rejestracją i obróbką wyników doświadczalnych. Na podstawie charakterystyk mechanicznych oraz zmiany temperatury materiału próbki zbadano termosprężyste oraz termoplastyczne efekty sprzężeń termo-mechanicznych. Wykazano, że efekty tych sprzężeń wzrastają w miarę wzrostu umocnienia materiału.

W próbkach po walcowaniu przeanalizowano rozwój lokalizacji odkształcenia plastycznego. Zaobserwowano, że odkształcenie plastyczne zlokalizowane podczas pierwszego cyklu, rozwija się w tym samym miejscu w kolejnych cyklach deformacji. Wyższy wzrost temperatury w próbkach po walcowaniu występuje w miejscu lokalizacji, natomiast w miarę wzrostu odległości od tego miejsca stwierdzono coraz mniejsze przyrosty temperatury.

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