MECHANIKA TEORETYCZNA
I STOSOWANA
Journal of Theoretical
and Applied Mechanics
2, 34, 1996

APPLICATION OF INFRARED RADIATION DETECTION TO THE METAL BEHAVIOUR INVESTIGATION UNDER MECHANICAL LOADING

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The experimental methods of metal testing, being producent, employed and under development in Laboratory of Thermoplasticity of Institute of Fundamental Technological Research, based on contactless measurements of the temperature field are presented. These methods are: determination of the onset of plastic deformation on a macroscopic scale during the uniaxial tension, observation of the non-uniform and localised deformation in the samples under mechanical loading, determination of the stored energy during the uniaxial tensile deformation of austenitic steel.
The present paper includes also the essence of non-contact measurement of temperature method and presents the integration of 680 AGA Thermovision System with the PTR WIN System, which allows for digitising and then storing the thermal images on hard disk.

1. Introduction

Deformation processes always modify the temperature field of a material. This phenomenon called thermomechanical coupling has been observed for a long time by experimentalists (cf Bojar (1983); Chrysochoos and Martin (1989); Chrysochoos et al. (1989); Klepaczko (1975), (1978); Krempel (1985); Tandon and Tangri (1975); Taylor and Quinney (1934)).

Immediately after loading of the elastic-plastic material the elastic deformation dominates, whereas the plastic contribution, although marked in some individual grains (cf Tandon and Tangri (1975)), does not produce any observable macroscopic effect. In the elastic stage of deformation under adiabatic conditions, the temperature of the deforming sample changes. This temperature change is caused by mutual conversion of the potential and kinetic energy

of lattice atoms and can be explained within the framework of linear thermodynamics. During the homogenous uniaxial elastic deformation, on the assumption of linear and isotropic material elastic behaviour, the adiabatic temperature change can be expressed by the Kelvin formula

$$\Delta T = -\frac{\alpha T \Delta\sigma}{c_\sigma} \tag{1.1}$$

where

α – coefficient of linear thermal expansion

T – initial absolute temperature

$\Delta\sigma$ – change in the uniaxial Cauchy stress tensor

c_σ – heat capacity per unit volume at constant stress.

It follows from Eq (1.1) that, in "normal" materials having a positive coefficient of thermal expansion, the temperature decreases during adiabatic elastic extension and increases during adiabatic compression. The phenomenon of temperature change accompanying the elastic deformation is named thermoelastic effect.

During the deformation process an instant appears at which the temperature of sample suddenly increases, because a certain amount of the mechanical energy expended in plastic deformation is dissipated. At this stage the macroscopic plastic deformation becomes dominant. Such an increase in the temperature can be used to determine the onset of macroscopic plastic deformation.

The measurements of the temperature field of the sample under mechanical loading allow one to investigate the non-uniform and located deformation. Such temperature measurements are also necessary for studying the energy balance during the plastic deformation.

The aim of the present paper is to present the experimental methods of metal testing based on the contactless measurement of temperature fields, elaborated and under development in the Laboratory of Thermoplasticity of Institute of Fundamental Technological Research.

The methods are:

- Determination of the onset of the plastic deformation on a macroscopic scale during the uniaxial tension
- Observation of the non-uniform and located deformation in the samples under mechanical loading
- Determination of the stored energy during the uniaxial tensile deformation of austenitic steel.

2. Temperature measurements based on infrared radiation detection

Every object of the temperature greater than 0 K emits electromagnetic radiation in a infrared (IR) range.

Max Planck described the spectral distribution of black-body radiation by means of the following formula

$$M_{\lambda bb} = \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT} - 1\right)} 10^{-6} \tag{2.1}$$

where

M – black-body spectral radiant emittance within the spectral interval 1 μm at the wavelength λ

c – speed of light, $c = 3 \cdot 10^8$ m/s

h – Planck constant, $h = 6.6 \cdot 10^{-34}$ Js

k – Boltzmann constant, $k = 1.4 \cdot 10^{-23}$ J/K

T – absolute temperature of the black-body and λ wavelength.

Integrating Planck's formula from $\lambda = 0$ to $\lambda = \infty$ we obtain the total emissive power M_{bb} of black-body

$$M_{bb} = \xi T^4 \tag{2.2}$$

where ξ is the Stefan-Boltzmann constant, $\xi = 5.7 \cdot 10^{-8}\,\mathrm{Wm^{-2}K^{-4}}$.

The contactless temperature measurements are based on the Stefan-Boltzmann formula (2.2), stating that the total emissive power of black-body is a single-valued function of its temperature. Thus, by measuring the IR radiation power, it is possible to determine the temperature of the tested object. Such a measurement does not disturb the temperature field of this object. The temperature measurement based on the infrared (IR) radiation detection is almost free from inertial effects.

The IR radiation emitted by the object under test falls on the detector. The electric signal appearing on the detector output is proportional to the power of this radiation. This signal can be amplified and processed in various ways.

However, the real objects behaviour never comply Eqs (2.1) and (2.2). There are three interacting factors which prevent an object from acting like a black-body. They are absorptance δ, reflectance α, and transmittance τ. The sum of the aforementioned three factors must always add up to unity for

any object and any wavelength. Thus

$$\delta_\lambda + \alpha_\lambda + \tau_\lambda = 1 \tag{2.3}$$

For non-transparent materials $\tau_\lambda = 0$, and then

$$\delta_\lambda + \alpha_\lambda = 1 \tag{2.4}$$

Another factor, required to describe the IR radiation produced by real object is called emissivity. The spectral emissivity ε_λ is defined as the ratio of spectral radiant emittance from an object to that from a black-body at the same temperature and wavelength.

According to Kirchoff's law, for any material the spectral emissivity is equal to the spectral absorptance of a body at any specified temperature and wavelength. Thus

$$\alpha = 1 - \varepsilon_\lambda \tag{2.5}$$

Taking emissivity into account the Stefan-Boltzmann formula for real object takes the form

$$M = \varepsilon \xi T^4 \tag{2.6}$$

where ε is the average emissivity within the range from $\lambda = 0$ to $\lambda = \infty$.

When the object is non-transparent, the formula for the complex IR detector response signal S can be written as

$$S = \varepsilon f(T_0) + (1 - \varepsilon) f(T_a) \tag{2.7}$$

where

T	–	object temperature
T_a	–	ambient temperature
$\varepsilon f(T_0)$	–	signal as a function of the object temperature
$(1 - \varepsilon) f(T_a)$	–	signal as a function of ambient temperature.

As a result, in order to determine the non-transparent object temperature the emissivity of this object, ambient temperature and function $f(T)$ which is the calibration curve of IR detector or whole measurement instrument must be known.

In the experiments described hereafter the temperature of sample surface was determined using the Thermovision System of 680 type, manufactured by AGA Company. It is equipped with the indium antimonide (InSb) IR detector. The response time of this detector is shorter than one microsecond. However the response of the InSb detector is limited to wavelengths shorter than $5.5\,\mu$m.

The Thermovision System principle of operation is as follows: an optical-mechanical scanner scans the tested surface and focuses the IR radiation on the InSb detector, which converts the IR signal into an electrical video one. The scanner allows obtaining the thermal image of tested surface.

Operation of the Thermovision System 680 is modified by application of the PTR WIN System manufactured by CEDIP Company. The PTR WIN consists of the image capture board and the PTR 9020 software running under WINDOWS. The image capture board allows to digitise video signal into 12 bits numerical signal at the sampling frequency =1 MHz. The video signal can be divided into 4090 digital levels.

A thermal image is displayed on the computer screen where each colour tone correspond to the specific power of IR radiation. The number of pixels per line equals 250. The PTR WIN System allows digitising and then storing in the hard disk a film of IR images (16 frames per second). This is of particular interest when studying transient thermal phenomena, for example the sample temperature increase during the deformation process. The PTR 9020 software allows the digital processing of thermal images. The software offers possibility for masking zones on the screen. In these zones measurements of minimum, maximum and average temperature values can be taken and the area of each zone can be calculated. An emissivity value for each zone must be known. The PTR 9020 software allows measuring temperature of selected spots of the tested surface and determining the co-ordinates of those spots. The temperature along an arbitrary selected line of the tested surface can also be measured.

The integration of the Thermovision System 680 with PTR WIN System resulted in the state-of-the-art instrumentation basis.

The PTR WIN System has been bought by the Foundation for Polish Science.

3. Determination of the onset of plastic deformation on a macroscopic scale

When certain materials such as some of austenitic steels are deformed in tensile tests, it is found that the stress-strain curve is smooth (Fig.1). In such a case determination of the yield begining is more difficult than in materials in which the Luders bands take place.

The plastic deformation may occur immediately after loading in some adequately oriented grains of the sample but the dominant deformation mode is

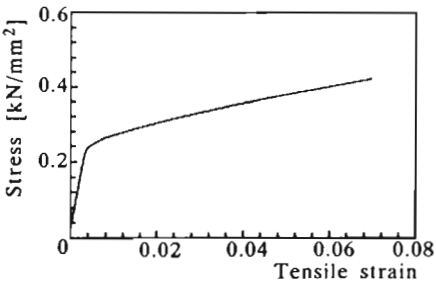

Fig. 1. The stress-strain curve obtained during tension of austenitic steel

elastic. The development of micro-plastic deformation causes that the stress at which plastic deformation or yielding is observed to begin, depends on the sensitivity of measurements and the determination of yield initiation on macroscopic scale becomes a matter of convention.

Usually it is assumed that plastic deformation begins when on a given experimental set-up any macroscopic parameter describing the material behaviour shows detectable irregularities.

The majority of methods for determining the onset of elastic deformation are based on the stress-strain curve (cf Dieter (1985)). In tests of materials under uniaxial loading, three criteria of the initiation of yielding have been applied: elasticity limit, proportionality limit, and yield strength. The elasticity limit is the greatest stress the material can withstand without any measurable permanent deformation remaining after the complete unloading. As the sensitivity of strain measurement increasing, the value of elasticity limit decreases until it reaches the true elasticity limit determined from micro strain measurements. Determination of the elasticity limit requires a tedious incremental loading-unloading test procedure. For this reason, it is often replaced by the proportionality limit.

The proportionality limit is the highest stress at which stress is directly proportional to strain. It is obtained by observing deviation from the straight-line part of the stress-strain curve.

The yield strength is the stress necessary for producing a small specified amount of plastic deformation. It is usually specified as 0.2% strain.

Measurements of temperature field of the tested sample offer the possibility of determination of the instant at which plastic deformation begins basing on the thermomechanical coupling. When the sample subject to an uniaxial tensile test within the range of elastic strain a thermoelastic effect is observed. The sample temperature falls initially below the ambient temperature.

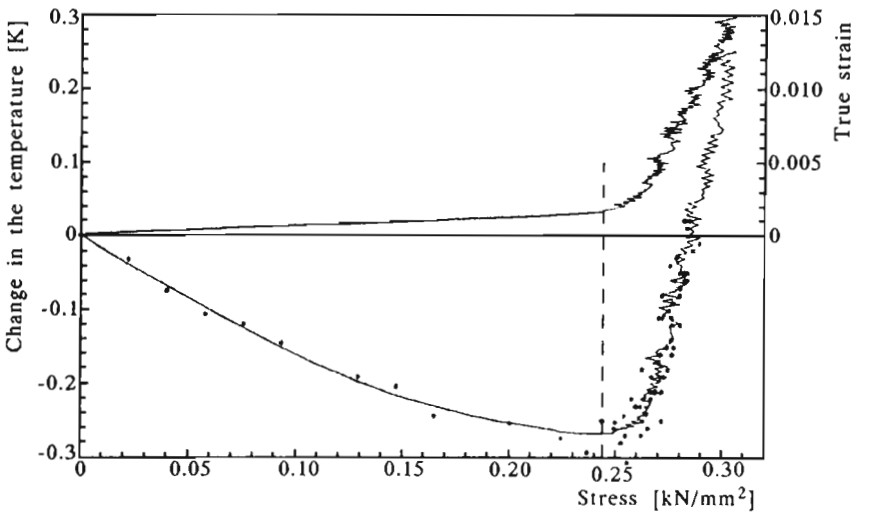

Fig. 2. The dependencies of strain and change in the surface temperature on stress in very early stage of tension

Even in early stages of straining, due to micro-yields some irreversibility appears. With growing stress the sample temperature reaches minimum and then starts to rise rapidly. Sample dependencies ΔT and ε vs. σ, obtained by author, in a very early stage of the uniaxial tensile tension of austenitic stainless steel are presented in Fig.2, ΔT is the surface average temperature of the sample gauge part. The experiment was performed on a specially prepared batch of austenitic steel of the percentage: 0.05 wt%C, 1.35 wt%Mn, 1.0 wt%Si, 0.016 wt%P, 0.008 wt%S, 18.58 wt%Cr, 17.3 wt%Ni, 0.025 wt%W, 0.02 wt%Mo, 0.04 wt%Cu, 0.03 wt%V, 0.013 wt%Ti and balance Fe. The samples were strained on an Instron machine at the constant strain rate, which equaled $0.002\,s^{-1}$. The temperature distribution on the sample surface was measured by means of the Thermovision System 680 with application of the PTR WIN System. A very rapid increase of the surface temperature of the sample after the minimum enables assuming that the heating of sample due to micro-plastic deformation before the temperature minimum is reached is negligibly small. Consequently, the stress corresponding to the minimum can be assumed to be the critical resolved stress at which plastic deformation on the macroscopic scale begins. The instant at which the temperature reaches the minimum value can be found more precisely then the point when the stress-strain curve ceases to be the straight-line. A unique feature of the presented approach is the stress value corresponding to the temperature minimum, in-

dependence of the sensitivity of measurements.

It has been found that in tested steel the critical resolved stress determined on the base of the termomechanic coupling is equal to the value determined on the base of the stress-strain curve (Fig.2). This fact can be useful for thermodynamic description of the tested steel behaviour.

Some investigators assume that during uniaxial adiabatic tension the plastic deformation on macroscopic scale begins when the ΔT vs. σ relation obtained experimentally starts to be non-linear (cf Gabryszewski and Pindur (1985)). Such assumption requires fulfilling the adiabatic straining conditions. Moreover the value of yield stress obtained on the base of this assumption suffers from the same errors as the value obtained following the methods based on the stress-strain curve, since in depends on the sensitivity of measurements.

4. Observation of non-uniform and localised deformation

In early stages of straining pure metals and alloys, which in the initial state have low and uniform dislocation density, exhibit deformation patterns, which on macroscopic scale, are homogeneous. With continued straining the plastic deformation and microscopic shear bands appear. Subsequently they organise into macroscopic shear bands (cf Korbel and Martin (1986); Korbel and Richert (1985); Korbel et al. (1986)). The result of shear band propagation is necking which we can observe in the deformed sample.

For monitoring a sample under mechanical loading the Thermovision System 680 with the PTR WIN System can be used. We can obtain and store in a hard disk 16 IR images of the sample surface per second.

When the sample deformation is uniform its surface is isothermal. This effect during uniaxial tensile straining of the austenitic stainless steel is shown in Fig.3. The IR images are converted by the PTR WIN System into the images of temperature field on the sample surface. With growing strain the temperature of the sample rises, however in the initial stages of straining the sample surface retain isothermal (Fig.3).

Some images of the temperature distribution on the sample surface corresponding to higher values of strain show that the non-uniform and localised deformation has appeared. Fig.4 shows the beginning and evolution of localised plastic zone during the uniaxial tension of austenitic stainless steel at the strain rate $\dot{\varepsilon} = 0.002\,\mathrm{s}^{-1}$.

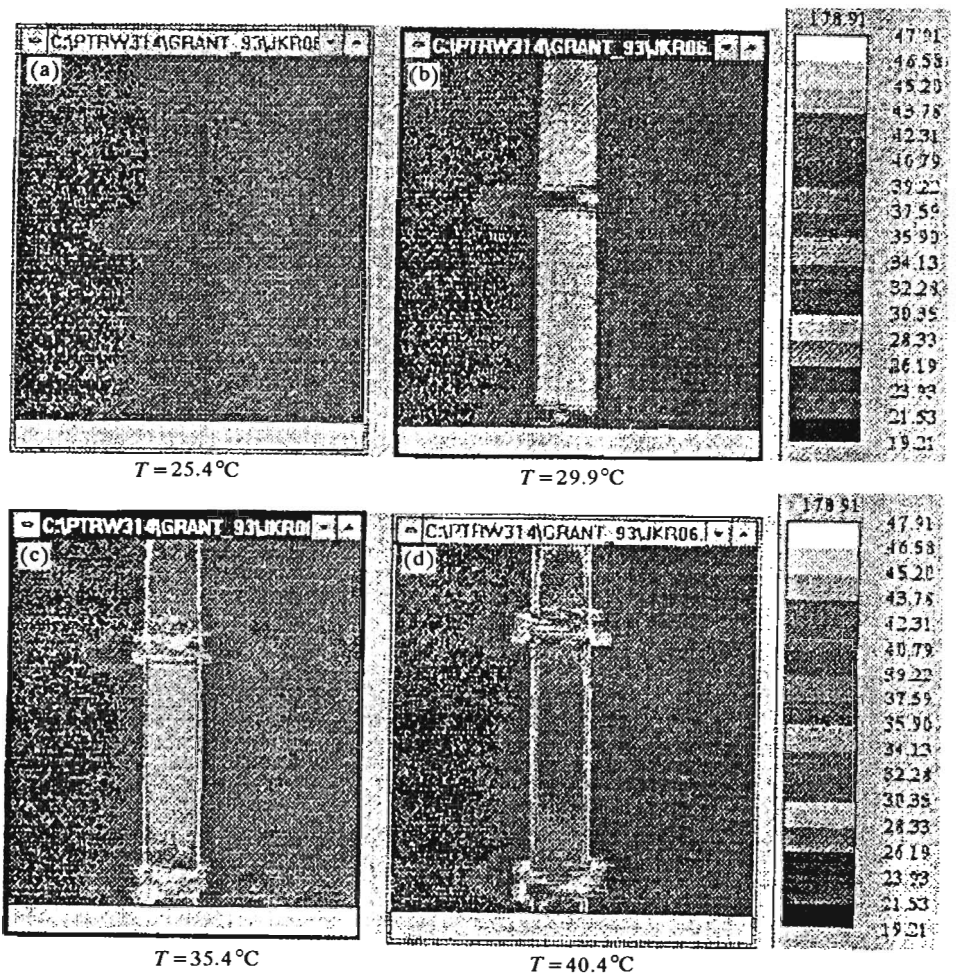

Fig. 3. Temperature distribution over the gauge part of sample of austenitic steel during the initial stage of uniaxial tension ($\dot{\varepsilon} = 0.002\,s^{-1}$); (a) – $\varepsilon = 0.05$, (b) – $\varepsilon = 0.14$, (c) – $\varepsilon = 0.22$, (d) – $\varepsilon = 0.30$

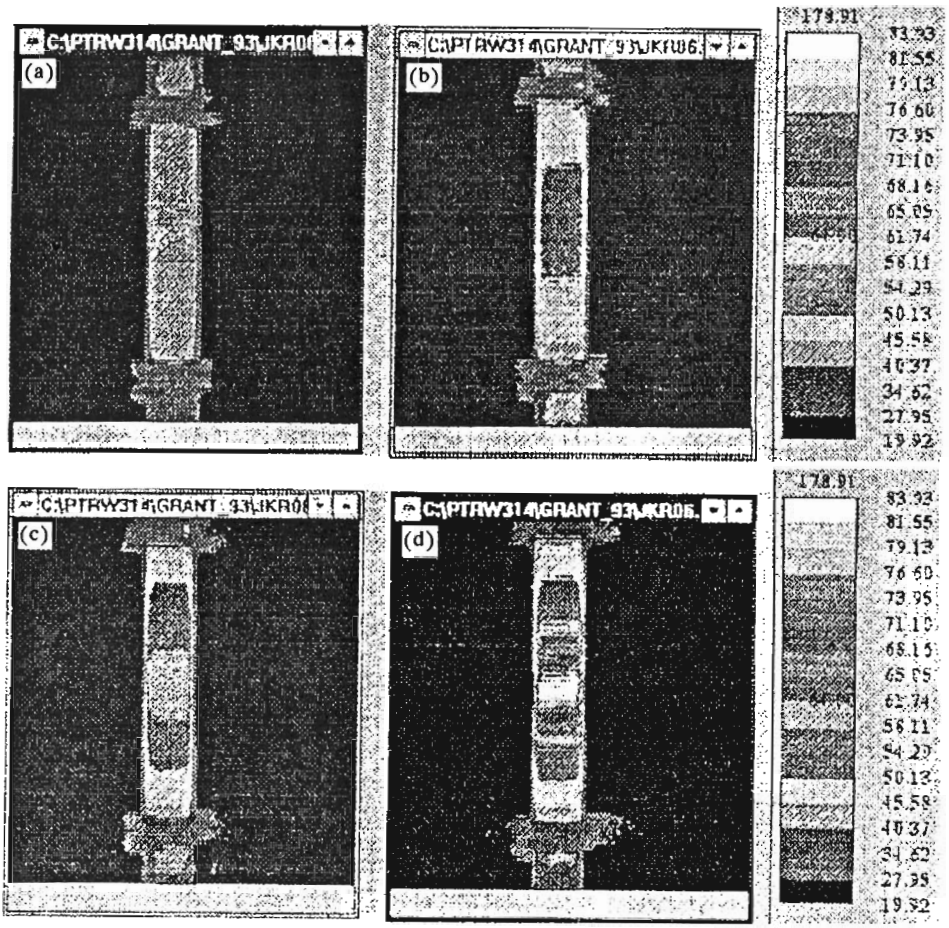

Fig. 4. Evolution of the localised plastic zone during the uniaxial tension of austenitic steel ($\dot{\varepsilon} = 0.002\,\mathrm{s}^{-1}$); (a) - $\varepsilon = 0.36$ the initiation of the localised plastic zone, (b) - $\varepsilon = 0.43$, (c) - $\varepsilon = 0.47$, (d) - $\varepsilon = 0.51$

The necking is associated with reaching the ideally plastic state. It corresponds to the maximum of the σ vs. ε dependence, where σ is a stress and ε is a strain. Using the Thermovision System we have been able to predict location of the necking along sample. Relating IR or temperature images of the sample under straining to the σ vs. ε curve we can determine the value of σ or ε at which, for a given material, non-uniform deformation appears. We can also determine increase of the maximum or average temperature value of the sample surface during straining. The results for uniaxial tensile straining of austenitic stainless steel are shown in Fig.5. On the σ vs. ε curve the points

at which the temperature images of the sample surface have been presented are marked. The e point corresponds to the instant, in which non-uniform deformation appears (Fig.4 and Fig.5).

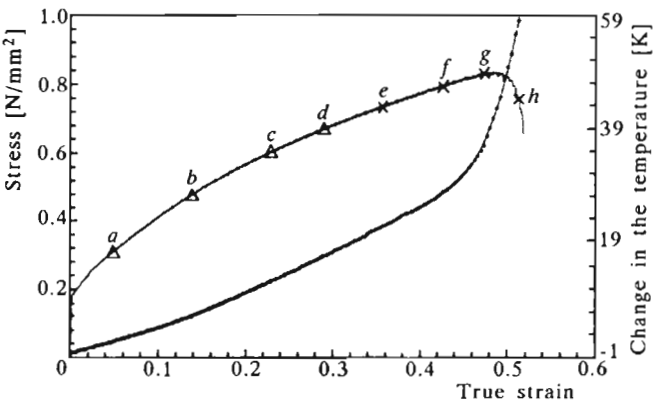

Fig. 5. The increase of maximum temperature value on the surface of the gauge part of the sample and the stress-strain curve obtained during tension of austenitic steel. The points at which the temperature images of sample surface were presented are marked

5. Method of stored energy measurements

When metals are cold worked, a certain amount of the mechanical energy E_w expended in plastic deformation is retained in the structure of material while the remaining amount of energy is dissipated in the form of heat Q_d. The retained amount energy is called the stored energy E_s. It has been found experimentally that changes in the stored energy amount appear on a microscopic level mainly due to the generation, blocking and annihilation of dislocations leading to changes in the density and arrangements of dislocations. Thus the process of energy storage is a macroscopic manifestation of these microscopic phenomena. The storage of energy is usually characterised by the dependence of E_s on strain or E_w. The energy E_s and the ratio E_s/E_w at each moment of deformation depend on the deformation history. The energy conversion at a given instant should be determined by the instantaneous rate dE_s/dE_w of energy storage (cf Bever et al. (1973); Oliferuk et al. (1985)). This quantity is calculated by differentiation of E_s as a function of E_w, provided that the function is determined by dynamic measurements, i.e. no

interruptions during the deformation occure. The dependence of dE_s/dE_w on E_w reflects the change of the dislocational processes, leading to the energy conversion at a given instant.

Unfortunately, none of the methods employed so far for determination of stored energy has met the requirement of being instantaneous. The so-called two-step method, which consists in measuring the energy released from a deformed sample during annealing, does not permit observation of the process of energy storage but only of the heat effects related to the processes of recovery and recrystallization (cf Bell (1965); Bojarski et al. (1980); Lugscheider and Wildhack (1968); Wencel (1963ab)). However, although single-step methods based on the deformation of a material in a calorimeter enable the ratio $\delta E_s/\delta E_w$ of the increment of stored energy to the increment of expended energy to be determined, they do not allow continuous measurements of E_s versus deformation to be made, as the particular values of $\delta E_s/\delta E_w$ are determined for successive deformation steps and, at the beginning of each step, the load acting on the sample equals zero (cf Williams (1964)).

In the present paper modification of the single-step method which allows the energy storage to be determined without interruption of the deformation process is described. This method has been worked out in the Laboratory of Thermoplasticity in the IFTR.

As in other single-step methods, the stored energy is determined as the difference between the mechanical energy supplied to and the heat released from the sample during deformation. However, the heat released is determined in the present investigation by semi-continuous detection of the IR radiation emitted directly from the strained sample and so the necessity for unloading of the sample after successive strain increments is avoided.

Metals usually exhibit elastic-plastic properties. Therefore the energy E_m expended by tensile machine during quasi-static deformation of the gauge part of sample can be decomposed as follows

$$E_m = E_e + E_w \tag{5.1}$$

where E_e is the energy expended in elastic deformation and E_w – the energy expended in plastic deformation of the gauge part of sample. The energy E_w can further be decomposed into the energy dissipated in the form of heat Q_d and the energy E_s stored in the structure of the material

$$E_w = E_s + Q_d \tag{5.2}$$

Consequently

$$E_s = E_w - Q_d \tag{5.3}$$

After unloading the sample at low temperature the stored energy is equal to the change in the internal energy.

In the case of tensile tests the instantaneous value of the energy E_w can be found with high accuracy from the force vs. elongation curve (Fig.6).

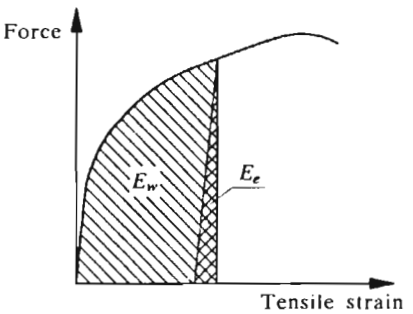

Fig. 6. The procedure of determining of energy E_w expended in plastic deformation

The heat Q_d cannot be easily determined as it is not equal to the heat Q which would be transferred to the surroundings when the temperature of unloaded sample is returning to ambient temperature. This connected to thermoelastic coupling that appears during loading and elastic unloading of the specimen. It is manifested by a decrease in the sample temperature which in the case of austenitic steel is noticeable at the elastic stage of deformation. However, when the deformation reaches the plastic stage, the resulting temperature increase very rapidly masks the effect (Fig.7). The energy E_{te} connected with the thermoelastic coupling is called the isentropic energy (cf Chrysochoos and Martin (1989)). During homogeneous tensile deformation, on the assumption of linear and isotropic elastic sample behaviour, this energy can be calculated from the Thomson formula (1.1)

$$E_{te} = V_0 c_v \Delta T = -\alpha V_0 T \Delta\sigma \tag{5.4}$$

where V_0 is the volume of the gauge part of sample.

During the tensile test of austenitic steel the heat sources related to the thermoelastic effect can be regarded as negative when compared to the sources generated by the plastic deformation. Then

$$Q_d = Q - E_{te} \tag{5.5}$$

and, from Eq (5.3)

$$E_s = E_w - Q + E_{te} \tag{5.6}$$

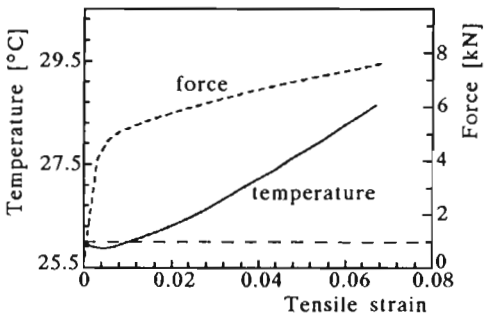

Fig. 7. Change in the temperature of sample surface and the force-elongation curve obtained during tension of austenitic steel

This formula can be used to determine the stored energy during homogeneous deformation on the assumption of linear and isotropic law of elastic behaviour.

The instantaneous value of E_w is determined from the force vs. elongation plot recorded during tension. The instantaneous value of E_{te} was calculated from Eq (5.4). The heat Q transferred to the environment is determined on the basis of the Joule-Lenz effect by simulating the deformation-induced temperature increase during the straining process by means of controlled resistance heating of an unstrained sample with an electric current. During the simulation the electrical energy is supplied to the sample in such a way that the temperature increase with time at each point of the sample surface is identical with that observed experimentally during the tensile testing.

The temperature distribution over the sample surface during tension is determined by means of the IR radiation which was measured with the Thermovision System 680 equipped with the PTR WIN System.

The difference between the specific electrical resistance of unstrained sample and that of the sample strained to 25% was found experimentally to be smaller than 1%; so the resulting changes were smaller than the experimental error and did not affect the results of simulation. Since the simulation and the straining are conducted under identical geometrical and environmental conditions, the heat Q transferred to the environment is equal to the amount of electric power supplied during simulation, i.e.

$$Q = \int_0^1 M(t)\, dt \tag{5.7}$$

where M is the power supplied to the sample. Then the stored energy is obtained as

$$E_s = E_w - \int_0^1 M(t)\,dt - \alpha V_0 T \Delta\sigma \tag{5.8}$$

An advantage of the method is the fact that it gives a complete IR image of the sample whether or not it is being strained homogeneously, and therefore experimental errors produced by improper averaging of the strain and energy over the gauge length during non-uniform deformation can be avoided.

A random relative error of the method decreases as the sample elongation increases (see the Appendix, square deviation in Fig.10).

The unique feature of this method is the possibility for determining the stored energy at any given instant, without interrupting the tensile tests. This feature is suitable for continuous analysing of the plastic deformation energetically because all measured quantities are determined during the deformation process.

6. Conclusions

The integration of the Thermovision System 680 with PTR WIN System allows digital processing of the IR images.

Non-contact measurements of temperature distribution over the sample surface under test provide the criterion for determination of the initiation of yielding on a macroscopic scale, based on the thermomechanical coupling. This criterion is independent of the measurement sensitivity.

The temperature measurements based on the IR radiation detection makes it possible to observe the evolution of plastic zone and to predict a location of the necking in the sample under test.

It has been shown that the non-contact measurements of temperature make it possible to measure the stored energy in a metal being strained under dynamic conditions without interrupting the deformation process.

The methods described briefly in this paper do not cover complety the application of IR radiation detection to investigation of the metal behaviour under mechanical loading. The Thermovision System can be used, for example, to determine the temperature field in a sample subjected to Taylor's test.

Acknowledgements

The author is deeply grateful to the Foundation for Polish Science for the purchase the PR WIN System. This work has been supported by the State Committee for Scientific Research under Grant No. 3P407 007 05.

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Appendix – Details of stored energy determination method

Figure 8 shows a schematic diagram of the measuring system. The samples are coated with carbon powder to ensure homogeneous emissivity of the surfaces. During deformation the film of IR images (16 frames per second) is stored in the hard disk by means the Thermovision System 680 and PTR WIN System.

During the simulation tests the samples are mounted in tensile grips under the environmental conditions identical with those in the straining experiment. The samples in both cases are electrically isolated from the machine. The electric power is determined by measuring both the potential difference on the gauge length of the sample and the current intensity. In order to match the temperature increments during simulation and during tensile testing the electric current must be accurately increased with time. This means that power of the heat emission sources acting in the sample during the straining increases. Matching is achieved by employing the method of successive trials.

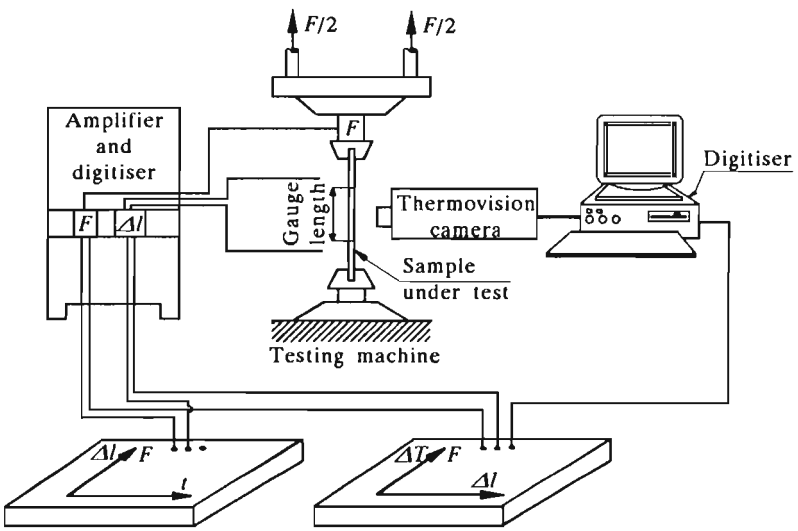

Fig. 8. Schematic diagram of the experimental set-up designed for determination of the stored energy in the sample subjected to tensile deformation

As such a procedure is very laborious, the temperature increases versus time are recorded for various currents and corresponding powers; thus a family of calibrating $\Delta T(t)$ curves is provided in which the electric power is taken as a variable parameter. Successive segments of the curve of temperature increase during a tensile test are then matched with corresponding segments of the calibration diagrams. This operation is carried out in such a way that the temperatures corresponding to the starting points of the matching segments are set equal to each other. Examples of the procedure for austenitic stainless steel are shown in Fig.9. The solid line on the diagram is a plot of the temperature increment versus time during straining. The calibration points obtained during simulation are shown on the same diagram.

Figure 9 shows how the electric power should increase so as to obtain the same increment of temperature as during the corresponding tensile test. If the deformation and simulation are conducted under identical geometrical and environmental conditions, it can be assumed that the rate of power increase corresponds to the rate of increase of heat sources in the sample. Then, in accordance with Eq (5.8), the heat Q transferred from the sample to environment for successive values of the deformation time, i.e. for successive values of elongation, can be calculated. Consequently, Eq (5.8) can be used to determine the stored energy.

The method have been applied to investigation of the energy storage during

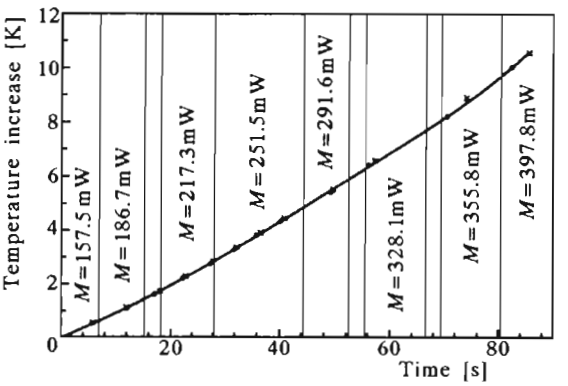

Fig. 9. An example of the calibration of temperature increments by matching results obtained during the tensile testing and during the heating of the sample: • • • – during the tensile testing, × × × – during the heating of the sample with an electric current

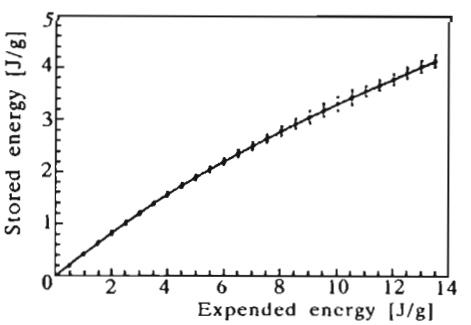

Fig. 10. Stored energy as a function of the expended energy during tension of austenitic steel averaged from measurements carried out on ten samples. The mean square deviation is marked

uniaxial tensile deformation of the austenitic stainless steel. (Its composition is given in Section 3). The stored energy e_s as a function of the energy e_w expended during plastic deformation was determined on the basis of experimentally found values of the dependencies $e_w(t)$ and $\Delta T(t)$, where both quantities, e_s and e_w are taken per unit mass, t is the tension time and ΔT is the increase of sample temperature. The plot of the function averaged over ten samples strained in tensile tests carried out on the Instron 1251 machine with the constant strain rate $\dot{\varepsilon} = 0.002\,\mathrm{s}^{-1}$ is presented in Fig.10. The curve obtained was differentiated and the result is shown in Fig.11. The dependence de_s/de_w vs. e_w is related to the microstucture evolution of the samples in papers by Oliferuk et al. (1993) and (1995).

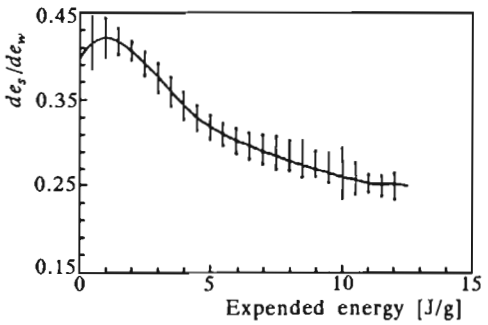

Fig. 11. The averaged instantaneous rate of energy storage as a function of the expended energy during tension of austenitic steel. Bars represent the mean square deviation

The method cannot be applied to materials with low electrical resistivity, such as gold, copper and silver, because it is then rather difficult to make electrical contacts which have resistivities lower than those of the samples.

Zastosowanie detekcji promieniowania podczerwonego do badania metali poddanych obciążeniom mechanicznym

Streszczenie

W pracy przedstawiono metody badania metali stosowane, opracowane i rozwijane w Laboratorium Termoplastyczności Instytutu Podstawowych Problemów Techniki, oparte na bezkontaktowych pomiarach pól temperatury. Są to metody wyznaczania granicy plastyczności, obserwacji zlokalizowanego, niejednorodnego odkształcenia plastycznego oraz wyznaczania energii zmagazynowanej podczas jednoosiowego rozciągania stali austenitycznej.

W pracy zamieszczono także krótki opis podstaw bezkontaktowego pomiaru temperatury oraz przedstawiono integrację systemu termowizyjnego AGA 680 z systemem PTR WIN francuskiej firmy CEDIP, który umożliwia zapis obrazów termicznych na twardym dysku oraz ich komputerową obróbkę.

Manuscript received August 22, 1995; accepted for print October 19, 1995