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EFFECT OF SURFACE MACHINING ON ENERGY STORING PROCESS IN AUSTENITIC STEEL SUBJECTED TO TENSILE DEFORMATION

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The paper presents the results of investigation of the effect of abrasive mechanical and electrochemical machining on the behaviour of the energy storing process in austenitic steel subjected to tensile deformation. The stored energy is found as the difference of the mechanical energy supplied to the sample and the heat released during its deformation. It has been found that the behaviour of the energy storing process in austenitic steel depends to a large extent on the applied machining technique. It is supposed that this effect is related to the increase of dislocation density due to the abrasive mechanical machining of the sample.

1. Introduction

Machine parts are machined and treated to obtain required shapes and properties. Machining and treatment techniques are determined usually by employing the trial method. It is an open question what are the effects of machining and treatment on the processes accurring in metals under loads. An answer to this can be obtained by investigating changes in the properties of a metal when it is subjected to loads. One of the methods enabling to analyze these changes consists in observing the energy storing process in the metal subjected to plastic deformation.

When metals are cold worked, a certain fraction of mechanical energy E_w expended for plastic deformation is retained in the structure of the material, causing thus an increase of its internal energy ΔE, while the remaining energy is dispersed in the form of heat Q. The retained energy is called the stored energy E_s, hence, according to the first law of thermodynamics the following can be written:

$$\Delta E \equiv E_s = E_w - Q. \tag{1.1}$$

The problems of the stored energy in metals have recently been treated in two comprehensive reviews [1, 2].

There are two groups of methods employed for the determination of stored energy, namely:

i. Methods based on the direct application of the first law of thermodynamics; the work is calculated from the diagram of deformation versus force, while heat is the product of heat capacity and increase of sample temperature. These methods require the deformation of the metal in the calorimeter or the determination of the heat released to the surrounding.

ii. Methods based on the determination of the difference between enthalpies of the deformed and reference samples. This difference is determined during isothermal or nonisothermal soaking.

The above methods cannot be used for investigation of the energy storing process during deformation. Such a possibility exists theoretically provided the sample is deformed inside the calorimeter. However, such a measurement is difficult to perform in practice since the calorimeter temperature changes as an inertial process.

Measurements carried out after the sample has been deformed may provide lower values because energy is released during ageing. Moreover, the values of the energy stored during successive stages of deformation are obtained from different samples. Thus, it is then necessary to perform a large number of measurements to draw the diagram of the stored energy as a function of deformation. Bearing all these disadvantages in mind, the authors of the present work have developed a modified method for the determination of stored energy enabling to investigate the energy storing process as the deformation is in progress [3]. This method can also be applied to analyze the effect of material history on the energy storing process in tension.

This report presents the results of investigation on the effect of abrasive mechanical machining (AMM) and electrochemical machining (ECM) on the behaviour of the energy storing process when a sample made of type 1H18N9T austenitic steel is strained in the tensile tester. This type of investigation cannot be found in the literature available.

2. Description of the experiment

The experiments were performed on 1H18N9T austenitic steel. The samples were cut out from a metal sheet 3.4 mm thick in the direction of hot rolling. The sample surfaces were initially ground and then milled to obtain the dimensions required. Then the samples were vacuum-annealed at a temperature of 1070°C for 40 min. to obtain a homogeneous structure. After annealing the surface layer was constituted with the methods: abrasive mechanical machining (AMM) and electrochemical machining (ECM).

The obtained samples of equal dimensions (Fig. 1) can be classified as follows:

samples subjected to electrochemical machining (ECM),

samples abrasively mechanically machined by means of corundum wheels (AMM),

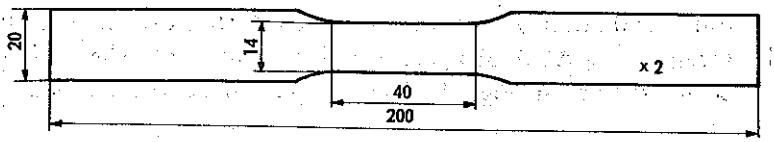

FIG. 1. Shape of samples.

samples not machined after annealing (A).

The samples were subjected to tensile deformation at a rate of 0.11 1/min on a strength testing machine Instron of type 21–51.

According to the relation (1.1), the stored energy was determined as the difference between the work expended to strain the sample and the amount of heat released. The instantaneous value of the work of deformation was calculated from the force versus the elongation plot recorded by the tensile tester.

The evoluted heat is determined on the basis of the Stefan Boltzmann law which states that the power radiated out from a homogeneous surface is a unique function of its temperature. Thus, by measuring the power of infrared radiation emitted by the sample being deformed, it is possible to find the temperature distribution on the sample surface. Consequently, by recording this distribution at definite time intervals during the deformation it is possible to obtain the relation between the temperature increase and the time of deformation. Since the sample shape is complex and the coefficients of heat exchange with the environment are unknown, the accurate determination of the heat transferred to the environment is unfeasible in practice. For this reason the calibration by the simulation of the temperature variation during straining was performed by means of the controlled heating of the sample by electric current under assumption that the Joule–Lenz law is obeyed. The electric energy should be delivered to the sample in such a way that the temperature rise with time during the simulation is identical to that observed experimentally during tensile testing. Since the simulation was conducted under identical geometrical and environmental conditions as was the straining, the heat released is equal to the amount of electric power supplied to the sample during simulation, that is

$$Q = \int_0^t M(t)\,dt, \tag{2.1}$$

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

$$E_s = E_w - \int_0^t M(t)\,dt. \tag{2.2}$$

The infrared radiation power was measured during the simulation experiments by means of an AGA 680 thermovision equipment. The scheme of the system used is shown in Fig. 2. The samples were coated with soot to

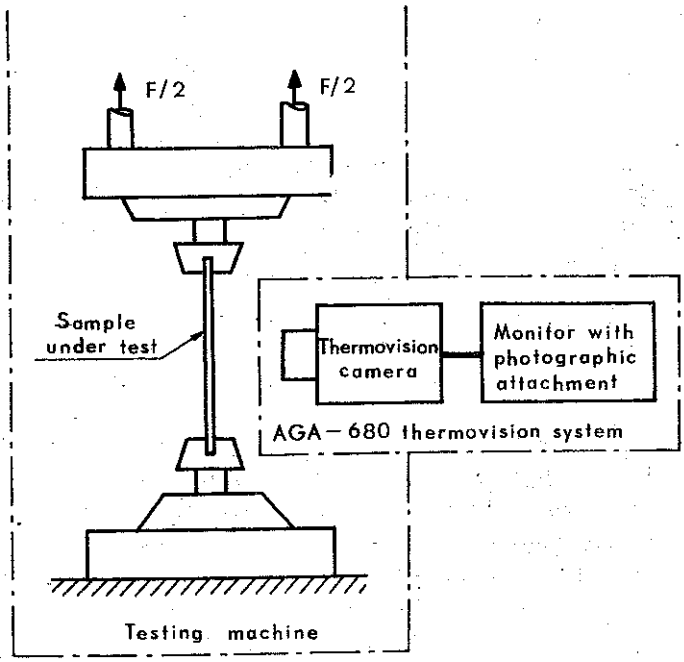

FIG. 2. Schematic diagram of experimental set-up designed for determination of energy stored in the sample subjected to tensile deformation.

ensure the reproductible emissivity of their surfaces. The samples were mounted in the tensile tester in an identical way as for straining experiments in special insulated grips.

3. DISCUSSION OF THE RESULTS

It follows from the experimental results (Fig. 3) that the technique of surface machining of a sample exerts an effect on the behaviour of the energy storing process as the metal is subject to tensile deformation.

The electro-chemical machining (ECM) introduces no changes in the surface layer of metals such as stresses or plastic deformations. A layer of 0.5 mm thickness is removed during the ECM and this fact guarantees that there are no residuals of the premachnining of the surface. The metal

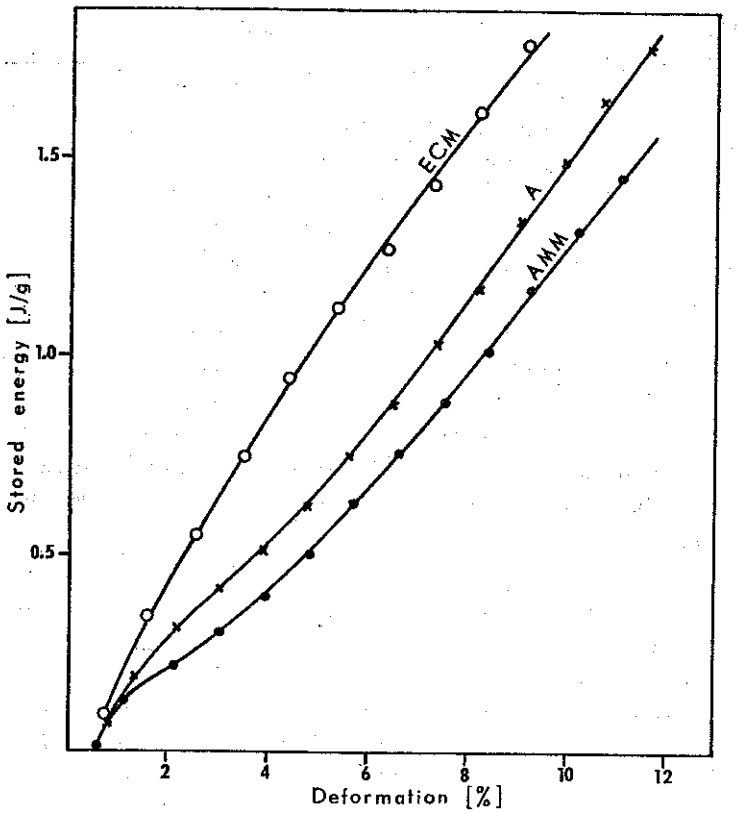

FIG. 3. Stored energy as function of tensile deformation of samples made of 1H18N9T steel after various surface machining.

shows no gradients of physical properties apart from those resulting from the existence of the surface itself.

Grinding causes changes in the properties of the surface layer such as for example, hardness and internal stress. The depth of these changes depends on the grinding parameters and ranges from several to a dozen or so micrometers [4]. These changes effect the behaviour of the energy storing process as the specimen is being subjected to extensional deformation.

In the electrochemically machined samples the energy storing process is similar over the entire range under consideration. The stored energy versus tensile deformation is an almost linear function (Fig. 3, ECM line).

The energy stored in the AMM samples is a clear nonlinear function in the initial stage of plastic deformation (Fig. 3, AMM line).

The relation of stored energy versus defomation becomes linear in the second range of the deformation. This effect can be explained as follows:

an amount of energy is stored in the sample as it is being abrasively mechanically machined. This energy is stored in the form of dislocations, the density of which in the plastically deformed surface layer is higher as compared to that existing after ECM. It can be supposed that these dislocations are activated after a certain value of stresses has been exceeded. In the energy conversion processes occurring in the metal subjected to plastic deformation, the contribution of the motion of dislocation is larger than the contribution of the generation of dislocations. This effect is represented on the diagram by a smaller slope of the curve $E_s(\varepsilon)$ (ε–elongation). As the deformation increases, this slope also increases and it attains the same magnitude as that corresponding to the deformation of the ECM samples. This effect is presumably due to the stopping of the primary slip planes and starting the secondary slip planes. The same slope of the diagrams $E_s(\varepsilon)$ for ECM samples and those for AMM can be explained by the identical density of dislocation in the total bulk of the gauge part of the sample for a certain value of deformation.

In the ECM samples, the initial dislocation density is uniform over the total bulk of the material because no energy is stored during electrochemical machining.

It can be concluded from the above results that the annealing of 1H18N9T steel only decreases the energy state of samples (Fig. 3, A line) but does not reduce the effect of the grinding. Probably the dislocation structures produced during the grinding still exist.

4. Conclusions

The behaviour of the energy storing process in 1H18N9T steel depends to a large extent on the applied machining technique. It is supposed that this effect is related to the increase of dislocation density due to the AMM of the sample. The annealing of 1H18N9T steel does not remove this increase density of dislocations.

The surface layer which has been subjected to plastic deformation during AMM is an additional source of moving dislocation during the initial stage of extensional deformation.

In the samples after ECM the initial dislocation density is uniform over the total bulk of the material. In this kind of samples, the energy is stored over the entire range of deformation in the same way. In other words, the energy stored in the sample is an almost linear function of tensile deformation.

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