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The measurement uncertainty of reduction in area of metals in tensile testing system

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ABSTRACT

International Standard ISO 6892-2 maintains that the strain rate variations and test temperature variations can induce the measurement uncertainty of mechanical properties in tensile testing, which will imperil the reliability of tension tests. In this paper, the measurement uncertainty of reduction in area is first described experimentally. Second, the fundamental results on the microscopic theory of elastic deformation in metals were briefly mentioned. Then the measurement uncertainty is clarified based on this theory. It is shown that the elastic deformation of tension test induces the segregation of impurities to grain boundaries and the relevant embrittlement which produces the measurement uncertainty of reduction in area in tensile testing. This work gives a theoretical basis for correcting the present tension testing system to avoid the measurement uncertainty of reduction in area.

1. Introduction

The tensile test, as a measurement system is used to evaluate the strength and ductility of metals and alloys. In this test system, a metal sample is pulled to failure in a relatively short time at a constant rate. The mechanical properties of metals and alloys that are of engineering importance for structural design and can be obtained from the tensile test system are: modulus of elasticity, yield strength at 0.2% offset, ultimate tensile strength, percent elongation and percent reduction in area at fracture. The standard test methods for elevated temperature tension test of metallic materials were originally approved by ASTM international in 1933 [1]. In 1947 International Organization for Standardization (ISO) also carried out a technical standard for elevated temperature tension test of metallic materials [2]. Since then, these standards were subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either re-approved or withdrawn. But in 2011, for such an important and comprehensive applicative measurement system it was pointed out by technical committee mechanical testing of metals, ISO/TC164 that the variations in temperature and strain rate of this measurement system have been found to have a larger potential effect on test results, which is a kind of uncertainty contribution not related to test equipment. Therefore, uncertainty components relative to temperature and strain rate variations should be considered when estimating measurement uncertainty of testing results [2]. ISO / TC164 used Figs. 1 and 2 to show the measurement uncertainty relative to temperature and strain rate variations. Fig. 1 shows that for different temperatures at a constant strain rate, there are large differences in the material response. Fig. 2 shows that for different strain rates at a constant temperature, there are also large differences in the material response.

Figs. 1 and 2 show that for a metal, which underwent a same thermal cycle, the variations of temperature and strain rate in tensile test system can produce the change of stress–strain curves which indicates a large difference

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in testing results. Such a large difference occurs during the process of tensile test and is not the expression of original properties of tested metal. Technical committee mechanical testing of metals, ISO/TC164 named such a difference as measurement uncertainty of mechanical properties relative to test temperature and strain rate variations of tension test system, which includes the uncertainties of modulus of elasticity, yield strength, ultimate tensile strength, percent elongation and percent reduction in area at fracture [2]. They pointed out that the uncertainty of the test results influenced by temperature and strain rate variations must be determined experimentally since these uncertainty values are highly materials dependant. For this reason, it is not possible at this time to assign predictable values for temperature and strain rate components to be used in an example [2]. That means that present tensile test system is lack of reason on adoption of temperature and strain rate components to produce erroneous measurement of mechanical properties for tested materials that imperil the reliability of tension test system. It is clear that the measurement uncertainty of mechanical properties in tensile test system suggested by this committee shakes the experimental basis of metallic mechanics.

2. Experimental observations of measurement uncertainty

Figs. 1 and 2 show only that for a metal, which underwent a same thermal cycle, a measurement uncertainty of mechanical properties can be produced by the variations of temperature and strain rate in tensile test system but its mechanism is still unclear. The uncertainty phenomena of reduction in area relative to variations of temperature and strain rate will be described experimentally in oncoming section in order to suggest a mechanism for the uncertainty.

2.1. Uncertainty relative to temperature – intermediate temperature embrittlement

Fig. 3 shows tensile test results by Sun et al. [3,4] with five strain rates at different temperatures for Fe17Cr stainless steel. It is shown that for each strain rate reduction in

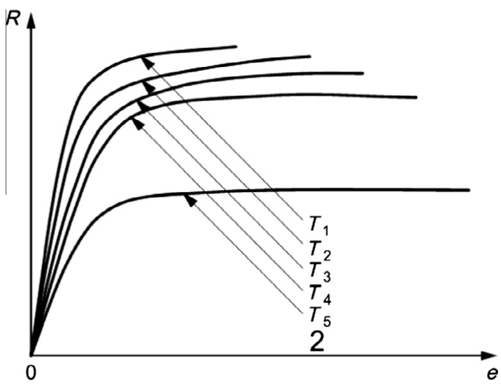

Fig. 1. Stress–strain curves at a given strain rate and different temperatures [2].

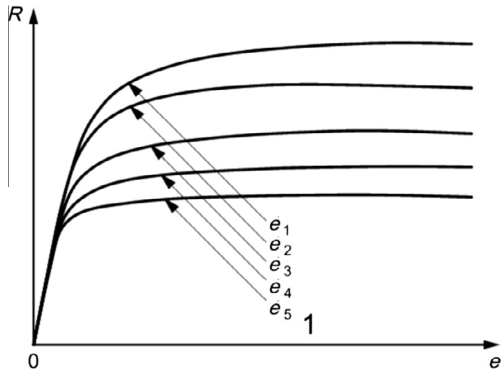

Fig. 2. Stress–strain curves at 850 °C and different strain rates [2].

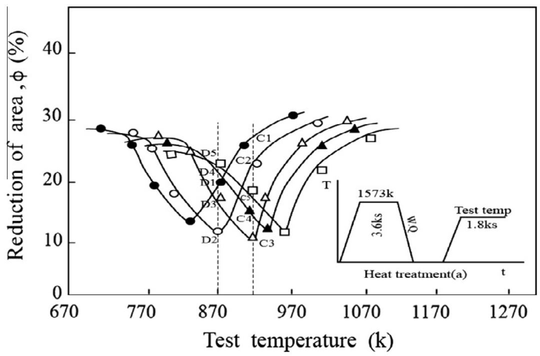

Fig. 3. Changes of fracture reduction of area of Fe–17Cr alloy with test temperature and strain rate. (● $\dot{\varepsilon} = 1.43 \times 10^{-5}\ s^{-1}$, ○ $\dot{\varepsilon} = 1.43 \times 10^{-4}\ s^{-1}$, △ $\dot{\varepsilon} = 1.43 \times 10^{-3}\ s^{-1}$, ▲ $\dot{\varepsilon} = 1.43 \times 10^{-2}\ s^{-1}$, □ $\dot{\varepsilon} = 1.43 \times 10^{-1}\ s^{-1}$, $d = 0.60$ mm) [3,4].

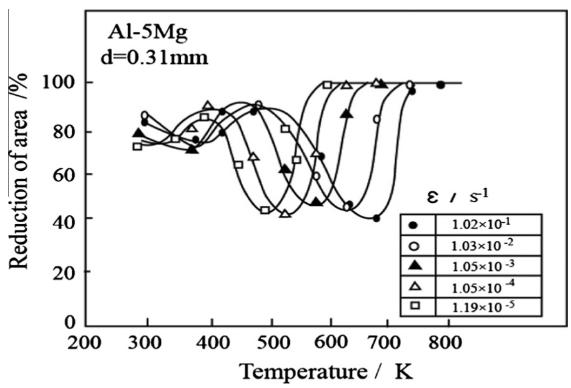

Fig. 4. Reduction of area vs. test temperature for Al–5% Mg alloy, after deformation with various strain rates from $1.02 \times 10^{-1}\ s^{-1}$ to $1.19 \times 10^{-5}\ s^{-1}$ [5].

area will vary with the variation of test temperature, a measurement uncertainty relative to temperature. For each strain rate there is an intermediate temperature at which embrittlement reaches a maximum (a minimum of reduction in area) [3,4]. This temperature will reduce with decrease in strain rate.