UNIVERSITY OF ŽILINA
Faculty of Mechanical Engineering
Department of Materials Engineering

SEMDOK 2015

20th Jubilee International seminar of Ph.D. students

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dean of the Faculty of Mechanical Engineering of the University of Žilina

Terchová, Slovakia
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VARIATION OF THE NORMAL ANISOTROPY COEFFICIENT OF AUSTENITIC STAINLESS STEELS AT ELEVATED TEMPERATURES

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Abstract

The paper presents an investigation of the anisotropy properties of austenitic steel AISI 304 (X5CrNi18-10) at elevated temperatures. Anisotropy was considered both theoretically and experimentally. The objective of conducting the experiments was to investigate influence of temperature on normal anisotropy, as well as on the material's mechanical properties. The normal anisotropy was monitored by its coefficient, the so-called "r-value". The tests were done on the 0.7 mm thick sheet metal within the temperature range 20 to 700°C.

Keywords: *Normal Anisotropy; Sheet Metal; Stainless Steel; r-value, Elevated Temperatures*

1. Introduction

The normal anisotropy represents unevenness of material properties over its thickness, with respect to properties within the thin sheet plane. It is expressed by the coefficient of normal anisotropy – the r-value, which shows the resistance of the thin sheet against thinning. The value of this coefficient is influenced by the in-plane anisotropy, as well. Certain materials exhibit the best characteristics in the direction of the thin sheet rolling (0°), some in the direction perpendicular to the rolling direction (90°), or even in the direction at certain angle (45°) [1-2]. The low-carbon steel's thin sheet DC 04 has higher r-values in directions at 0° and 90°. On the contrary, the aluminum alloy AlMg4.5Mn0 and austenitic AISI 304 and ferritic stainless steels AISI 430, exhibit maximum of the r-value in the direction of 45° with respect to the rolling direction. Besides investigation of the r-value for steels, some authors [2] were investigating anisotropy properties of aluminum alloys, while in papers [3-4] were investigated influence of thin sheet manufacturing on change of the anisotropy properties of magnesium alloys, both at room and elevated temperatures. Influence of temperature on change of mechanical properties and anisotropy of molybdenum thin sheets was investigated in [5]. Conclusions of all those authors were that temperature does not impose strong influence on the r-value, but that it does strongly affect tensile strength and the yield stress.

2. Theoretical determination of the r-value

Determination of the anisotropy characteristics is of the practical importance when material is tested by the uniaxial tensile test of samples cut-out from the thin sheet's plane in directions at certain angle with respect to the rolling direction (0°, 45° or 90°). The x-axis coincides with the rolling direction; the y-axis is perpendicular to that direction within the sheet's plane, while the z-axis is perpendicular to the sheet's plane, Figure 1 [2].

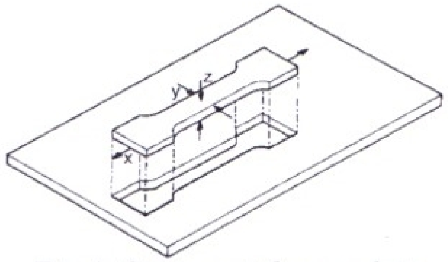

Fig. 1. Cutting out the sample in the thin sheet's rolling direction

Definition of the r-value for determination by uniaxial tension is given as [1, 6]:

$$r = \frac{\phi_b}{\phi_s} = \int_{b_0}^{b} \frac{db}{b} \Big/ \int_{s_0}^{s} \frac{ds}{s} = \ln \frac{b}{b_0} \Big/ \ln \frac{s}{s_0} = \log \frac{b_0}{b} \Big/ \log \frac{s_0}{s} \tag{2.1}$$

where: φ_b – natural (logarithmic) deformation over the thin sheet sample's width (*b*), φ_s – natural deformation over the thin sheet sample's thickness (*s*). By adopting the volume constancy ($l_0 \cdot b_0 \cdot s_0 = l \cdot b \cdot s = const.$), expression (2.1) can be transformed into the form:

$$r = \ln \frac{b}{b_0} \Big/ \ln \frac{l_0 b_0}{l b} = \log \frac{b}{b_0} \Big/ \log \frac{l_0 b_0}{l b} = \ln \frac{b_0}{b} \Big/ \ln \frac{l b}{l_0 b_0} \tag{2.2}$$

where: b_0 and b – is the sample's width before and after tension, respectively; l_0 and l – is the sample's initial and final length, respectively.

Considering the accuracy in determination of the r-value, it is preferable that the final deformations of length and width be as large as possible. The sample's tension is stopped within the area of homogeneous deformation, somewhat prior to reaching the maximum force. That is usually 1 to 3 % less than the expected percentage elongation at point M. Elongation value at maximum tensile force for majority of low carbon steel thin sheets for car's body amounts to 20%, while for the other it could be significantly higher. In Table 1 are presented values of the r-valueand expected materials' machinability corresponding to those r-values or range of r-values, obtained in previous investigations [1].

Table 1. Review of the r-values

r = 0.5 – 1 (r < 1)	very poor machinability
r = 1 – 1.2	poor machinability
r = 1.2 – 1.5	good (medium) machinability
r = 1.5 – 1.8	very good machinability
r > 1.8	exceptionally good machinability

In Figure 2 are shown curves that illustrate the difference in the r-value depending on material and angle at which the samples are cut-out [1]. The diagram confirms the fact that the low carbon steel thin sheet is the optimal material for plastic forming, where the best properties of the r-values are exhibited in the rolling direction and in direction perpendicular to it (90°).

Table 2. Chemical composition of AISI 304 (X5CrNi18-10) steel

Alloying element	C	Si	Mn	P	S	Cr	N	Ni
Content, %	0.07	1.00	2.00	0.045	0.030	17 - 19.5	0.110	8 - 10.5

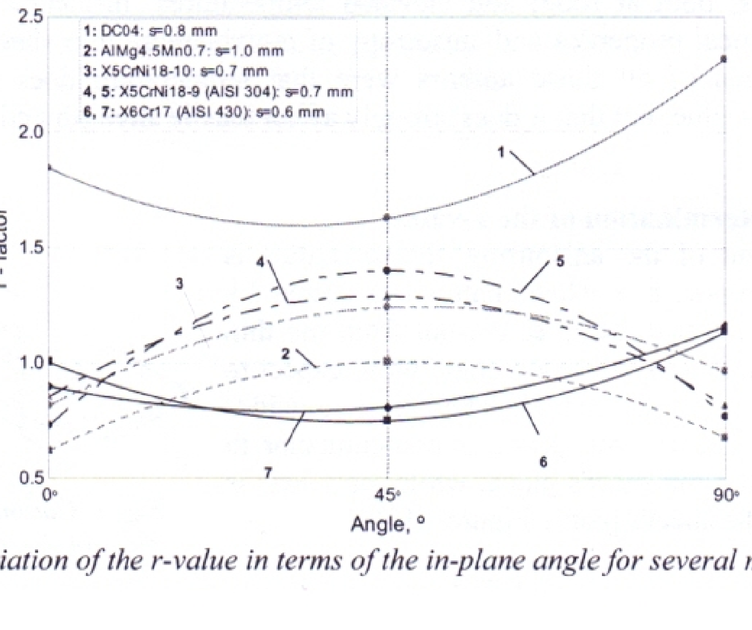

Fig. 2. Variation of the r-value in terms of the in-plane angle for several materials

3. Experimental testing

The samples testing were done at room and elevated temperatures on the computer-controlled machine for mechanical testing ZWICK/Roell Z 100; the temperature range was 20 to 700°C. A special chamber, which is mounted to the machine, was used for samples heating. Samples were cut out from thin sheets in the rolling direction (0°).

In Figure 3 are shown the tension diagrams of the thin sheet samples testing. For samples tested at 20 and 700°C the loading was stopped at 35% and 15 %, respectively, so that samples would remain in the region of the material homogeneous deformation; results thus obtained are relevant for calculation of the r-value.

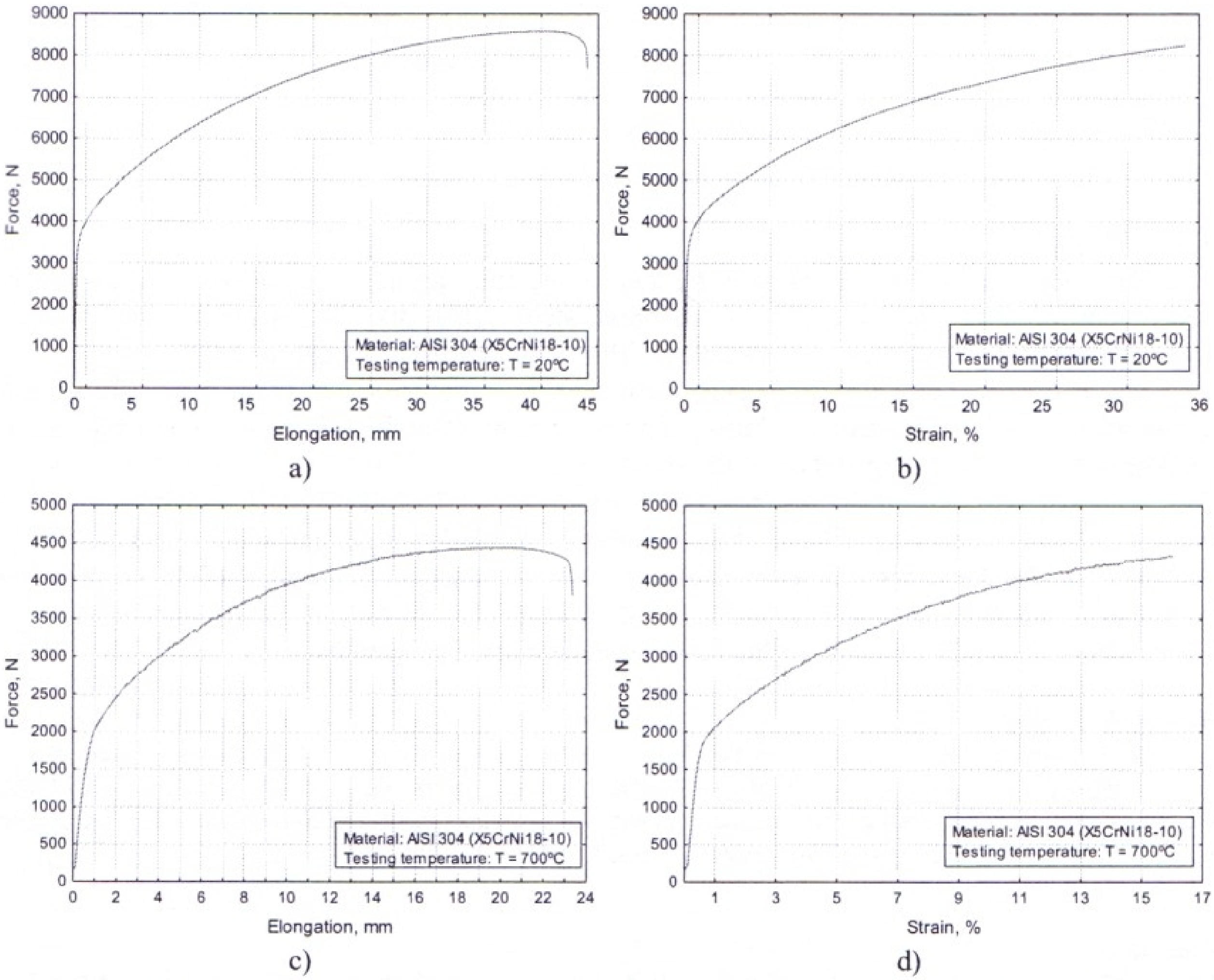

Fig. 3. Tension diagrams: a) 20°C; b) 700°C; The r-value determination: c) 20°C; d) 700°C

Characteristic values of width (b) and length (l) were measured on the tested samples. Width was measured at 6 points. Then, the r-value was calculated according to expression (2.2). Obtained values are shown in Table 3 and Figure 4.

Table 3. Experimental results of the r-value calculated based on expression (2.2)

Temperature, °C	20	200	400	500	600	700
r-value	0.889	0.811	0.797	0.793	0.768	0.752

Experimental results showed that the anisotropy coefficient – the r-value of the AISI 304 steel is dropping at elevated temperatures. It has dropped for 0.14 (in absolute amount), namely from value 0.89 at 20°C to 0.75 at 700°C.

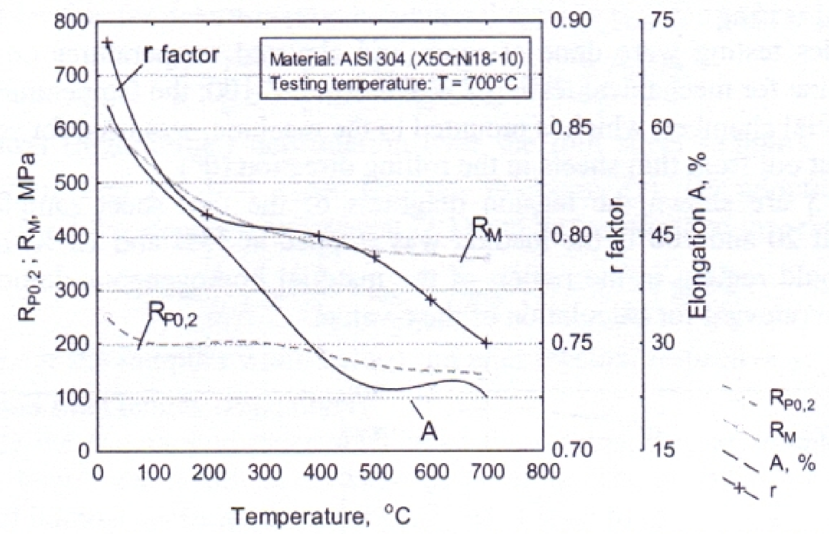

Fig. 4. Diagram of the r-value and mechanical properties variation with temperature

4. Conclusion

The objective of this work was to investigate the variation of the normal anisotropy coefficient of thin sheets made of stainless steel AISI 304 at elevated temperatures. Experiments were conducted on 7 samples within temperature range 20 to 700°.

Analysis of obtained experimental results provided the conclusion that the r-value is dropping at elevated temperatures, namely during the forming the thin sheet is more deforming in the thickness direction (thinning) than in the sheet's plane.

The drop of the r-value was not large from 0.89 to 0.75 (15.7%). The decrease of the most important material's mechanical properties (the tensile strength and yield stress) was also recorded, while the drop was also recorded in the elongation at break. All these point to conclusion that this material should be used in cold conditions, i.e., at room temperature, since heating causes worsening of the material deformation properties.

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