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Original article

Effect of plastic strain and specimen geometry on plastic strain ratio values for various materials

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ABSTRACT

The aim of this paper is to show influence of two elements on plastic strain ratio value, or "r" value. The first element is value of plastic strain, and second is specimen geometry. Extensive experiment was conducted according to appropriate tensile test procedure with 3 materials and 5 different specimen geometries. Steel sheet S235JR, austenitic stainless-steel sheet X5CrNi18-10 and Al alloy sheet AlSi0.9MgMn (i.e. ENAW 6081) were used during the experiments. Nominal thickness for all three sheets was 1 mm. Three out of five specimen geometries had 20 mm width and gage length of 60, 120 and 160 mm while the rest of specimens had width of 15 mm and gage length of 50, 100 mm. All the specimens were laser cut in rolling direction. In preparation part of the experiment, behind material characterization (obtaining base mechanical properties) identification of homogenous deformation field was performed, i.e. plastic strain at the beginning of localization, for each specimen. Related to that strain value 6 degrees of deformation were realized: 75%, 80%, 85%, 90%, 95% and 100%. Results showed expected and significant difference in "r" value for used materials, but influence of specimen geometry and realized plastic strains were low.

Key words: *sheet metal, anisotropy, plastic strain ratio, S2235JR, X5CrNi18-10, AlSi0.9MgMn;*

1. INTRODUCTION

Thin sheet metals usually are anisotropic materials. This property is expresses most often in two ways: plane anisotropy and normal (orthogonal) anisotropy. Normal anisotropy is related to the difference in sheet metal strains in plane and along its thickness. Main characteristic which completely explains normal anisotropy is plastic strain ratio or "r" value. Significance of "r" value outgoing from its appliance in anisotropic plasticity theory, numerical simulation of metal forming processes and from its direct practical using as formability parameter in deep drawing sheet metal forming processes. "r" value usage lasts for decades and there is extensive literature about theory and process of experimental determination [1-12]. In modern research activities "r" value is important parameter for consideration of anisotropy influence in different forming processes or theoretical investigations [13-19].

Determination of "r" value can be done only trough experiment [1], [5], [7], [8], [10] and that is matter of standards [7-8]. However, recommendations given in standards in many cases are not precise and obligate. In standard procedures such a situation is with influence of specimen geometry and degree of plastic strain.

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Thereabout is main goal of this research. Process used for experimental determination of "r" value is uniaxial tension. Form of specimen is known, but dimensions can be different and that makes geometry insufficiently defined. So, because of that, there is a space for investigation. Similar matter is also about amount of plastic strain.
According to [1], [5], [7], [8], [12] definition of "r" value is given as following expressions:

$$r=\frac{\varphi_b}{\varphi_s}=\frac{\ln\frac{b}{b_0}}{\ln\frac{s}{s_0}} \quad (1)$$

$$l_0 \cdot b_0 \cdot s_0 = l \cdot b \cdot s = const. \quad (2)$$

$$\frac{s}{s_0}=\frac{l_0 b_0}{lb}\text{, and finally} \quad (3)$$

$$r=\frac{\ln\frac{b}{b_0}}{\ln\frac{l_0 b_0}{lb}}=\frac{\ln\frac{b_0}{b}}{\ln\frac{lb}{l_0 b_0}} \quad (4)$$

φ_b is logarithmic (true) plastic strain of specimen width; φ_s is logarithmic (true) plastic strain of specimen thickness, l_0, b_0, s_0 are initial specimen dimensions, length, width and thickness; l, b, s are final, specimen dimensions, length, width and thickness. Fig. 1 shows specimen appearance.

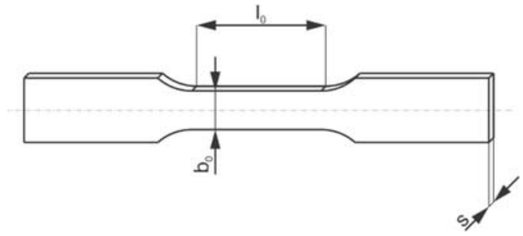

Fig. 1. *Uniaxial tension test specimen*

2. EXPERIMENT

Extensive experiment was planned according to appropriate uniaxial tensile test procedure with 3 materials and 5 different specimen geometries. Materials that were used: steel sheet S235JR (here signed S), austenitic stainless-steel sheet X5CrNi18-10 (here signed X) and Al alloy sheet AlSi0.9MgMn (i.e. ENAW 6081) (here signed A). Nominal thickness of all of three sheets was 1 mm.
Test specimen geometry was defined in following way: three specimens are with 20 mm width and gage length of 60, 120 and 160 mm; two specimens are with 15 mm width and gage length of 50, 100 mm (Fig.2). According to Fig. 2 specimens signs from top to the bottom were: a, b, c, d and e. All the specimens were laser cut in rolling direction. In preparatory part of experiment, behind material characterization (obtaining base mechanical properties) performed was identification of homogenous deformation field, i.e. plastic strain at the beginning of localization A_g, for each specimen. Related to that strain value realized were 6 deformation degrees: 75%, 80%, 85%, 90%, 95% and 100%, and signed 2, 3, 4, 5, 6, and 7. Mark 1 is related to specimen for fracture test. This plan gives need of 105 successfully tested specimens in total. Prepared were about 120 specimens (Fig. 3).
Uniaxial tests were performed on computerized test machine Zwick/Roell Z 100 [9]. Deformations were measured manually, without extensometers. Reasons were following:

1. very difficult measuring width change on minimum 5 places;
2. problems with elimination of elastic deformation, i.e. precise measuring of plastic strain;
3. problems of using extensometers with sharp edges [10].

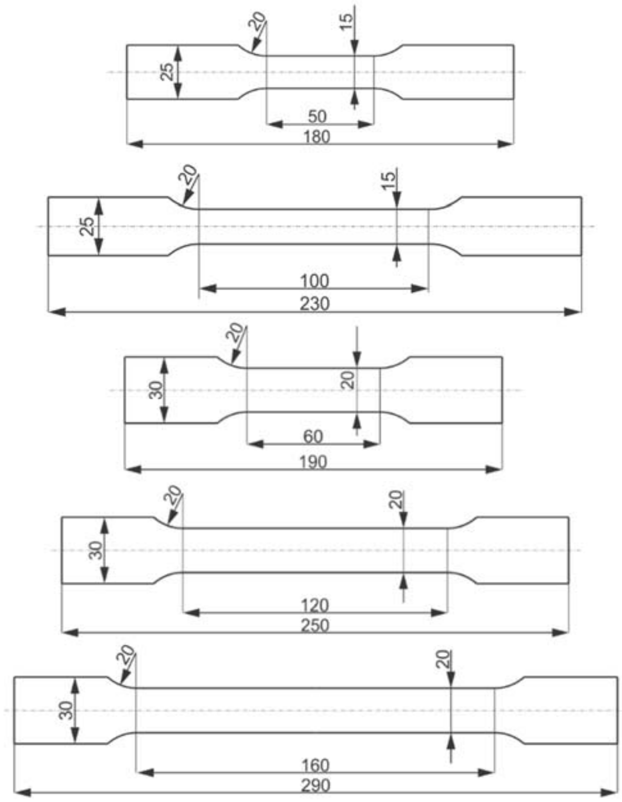

Fig. 2. *Geometry of test specimens*

Fig. 3. *Samples of test specimens*

Longitudinal strains were measured with digital caliper (accuracy 0.01 mm), and lateral strains with micrometer (accuracy 0.005 mm).

Width locations for measuring lateral deformations were carefully marked (Fig. 3). First and the last mark were used for measuring longitudinal deformation, at the same time.

In appropriate literature and standards [1], [2], [5], [7], [8] one can find noted general recommendations about necessary previous plastic deformation. It is convenient that elongation should be as larger as possible, but in field of homogenous forming, i.e. before point of maximum force on the force-elongation (or stress-strain) diagram. Larger strain is needed in order to decrease error during measuring. For low carbon steels recommended elongation is about 20%, but for any other material must be checked end of homogenous and start of localized forming. In particular case fracture tests were performed and exactly defined maximal plastic strain at the end of homogenous forming. Adopted were 6 amounts of deformation for evaluation of strain degree influence on "r" value determination, as previously mentioned.

Similar is in case of specimen geometry influence. Recommendations are general. In this experimental study goal is evaluate influence of specimen geometry with different length-width ratio.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Conducted extensive experiment resulted with large quantity of data: diagrams, tables, histograms and all of that can't be presented here because of limited space. Shown will be selected significant results like illustrations of completeness.

In the Figures 4, 5 and 6 shown are stress-strain tensile diagrams which main purpose is determination of strain at the end of homogenous forming. Other strains that are employed are dependent on this strain. Marks (Sd1, Xd1, Ad1) were explained in previous section.

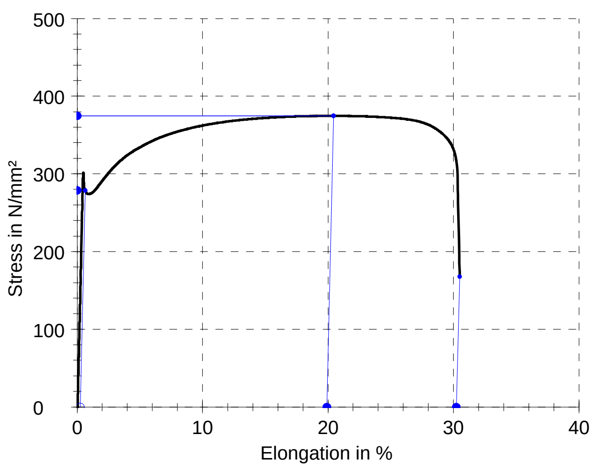

Fig. 4. *Tensile diagram for specimen Sd1*

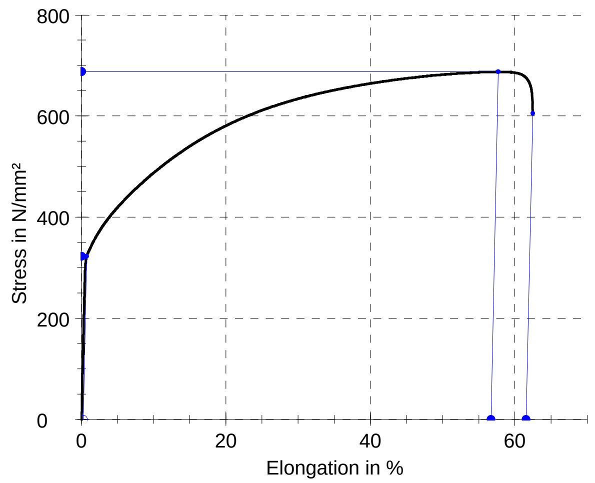

Fig. 5. *Tensile diagram for specimen Xd1*

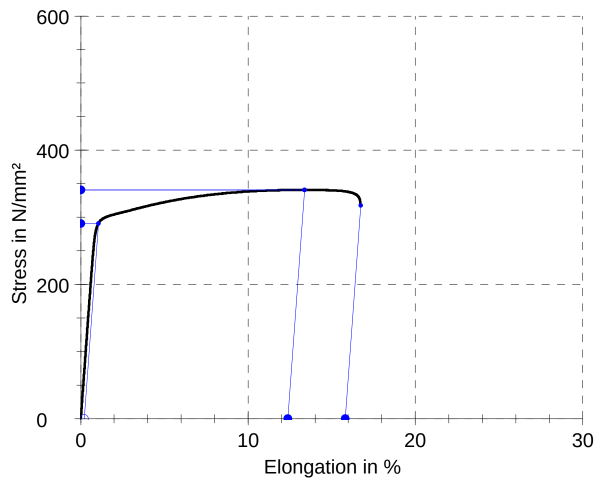

Fig. 6. *Tensile diagram for specimen Ad1*

Figures 7, 8 and 9 show relations of, so called, error on "r" value. True meaning of term "error" is how changes "r" value depending on kind of material and type of geometry. For calculating "error", exactly true "r" value is needed, but in this case it is unknown. Therefore minimal "r" valued were adopted as true and referent values.

In Fig. 7 one can notice, first of all, influence of specimen type on "r" value and at same time change of "error" for structural steel sheet S235JR. Based on engineering logic it is expected to require to accept lower values, so according to that specimens ***c*** and ***e*** are more convenient. For austenitic stainless steel (Fig. 8) slightly better is specimen ***d*** and for aluminium alloy (Fig. 9) specimen ***e***.

Fig. 10 shows that cloud of points and fitted line indicate very slightly influence of plastic strain on "r" value. With increasing strain "r" value decreasing but almost negligible. Similar annotation is valid for stainless steel and Al alloy both (Fig. 11 and Fig. 12).

Figures 13, 14 and 15 more clearly show influence of specimen type on "r" value than Figures 7, 8 and 9. Annotations are the same. For structural steel lower "r" values (here adopted as better, more precise) are with specimens' ***c*** and ***e***.

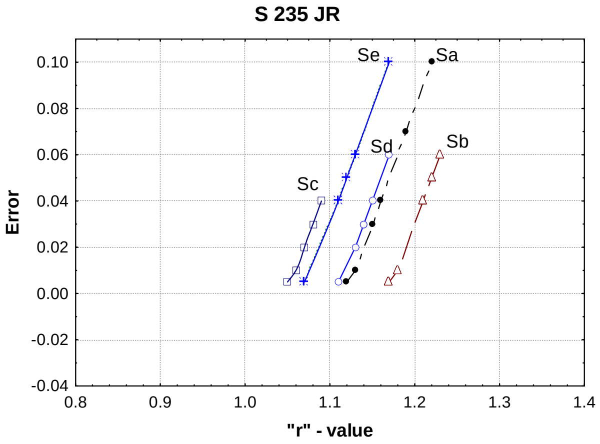

Fig. 7. *"Error" relation to "r"-value (S2235JR)*

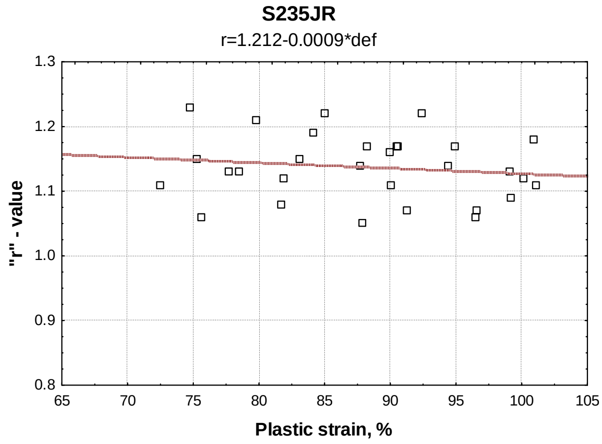

Fig. 10. *"r"-value dependence on plastic strain (S2235JR)*

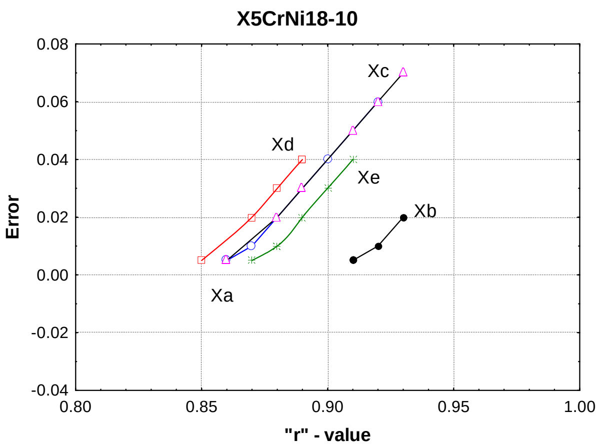

Fig. 8. *"Error" relation to "r"-value (X5CrNi18-10)*

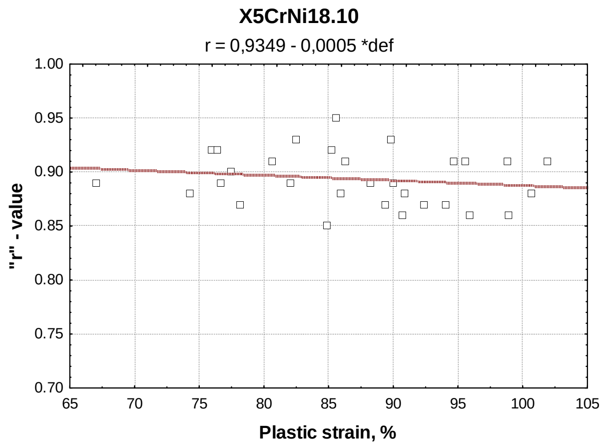

Fig. 11. *"r"-value dependence on plastic strain (X5CrNi18-10)*

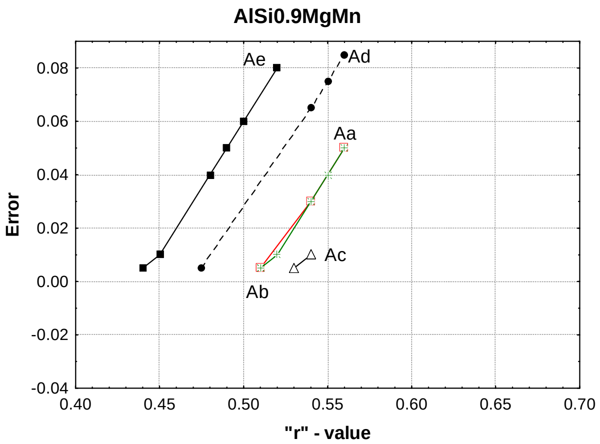

Fig. 9. *"Error" relation to "r"-value (AlSi0.9MgMn)*

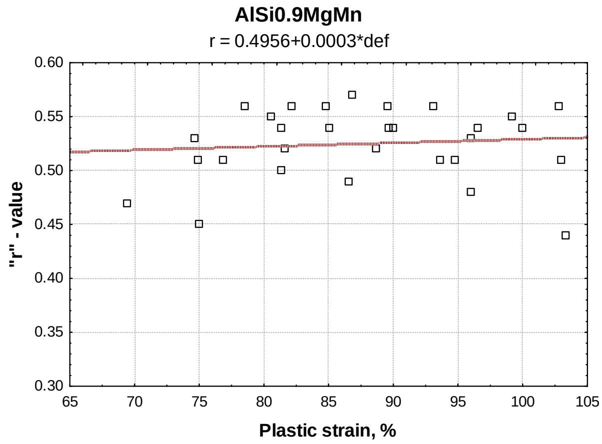

Fig. 12. *"r"-value dependence on plastic strain (AlSi0.9MgMn)*

For stainless steel sheet slightly more convenient specimen is ***d*** (Fig. 14). Specimen ***e*** is better for Al alloy (Fig. 15). Influence of plastic strain on "r" value can be expressed in different ways, such as expressed in Fig. 16. This figure illustrates almost negligible influence of plastic strain on the "r" value. Due to that small influence, the diagrams for other materials are not shown.

Presented in Fig. 17 is summary histogram which shows specimen geometry influence on average "r" value. Once again can be confirmed previous annotations. For structural steel more convenient are specimen ***c***, for stainless steel specimen ***d*** and for Al alloy specimen ***e***.

In Fig. 18 dependence of "r" value on real plastic strain of samples with geometry ***a*** is presented in form of histogram. Nominal plastic strain as set up value can't be reach exactly in every measurement. These small differences are visible in Fig. 18. However, more precise is Fig. 19 which shows "r" value dependence on nominal plastic strain. Because of relatively small plastic strain influence on "r" value, once again given are only histogram for specimen ***a***, as example.

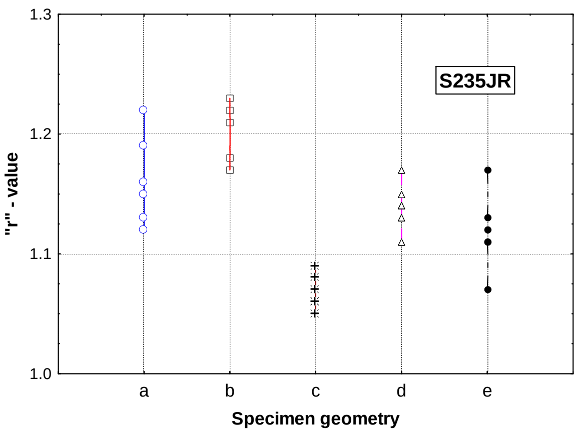

Fig. 13. *"r"-value dependence on specimen geometry (S235JR)*

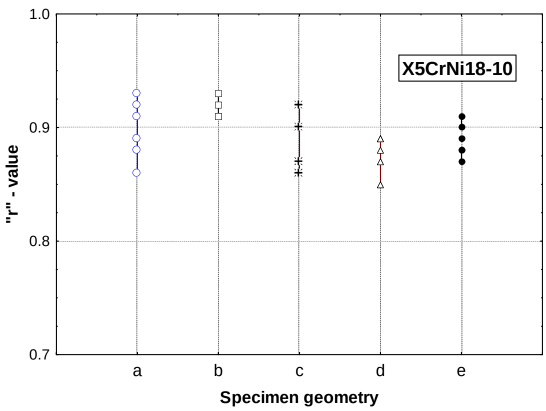

Fig. 14. *"r"-value dependence on specimen geometry (X5CrNi18-10)*

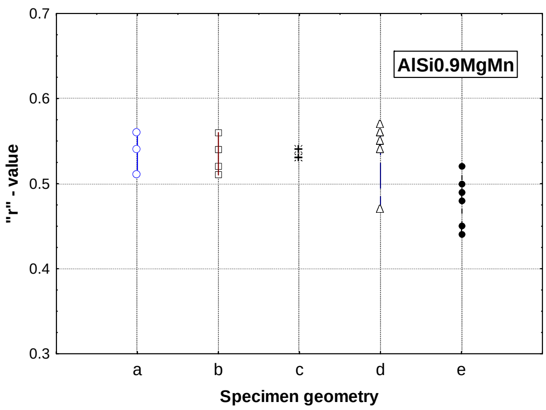

Fig. 15. *"r"-value dependence on specimen geometry (AlSo0.9MgMn)*

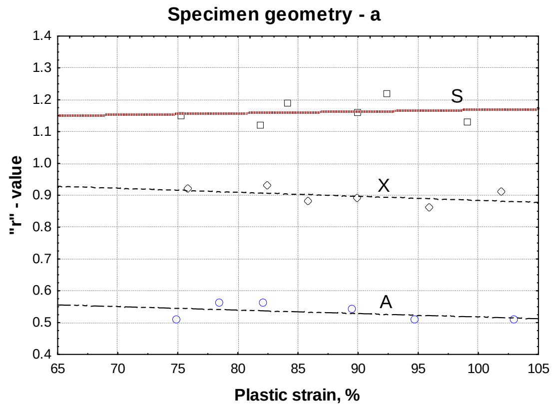

Fig. 16. *"r"-value dependence on plastic strain*

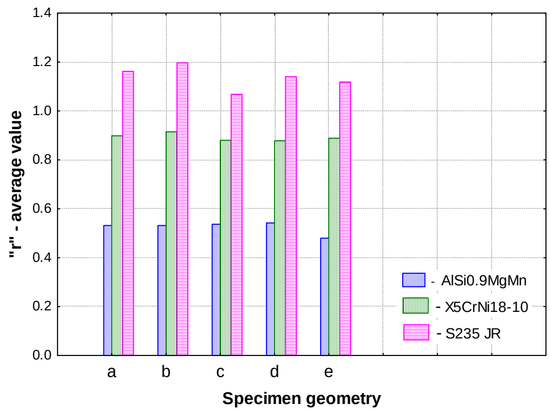

Fig. 17. *"r"-average value dependence on specimen geometry*

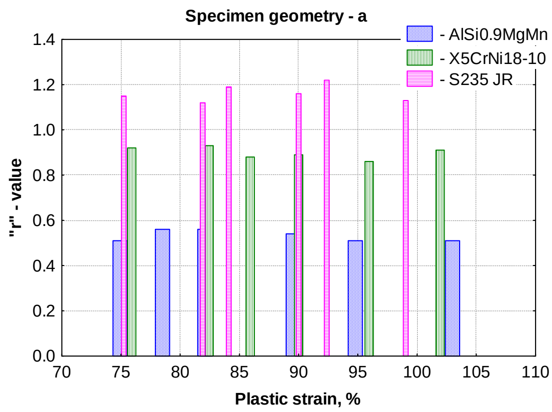

Fig. 18. *"r"-value dependence on real plastic strain*

In Fig. 20 the average "r" values for each specimen geometry are displayed. This histogram once again confirms that influence of specimen geometry is in most of the cases visible, but influence on obtained values is almost negligible.

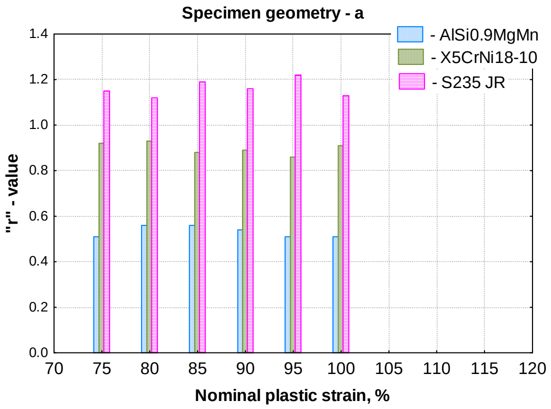

Fig. 19. *"r"-value dependence on nominal plastic strain*

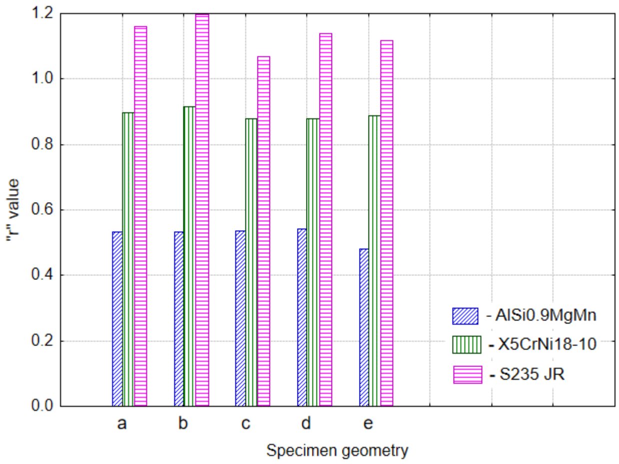

Fig. 20 *Average "r"-values for various materials*

4. CONCLUSIONS

Based on the results of performed extensive experiments the following observations and conclusions can be drawn:

- Influence of specimen geometry is visible. Increasing specimen width cause increasing width measurement accuracy, thus smaller "r" value is obtained.
- Influence of specimen length can't be isolated in this approach.
- Precise reaching of plastic strain goal value was difficult in experiment because of relatively large elastic deformation. So, there previously evaluation of intensity of elastic strains in preparation part of experiment is needed.
- Realised plastic strain in tensile process have relatively small effect, almost negligible. Possible cause may be quite large strain intensity. Minimal strain value was 75% of maximum allowed strain. In further experiment it is needed to smaller plastic strain values.
- In working without extensometers in uniaxial tensile process, like in this case, must be aware about volume that really deformed. Best results were obtained when jaws of tensile machine clamping test specimen were very close to the beginning and last mark line.
- In further experiments in attempts to evaluate influence of different test specimen geometries and plastic strain intensities on "r" value both extended fields of strain intensities and specimen geometries are needed.
- In working without extensometers based on experience from this experiment seems suitable to use series of simple test specimens in form of strip with different width.

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NOTE

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