MOBILITY & VEHICLE MECHANICS

https://doi.org/10.24874/mvm.2024.50.01.02
UDC: 621.7-4

EXPERIMENTAL DEFINING OF NORMAL ANISOTROPY COEFFICIENT AS FORMABILITY FACTOR OF THIN CAR BODY SHEETS

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Received in March 2024 *Accepted in March 2024*

RESEARCH ARTICLE

ABSTRACT: It is well known that anisotropy have very significant influence on car body sheet metals formability in deep drawing process. At the other hand deep drawing is essential technology of all car body parts. Anisotropy can be observe as planar and orthogonal (normal). For deep drawing more significant is normal anisotropy which is represent by coefficient of normal anisotropy or plastic strain value or so called "r" factor. It is numeric value which is obtaining experimentally by uniaxial tension in field of homogenous plastic strain. There is no precise recommendation about intensity of maximal allowed plastic strain during the tensile experiment. In this paper presented is experimental investigation of smaller plastic strains intensities influence on final "r" value. Used are two thin sheet metals: stainless steel X5CrNi18-10, 0.8 mm nominal thick and Al alloy sheet AlMg4.5Mn0.7 (i.e. ENAW 5083) 1 mm nominal thick where the samples are cut in the rolling direction for both materials. Plastic strain was relate to maximal homogenous plastic strain A_g in the following way: 10, 20, 30, 40, 50, 60, 65, 70 and 75 percent of A_g. After the results evaluation can be concluded that there is relatively small influence of plastic strain intensity on "r" value occurred i.e. determining of "r" value can be successfully obtained with smaller intensity of plastic strain.

KEY WORDS: *car body sheet metals, anisotropy, "r" value*

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EKSPERIMENTALNO ODREĐIVANJE KOEFICIJENTA NORMALNE ANISOTROPIJE KAO FAKTORA DEFORMABILNOSTI KAROSERIJSKIH LIMOVA

Srbislav Aleksandrović, Darko Perić

REZIME: Dobro je poznato da anizotropija ima veliki uticaj na deformabilnost karoserijskih limova u procesu dubokog izvlačenja. S druge strane, duboko izvlačenje je ključna tehnologija za sve delove karoserije vozila. Anizotropija može da se posmatra kao ravanska i normalna. Za duboko izvlačenje znatno je važnija normalna, koja se izražava preko koeficijenta normalne anizotropije ili tzv. "r" faktora. To je brojna vrednost koja se određuje eksperimentalno jednoosnim zatezanjem u oblasti ravnomerne plastične deformacije. Ne postoje precizne preporuke u vezi intenziteta najveće dozvoljene plastične deformacije tokom procesa. U ovom radu je dato eksperimentalno istraživanje uticaja manjih vrednosti plastičnih deformacija na konačnu vrednost "r" faktora. Korišćena su dva lima: čelik X5CrNi18**-10,** nominalne debljine 0,8 mm i lim od Al legure AlMg4,5Mn0,7 nominalne debljine 1 mm, pri čemu su epruvete sečene u pravcu valjanja za oba materijala. Plastična deformacija je bila vezana za maksimalnu ravnomernu plastičnu deformaciju A_g na sledeći način: 10, 20 30, 40, 50, 60, 65, 70 i 75 procenata od A_g. Posle razmatranja rezultata može se zaključiti da postoji relativno mali uticaj intenziteta plastične deformacije na vrednost "r" faktora, t.j. da se vrednost "r" faktora može uspešno odrediti i pri manjim stepenima deformacije.

Ključne reči: karoserijski limovi, anizotropija, "r" faktor

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INTRODUCTION

Car body structure (Fig. 1), including outer panels, is being made almost from steel and Al alloys sheets. Main technology in forming processes is deep drawing. In these processes very important is to know how to evaluate formability of sheet materials. In numerous researches [1, 2, 3, 4, 5 etc] has been established that relatively simple but effective way to evaluate sheet metals formability in deep drawing processes is determination of anisotropy parameters, especially normal (orthogonal) anisotropy parameters.

Figure 1. Car body structure

Car body thin sheet metals are almost always anisotropic materials. Anisotropy can be expressed as plane i.e. planar and normal (orthogonal). Plane anisotropy is related to different mechanical and formability characteristics variation considering different directions in sheet metal plane, where the referent direction is the rolling direction. Normal anisotropy is related to the direction of 90 degree towards the sheet surface i.e. in the direction of sheet thickness, and that material property has a special importance. It was theoretically considered for a long time that is most suitable for the sheets to be isotropic. It is the state where the properties are equal in all directions in volume. In technological practice, the opposite conclusion was reached very soon. Actually, very convenient is the situation where deformations in sheet plane are large but at the same time thickness deformation (thinning or thickening) very small.

The significance of the influence of the "r" factor on deep drawing formability can be seen in Fig. 2. There is a high degree of correlation between "r" factor and LDR of cylindrical sheet metal part. As the value of the "r" factor increases above 1, the LDR also increases intensively.

The most suitable parameter to express normal anisotropy is parameter known by several names: coefficient of normal anisotropy, plastic strain ratio, "r" value, "r" factor etc. Here in the text the term "r" factor is adopted. In addition to its importance as a formability parameter "r" factor is important parameter in anisotropic plasticity theory and numerical simulation of metal forming processes. "r" factor can be determined experimentally only ([4], [5], [6], [7], [8]) and it's a matter of standards ([9], [10]). "r" factor is important parameter for consideration of anisotropy influence in different forming processes beside deep drawing, or theory investigations (e. g. [11]). Many studies have been devoted to the influence of anisotropy for specific materials and technological processes (e.g. [12], [13]).

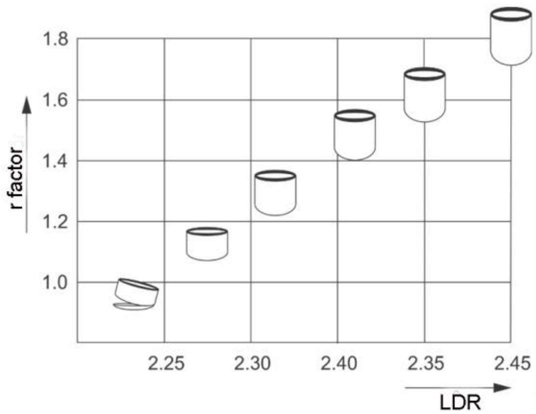

Figure 2. Limiting drawing ratio (LDR) dependence on "r" factor

Main experimental procedure for "r" factor determination is uniaxial tension in a field of a homogenous plastic strain. In standards ([9], [10]), scientific articles ([5], [8] etc). and other publications ([1] etc). there is no exact recommendation about intensity of that strain which must be given. Recommendation are general and because of that there is a space for research and answer the question: how given intensity of plastic strain affects the final value of "r" factor for different materials. Here in this paper special attention is paid to the influence of low intensities of plastic strains. In article [14] given is extensive investigation of the influence of strain higher degrees and sample geometries both. This article actually gives continuations of those researches.

1. EXPERIMENT

Procedure for "r" factor experimental determination is uniaxial tension, as previously noted. In [14] concluded was that there is no important influence of sample geometry on the "r" factor final value. So, here is adopted specimen geometry given at Fig. 3.

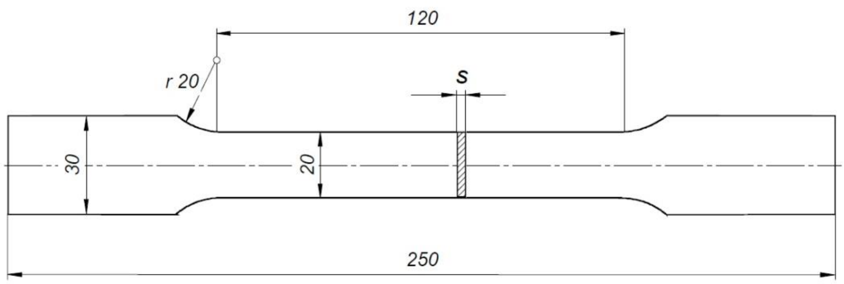

Figure 3. Specimen geometry for uniaxial tension

The definition of the "r" factor is given by well-known formulas:

$$r = \frac{\varphi_b}{\varphi_s} = \frac{ln\frac{b_0}{b}}{ln\frac{s_0}{s}} \tag{1}$$

$$l_0 \cdot b_0 \cdot s_0 = l \cdot b \cdot s = const. \quad \frac{s_0}{s} = \frac{l \cdot b}{l_0 \cdot b_0} \quad r = \frac{ln\frac{b_0}{b}}{ln\frac{l \cdot b}{l_0 \cdot b_0}} \tag{2}$$

where $\boldsymbol{\varphi_b}$ is logarithmic (true) plastic strain of specimen width; $\boldsymbol{\varphi_s}$ is logarithmic (true) plastic strain of specimen thickness, $\mathbf{l_0}$**,** $\mathbf{b_0}$**,** $\mathbf{s_0}$ are initial specimen dimensions, length, width and thickness; **l, b, s** are in process, or final, specimen dimensions, length, width and thickness. It is useful to note that for much higher accuracy, width measurement is used instead of thickness measurement. Measuring of the width changes usually performs at several places (up to nine) and then calculate average value ([8], [9], [10], [14]).

If the "r" factor r=1 there is isotropic sheet, i.e. deformation in sheet plane is equal as the deformation of thickness. If r<1 thickness deformation (thinning) is higher than deformation in sheet plane. This situation is inconvenient because thinning quickly leads to localized deformation and fracture appearance. Suitable situation is r>1. The higher r is than 1, the larger is the deformation in the plane of the sheet and the lower is thinning. In practice, the most suitable values of the "r" factor are r>1.2 [1]. "r" factor actually represent resistance of the material to thinning which can be dangerous because of fracture appearance.

Materials used in the experiment are: austenitic stainless steel sheet X5CrNi18-10 with measured mechanical properties (Fig. 4): tensile strength R_M=679,2 MPa, flow stress R_P=266,5 MPa, percentage elongation at fracture A=62,1% and percentage elongation at maximal force i.e. maximal homogenous strain Ag≈60%; Al alloy AlMg4,5Mn0,7 (or ENAW 5083) sheet metal with properties (Fig. 5): tensile strength R_M=253,5 MPa, flow stress R_P=109,2 MPa, percentage elongation at fracture A=24,4% and percentage elongation at maximal force i.e. maximal homogenous strain Ag=23%; Al alloy temper is F (fabricated, as cast) [15]. Samples was cut in rolling direction. Should be noted that this Al alloy sheet metal is intended for cold forming and can be successfully used for car body parts.

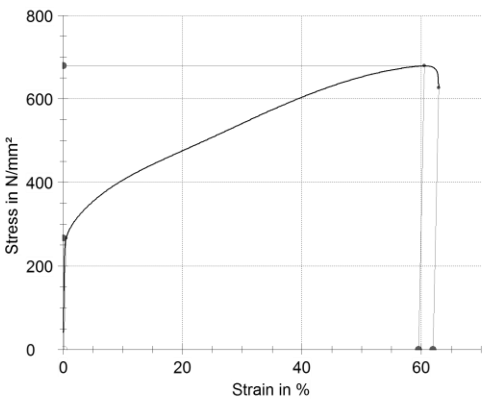

Figure 4. Stress-strain curve for stainless steel

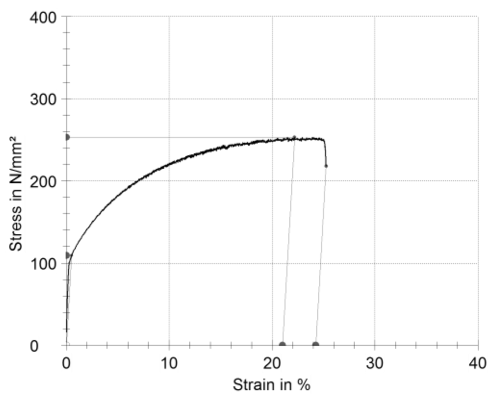

Figure 5. Stress-strain curve for Al alloy

For investigate the influence of the intensity of plastic strain first were determined reference values i.e. percentage elongations at maximal force for both materials. That is the preparatory part of the experiment. In relation to those values, a series of strain values that should be set is defined. The following plastic strain values are selected: 10, 20, 30, 40, 50, 60, 65, 70, 75 percent of Ag.

The experiment was performed on computerized tensile machine Zwick/Roell Z 100 (Fig. 6). The physical appearance of one series of specimens is given in Fig. 7.

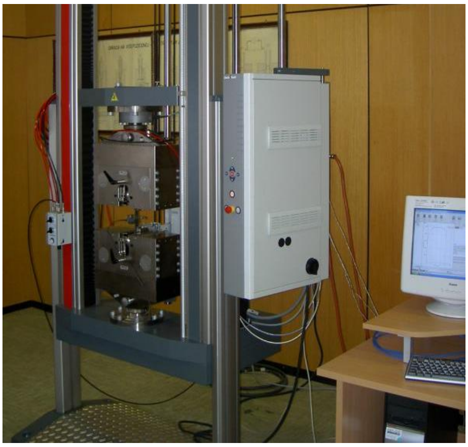

Figure 6. Computerized tensile machine

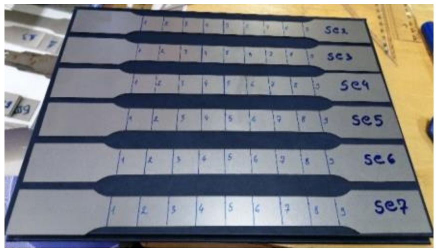

Figure 7. One series of specimens

It should be noted here that it is necessary to reject all the general and imprecise recommendation and perform uniaxial tensile testing with a aim of determining the real values of maximal homogenous strains. Later can be adopted appropriate value of plastic strain necessary for "r" factor.

2. RESULTS AND CRITICAL CONSIDERATIONS

After defining the required intensities of plastic strains, it was started with uniaxial tension tests. There were difficulties with elastic strains that needed to be determined as exactly as possible. This was done in previous experiments. Influence of the elastic strains must be eliminated. In Table 1 and Table 2 given are the results. Values for **b** (appropriate width change) and **l** (appropriate length change) are related to the pure plastic strain without elastic strain. Realized plastic strains values are signed as percent of maximal homogenous strain Ag, and can be calculated from $\mathbf{l_0}$, and **l**.

Table 1. Results for X5CrNi18-10 sheet metal

b_0 [mm]	*b* [mm]	l_0 [mm]	l [mm]	s_0 [mm]	% of Ag	**r** [-]
20,08	17,41	118,4	166,0	0,77	75	0,731
20,06	17,61	116,6	157,8	0,76	70	0,755
20,06	17,76	117,9	156,4	0,76	65	0,757
20,06	17,89	117,5	153,4	0,77	60	0,752
20,10	18,23	117,4	147,8	0,76	50	0,736
20,06	18,50	116,8	140,6	0,76	40	0,744
20,04	18,85	118,2	136,2	0,76	30	0,760
20,06	19,21	118,0	130,6	0,76	20	0,744
20,08	19,64	118,3	125,0	0,77	10	0,673

Table 2. Results for AlMg4.5Mn0.7 sheet metal

b_0 [mm]	*b* [mm]	l_0 [mm]	l [mm]	s_0 [mm]	% of Ag	r [-]
19,93	19,04	116,2	135,8	1,06	75	0,472
19,93	19,05	118,0	135,6	1,06	70	0,481
19,93	19,07	117,8	134,2	1,06	65	0,511
19,91	19,12	117,8	132,6	1,07	60	0,520
19,93	19,22	117,0	130,0	1,06	50	0,525
19,94	19,42	116,6	126,8	1,06	40	0,460
19,90	19,48	117,3	125,2	1,06	30	0,486
19,94	19,68	117,4	123,2	1,07	20	0,374
19,93	19,79	117,4	120,6	1,06	10	0,354

Figure 8 and Figure 9 shows tensile diagrams for part of the experiment. Figure 8 are related to steel sheet, and Figure 9 to Al alloy sheet. It should be noted that the curves in the diagrams show the realized previously given plastic strains. The curves are shown with the appropriate offset, i.e. the distance between them.

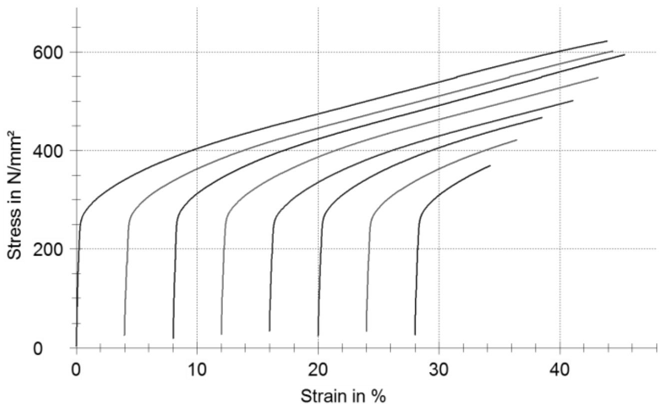

Figure 8. Tensile diagrams for X5CrNi18-10 sheet

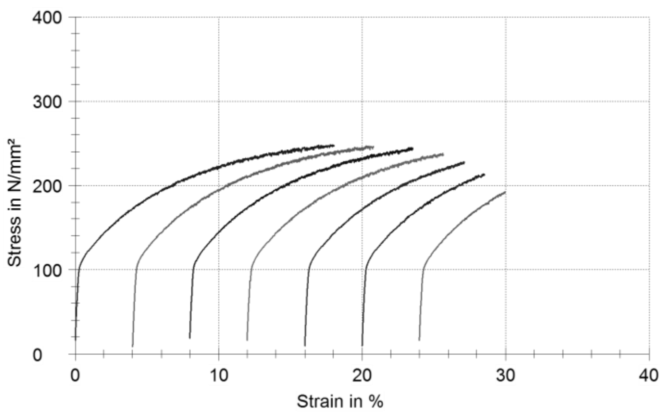

Figure 9. Tensile diagrams for AlMg4.5Mn0.7

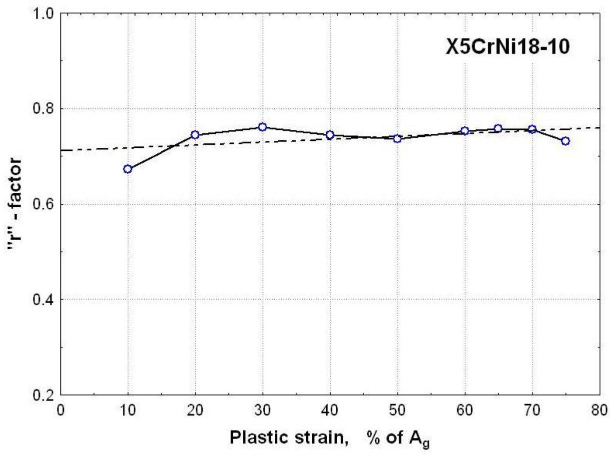

Figure 10. "r" factor dependence on plastic strain

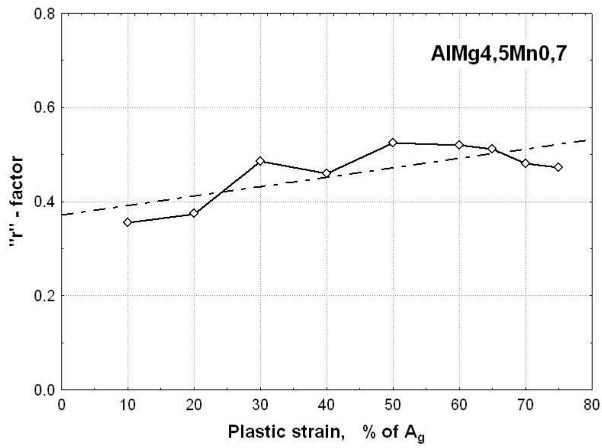

Figure 11. "r" factor dependence on plastic strain

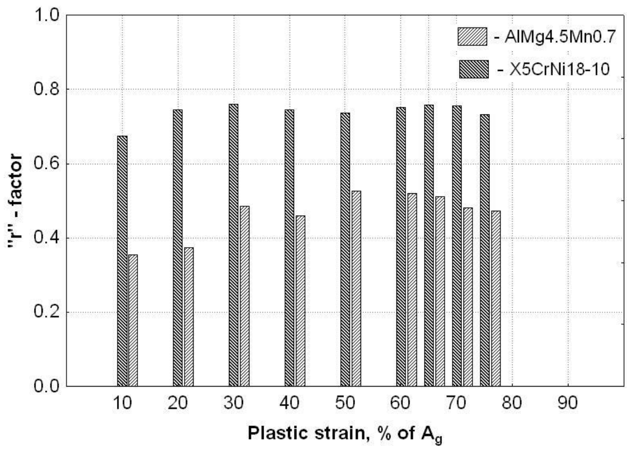

Figure 12. "r" factor dependence on plastic strain

Based on the results in Table 1 and Table 2 the diagrams in the Figure 10 and Figure 11 were formed, and also histogram in Figure 12. Diagrams and histogram shows "r" factor dependence on previously set plastic strain signed as percent of maximal homogenous strain Ag. Clearly can be seen the influence of the degree of deformation on "r" factor value. The formed curve for steel sheet deviates relatively little from the slightly inclined straight line representing the average value. Irresistibly conclusion is that a large decreasing of plastic deformation has a relatively small, almost negligible effect on the values of the "r" factor.

For the Al alloy sheet the situation is somewhat different. First, inclination of the straight average line is larger than the steel. Second, points deviations from average line are larger. Therefore, the conclusion is not so clear, although as the plastic strain decreases, the "r" factor value also decreases to a certain extent. The histogram from Figure 12 shows the same as Figure 10 and Figure 11.

The probable reasons for the previous considerations are, firstly, the materials are completely different, and secondly, the realized absolute intensities of plastic strains are also very different. Plastic strain absolute intensity of Ag for sheet X5CrNi18-10 is 60%. Ten percent of that is 6%. Plastic strain absolute intensity of Ag for sheet AlMg4.6Mn0.7 is 23%. Ten percent of that is 2.3%, almost 3 times lower. Therefore, one can be careful and use plastic strain closer to Ag for determining the "r" factor in materials with lower plasticity. Something is different in the case of material with better plasticity like with austenitic stainless steel in this case. There is possible to use significantly less intensities of the plastic strains without reducing measuring accuracy.

3. CONCLUSIONS

After considering the results of the conducted experiment, the following observations and conclusions can be made:

- the influence of the type of material on the "r" factor value determination related to the application of different intensities of plastic strains is clearly visible,
- with materials that have better plasticity lower intensity of plastic strain can be used,
- with materials that have lower plasticity must be used intensity of plastic strain closer to Ag,
- in the experiment, one should be careful of the harmful influence of elastic deformations, which must be eliminated,
- in the following investigations, the intensities of plastic strains and their range should be defined even more carefully,
- also, in the following investigations it would be useful to include more different materials.

AKNOWLEDGEMENT

The experimental research reported in this paper was partially supported by the Ministry of Education, Science and Technological Development, Republic of Serbia through contract TR34002.

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