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Intralaboratory comparison for the anisotropy test of sheet metals

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Abstract. The plastic strain ratio is an important parameter for the evaluation of the anisotropy of sheet metals in deep-drawing processes. This paper presents the results of an intralaboratory comparison for the anisotropy test, using normalized error as statistic method of analysis. The study was carried out through the comparison of the results obtained from different operators for the same sheet metal. The results of the study are considered satisfactory.

1. Introduction

According to ASTM E517:2010 [1], the plastic strain ratio (r) is a parameter that indicates the ability of a sheet metal to resist thinning or thickening when subjected to either tensile or compressive forces in the plane of the sheet. It is a measure of plastic anisotropy and is related to the preferred crystallographic orientations within a polycrystalline metal. The r value, therefore, is considered a measure of sheet metal drawability.

The value of r can be calculated according to equation (1), where w_o and l_o represent the initial width and length of test specimens, and w_f and l_f represent the final width and length, respectively.

$$r = \frac{\ln\left(\frac{w_o}{w_f}\right)}{\ln\left(\frac{l_f w_f}{l_o w_o}\right)} \quad (1)$$

Another parameter of the anisotropy test is the r_m value, which represents the weighted average of r values obtained in three directions: parallel (r_0), diagonal (r_{45}), and transverse (r_{90}) to the rolling direction [1], according to equation (2).

$$r_m = \frac{r_0 + 2r_{45} + r_{90}}{4} \quad (2)$$

ISO/IEC 17025:2005 standard establishes management and technical requirements for the competence of testing and calibration laboratories. Among the technical requirements, there is the



quality assurance of test results: the standard demands the laboratory to apply periodically procedures to monitor the quality of the measurements, using statistical techniques to analyze the results [2].

The Normalized Error (E_n) method tests the compatibility of measured values (X_1 and its uncertainty, u_1) to a reference value (X_2 , with its uncertainty, u_2). E_n is calculated according to equation (3), and the result is considered compatible when $E_n \leq 1$. This method is widely used in quality assurance programs (intralaboratory and interlaboratory comparisons) according to the literature [3–7].

$$E_n = \frac{|X_1 - X_2|}{\sqrt{u_1^2 + u_2^2}} \quad (3)$$

Several cases of intralaboratory comparison are found in literature. For example, Cools *et al.* [8] have studied forest soil analysis, evaluating interlaboratory and intralaboratory variation. Lee and Hill [9] have evaluated intralaboratory repeatability of residual stress determined by the slitting method and, finally, Smagunova *et al.* [10] have discussed on-line control of the intralaboratory precision in chemical analysis.

Thus, the main purpose of this paper is to present the results of an intralaboratory comparison for the anisotropy (plastic strain ratio) test for sheet metals, using normalized error.

2. Material and methods

Test specimens have been taken from a sheet metal with dimensions 500 x 300 mm (figure 1) in three directions: 0° (parallel), 45° (diagonal), and 90° (transverse) to the rolling direction, in order to calculate r_m .

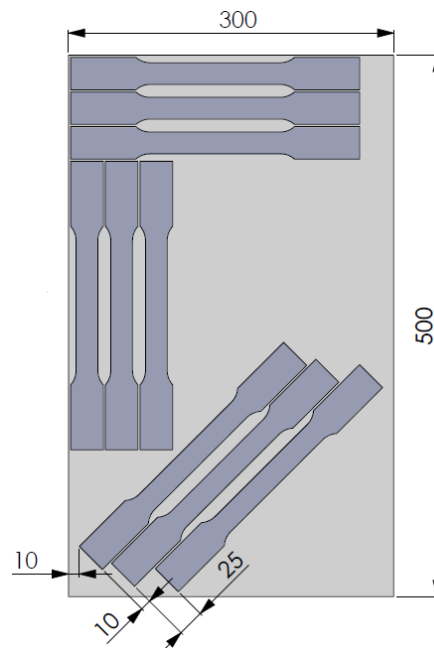


Figure 1. Position of the specimens along the sheet, dimensions in millimeters.

The geometry of each test specimen, accordingly to ASTM E517:2010 standard, is represented in figure 2.

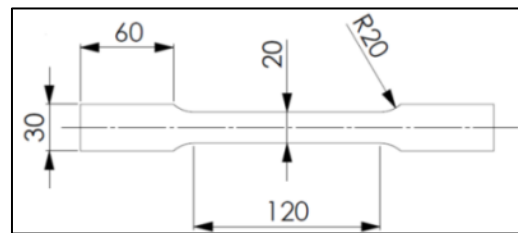


Figure 2. Test specimens, dimensions in millimeters.

Two operators ('A' and 'B') have received three test specimens, one from each direction (0° , 45° and 90°). They were individually instructed to carry out the test using a caliper rule for dimensional measurement, and a universal testing machine for the elongation of test specimens.

The values of l_o and w_o were measured before executing the test. Then, test specimens were inserted in the testing machine. The specified elongation was 10%, i. e., test specimens should be deformed until the relation $(l_f - l_o)/l_o$ was approximately equal to 0.1. After the deformation, the values of l_f and w_f were measured and used in the calculation of r_0 , r_{45} , r_{90} and r_m .

Finally, measurement uncertainty of the results was estimated according to ISO/GUM [11].

3. Results and discussion

Tests were carried out using a universal tensile testing machine as illustrated in figure 3. Longitudinal strains were measured using a strain gauge extensometer while the strain in the width was measured with a digital caliper.



Figure 3. Test execution.

Results of r , r_m and the uncertainty (u) associated to r_m ($u(r_m)$) are shown in table 1. The estimation of the uncertainty was according to ISO/GUM, considering the resolution, standard deviation and calibration data for each dimensional variable (w_o , l_o , w_f , l_f).

Table 1. Anisotropy test results.

Specimen	r	r_m	$u(r_m)$	Operator
A-0°	1.32			
A-45°	0.80	0.99	0.20	A
A-90°	1.05			
B-0°	1.27			
B-45°	0.83	0,98	0.16	B
B-90°	0.99			

The value of the normalized error associated to r_m was calculated according to equation (4).

$$E_n = \frac{|0.99-0.98|}{\sqrt{(0.20)^2+(0.16)^2}} = 0.039 \quad (4)$$

Since $E_n = 0.039 \leq 1$, the result of the intralaboratory program is considered satisfactory. The differences between test executors (operators ‘A’ and ‘B’) were smaller than the measurement uncertainty.

The use of normalized error in intralaboratory comparisons and test validation is consistent with literature. For example, Alves *et al.* [12] have used this method in atomic absorption spectroscopy, obtaining $E_n \leq 1$ and, consequently, validating the results. Similar studies have been carried out by other authors [3–7], in the fields of hardness, dimensional and hygrometry measurement, using the same acceptance criteria.

However, the uncertainty values in this work have been large, approximately equal to 20% of the calculated values of r_m . Measurement uncertainty of r_m was estimated considering the following uncertainty sources for each dimensional variable: data from equipment calibration, equipment resolution and standard deviation of repeatability. The deviation of repeatability was responsible by approximately 75% of combined uncertainty, while data from calibration certificate was responsible by 16% of contribution and resolution by 9%.

The large deviation of repeatability is probably caused by the type of measurement equipment used (digital caliper). Perhaps different equipment could improve uncertainty values. Thus, future works could focus on further evaluation and improvement of the uncertainty of this test.

4. Conclusions

This paper has presented the implementation of a procedure to evaluate quality assurance of the anisotropy test of sheet metals. An intralaboratory comparison through the normalized error has been carried out, and the results were satisfactory.

Nevertheless, the uncertainty of the test was large, about 20% of the measured values of r_m . Future work is necessary to analyze and reduce measurement uncertainty caused by deviation of repeatability in dimensional measurement for this test.

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