ANISOTROPY DETERMINATION OF DEEP-DRAWING SHEET BY MEANS OF CONTACT-LESS OPTICAL SYSTEM FOR MEASURING DEFORMATION

ZJIŠŤOVÁNÍ ANIZOTROPIE HLUBOKOTAŽNÉHO PLECHU POMOCÍ BEZKONTAKTNÍHO OPTICKÉHO SYSTÉMU PRO MĚŘENÍ DEFORMACE

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Abstract

During last years there was a huge progress in contact-less systems for measuring deformation by means of photogrammetry which in its consequence leads to improve knowledge about material behavior under plastic deformation. This is mainly due to possibility e.g. to clearly identify important point during static tensile test like yield strength, ultimate strength or moment right before rupture and for each of these moments these systems immediately exhibit all important parameters from the metal forming point of view i.e. distribution of major and minor strains, Tresca or von Mises strain, strain rate and so on. Thus values which are sometimes really quite difficult to measure only by means of static tensile test. This paper describes possibility to determinate anisotropy of deep-drawing material by means of optical system ARAMIS v6.2.0-3 during whole evolution of static tensile test and comparison of results from those measured in values of deformation given by standard ČSN ISO 12 275.

Key words: Photogrammetry, Anisotropy, Deep-drawing Materials

1. INTRODUCTION

Anisotropy represents very important material property not only during sheet processing but also already for numerical simulation where anisotropy is very important input parameter. Commonly anisotropy is measured under given nominal strain ε (according standards) thereby coefficient of normal anisotropy r_n is calculated only in this value of ε. However modern optical systems for contact-less deformation measurement (like ARAMIS system) enable to determinate r_n during whole static tensile test. And comparison of conventional measurement of r_n and by ARAMIS system is main part of this paper. As a testing material was used commonly using zinc-coated deep-drawing material marked like DC 05B (electro-galvanized) with thickness 0,8 mm. In fig. 1 are shown basic stress-strain curves for 3 mainly using rolling directions (0°, 45° and 90°) of tested material.

Fig. 1. Static tensile test of measured materials
2. **ANISOTROPY IN SHEET METAL FORMING – CONVENTIONAL MEASUREMENT**

Anisotropy generally means to be directionally dependent (to the contrary of isotropy). In sheet metal forming anisotropy represents directionality of properties (mainly mechanical). Anisotropy is thus dependence of measured material properties on specimen's direction and thereby is necessary to relevant result of material anisotropy. Add also direction of specimen toward rolling direction mostly 0°, 45° and 90°. To achieve material anisotropy is always necessary to orient crystal lattice of given material. The most suitable orientation from the sheet anisotropy point of view is when direction $\{111\}$ is normal to sheet surface [1]. Generally is possible to define normal anisotropy $r_a$ [-] like ratio of stain in the width direction $\varphi_b$ and strain in the thickness direction $\varphi_s$ (thickness reduction) at corresponding direction $\alpha$:

$$r_a = \frac{\varphi_b}{\varphi_s} \tag{1}$$

For isotropic material is valid $r_a = 1$. However it is difficult to measure change of thickness and equation (1) is modified by using reality that plastic deformation is a constant volume process (strain in length direction $\varphi_L$):

$$\varphi_L + \varphi_b + \varphi_s = 0 \Rightarrow \varphi_s = -(\varphi_L + \varphi_b) = -\ln \frac{L_b}{L_0 b_0} \tag{2}$$

By using (2) is possible to find the final equation for $r_a$ which contains only length and width measurement, where $L_0$ is initial length, $L$ actual length, $b_0$ initial width and $b$ actual width (both as average from 3 values):

$$r_a = \frac{\varphi_b}{\varphi_s} = \frac{\ln \frac{b}{b_0}}{-\ln \frac{L_b}{L_0 b_0}} = \frac{\ln \frac{b_0}{b}}{-\ln \frac{L_b}{L_0 b_0}} \tag{3}$$

Measurement of normal anisotropy $r_a$ is commonly carried out in 3 main directions (0°, 45° and 90°) towards rolling direction. By using $r_a$ is thereby also possible to define so-called planar anisotropy $\Delta r$ and mean anisotropy value $r_m$ as:

$$\Delta r = \frac{1}{2} (r_0 + r_{90} - 2r_{45}) \text{ and } r_m = \frac{1}{4} (r_0 + r_{90} + 2r_{45}) \tag{4}$$

These equations are used during measurement of normal anisotropy $r_a$ and different standards define the amount of nominal strain $\varepsilon$ to which specimens have to be deformed. Here for conventional measurement of normal anisotropy $r_a$ were used: $\varepsilon = 0,1$, $\varepsilon = 0,2$ and $\varepsilon = 0,25$ and were measured following results:

**Table 1** Values of normal anisotropy $r_a$ measured by conventional method

<table>
<thead>
<tr>
<th>Coefficient of normal anisotropy $r_a$ [-]</th>
<th>Rolling direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal strain $\varepsilon$ [-]</td>
<td>0°</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>0,1</td>
<td>1,99</td>
</tr>
<tr>
<td>0,2</td>
<td>1,84</td>
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<tr>
<td>0,25</td>
<td>1,76</td>
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</table>
3. MEASUREMENT OF NORMAL ANISOTROPY $r_a$ BY MEANS OF ARAMIS SYSTEM

Using contact-less optical systems for deformation measurement made a great progress during last years. They represent very good solution e.g. for measurement deformation behavior both of widely used materials and newly developed materials (TRIP, TWIP, ...). In this paper such system (marked like ARAMIS system) was used to measure normal anisotropy $r_a$ from static tensile test and workplace lay-out is shown in fig. 2. Its optical system thus there is couple of cameras (to be able to measure 3D), strong lighting device, T-box for controlling signal for cameras and PC for data scanning and results evaluation. In principle this system measures displacements $(x,y,z)$ of so-called facets [pixels] from observed area and from such displacement calculates mainly strain distribution (if interest also e.g. strain rate, velocity, acceleration, ...). For more detail description see internet page about GOM company (producer) or e.g. [2].

Fig. 2. Workplace lay-out for deformation measurement by system ARAMIS

In the following figures is shown principle of the normal anisotropy $r_a$ measurement by means of ARAMIS system. In principle was measured strain but it wasn’t used more in this experiment. Fig. 3 illustrates first measured stage $\tilde{\varepsilon}$ stage 0 (unloaded) and that is why major strain $\tilde{\varepsilon}_1$ equals 0. But from strain distribution is possible to measure distances of any points on this surface. Thus here was used "virtual" strain gauge and in 3 places was measured width $\tilde{b}$ width $b_1$, $b_2$ and $b_3$. From these 3 widths was subsequently calculated mean average. Fig. 3 shows initial value (nominal), actual and difference between actual and initial value. Fig. 4 illustrates situation when $\varepsilon = 0.3$ (left) and right before rupture (right) which already contains necking area. Thus is possible to observe these data during whole evolution of static tensile test and by using equation (3) to calculate value of normal anisotropy $r_a$ for each moment of test.
Fig. 3 and 4 clearly illustrate possibility how to measure normal anisotropy $r_a$ by means of optical system ARAMIS. For each measured stage (final number of stages and sensitivity strongly depend on used frame rate $\dot{v}$ commonly 4-6 frames per second). All observed parameters (strain gauge $\dot{\epsilon}$, measurement of length, widths $b_1, b_2, b_3$) were exported and by means of programme OriginPro 7.5 was calculated coefficient of normal anisotropy $r_a$. For each rolling direction was used 3 specimens and final dependence on normal anisotropy $r_a$ was calculated as mean average from these data $\bar{\epsilon}$ see fig. 5. Final comparison of all used rolling direction (0°, 45° and 90°) was also carried out with the help of programme OriginPro 7.5 $\bar{\epsilon}$ see fig. 6.
Following figures illustrate data processing measured by means of ARAMIS system. For whole evaluation of static tensile test was measured relevant data about change of width (in 3 places) and length. To calculate normal anisotropy $r_a$ was used equation (3). In fig. 5 (left) is clearly seen whole evolution of $r_a$ in dependence on nominal strain and also strong influence coming from necking area (red dashed curve). That is why all curves are ended at $\varepsilon = 0.3$. For each rolling direction were measured 3 specimens – fig. 5 (right).

![Fig. 5. Used range of nominal strain $\varepsilon$ (left) and average of measured curves (right) by system ARAMIS.](image)

Final result in graphical illustration is shown in fig. 6 (rolling direction 0°) which exhibits comparison of both used method for measurement $r_o$. Comparison itself is made in 3 places: $\varepsilon = 0.1; 0.2$ and 0.25.

![Fig. 6. Comparison of normal anisotropy $r_o$ measured both by ARAMIS and conventional measurement.](image)
4. CONCLUSION

This paper describes possibility how to measure normal anisotropy $r_a$ during whole evolution of static tensile test by means of contact-less optical system (here ARAMIS system) and comparison of results with values of normal anisotropy measured by conventional method (using different standards). Main advantage rising from using ARAMIS system lies in possibility to find $r_a$ in every part of static tensile test. Fig. 7 shows comparison of these two methods hot to find normal anisotropy coefficient. One can see that differences between used measurement lie within interval: $(0.59; 1.33)\%$. Thus it's possible to state that newly used method (ARAMIS) reveals very good matching with conventional method and beside that is e.g. more transparent. However is necessary to admit that this method is quite time-consuming. As a recommendation for further research there is e.g. topic about influence of elastic deformation on results measured by ARAMIS system because this is maybe the most important difference between conventional and ARAMIS measurement.

![Graph](image)

**Fig. 7.** Comparison of normal anisotropy $r_0$ measured values for all used rolling direction

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**LITERATURE**
