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# Formability analysis of thin steel plates

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-------------------------------------------------------***ABSTRACT***-------------------------------------------------------
*The paper deals with the analysis of the compressibility of batch annealed packaging sheets. Tin-plated packaging sheet is still one of the most preferred materials for the production of thin packaging. Nowadays, material processors employ various tests to assess the properties of these sheets. The paper focuses on analyzing 16 different sheet types, with thicknesses ranging from 0.155 to 0.30 mm. It presents the evaluation methods and findings from tensile tests, biaxial tests, and cupping tests.*

***Keywords*** *– formability, ears creation, uniaxial tensile test, biaxial test, cupping test*
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## I. INTRODUCTION

Batch-annealed packaging sheets meet all the requirements for deep-drawing processing. The annealing process in batch furnaces creates conditions for achieving a uniform ferritic grain throughout the material. This group of sheets was developed for deep drawing applications of demanding packaging made from thin steel sheets. These materials are characterized by a low, inconspicuous yield point, significantly lower than their tensile strength, and high ductility. The sheets are manufactured either by a conventional method or as double-reduced (DR sheets). The second reduction occurs after batch annealing, which results in sheets with a higher yield point and lower plastic properties.

The paper will compare sheets produced by the conventional method, batch-annealed with thicknesses of 0.17 – 0.3mm, with sheets made by a second reduction from batch-annealed sheets. The comparison will be based on two types of tests: uniaxial tensile test and biaxial tensile test. These two tests were chosen to compare the achieved strength and plastic properties of thin batch-annealed packaging sheets of various thicknesses and manufacturing methods. The results should lead to the optimization of the testing method for determining the objective properties of the sheets, thereby creating conditions for their seamless processing by drawing.

The formability of batch-annealed packaging sheets was also verified through the cupping test, which, in addition to material properties, includes the influence of technological conditions and the geometry of the active parts of the drawing tool on the drawing process. The cupping test was used to evaluate the anisotropic properties of thin packaging sheets, as evidenced by the formation of ears on the drawn products.

## II. MATERIAL USED IN THE EXPERIMENTS

For the experimental research on the formability analysis of batch-annealed sheets, batch-annealed materials of various thicknesses and alloys were used. In total, 16 types of sheets across four grades—TS 245 BA, TS 260 BA, TS 275 BA, and TS 480 BA, with thicknesses ranging from 0.155 to 0.30 mm—were used (Table 1).

## III. EXPERIMENTAL METHODOLOGY

### 1. Uniaxial tensile test

The tensile test was conducted in accordance with the STN EN 10002-1+AC1 and STN 42 0321 standards using a TIRA test 2300 device. The evaluation of results was carried out in line with the referenced standards. To determine the anisotropic properties of the material, samples for the uniaxial tensile test were taken in the 0° and 90° directions relative to the rolling direction. From the tensile test, the yield strength ($R_e$), tensile strength ($R_m$), and total ductility ($A_{50}$) were evaluated.

In Fig. 1a), sample No. 56 of quality TS 480 BA after uniaxial tensile testing, which failed both in the measured section and outside the measured section. The slip propagated at an angle of 45°.

Tab. 1 Material used in the experiments

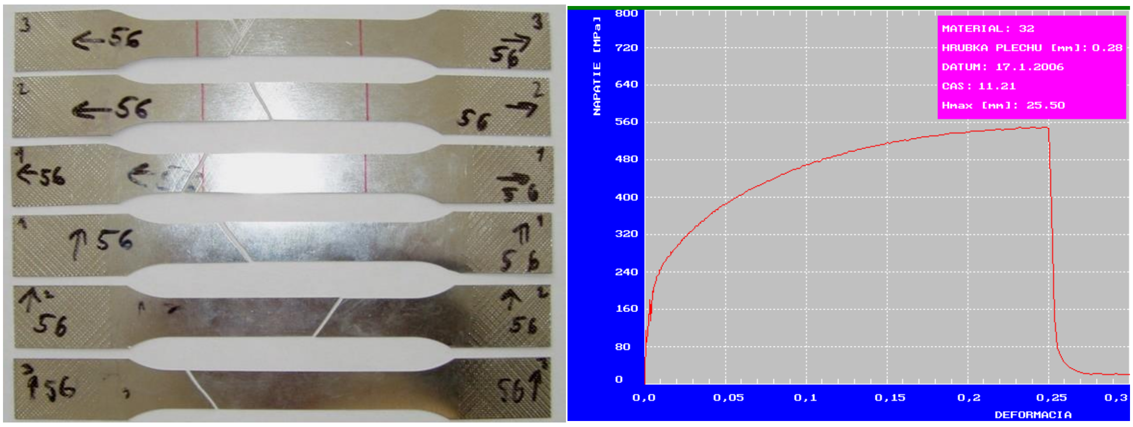
| Material | sample thickness [mm] | sample number |
|---|---|---|
| **TS 245 BA** | 0.24 | 36 |
| | 0.26 | 34 |
| **TS 260 BA** | 0.17 | 86 |
| | 0.18 | 25 |
| | 0.25 | 76 |
| **TS 275 BA** | 0.18 | 16 |
| | 0.18 | 21 |
| | 0.18 | 28 |
| | 0.18 | 98 |
| | 0.28 | 32 |
| | 0.3 | 26 |
| **TS 480 BA** | 0.155 | 14 |
| | 0.155 | 56 |
| | 0.155 | 65 |
| | 0.157 | 73 |
| | 0.157 | 74 |

## 2. Biaxial tensile test

Biaxial tensile test is among the most challenging stress schemes during the plastic deformation of a material.

For this reason, it is highly advantageous to utilize this stress method when assessing the plastic properties of sheets. Subjecting the material to biaxial tensile test closely simulates the conditions found in the hydraulic biaxial tensile test, also known as the bulge test. The measured signals are processed through a technology card and proprietary software program into a graphical "stress-deformation" relationship. From the diagram, the magnitude of stress and deformation at any point on the diagram can be determined. (Fig. 1b).

Three types of samples can be used for the test on this device: square samples of 130x130 mm, rectangular samples of 130x260 mm (both sides can be tested), circular samples of ø130 mm.




a) b)

Fig.1 Samples after uniaxial tensile test (a), record of the “stress-deformation” diagram of the biaxial tensile test of the material TS 275 BA, thickness 0.28 mm (b)

From the test, the yield strength ($R_e$), the stress at the tensile strength limit ($R_m$) upon sample failure, bulge height, and total deformation at the sample failure were evaluated. The equipment used for the biaxial tensile test is available at the Department of Technology, Materials, and Computer-Aided Manufacturing Support. The same materials used in the uniaxial tensile test were employed for the biaxial tensile test (Fig. 2).

a) b)

Fig.2 Sample after biaxial tension test of TS 480 BA (a), TS 275 BA (b)

**3. Cupping test**

For the assessment of ears creation in packaging sheets, a drawing tool with a mechanical blank holder was designed and manufactured by the Department of Technology, Materials, and Computer-Aided Manufacturing Support (Fig. 3). The sheet (blank) is pressed by the holder and drawn through a die and punch from the flange. The cupping test was conducted for cylindrical draws. From a circular blank with a diameter of D = 55 mm, a cup with a diameter of d = 33 mm was drawn. The drawing ratio was 1.66.

Fig. 3 Cupping test tool

Because cold-rolled sheet metal exhibits anisotropy of mechanical properties, uneven ears are produced.

The ears creation of the yields can be expressed:

- degree of ears creation

$$h = \frac{h_0 - 2h_{45} + h_{90}}{2} \qquad [\mathrm{mm}] \qquad (1),$$

- ears creation coefficient

$$Z_c = \frac{h_{\max} - h_{\min}}{h_{\min}} * 100 \qquad [\%] \qquad (2),$$

- maximum yield difference.

$$h_{max} - h_{min} \qquad [\mathrm{mm}] \qquad (3).$$

The ears creation is evaluated by measuring the four lowest and four highest points on each calyx. The recommended criteria for the evaluation of ears creation using the above parameters are given in Table 2. Figure 4 shows the samples after the cupping test.

Tab. 2 Criteria for the assessment of the ear's creation of packaging sheets [5]

| Sample thickness [mm] | Maximum yield difference [mm] | Median yield [mm] | Ears creation [%] |
|---|---|---|---|
| 0.140 | < 0.85 | 16.2 ± 0.1 | < 2.5 |
| 0.155 | < 0.85 | 16.2 ± 0.1 | < 2.5 |
| 0.170 | < 0.90 | 16.2 ± 0.1 | < 3 |
| 0.180 | < 0.90 | 16.2 ± 0.1 | < 3 |

Fig. 4 Samples after cupping test

## IV. RESULTS

The measured results for the strength and plastic properties of batch-annealed packaging sheets are graphically presented in Figures 5 to 7. Figure 5 compares the yield strength values obtained from the uniaxial and biaxial tensile tests. The figure indicates that materials produced by the conventional method have significantly lower yield strength in both tests compared to the double-reduced material. The measured yield strength values for materials TS 245 BA, TS 260 BA, and TS 275 BA are approximately the same and fall within the range recommended by the relevant standard. The yield strength of the TS 480 BA material is significantly higher, and for all measured samples, it is at the upper limit or higher than what the relevant standard specifies.

Figure 6 compares the tensile strength obtained from the uniaxial tensile test with that from the biaxial tensile test. The tensile strength values measured in the uniaxial tensile test for sheets that were single-reduced are lower than the measured and calculated tensile strength results from the biaxial tensile test. This difference is due to the uniform plastic deformation of the thin steel sheet throughout its volume, which causes significant material hardening and, consequently, a higher stress required to cause failure. For sheets made from materials produced by the second reduction, TS 480 BA, the tensile strength values measured in both the uniaxial and biaxial tensile tests are approximately the same.

The comparison of the ductility of the examined packaging sheets is presented in Figure 7. The figure clearly shows that the double-reduced packaging sheet exhibits significantly lower ductility compared to the material that was single-reduced, which is attributed to the sheet's deformation during the second reduction. The results of the experiments also definitively indicate that the measured ductility in directions perpendicular and parallel to the rolling direction is very low for these sheets, as confirmed by the results of the biaxial tensile test, where failure of all samples occurred in the rolling direction and the resulting cracks are very small. The ductility in both the uniaxial and biaxial tests for single-reduced, batch-annealed packaging sheets also depends on the thickness of the material. The greatest ductility is achieved at the largest material thicknesses, where the impact of geometry and microgeometry of the produced sample on its values is less significant than with very thin sheets.

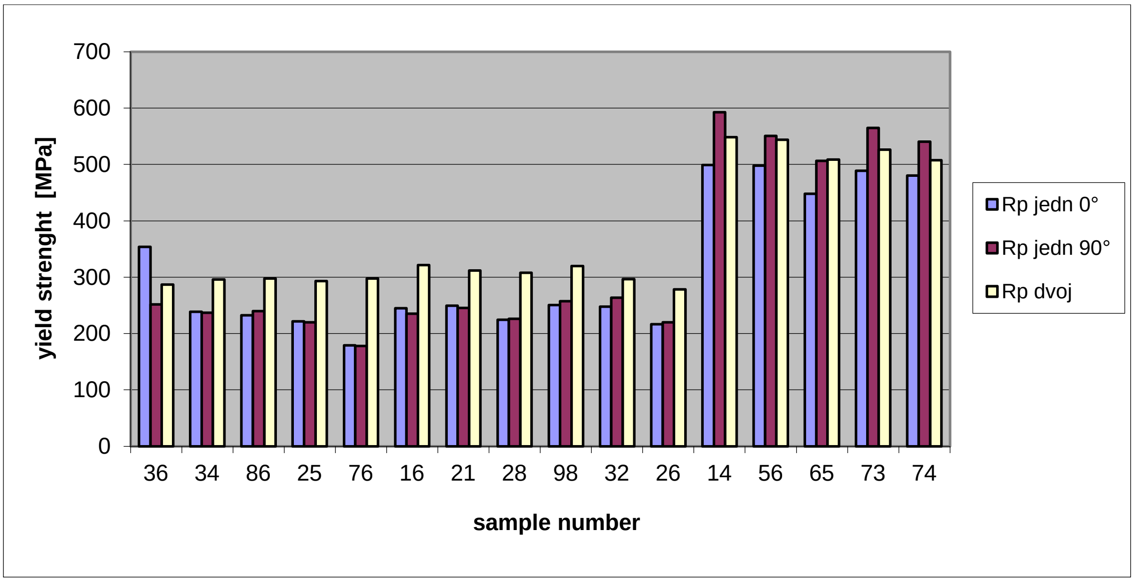



Fig. 5 Comparison of the yield strength obtained in the uniaxial tensile test in the 0° and 90° directions and the yield strength obtained in the biaxial tensile test

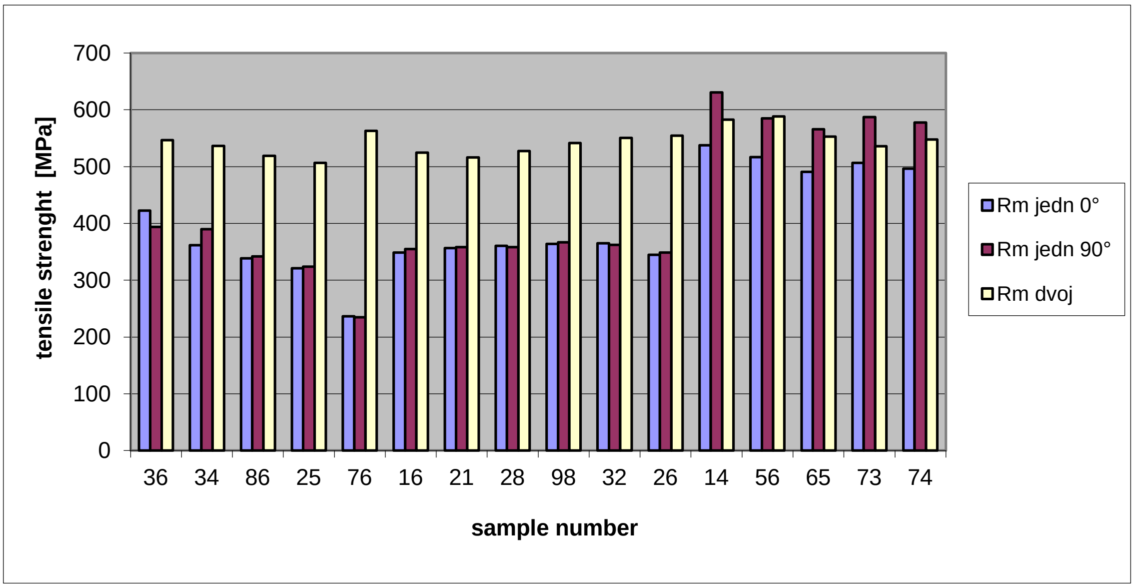



Fig.6Comparison of the tensile strength obtained in the uniaxial tensile test in the 0° and 90° directions and the tensile strength obtained in the biaxial tensile test

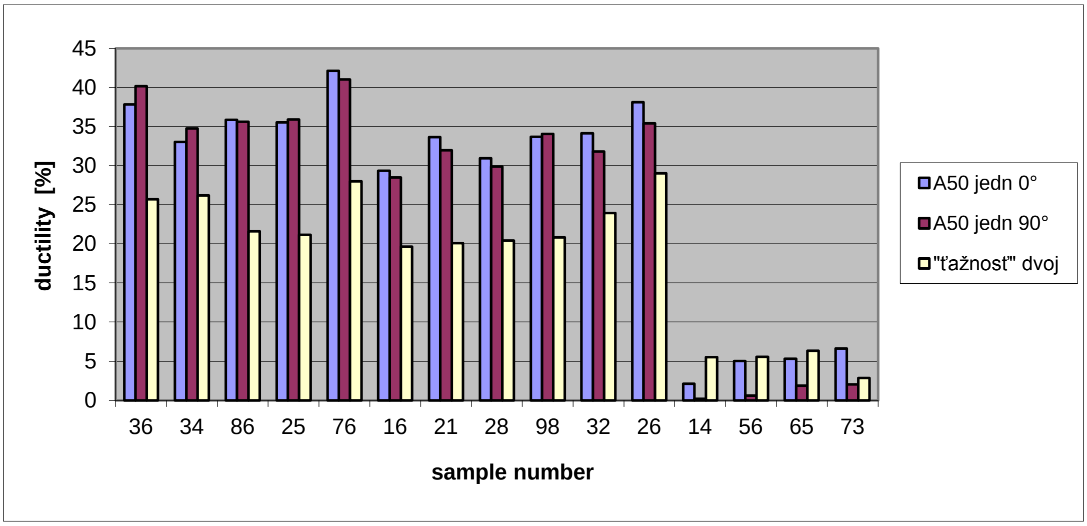



Fig. 7 Comparison of the ductility A50 obtained in the uniaxial tensile test in the 0° and 90° directions and the "ductility" obtained in the biaxial tensile test

The results of the cupping test are presented in Table 3. The measured and calculated values clearly show that single-reduced sheets have lower degrees of ear creation, maximum yield difference, and ear creation coefficient compared to the material that underwent double reduction. However, none of the examined batch-annealed packaging sheets meet all three criteria for assessing ear creation recommended by SEFL [5].

Tab. 3 Measured and calculated values of the ears creation coefficient, ears creation degree, and maximum yield difference achieved through the cupping test.

| material | sample number | nominal thickness [mm] | Z [%] | Δh [mm] | maximum yield difference [mm] |
|---|---|---|---|---|---|
| **TS 245 BA** | 36 | 0.24 | 6.56 | -0.45 | 1.16 |
| | 34 | 0.26 | 2.68 | 0.22 | 0.46 |
| **TS 260 BA** | 86 | 0.17 | 2.72 | -0.10 | 0.47 |
| | 25 | 0.18 | 1.58 | 0.03 | 0.26 |
| | 76 | 0.25 | 3.74 | -0.07 | 0.64 |
| **TS 275 BA** | 16 | 0.18 | 1.81 | -0.06 | 0.34 |
| | 21 | 0.18 | 2.48 | -0.11 | 0.41 |
| | 28 | 0.18 | 3.32 | -0.19 | 0.54 |
| | 98 | 0.18 | 3.10 | -0.24 | 0.53 |
| | 32 | 0.28 | 6.56 | -0.45 | 1.16 |
| | 26 | 0.3 | 5.80 | 0.11 | 0.99 |
| **TS 480 BA** | 14 | 0.155 | 4.16 | -0.44 | 0.68 |
| | 56 | 0.155 | 4.72 | -0.15 | 0.76 |
| | 65 | 0.155 | 4.09 | -0.34 | 0.67 |
| | 73 | 0.157 | 4.30 | -0.21 | 0.71 |
| | 74 | 0.157 | 3.51 | -0.44 | 0.58 |

## V. CONCLUSION

Based on the measured results of values characterizing the formability of batch-annealed sheets from the uniaxial tensile test, biaxial tensile test, and cupping test, the following conclusions can be drawn:

- single-reduced packaging sheets exhibit significantly better plastic properties, as measured by ductility ($A_{50}$), compared to double-reduced materials,
- it is not possible to directly compare the results of uniaxial and biaxial tension tests,

- we recommend using the uniaxial tensile test for single-reduced batch-annealed packaging sheets, due to the significant variation in ductility observed in double-reduced packaging sheets,
- none of the examined materials met all three SEFL recommendations for assessing the ears creation of packaging sheets; therefore, we do not recommend using all the criteria simultaneously.

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## REFERENCES

[1]. SPIŠÁK, E., SLOTA, J., MAJERNÍKOVÁ, J.: Hodnotenie anizotropie tenkých obalových plechov. In: Visnik: Naukovo-mechničnij zbirnik. Kijev: Nacionaľnij transportnij universitet, 2006, p. 23-29.
[2]. SPIŠÁK, E. et al.: The influence of tandem mill reduction on double reduced (DR) tinplates anisotropy. In.: Metalurgija. ISSN 0543-5846. Vol. 45, no.1, 2006, p.45-49.
[3]. SPIŠÁK, E., SLOTA, J., MAJERNÍKOVÁ, J.: Anisotropy evaluation of tinplates. In: PRO-TECH-MA '07: Progressive Technologies and Materials: International Scientific Conference: Rzeszów - Bezmiechowa, Poland, 28th June – 30th June 2007. Rzeszów: Politechnika Rzeszowska, 2007. ISBN 978- 83-7199-443-2. p. 217-222.
[4]. SPIŠÁK, E., SLOTA, J., MAJERNÍKOVÁ, J.: Analýza začiatku plastickej deformácie DR obalových plechov. In: Acta Mechanica Slovaca. year 10, no. 2b Pro-tech-ma (2006), p. 387-392. ISSN 1335-2393
[5]. GADE, D.: Recommendation SEFL N0 7 Tinmil Products, Buxeles 1991