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Determination of yield strength of thin steel plates by various tests

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ABSTRACT

The paper deals with the determination of the yield strength of tinplate packaging sheets with thicknesses of 0.14-0.191 mm. Given the significant changes in the production of tin-coated packaging sheets and the ever-increasing demands on their properties, there is a requirement to use evaluation methods that can quickly and at low costs determine especially the mechanical and plastic properties of the sheets. Based on the existing know-how, new test methods have been developed that more closely correspond to the stress state of steel sheets during technological processing. The paper compares the yield strength in the test with uniaxial and biaxial tension and in the springback test. The paper describes the methods of its evaluation by the mentioned tests and graphically interprets the results achieved by these methods.

Keywords *– yield strength, uniaxial tensile test, biaxial test, springback test*

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I. INTRODUCTION

The production of tin-coated sheets has undergone significant changes over the past few years. Among these changes, the most notable is the substantial reduction in the thickness of packaging sheets from the original 0.24–0.22 mm to 0.14–0.16 mm. These thicknesses are achieved by introducing a second reduction. Packaging sheets produced in this way achieve higher strength properties, especially the yield strength, while maintaining sufficient plastic properties for further processing by forming [1-3]. Given the significant changes in the production of packaging sheets and the increasing requirements for determining their properties, it is necessary to seek objective, quick, and cost-effective test methods to determine their mechanical and plastic properties [3-5]. Given that manufacturers and processors of sheets often use different methods to evaluate the properties of sheets, this paper compares the results of mechanical properties determined by uniaxial tensile test, biaxial tensile test, and springback test. The aim of the paper is to determine the yield strength value obtained by the three most commonly used tests of twice-reduced packaging sheets.

II. MATERIAL USED IN THE EXPERIMENTS

For the experimental research on determining the yield strength of tin-plated sheets by various tests, twice-reduced packaging sheets were used. These were continuously annealed (CA) and batch annealed (BA) before the second reduction, of various thicknesses and from different melts. Annealing is performed either by a continuous process (CA – Continuous Annealing) or a batch process (BA – Batch Annealing). For very thin tin-plated sheets, a second thickness reduction by cold rolling in intervals of 10 – 36% is performed after annealing. The final product has higher hardness and strength after the double reduction compared to simply rolled material. The finalization of the production of packaging sheets is a process of double-sided electrolytic tin-plating. The tin layer serves an anti-corrosive function for the sheet. In total, 17 types of sheets of two qualities, TH 550 CA and TS 550 BA, with thicknesses of 0.14 – 0.191 mm, were used for the experiment.

III. EXPERIMENTAL METHODOLOGY

1. Uniaxial tensile test

The test is currently the most used by sheet processors to obtain the basic mechanical characteristics of the sheet. The conditions and shape of the test sample are specified by standards STN EN 10002-1+ AC1 and STN 42 0321. For thin sheets from the tensile test, we determine the yield strength, tensile strength, and elongation.

To assess the anisotropic properties of the material, samples for the tensile test were taken in the direction of 0° and 90° relative to the rolling direction.

2. Biaxial tensile test

Biaxial tensile is among the most unfavourable stress schemes during the plastic deformation of a material. Therefore, utilizing this method of stressing the sheet when assessing the plastic properties of sheets is very advantageous. Stressing the material with biaxial drawing closely mimics the hydraulic test called biaxial tensile test, also known as the bulge test (hereinafter referred to as the biaxial tensile test). The principle of the test is indicated by the scheme in Fig.1.

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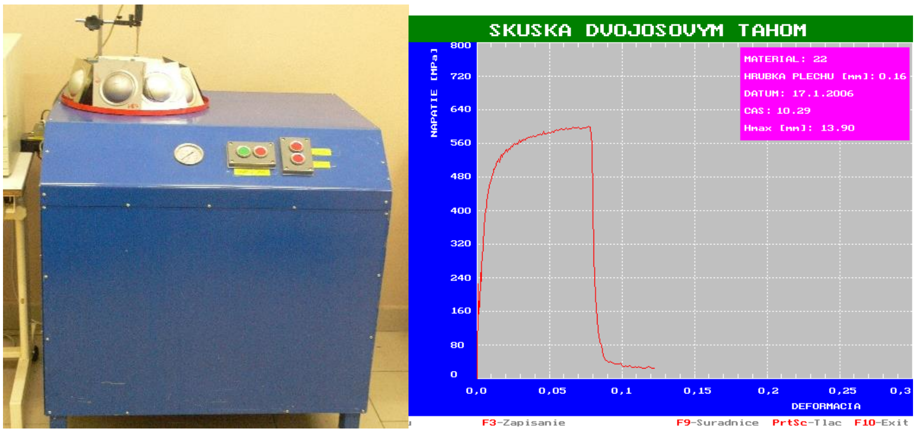


a) b)

Fig.1 Biaxial tensile test apparatus (a) and record of the stress-deformation diagram (b)

The principle of the test consists of bulging the samples of the tested sheet (130x130mm) with hydraulic fluid supplied under pressure. The sample is firmly clamped between the lower plate and the draw bar with a diameter of 80 mm. The force of the holder can be regulated using a valve. The sample flange prevents the material from being drawn in through a restraining rib located in the draw bar, which consists of a ridge on the holder and a corresponding groove on the opposite side. The supplied pressurized fluid bulges the tested sheet until it fails. The measure of the plastic properties of the tested sheet is the height of the spherical cap at the sheet's failure, the shape of the crack after failure, and the surface of the spherical cap.

The biaxial tensile test was conducted on equipment available to the Department of Technology, Materials, and Computer Supported Production. The same materials were used for the biaxial tensile test as for the uniaxial tensile test.

3. Springback test

The resilience test describes the "temper" of the tinplate sheet in terms of yield strength and also characterizes some of its plastic properties. A sample of 152.4 x 25.4 mm is used to perform the test. The sample is clamped at one end, and the other free end is bent 180° around a mandrel with a diameter of 25.4 mm using a roller. The roller returns to the starting position, and the angle of springback is directly read from a scale (Fig. 2).

Fig. 2 Springback test device

The degree of curvature of the plate is characterised by the relationship:

$$\theta / 180° = 1 - (r_0 / r_1)\,, \qquad (1),$$

where:
θ – angle of springback [°]
r_0 - bending mandrel radius [mm]
r_1 - sample radius after springback [mm]

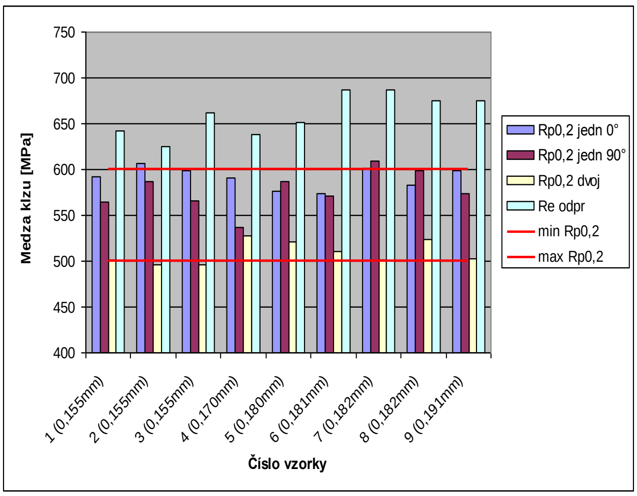
The relationship between the angle of springback θ and R_e is:

$$\theta / 180° = 3[(R_e.r)/E.t] - 4[(R_e.r)/E.t]^3 \qquad (2),$$

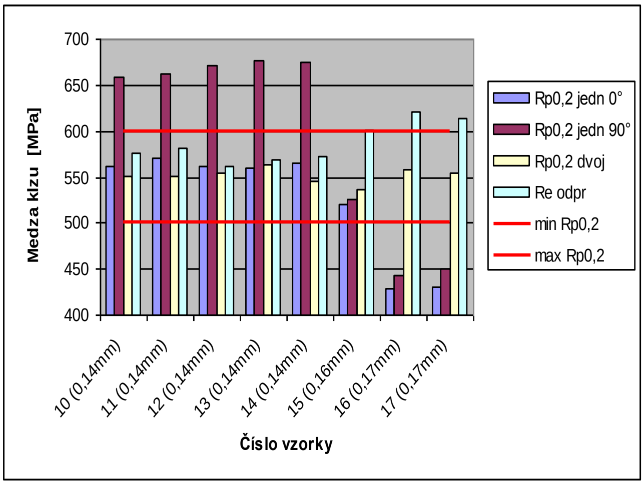
where:
R_e – yield strength [MPa]
E – springback module in drawing [MPa]
θ – angle of springback [°]
r - bending radius [mm]
t - sample thickness [mm]

IV. RESULTS

The obtained yield strength values from the three mentioned tests are shown in Figures 3a, b. These figures display average values from measurements on 5 samples for each material. In cases where extreme values were measured during the tensile test (almost zero ductility because the sample failed very quickly), these values were not included in the calculation of the average values.



a)



b)

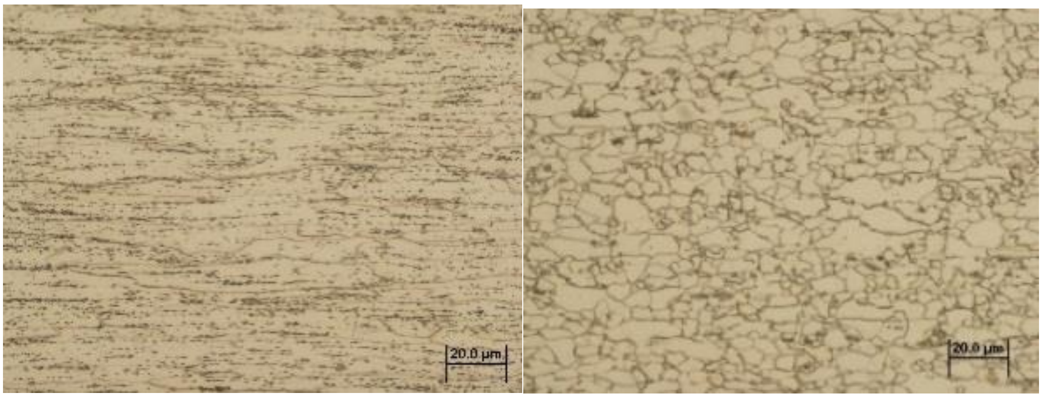
Fig. 3 Comparison of the yield strength in uniaxial tensile testing at 90° and 0° directions, the yield strength in biaxial tensile testing, and the yield strength obtained in springback testing for material a) TH 550 CA, b) TS 550 BA.

From the obtained results, it can be stated that the yield strength values for the material TH 550 CA are highest in the springback test and do not comply with the standard requirements. These values represent on average from 112 to 114% of the yield strength values obtained by the uniaxial tensile test. The lowest values for this material were achieved in the springback test, representing on average from 86 to 88% of the yield strength values measured in the uniaxial tensile test.

For the material TS 550 CA, as indicated in Fig. 3b for samples No. 15, 16, and 17, there was a significant decrease in the yield strength value in the uniaxial tensile test; therefore, we observed the microstructure of the material in these samples.

For samples No. 10, 11, 12, 13, 14 (Fig. 3b), the yield strength values obtained by the uniaxial tensile test were substantially higher than those for samples No. 15, 16, and 17. These higher yield strength values result from the greater purity of the steel (Fig. 4a).

Fig. 4b shows the microstructure of sample No. 16, which experienced a significant drop in yield strength values (as indicated in Fig. 3b). The image reveals that impurities were present throughout the volume and were primarily arranged at the grain boundaries.



a) b)

Fig. 4 Microstructure of the TS 550 BA material (4a), microstructure of the TH 550 CA material (4b).

The yield strength values obtained in the springback test represent on average from 104 to 118% of the yield strength values measured by the uniaxial tensile test. The yield strength values achieved by the biaxial tensile test are in accordance with the standard requirements and represent on average from 96 to 109% of the yield strength values measured by the uniaxial tensile test.

V. CONCLUSION

The objective of the paper was to determine the interdependency of yield strength values obtained from uniaxial tensile testing, biaxial tensile testing, and springback testing.
From the measured results, it can be stated:

- The uniaxial tensile test is very frequently used for evaluating twice-reduced packaging sheets. However, the results achieved by this test show a large dispersion in yield strength, caused not only by the testing methodology itself but especially by the production of test samples. Factors such as the precision in sample production, the coaxiality of the measured part of the test samples, surface roughness on the measured samples, and thermal effects on the sample during production by machining have a significant impact on the results.
- The yield strength values obtained by the biaxial tensile test showed significantly less dispersion compared to the uniaxial tensile test and did not correspond clearly to the yield strength values determined by the uniaxial tensile test. The advantage of this test is the short execution time and the undemanding sample production.
- The yield strength values obtained by the springback test do not correspond to the values determined by either the uniaxial or biaxial tensile tests. Their use is possible only for a preliminary comparison of yield strength results.

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