EVALUATION OF FORMABILITY OF THIN SHEET-METAL

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Abstract
Paper concerns evaluation of formability of sheet-metal with the use of tensile tests according to standard ČSN EN 10002-1. It is described, that the properties of sheet-metal must be tested by tensile specimens parallel, perpendicular and diagonal to the rolling direction.

For elaboration of the tensile tests results the author has made program in Turbopascal for computers, compatible with IBM PC. The program calculates directional and mean values of mechanical properties of tested sheet-metal, the values of coefficients of planar anisotropy of mechanical properties, directional and mean values of coefficients of normal plastic anisotropy ratio according to standard ČSN ISO 10113, directional and mean values of strain-hardening exponents according to standard ČSN ISO10275.

INTRODUCTION
Thin sheets from steel afford a wide scope for shaping and utilisation because of their high rigidity and cold-forming properties. They are therefore widely used in industry for manufacturing the most varied components and products. However, for economic production reliable conditions and limiting values are required.

Formability of sheet metal is dependent on the mechanical properties of the material. Some materials form better than others. A material that has the best formability for one stamping may behave poorly in a stamping of another configuration.

Complex stamping require varying amounts of stretching and drawing, to which bending, unbending, buckling and other complications are added. Most forming operations can be qualitatively, though not quantitatively, categorized as primarily stretching, primarily drawing, or varying ratios of each.

The important material characteristics which determine the forming capacity of sheet metal are strength and ductility. Strength determines the size of the machinery needed for the forming process, while ductility determines the deformation a material can withstand without failure. In forming, ductility generally depends on the plastic properties rather than the fracture behaviour of materials, for ductile fracture occurs as a consequence of prior localization of the deformation to form a neck. The plastic properties characterizing ductility are usually obtained from uniaxial tension tests. It is recognized that the tension test does not duplicate sheet forming, but it is believed that the same factors are involved and that a correlation between them exists.

Recent research work in laboratories and press shops has shown that the forming capacity of sheet metal depends primarily on plastic anisotropy ratio \( r \), which is the ratio of the strain in the width direction to that in the thickness direction and the strain-hardening exponent \( n \). In drawing operations, \( r \) is of prime importance, while \( n \) is of lesser importance. In stretch-forming, however, the opposite is true. These two properties can be evaluated using a standard tension testing machine and normal tensile specimens.

The tensile test offers considerable advantages as compared with tests of the simulating type. The latter are always very slow to carry out, and are influenced by numerous technological parameters such as lubrication, surface condition of the sheets and tools, speed of testing, test-piece thickness, etc. Most of these parameters are outside the scope of a production laboratory check.

1 TESTING OF SHEET-METAL FORMABILITY BY TENSILE TESTS
Suitable choice of sheet-metal during production of stampings must secure as reliable production course as required properties of finished stamping. That is why it is important to know the formability of sheet-metal.
Formability of sheet-metal can be evaluated by basic tests or tests of the simulating type. Tensile test according to standard ČSN EN 10002-1 is mostly used from the group of basic tests (Fig. 1.1). This test is carried out on tensile testing machine, which is in accordance with ČSN 25 0251. The tensile specimens must have their dimensions according to standards ČSN EN 10002-1, ČSN 42 0321, ČSN ISO 10113 and ČSN ISO 10275. Taking of tensile specimens from sheet-metal tables or strips must be carried out in accordance with standard ČSN EN ISO 377, which determines the principles of taking and processing of tensile specimens from steels for mechanical testing.

![Fig. 1.1 Tensile test specimens before and after tensile tests](image)

According to the fact, that the sheets are unidirectionally rolled, the planar anisotropy of their mechanical properties exists. That is why it is important to evaluate the mechanical properties of sheet-metal in orientations 0°, 45° and 90° in relation to the direction of rolling.

Nevertheless the solitary mechanical properties are not sufficient for correct choice of sheet-metal according to its formability, so it is necessary farther to evaluate the planar anisotropy of mechanical properties, to calculate the directional and mean values of normal plastic anisotropy ratio and the strain-hardening exponents. According to these criteria it is possible to determine the formability of sheet metal for concrete shapes of stampings even to choose better the sheet-metal according to its formability.

2 EVALUATION OF PLANAR ANISOTROPY OF SHEET-METAL MECHANICAL PROPERTIES

At deep drawing of symmetrical shape stampings the planar anisotropy causes arising of peaks either on their external edge or on flange. The height of peaks depends on sheet-metal initial anisotropy grade and on drawing rate. The planar anisotropy also increases the
dimension deviations of deep stampings according to its required shape [1]. The influence of planar anisotropy of mechanical properties from this point of view is thought as negative [2].

At drawing of intricate shape stampings thanks to planar anisotropy of mechanical properties the orientation of initial blanks at blanking from sheet-metal table or strip and the blanks orientation at placing in the drawing tool are very important. The directions at initial blank, in which the plastic properties of sheet-metal are the best, need to be in directions or places of the biggest deformations at the stamping.

From evaluated directional and mean values of mechanical properties the values of coefficients of planar anisotropy can be calculated according to the additional example:

\[
PR_{m(x)} = \frac{R_{m(x)} - R_{m(0)}}{R_{m(0)}} \cdot 100 \quad (\%) \quad (1)
\]

where \(P\) is the coefficient of planar anisotropy of separate mechanical property, \(x\) (°) is angle between tensile axis and rolling direction, 0° is angle of rolling direction.

The values of maximum coefficients of planar anisotropy can be calculated according to the additional example:

\[
\max PR_m = \frac{\max R_m - \min R_m}{\min R_m} \cdot 100 \quad (\%)
\]

where \(\max PR_m\) is the maximum coefficient of planar anisotropy of tensile strength, \(\max R_m\) is maximal directional tensile strength, \(\min R_m\) is minimum directional tensile strength.

3 EVALUATION OF NORMAL ANISOTROPY OF SHEET-METAL

Normal anisotropy describes variations in properties between directions in the plane of the sheet and normal to it, i.e. in the direction of thickness. Its practical importance turns on the fact that the resistance of sheet metal to thinning, which is advantageous for deep pressing operations, is a function of its normal anisotropic plasticity. The lower the value of normal plastic anisotropy ratio, the poorer the formability (deep-drawability) of tested sheet-metal.

The value of normal plastic anisotropy ratio can be used as criterion of sheet-metal formability in cases of deep drawing, where pressure-tension mechanical schemes of deformation predominate [3].

The values of normal plastic anisotropy ratio, \(r\), can be determined from measurements according to ČSN 42 0435 using the relationship:

\[
r = \frac{\ln \frac{b_0}{b_k}}{\ln \frac{L_k b_k}{L_0 b_0}} \quad (3)
\]

where \(\ln\) indicates natural logarithm, \(L_0\) and \(b_0\) are the initial length and width of the gauge section and \(L_k\) and \(b_k\) their values after deformation.

The mean normal plastic anisotropy ratio, \(r_m\), can be calculated from formula:

\[
r_m = \frac{1}{4} (r_0 + 2r_{45} + r_{90}) \quad (4)
\]

where \(r_0\), \(r_{45}\) and \(r_{90}\) are the values of normal plastic anisotropy ratio in orientations 0°, 45°, 90° in relation to the direction of rolling.
Planar anisotropy of normal plastic anisotropy ratio is in direct relation to the traditionally ascertained value of the peak height. The values of mean planar anisotropy of normal plastic anisotropy ratio can be calculated from formula:

\[
\Delta r = \frac{1}{2} \left( r_0 - 2r_{45} + r_{90} \right)
\]  
(5)

With \(\Delta r\) the peaks show up at 0° and 90°; with \(-\Delta r\) they show up at 45° in relation to the direction of rolling; with \(\Delta r = 0\) there is no peak.

4 EVALUATION OF STRAIN-HARDENING EXPONENT

The strain-hardening exponent characterizes the intensity of sheet-metal strain hardening during uniaxial tension plastic deformation. The value of strain-hardening exponent can be used as criterion of sheet-metal formability in cases of deep drawing, where tension mechanical schemes of deformation predominate. The high value of mean strain-hardening exponent, i.e. high speed of strain hardening of sheet-metal, causes more uniform distribution of deformations at biaxial state of tension stress and by it helps to reach higher value of general deformation. The higher the value of strain-hardening exponent, the better the formability (deep-drawability) of tested sheet-metal.

The mean strain-hardening exponent \(n_m\) can be calculated from formula:

\[
n_m = \frac{1}{4} \left( n_0 + 2n_{45} + n_{90} \right)
\]  
(6)

where \(n_0\), \(n_{45}\) and \(n_{90}\) are the values of strain-hardening exponent in orientations 0°, 45°, 90° in relation to the direction of rolling.

The values of mean planar anisotropy of strain-hardening exponent can be calculated from formula:

\[
\Delta n = \frac{1}{2} \left( n_0 - 2n_{45} + n_{90} \right)
\]  
(7)

6 CALCULATION OF FORMABILITY INDEX

For reciprocal comparison of formability of tested materials the formability index, \(I\), can be calculated \[1\]:

\[
I = r_{umin} \cdot n_m \cdot 1000
\]  
(8)

where \(r_{umin}\) is the minimal normal plastic anisotropy ratio from values of it in orientations 0°, 45°, 90° in relation to the direction of rolling, \(n_m\) is the mean strain-hardening exponent.

7 FORMING LIMIT DIAGRAM

Autobody stampings can generally be classified as rejects if any form of necking is visible, and it can therefore be argued that instability strains should be the limiting criteria of sheet-metal formability.

For comparison of formability of separate materials the forming limit diagram can be constructed, which comes out from criterion of plastic deformation stability loss at the tensile strength. To forming limit diagram the curve of limit deformations for every tested material can be drawn and then compared.

8 PROGRAM FOR EVALUATION OF TENSILE TESTS RESULTS

From previous paragraphs follows, that the properties of sheet-metal must be tested by tensile specimens parallel, perpendicular and diagonal to the rolling direction. The directional values must be calculated as arithmetic means from values, evaluated at separate tensile specimens. From mean values of mechanical properties in orientations 0°, 45° and 90°
in relation to the direction of rolling the mean values for tested material must be additionally calculated.

With regard to the fact, that the process of tensile tests evaluation is toilsome and complicated, the author made program in TurboPascal for computer, compatible with IBM PC (operating system MS DOS). The program has very easy and clear control, because it communicates with user in Czech with the use of windows. The selections are made by interactive method with the use of presented menu.

The program in Czech (TAHZKCS.EXE) can be started in operating system MS DOS after transliteration of display at monitor (e.g. with the use of VGAČS.EXE) and after transliteration of keyboard for setting in Czech (e.g. with the use of KEYBCS1.EXE). Adjustment of printer must also make possible to print in Czech.

User program in Czech without diacritics (TAHZK.EXE) can be started direct in operating system MS DOS and results can be printed direct without changes of printer adjustment.

The program calculates directional and mean values of mechanical properties of tested sheet-metal, the values of coefficients of planar anisotropy of mechanical properties, directional and mean values of coefficients of normal plastic anisotropy ratio according to standard ČSN ISO 10113, directional and mean values of strain-hardening exponents according to standard ČSN ISO10275.

9 CONCLUSIONS

Evaluation of formability of thin sheets and reciprocal comparison of their properties can be carried out by tensile tests with the use of tensile specimens, oriented in directions of 0°, 45° a 90° in relation to the direction of rolling. For carrying out of extensive calculations during elaboration of tensile tests results the program for computer made by author can be used.

From values, evaluated by tensile tests, the forming limit diagrams, which comes out from criterion of plastic deformation stability loss at the tensile strength, can be constructed. These diagrams are advantageous for comparison of sheet-metal plastic properties at various stress states or in range of stresses according to the working up technology.

REFERENCES


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