SPRINGBACK

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Abstract

When producing a part, either by deep drawing, stretch forming or bending, flat sheet is transformed into a design shape and dimension. At the end of the forming process, when the part has been released from the forces of the forming tool, there is a distortion in the shape and dimension of the formed oart. This distortion is termed springback. A depriction of springback in a simple bend can be. Springback is inherent in sheet metal forming. It can be can be understood by looking at a material is stress stain curve (discussed in the module on Tensile Testing) which characterizes the behaviour of metal under applied force. During forming, the material is strained beyond the yield strength in order to induce permanent deformation. When the load is removed, the stress will return to zero along a path parallel to the slope of the elastic portion of the curve, which is the elastic modulus. The permanent deformation will therefore be less then what is designed into the part unless springback is factored in. Springback dependent on various material material characteristics but can be affected by tooling desing. The most important parameters are elastic modulus, strength, thickness and bend radius. Other material characteristics, especially YPE, can also be important.

Keywords: forming**,** material**,** springback

1. Introduction

The term metal forming refers to a group of manufacturing methods by which the given shape of a workpiece (a solid body) is converted to another shape without change in the mass or composition of the material of the workpiece. This includes bending. It is important to know the springback (elastic return) (Figure 1).

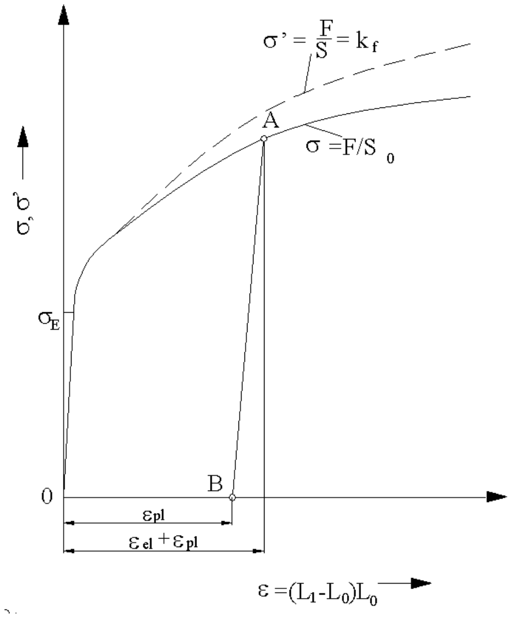

Figure 1. First part of the stress-strein

On the basis of data collected by different authors, previous research on sheet metal bending has pursued two basic goals, namely:

1. The sheet bending test procedure was carried out in order to obtain the material coefficients necessary for the calculation of the plastic flow stress curve and the unit moment curve.
2. The sheet bending test procedure was carried out for the purpose of calculating the stress distribution, and from it the springback (elastic return) and the required bending force.

He carried out the first calculations of bending stress P. Ludvig for uniaxial stress state. Many authors even today for the calculation and evaluation of the bending process use his elementary bending theory. A simplified elementary theory results from certain assumptions:

- sheet loading is performed by pure torque; the bending curve is thus part of a circle,
- the sheet for bending is wide enough, so a planar state of movement is obtained (transverse deformation of the sheet does not exist)
- cross-sections (straight and perpendicular to the longitudinal axis of the unloaded beam) remain straight and perpendicular to the curved neutral line of the bent beam even after bending,
- only stresses in the x-direction are taken into account. Bending stresses in the direction of width and thickness are ignored,
- the material is homogeneous and isotropic, the "stress-strain" curve for stretching and compression is symmetrical with respect to the zero point and
- the sheet thickness remains unchanged during bending.

For stress and deformation testing, it follows from the above that any cross-section can be observed. Coordinate axes in the picture Figure 2 are also the main axes, i.e. σ_x, σ_y i σ_z are the main stresses.

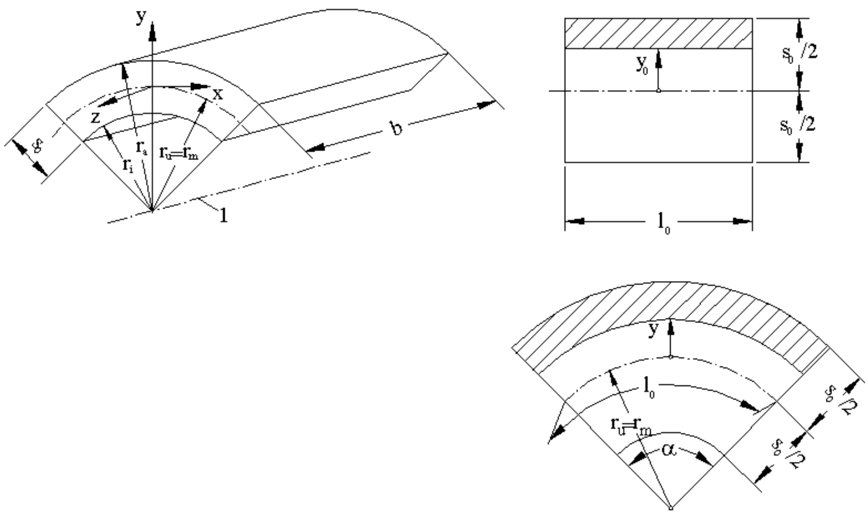

Figure 2. Markings on the sheet metal

(1- bending arm, 2- bending plane, 3- outer boundary line of bending, , 4- the inner boundary line of the bend, 5- outer crown line, 6- inner crown line) [1-3]

The stress tensor for pure bending is Tensor

$$\{\sigma\} = \begin{bmatrix} \sigma_x & 0 & 0 \\ 0 & \sigma_y & 0 \\ 0 & 0 & \sigma_z \end{bmatrix} \quad (1)$$

Components σ_y and σ_z are ignored, so the stress is decisive for the curvature σ_x. With this simplification, the stress tensor reads

$$\{\sigma\} = \begin{bmatrix} \sigma_x & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (2)$$

Based on what has been said, stress σ_x depends on the deformation ε_x and can be determined from the "stress-strain" curve by a stretching test.

The deformation in the cross section amounts to (Figure 2):

$$\varepsilon_x = \frac{\Delta l}{l_o} \quad (3)$$

$$\varepsilon_x = \frac{(r_m + y)\widehat{\alpha} - l_o}{l_o} = \frac{(r_m + y)\frac{l_o}{r_m} - l_o}{l_o} \quad (4)$$

$$\varepsilon_x = \frac{y}{r_m} \quad (5)$$

The deformation for the marginal position amounts to

$$\varepsilon_{xa} = \frac{s_o}{2r_m} \quad (6)$$

2. Calculation of deformations, stresses and elastic recovery

2.1 Elementary theory

By elementary theory, any cross-section of a sheet can be observed for stress and deformation testing. The coordinate axes of Figure 2 are also the main axes, and the stress tensor is given by the expression (1). From the condition of balance of external and internal forces follows according to [1-2] the expression for moment

$$M = b\, r_m^{\,2} \left[\int_{-\varepsilon_i}^{o} \sigma_{ekv} \cdot \varepsilon \cdot d\varepsilon + \int_{o}^{\varepsilon_a} \sigma_{ekv} \cdot \varepsilon \cdot d\varepsilon \right]. \quad (7)$$

At the symmetrical curve " stress-strain " for stretching and compression and replacement $\sigma_{ekv} = \sigma_x$ coming up:

$$M = 2 \cdot b \cdot \int_{o}^{\varepsilon_a} \cdot \sigma_x(\varepsilon) \cdot \varepsilon \cdot d\varepsilon \quad . \quad (8)$$

The deformation is determined by the expression (5), and the relationship $\sigma_x(\varepsilon)$ is obtained by tensile test.

After unloading, the bent sheet has a refund for the amount $\Delta\alpha$. For the calculation of the elastic recovery and the state of residual stress, it is assumed that the sheet deforms elastically during unloading.

When unloading is the moment of unloading $M_R = 0$ (Figure 3).

Remaining radius after unloading $\frac{1}{r_{mR}}$ is calculated according to [2] expression

$$\frac{1}{r_{mR}} = \frac{1}{r_m} - \frac{M_B}{E \cdot I_z} \quad . \tag{9}$$

The state of residual stress is determined by subtracting it from the stress during loading σ(y) linear stress distribution

$$\Delta\sigma_{el}(y) = y \cdot E \cdot \Delta \frac{1}{r_m} \quad . \tag{10}$$

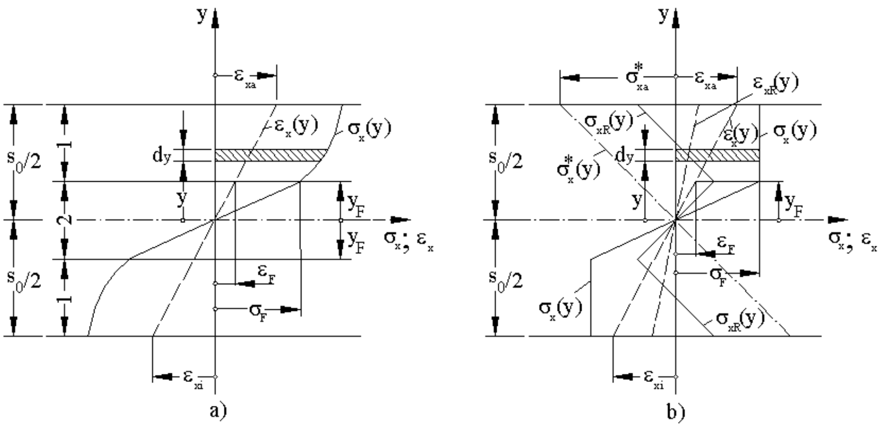

Figure 3. Formation of residual stress during bending [1]

The value of the elastic return is measured by the size K which is called the elastic return ratio, and is defined by the ratio $K = \frac{r_m}{r_{mR}}$ ($R_a = r_m$ $R_p = r_{mR}$) (Figure 4).

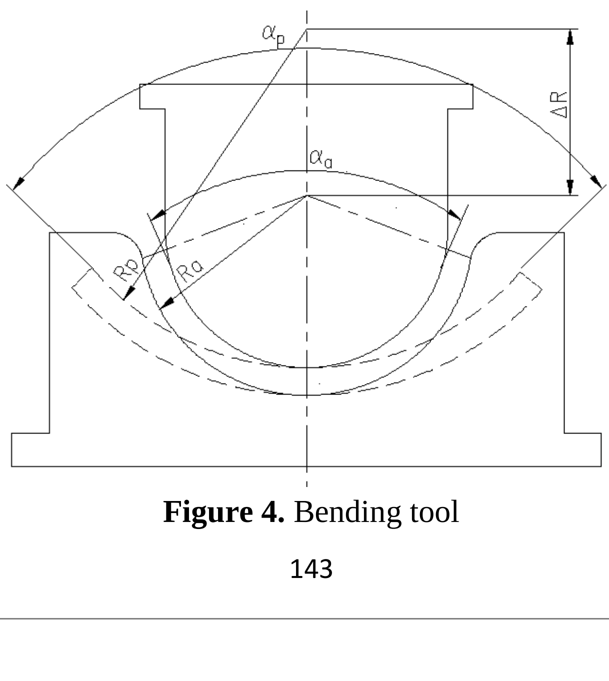

Figure 4. Bending tool

2.2 Extension of elementary theory

The assumption of a constant, neutral layer in the middle of the bent sheet turned out to be incorrect at large deformations. During bending, the following layers are distinguished, [1] Figure 5.

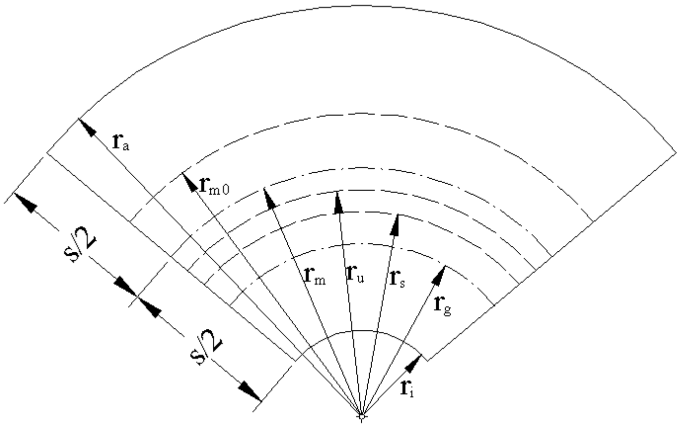

Figure 5. Layers when bending

Layers when bending:
Outer edge layer r_a
The original middle layer r_{m0}
Middle layer r_m
Upstretched layer r_u
Stress-free layer r_s
Layer at the limit of deformation r_g
Inner edge layer r_i.
All layers from r_a to r_{mo} stretch freely during bending; those between r_{mo} and r_u are first compressed and then stretched even more than they were compressed before; with r_u, the magnitudes of stretching and compression are equal; the layers between r_u and r_g are first compressed and then stretch less than they were compressed before; at r_g, compression is just ending, stretching has not yet occurred; between r_g and r_j the layers are freely compressed.

3. Residual stresses and stationary equilibrium conditions after unloading (removal of external force)

Value K is calculated using the expression

$$K = \frac{r_m}{r_{mR}} = \frac{\frac{s_o}{\varepsilon_{a1}}}{\frac{s_o}{\varepsilon_{a2}}} = \frac{\varepsilon_{a2}}{\varepsilon_{a1}} \tag{11}$$

According to the picture 6. (Figure 6) coming up [1]

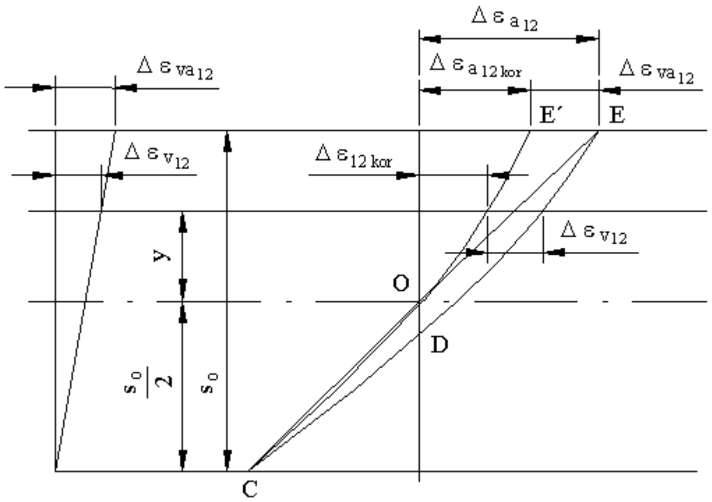

Figure 6. Calculation of values $\Delta\varepsilon_{v12}$

$$\varepsilon_{a2} = \varepsilon_{a1} - \Delta\varepsilon_{a12kor} \ , \tag{12}$$

$$\varepsilon_{a12kor} = \Delta\varepsilon_{a12} - \Delta\varepsilon_{va12} \ . \tag{13}$$

For the middle layer instead $\Delta\varepsilon_{va12}$ includes $\Delta\varepsilon_{v12}$. Size $\Delta\varepsilon_{v12}$ is calculated from the expression

$$\Delta\varepsilon_{v12} = \Delta\varepsilon_{va12} \left(\frac{y}{s_o} + 0{,}5 \right) . \tag{14}$$

If he is included in it y = 0 coming up:

$$\Delta\varepsilon_{v12} = 0.5 \ \Delta\varepsilon_{va12}. \tag{15}$$

If (12), (13), (14) i (15) include in the expression (11) coming up:

$$K = \frac{\varepsilon_{a1} - \Delta\varepsilon_{a12kor}}{\varepsilon_{a1}} \ ,$$

$$K = \frac{\varepsilon_{a1} - \Delta\varepsilon_{a12} + \Delta\varepsilon_{va12}}{\varepsilon_{a1}} \ ,$$

$$K = \frac{\Delta\varepsilon_{a12} - 0{,}5 \cdot \Delta\varepsilon_{va12}}{\varepsilon_{a1}} . \tag{16}$$

To determine the factor K should be determined $\Delta\varepsilon_{a12}$ i $\Delta\varepsilon_{v12}$ from the expression [1]

$$0 = M - b \cdot E \cdot \Delta\varepsilon_{a12}\left[\frac{1}{3}\left(\frac{s_o}{2}\right)^2 + \left(\frac{s_o}{2\varepsilon_{a1}}\right)^2 \left(\varepsilon_{a1}^2 - 1\right)\left(1 - \frac{1}{2\varepsilon_{a1}} \ln\frac{1+\varepsilon_{a1}}{1-\varepsilon_{a1}}\right)\right] + \frac{1}{3} E \cdot \Delta\varepsilon_{va12} \cdot \left(\frac{s_o}{2}\right)^2 \cdot b \tag{17}$$

$$0 = -E \cdot \frac{\Delta\varepsilon_{a12}}{2} \int_{-\frac{s_o}{2}}^{\frac{s_o}{2}} \left[1 + 2\varepsilon_{a1}\left(\frac{y_1}{s_o}\right) + \frac{\varepsilon_{a1}^2 - 1}{1 + 2\varepsilon_{a1}(\frac{y_1}{s_o})}\right] \mathrm{d}y + E \cdot \Delta\varepsilon_{va12} \int_{-\frac{s_o}{2}}^{\frac{s_o}{2}} \left(\frac{y_1}{S_o} + 0{,}5\right) \mathrm{d}y \tag{18}$$

$$\Delta\varepsilon_{va12} = \Delta\varepsilon_{a12}\left[\frac{1}{\varepsilon_{a1}}\left(1 + \frac{\varepsilon_{a1}^2 - 1}{2\varepsilon_{a1}} \ln\frac{1+\varepsilon_{a1}}{1-\varepsilon_{a1}}\right)\right] . \tag{19}$$

$$\Delta\varepsilon_{a12} = \frac{\dfrac{M}{b \cdot s_o^2 \cdot E}}{\dfrac{1}{3} - \dfrac{1}{4\varepsilon_{a1}^2}\left(1 + \dfrac{\varepsilon_{a1}^2 - 1}{2\varepsilon_{a1}} \ln\dfrac{1+\varepsilon_{a1}}{1-\varepsilon_{a1}}\right) - \dfrac{1}{12} A} . \tag{20}$$

$$\frac{1}{\varepsilon_{a1}}\left(1 + \frac{\varepsilon_{a1}^2 - 1}{2\varepsilon_{a1}} \ln\frac{1+\varepsilon_{a1}}{1-\varepsilon_{a1}}\right) = A$$

4. Conclusions

The paper presents different theories for calculating the springback (elastic return). The most important parameters are elastic modulus, strength, thickness and bend radius. Other material characteristics, especially YPE, can also be important (K=f(k_f) and k_f. specified sizes [4]).

5. References

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