Analysis of the Working Parameters in Some of the Plastic Deformation Processes

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The paper presents the factors and parameters that influence the straightening process, stresses and strains occuring in the plate material subjected to undergoing bending, in elasto-plastic field as well as determination of the curvature radius under load.

Keywords: straightening, stresses, curvature radius

Regarding the analysis of the running parameters in the processes of plastic deformation, there is considered the case of the straightening of the rolled steel plates.

In the papers [1,2] general aspects regarding the straightening, straightening technology and the removal of tensile strains are presented.

Factors and parameters influencing the straightening process

In industrial conditions, the most widely used and efficient straightening process is straightening on rotative-cylinders machines (fig. 1.).

Straightening is performed by repeatedly bending the product in opposite directions, hereby exceeding the elastic limit of the product material.

Bending being performed in most cases in cold condition, the straightening will generate cold-hardening of the product material, producing internal stress and remanent strains [3]. The deformation degree of the rolled preformed product being non-uniform, in certain areas with stronger deformations the critical deformation threshold will possibly be exceeded subsequently to the additional strains incurred during straightening. In these circumstances, as a result of the stress during the operation, it will be possible to deteriorate the material [4,5].

If the straightened preformed product is subject to a thermal cycle action (e.g. during welding or during operation of a component part made out of the respective preformed material), whereby the temperatures could go beyond the crystalline transformation point, without change of phase, an inner growth of crystalline grains will occur and consequently, the plastic characteristics of the material will remain low (despite of the fact that exceeding the recrystallization temperature results in the un-hardening of the material). This negative effect can be eliminated by thermal treatment.

In general, the bending process can be described efficiently by the following parameters:

-the deflection force, **P**, bending the steel sheet by means of the straightening cylinders;

-the bending torque, **M**, generated by the force of this bending deflection (**f**) resulting from the action of force, **P**,

-the curvature, **K**, incurred by the rod at mid-span deflection, **f**, (fig. 2).

Besides these characteristics which influence directly the straightening process, in the case of steel sheets straightening on draught rolling machines, this process is also influenced by the constructive and geometrical characteristics of the machine.

For the design of a draught straightening machine, the equations describing the force **P**, i.e.: $P=\sigma bh^2/t$ provide the basic necessary elements.

This equation leads to the conclusion that the individual straightening force **P**, which should be provided by the machine, increases with the steel sheet thickness **h** and depends on the cylinders pace **t.**

The steel sheets' thickness, **h,** being given, this means that with increasing **t**, the straightening force becomes smaller. On the other hand, the deflection, **f** is proportional to the pitch, **t**, so that with increasing **t**, the elastic deflection increases and the straightening result is smaller. Thus, these two effects should harmonize. In the case of steel sheets straightening machines, there is usually considered a constant pace **t** = (10….20)h and a diameter **d** of the straightening rolls approximately equal to **d**=(0.9…0.95)**t**.

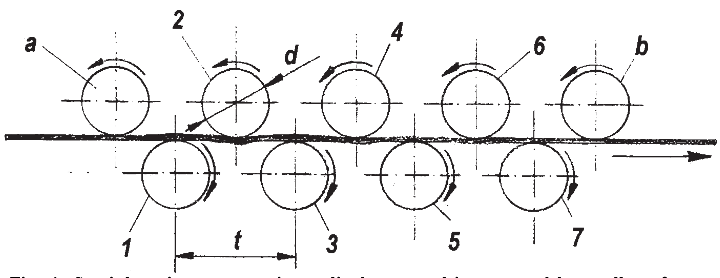

Fig. 1. Straightening on rotative-cylinders machine: a and b – rollers for guidance; 1…7 – rollers for straightening

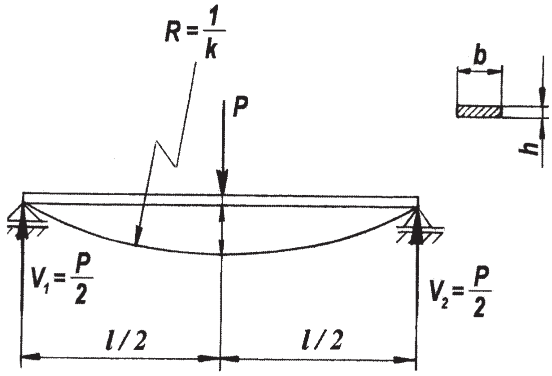

Fig. 2. Loading chart at straightening

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If a higher precision is needed, e.g. in the case of very thin steel sheets, the pace **t** and the diameter of the straightening cylinders are taken as big as possible, as the straightening accuracy increases inversely with diameter and pace. On the other hand, with decreasing diameter of the straightening cylinders, the straightening range of a machine - which is expressed by the ratio between the smallest and the largest thickness of the steel sheets to be straightened by this machine - decreases.

Tensile strains and deformations occurring within the material of bend-solicited steel sheets, in the elastic-plastic range

Let us consider a piece of rolled steel sheet of thickness s and width b, which presents, as deviation from the plane form, a transversal waviness of camber $K_o = 1/R_o$.

If at each end of this steel sheet a bending torque of appropriate intensity is applied in a direction opposite to the waviness, the steel sheet will straighten, the camber becoming zero. (R = ∞, K=0) (fig. 3).

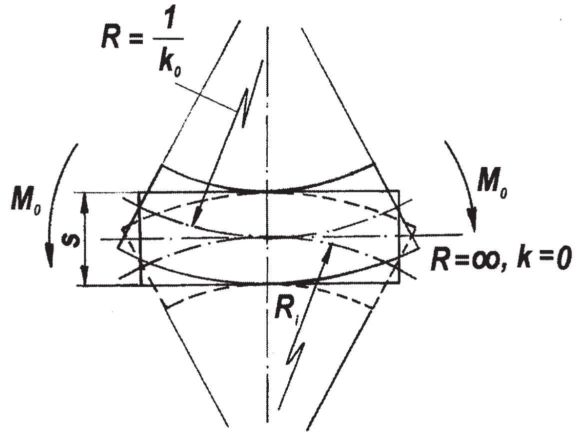

Fig. 3. Straightening equivalent loading chart

The value of the bending torque to be applied depends on the extent of the curvature to be straightened.

The distribution of deformations and tensile strains occurring inside the material of the steel sheet, strained in the elastic-plastic range of tensile solicitations, with the hardening mode placed in the plastic range, is shown in figure 4:

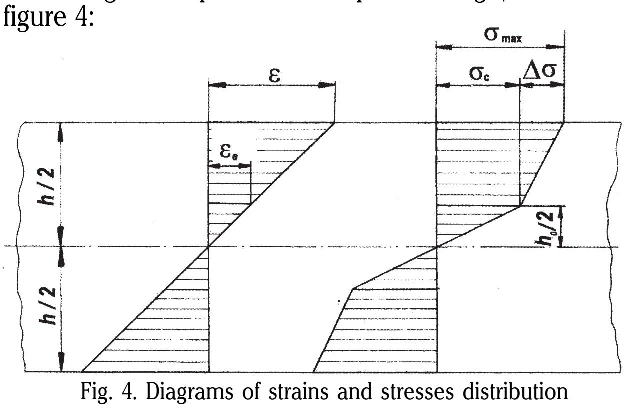

Fig. 4. Diagrams of strains and stresses distribution

$$\varepsilon_e = \frac{\sigma_c}{E}; \ \varepsilon = \frac{h}{2R}; \ h = 2R\varepsilon; \ => \ h_0 = 2R\frac{\sigma_c}{E};$$

$\sigma_{max} = \sigma_c + \Delta\sigma$; $\Delta\sigma = (\varepsilon - \varepsilon_c)D$, where D is the hardening module.

$$\Delta\sigma = \frac{h - h_0}{2R}D,$$

$M_i = Mi_{ie} + M_{ip} + M_{id}$, where:

M_{ie} - torque corresponding to the elastic deformed area;
M_{ip} - torque corresponding to the plastic deformed area;
M_{iD} - torque corresponding to the hardened area;

and :

$$M_{ie} = \frac{bh_0^2}{6}\sigma_c,$$

$$M_{ip} = \frac{b}{4}\left(h^2 - h_0^2\right)\sigma_c,$$

$$M_{iD} = b\frac{h - h_0}{2}\left[h_0 + \frac{2}{3}(h - h_0)\right]\frac{\Delta\sigma}{2},$$

$$=> M_i = \frac{b}{12}\left[\left(3h^2 - h_0^2\right)\sigma_c + \left(2h^2 - hh_0 - h_0^2\right)\Delta\sigma\right].$$

After deformation in the elastic-plastic condition and elastic recovery of the steel sheet, this one remains with remaining strains (fig. 5.). These strains are possible to be determined (upon outer fiber, where their value is maximum), by equalising the values of the torques needed to deform the entire cross section up to the plastic condition (plastic joint) with the torque value needed for the elastic re-bending of the section:

$$M_{ie} = \frac{bh^2}{4}\sigma_c; \ M_{ip} = \frac{bh^2}{4}\sigma_c$$

$$\frac{bh^2}{4}\sigma_c = \frac{bh^2}{6}\sigma'; \ \sigma' = \frac{3}{2}\sigma_c$$

$$\Delta\sigma = \sigma' - \sigma_c = \frac{1}{2}\sigma_c.$$

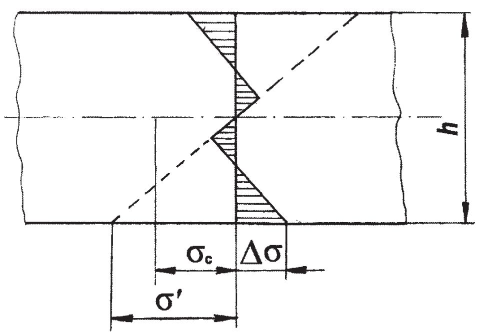

Fig. 5. Distribution of remanent strains

In the elastic range, the strains variation along the thickness of some transversal sections, as a function of the distance from the neutral axis and the bending radius in applied load condition, varies according to the equation:

$$\sigma_x = \frac{E}{1 - \mu^2}\frac{y}{R_0}$$

For the plastic and elastic-plastic range, we have:

$$\sigma_n = \pm\frac{A}{\left(\frac{3}{4}\right)\frac{1+n}{2}}\left|\frac{y}{R_0}\right|^m,$$

where A and m are constants of material.

The respective value of the bending torques varies according to the following relations:

$$M_{ie} = \frac{2}{3}\frac{E}{(1-\mu^2)R}\left(\frac{s}{2}\right)^3$$

in the elastic range;

$$M_{iep} = \int_0^{s/2} 2b\sigma_n y dy = Ab\frac{s^{2+m}}{(2+m)3^{\frac{1-m}{2}}R^m}$$

in the elastic-plastic range.

The diagram in figure 6., presents the variation of the bending torques as a function of the curvature, for the case of bending a steel sheet with rectangular cross section, in the elastic-plastic range, from an initial curvature ($K_0 = 1/R_0$) up to the zero curvature (K=0, R=∞) and the elastic recovery of the material up to a remaining curvature, $K_{01} = 1/R_{01}$

To be noted the parallelism of the loading up / discharging lines in the elastic range, and, after reaching the plastic flow yield limit at the outer fiber, the charging characteristic is smoothly changing its slope, up to reaching the hardening slope, corresponding to the plastic joint.

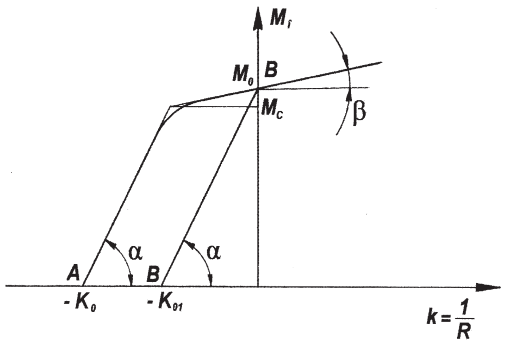

Fig. 6. Dependence of M_i(K), straightening (K=0, R=∞) and elastic returning at remanent curvature ($-K_{01}$)

Calculation of the bending radius under load

When straightening steel sheets on the straightening machine with rolls (fig. 7), curvature radius under load conditions, it is possible to compute as a function of the geometry of rolls disposal, their diameter and steel sheet thickness, according to the relation:

$$R = \frac{h^2 - D_1(h+s) - s^2 + \frac{a^2}{4}}{2(D_1 + s - h)}.$$

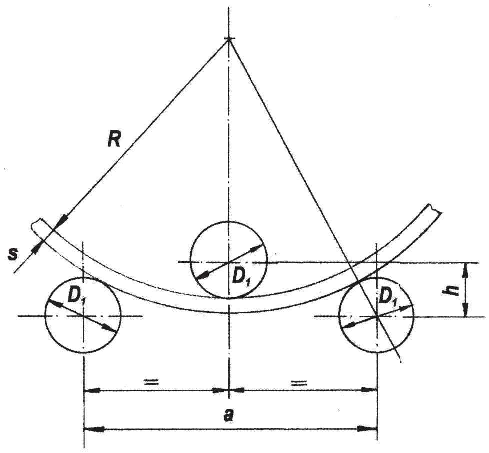

Fig. 7. Determination of the curvature radius under load

The remanent curvature radius is computed, after the elastic recovery of the material, by:

$$\frac{1}{R_r} = \frac{1}{R} - \frac{M_i}{EI}, \Rightarrow \quad R_r = \frac{R}{1 + \frac{A}{E}\frac{4}{2+n}3^{\frac{1-m}{2}}\left(\frac{R}{s}\right)^{1-m}},$$

where **A** and m are constants of the material.

Conclusions

The straightening has a positive effect on the preformed product shape (minimizing the deviations) and a negative effect on the plastic properties of the steel sheets material . In order to remove the negative effect, appropriate thermal treatments are to be applied (like complete annealing).

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