A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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CIRCUMFERENTIAL RESIDUAL STRESSES IN TUBES ESTIMATED BY MEANS OF DEFLECTION METHOD

OCENA OBWODOWYCH NAPRĘŻEŃ WŁASNYCH W TULEJACH ZA POMOCĄ METODY ŚREDNICH ODCHYLEŃ

Every process of metal forming causes formation of residual stresses in manufactured products. The residual stresses can be source of deformation. To determine, if residual stress from prior stage of processing is the cause of non-controllable distortion before next process a useful, cheap and easy deflection method can be used. In article were presented rules of this method, computer program for quick calculations and estimation of the level of surface residual stress in tubes manufactured in piercing – spreading process in Diescher's mill.

Keywords: residual stresses, piercing – spreading process in Diescher's mill

Każdy proces formowania metalu powoduje tworzenie się naprężeń własnych w wyprodukowanych wyrobach. Naprężenia własne mogą być źródłem odkształceń. Aby określić czy naprężenia własne z poprzedniego etapu przetwarzania są przyczyną niekontrolowanej zmiany kształtu przed kolejną operacją, można zastosować użyteczną, tanią i prostą metodę średnich odchyleń. Artykuł przedstawia podstawy tej metody, program komputerowy pozwalający na szybkie wykonanie obliczeń i określenie poziomu naprężeń własnych w tulejach wyprodukowanych w trakcie procesu dziurowania-rozszerzania w walcarce skośnej typu Diescher'a.

1. Introduction

Sectioning to allow relaxation of residual stress in actual components where stresses are thought to be present can be performed by several methods, from simple saw cutting to the more sophisticated compliance method [1, 2, 3].

One of the simplest methods of determination the circumferential hoop residual stress in tubes is to make slitting along the ring, which was cut off from the tube. Operation of slitting causes distortion of the ring as a result of release and redistribution of circumferential residual stress (macrostresses). In Fig. 1 a scheme of the residual stress distribution in rings manufactured from tube is presented.

Before slitting, it is necessary to measure the diameter of the tube: initial diameter D_0 and thickness t of the walls. Very often, for example in a seamless tube, the outer diameter and thickness are variable, thus it is advisable to make measurements in a few points and calculate average values.

Also after cutting, the outer diameter D_1 of the deformed tube must be measured in the same point as D_0 and the average value calculated, too. On the basis of the classical mechanics equations for beam were derived of formulas for calculating residual stress.

After slitting, the residual stresses are described by the following formula (1):

$$\sigma_C = E \cdot t \cdot \left(\frac{1}{D_0} - \frac{1}{D_1}\right), \quad (1)$$

where: E – Modulus Elasticity, t – thickness of the wall, D_0 – diameter before slitting, D_1 – diameter after slitting,

Error of stress determination by using formula (1) is dependent on precision of measurement and its relative value may be calculated from formula (2):

$$\frac{\Delta\sigma_C}{\sigma_C} = \frac{\Delta t}{t} + \frac{\Delta D_0}{D_0} + \frac{\Delta D_1}{D_1} + \frac{\Delta D_0 + \Delta D_1}{D_1 - D_0}. \quad (2)$$

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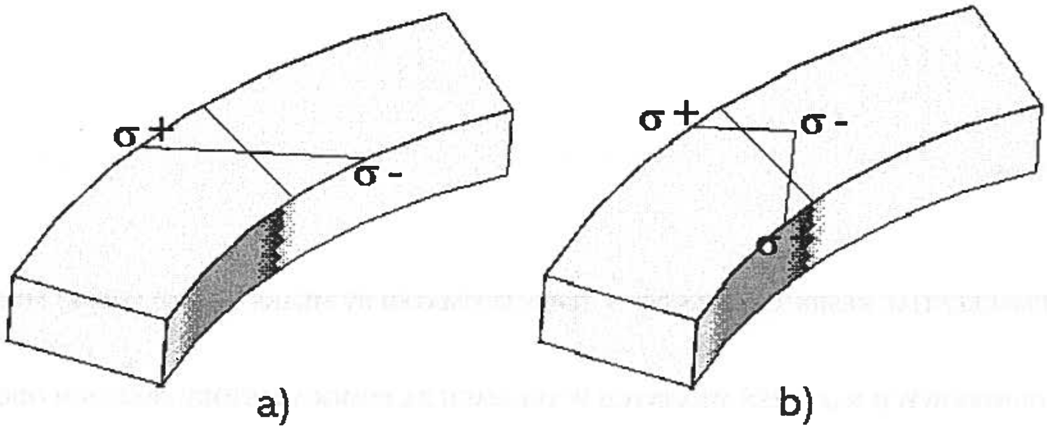

Fig. 1. Distribution of residual stress in rings: a) before slitting, b) after slitting

If $\Delta t = \Delta D_0 = \Delta D_1 = \Delta m$, the absolute error equals:

$$\Delta\sigma_C = \sigma_C \cdot \Delta m \cdot \left(\frac{1}{t} + \frac{1}{D_0} + \frac{1}{D_1} + \frac{2}{D_1 - D_0}\right). \quad (3)$$

If the saw blade width is known, it could be possible to measure net opening displacement. The circumferential residual stress is determined by the following formula (4):

$$\sigma_C = E \cdot t \cdot \left(\frac{1}{D_0} - \frac{1}{D_0 + \frac{x}{\pi}}\right), \quad (4)$$

where: x = d – s; – opening displacement, d – measured width of saw cut slit, s – saw blade width.

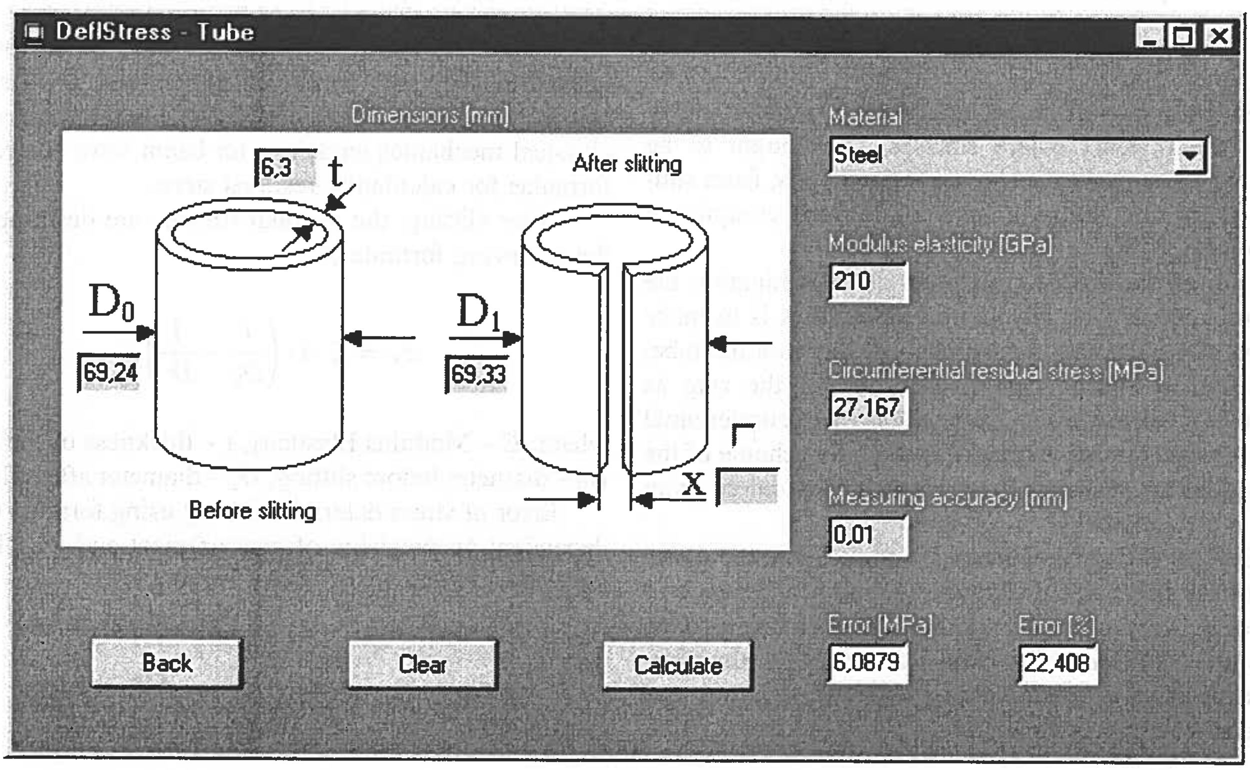

Fig. 2. Window of *DeflStress* program

For greater accuracy, in large cross section or high strength steels, Poisson's ratio should be taken into consideration, and the value of Young's modulus should be recalculated:

$$E = \frac{E}{1-\gamma^2}. \tag{5}$$

These formulas have been implemented in special program *DeflStress* for quick calculations for residual stress, assigned by the deflection method.

Application was written down in *C++ Builder 6.0 Personal* programming language. The program makes possible calculations for geometry as solid bar, tube and sheet/plate and for eight different materials (steel, aluminium alloys, etc.). For these materials the values of modulus of elasticity and Poisson ratio were stored. Moreover, there is a possibility to insert the exact value of Young module. The choice of geometry follows at the start of the program. Next, a window appears, which lets load data for the chosen shape. Figure 2 shows the window of application of circumferential hoop residual stress in tubes. As input data, the outer diameters of tubes are introduced before and after slitting; thickness of the wall and accuracy of the measurement. From the *"Material"* – database of the implemented materials, a suitable material is chosen or if the modulus of elasticity is not correct, options *"Insert Young's Modulus"* should be used to insert the right value. As a result of calculation the value of the circumferential residual stress and the value of relative and absolute error of computation are given.

2. Experiment

By using *DeflStress* application the residual stresses in seamless tubes manufactured in piercing – spreading process in Diescher's mill were determined. The rotary piercing in Diescher's mill is one of the best methods to produce pipes. The spreading-and-piercing process allowed expanding of the assortment of seamless tubes. One of the parameters of a pipe is the level of circumferential residual stresses. Walton [4] gives ranges of residual stresses acceptability (Table 1).

Overflow of 'unacceptable' level may result in crack on the tube surface.

TABLE 1

Ranges of residual stresses acceptability

Residual stress	Acceptability
<35 MPa	Acceptable
35 – 70 MPa	Borderline
>70 MPa	Unacceptable

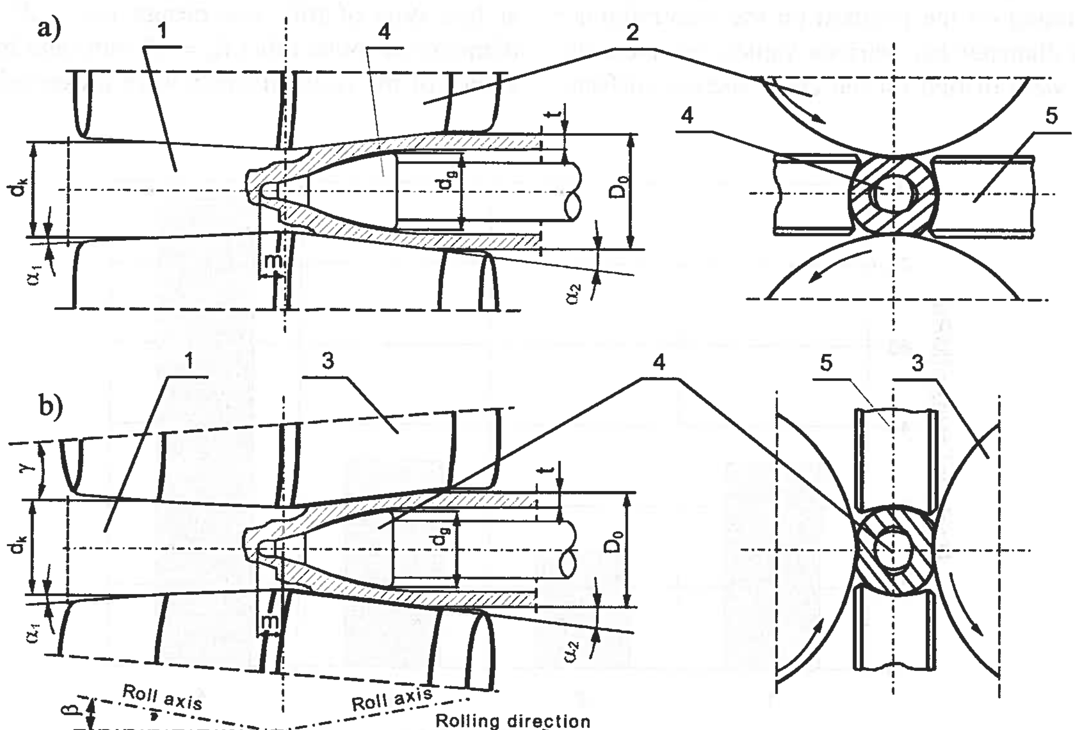

Fig. 3. Shape and position of the working tools in the strain area, roll pass design: a) of barrel type and b) of conical type, of the skew piercing in Diescher's mill was applied, where: 1 – round billet, 2 – roll barrel, 3 – conical type, 4 – plug piercing, 5 – disc guide

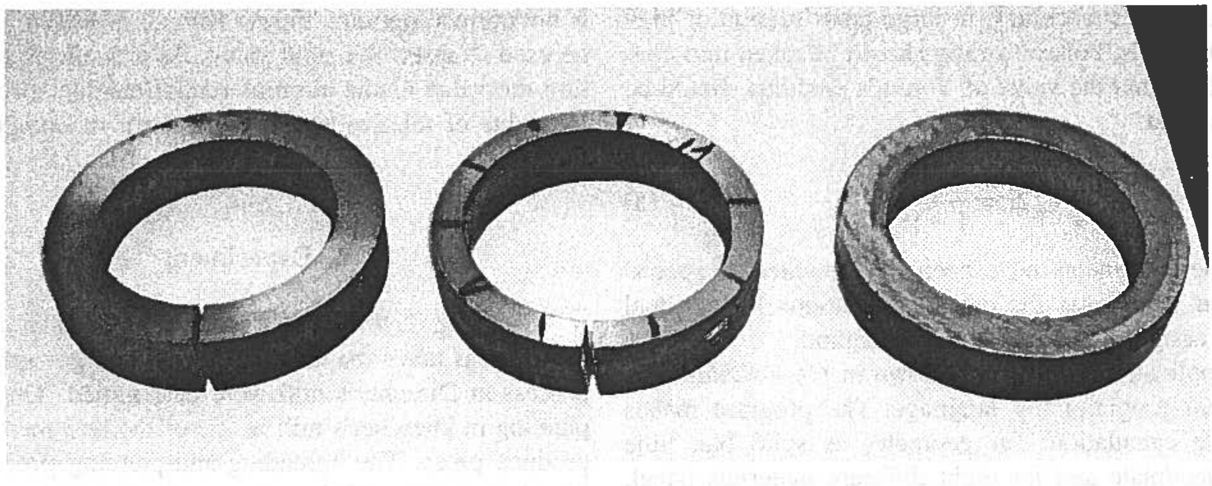

Fig. 4. Rings made from seamless tubes before and after slitting

For experiment seamless tubes produced in the rolling mill were used, as shown in figure 3. Steel C45 was used as a material. There were chosen ten tubes, produced at various parameters of the milling using a piercing plug of different diameters (d_g = 44÷52 mm) and advances (m = 16÷40 mm) and various feed angles (β = 10°; β = 12°) [5, 6].

From every tube the rings (15 mm high) were cut off by using a mechanical hacksawing machine with a plenty of coolant to avoid heating of the surfaces. Next, thickness and outer diameters of every ring were measured. Depending on the position on the circumference of rings, the diameter had various values; ten measurement points were drifted on the cross section surfaces. On the basis of ten measurements the average value of diameter D_0 was assigned.

After slitting, the residual stresses brought plastic distortion of the rings which appears in the escalation of gap width and diameter. The diameter D_1 was also measured in the same positions like before slitting and calculated as average. The measurements were carried out using electronic slide caliper and accuracy of reading was 0,01 mm. Figure 4 shows a view of the rings used for experiments.

In table 2 the parameters and results were collected at first type of roll pass design (α_1 = 3°, α_2 = 7°30' diameter of round billet d_k = 60 mm) and in figure 4 the values of the residual stress were presented graphically.

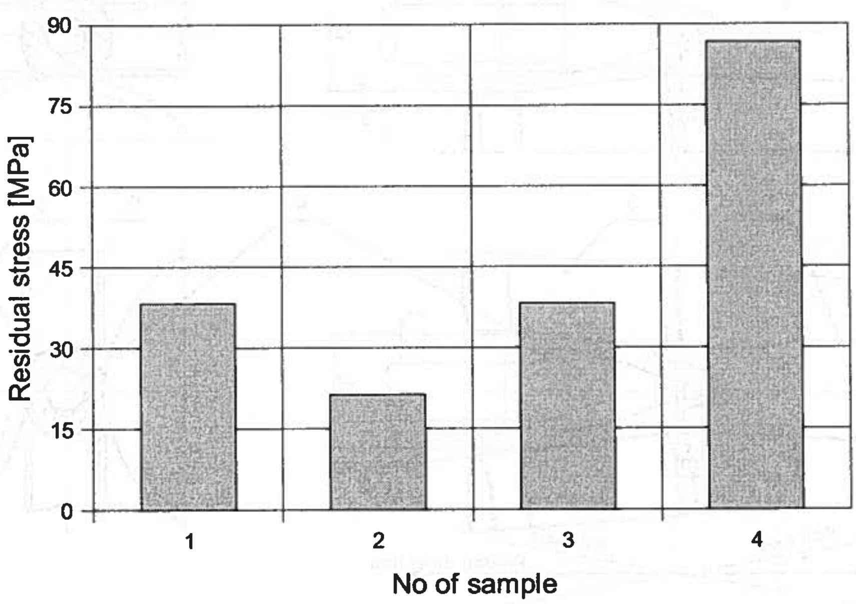

Fig. 5. Hoop residual stress for I type of roll pass design

TABLE 2
Parameters and results at first type of roll barrel pass design

No of sample	m [mm]	d_g [mm]	β [°]	t [mm]	D_0 [mm]	D_1 [mm]	σ_c [MPa]	$\Delta\sigma_c$ [MPa]
1	40	46	10	8,87	65,40	65,48	38,1	9,58
2	16	52	12	10,00	73,52	73,57	21,6	8,53
3	16	46	10	11,87	70,68	70,75	38,2	10,96
4	16	52	10	10,20	73,59	73,72	86,7	8,78

In table 3 the data and results for conical type of roll pass design were collected

TABLE 3
Results and data for conical type of roll pass design

No of sample	m [mm]	d_g [mm]	σ_c [MPa]	$\Delta\sigma_c$ [MPa]	No of sample	m [mm]	d_g [mm]	σ_c [MPa]	$\Delta\sigma_c$ [MPa]
1	32	48	20,79	6,91	4	22	46	22,37	8,98
2	32	50	25,07	6,31	5	16	46	23,05	9,25
3	32	52	27,16	6,08	6	8	46	23,48	9,42

3. Conclusions

Determined during the experiments, the circumferential residual stresses in seamless tubes after the piercing – spreading process in Diescher's mill show that their level is acceptable. The received results prove that the diameter of plug piercing has main influence on circumferential stress quantity. Application of increased feed angles is crucial in order to decrease the value of circumferential residual stresses.

The deflection method presented in this article, despite being destructive, is the one of cheapest methods to estimate the residual stress. Implementation of this method doesn't need complicated instrumentation and it is not consuming. Because this method isn't too accurate, it may be used especially to control or check quickly the residual stress level. The computer program, partially described above, is universal and has options for estimation of the residual stress for other geometry.

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