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THE EXPERIMENTAL ANALYSIS OF THE PIERCING AND SPREADING PROCESS IN DIESCHER'S SKEW ROLLING MILL

ANALIZA DOŚWIADCZALNA PROCESU DZIUROWANIA I ROZSZERZANIA W WALCARCE SKOŚNEJ TYPU DIESCHERA

This study presents influence of roll pass design and positioning of the piercing plug in the strain area on expansion external diameter pipes, forcing and twisting parameters in piercing and spreading process in Diescher's mill. Nowadays is tendency in the direction modernisation technology production of seamless tubes. This trend is a direct outgrowth of the continuing development of continuous-cast rounds as well as distinct economic benefits offered by the modern rotary Diescher's mill. In this paper has been shown also influence rolling parameters on the microstructure in transverse and longitudinal section of the pipes. The differences in volume and grain distribution were shown as well as micro-hardness of the phases of ferrite and pearlite in the internal, external and middle part and corrosion resistance of the tubes. seamless tubes.

Keywords: piercing and spreading rolling, Diescher's mill, seamless tubes

Nowe tendencje panujące wśród odbiorców i użytkowników wpływają na stosowanie nowoczesnej i bardziej ekonomicznej technologii produkcji stalowych rur bez szwu. Obecnie producenci zainteresowani są możliwością wykonania małej serii metrażowo – tonażowej, w wąskim zakresie ujemnych odchyłek wymiarowych, a zatem i masowych o wysokiej jakości wytwarzanych rur przy krótkim terminie dostawy. Zatem ważne jest żeby dokonać analizę, w jaki sposób uzyskać dobrą jakość tulei przy jednoczesnym dużym rozszerzeniu jej średnicy zewnętrznej i niskim zużyciu narzędzi roboczych. Określono wpływ kalibrowania walców beczkowych i stożkowych, główki dziurującej, na wartość współczynnika rozszerzenia, parametry skręcające i siłowe, a także na mikrostrukturę, mikrotwardości i odporność na korozję tulei rurowych po procesie dziurowania i rozszerzania w walcarce skośnej z prowadnicami typu Dieschera.

1. Characteristic spreading and piercing process

Nowadays is tendency in the direction modernisation technology production of seamless tubes [1, 2, 3]. This trend is a direct outgrowth of the continuing development of continuous-cast rounds as well as distinct economic benefits offered by the modern rotary Diescher's mill.

The rotary piercing and spreading is the main process of seamless tube manufacturing. This process is one of most complex among the methods of shaping of metals. Expand assortment dimensional is the primary objective of the piercing and spreading process. The industry is interested in this method of simultaneous piercing and spreading of pipes as in such a way the bigger and better qualitative dimensional assortment of pipes may be fabricated.

In literature can find general publications on this theme, so purposeful is analysis this problem. Spreading process in Diesher's mill disc guide rolls is at present one of the best seamless pipe production method [4]. Piercing and spreading process is characterised by choice of roll barrel shape in such way. To set up inclination angle, creating roll cone on exit, was larger than value of angle of inclination on input (Fig.1). This process is typical by joint in one deformation area, conditions of diagonal and along rolling [5]. During piercing process with concurrent spreading, may observe layers twisting of ready pipe.

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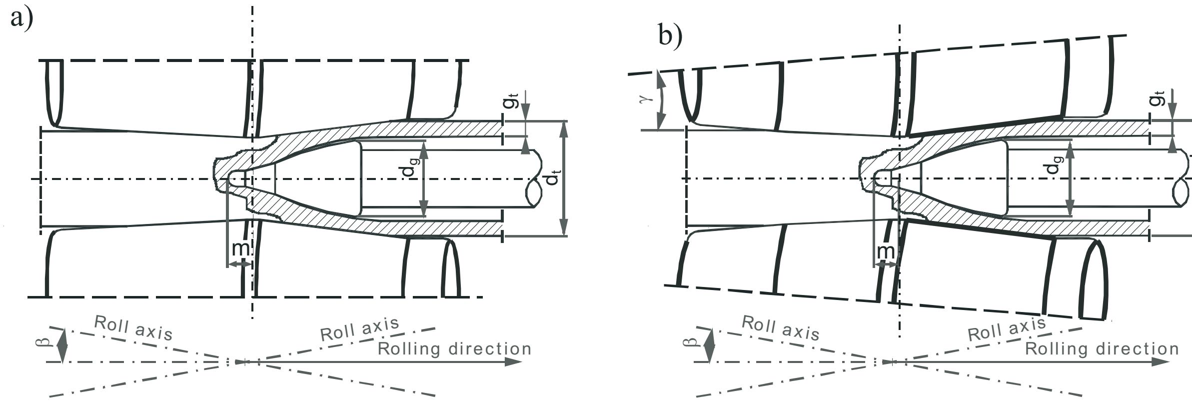

Fig. 1. Shape and position of the working tools in the strain area, roll pass design: a) of barrel type and b) of cone type, of the skew piercing-spreading rolling mill was applied

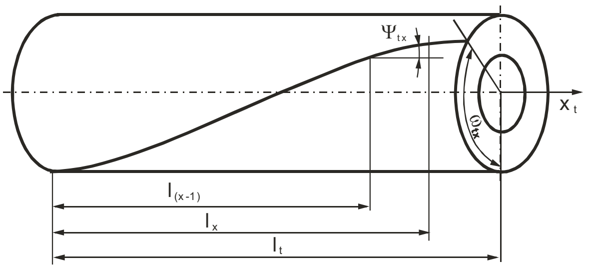

Fig. 2. Schema twisting line formed in outside layers pipe

Layers' twisting characterise real shape of the torsion curve for current length x_t (Fig. 2.), variable in interval $0 \leqslant x_t \leqslant l_t$, while the plastic deformation process proceeds in unceasingly rolling conditions. On the basis received during experiments, it was found that direct of twisting is consistent with sense of pipe rotation [5, 6, 7].

On the grounds of real absolute longitudinal torsion measurements tx, measured in cross-section coordinates $l_x = x_{ti}$, can be calculated twisting parameters, describing quantity of it:

• lateral torsion angle:

$$\omega_{txi} = \frac{2t_{xi}}{d_t}, \quad \text{rad} \tag{1}$$

• longitudinal torsion angle

$$\psi_{lx(i-1)} = \mathrm{arctg}\frac{t_{xi} - t_{x(i-1)}}{x_{ti} - x_{t(i-1)}}, \quad \text{rad} \tag{2}$$

The first stage of seamless pipe production is manufacture of tubes. At present, the skew rolling mills and piercing presses, including Mannesmann's, Stiefel's, tri-cylindrical, Diescher's mills with barrel and conical rolls, are most often used to manufacture the tubes [4, 8, 9, 10]. The piercing and spreading process in the skew Diescher's mill takes place in the closed area of deformation, where the triaxial state of stress appears. The piercing method with simultaneous expanding of the outer diameter of the tube allows to widen the assortment of the tubes' dimensions to produce seamless pipes using the permanent diameter of insert, and excluding the necessity of complicated rebuilding of the rolling mill. The received dimension (outer diameter of the tube, thickness of the wall) is adjusted by changing the diameter and protruding the piercing head as well as roll pass design of working rolls [5, 7, 11, 12, 13]. The tube is a semi-product in the process of pipe manufacture e.g. drilling pipes, boiler pipes, line pipes and constructional pipes. The seamless pipes must comply with certain resistance, mechanical and geometrical requirements. Depending on the method and parameters of the piercing method some surface and geometrical defects of different types may appear. Occurrence of diversity of the walls on the length and transverse section of the tube as well as 'waviness' of their surfaces are not desirable. Liquidation of such defects is important as it is very difficult, and sometimes impossible, to remove them in the final processes of pipe manufacture. Therefore, it is crucial to analyze the influence of parameters of the distortion area in the piercing and spreading process carried out in the skew Diescher's mill onto the microstructure, microhardness and corrosion resistance of the tubes.

2. Research project

Round billet from steel C45, with parameters: diameter d_k = 60 mm and length l_k = 170 mm was heated to 1200°C and introduced into two-rolls Diesher's mill with barrel and cone type calibration. In result of rotary – translation motion were made pipes with using of piercing plug with different diameters (d_g = 44÷52 mm) and advances (m = 16÷40 mm) and also various feed angles ($\beta = 10° \div 12°$). During experiments were made measurements of powers parameters-pressure on barrel rolls, guide discs and axial force effected on piercing plug. Was tested also needles cutting – twisting strain on external surface of pipe, through incision external surface in straight line along stock. At beginning, were rolling samples with constant angle of rolls $\beta = 10°$ and constant diameter piercing plug $d_g = 46$ mm while was changed advance of plug in interval m = 16÷40 mm. Then was set-up advance m = 22 mm and with the same feed angle as before, but was changed parameter of plug diameter in range $d_g = 44 \div 52$ mm. Last stage of research was done experiments with constant advance (m = 16 mm), diameter of piercing plug ($d_g = 48 \div 52$ mm) and various settings of feed angle. $\beta = 10° \div 12°$. During experiments was studied dependence of parameters (advance, diameter and feed angle) on external pipe extension, which is characterised by expanding ratio δ_r, defined as quotient diameter of pipe to diameter before process $\delta_r = d_t/d_k$. The most extension (25%) appears for diameter value $d_g = 52$ mm and the smallest advance m = 16 mm ($\delta_r = 1.25$). It may be explained by decreasing of crack between internal and external tools and influence of increasing inclination generating plug line angle. In a result of it, wall thickness is decreased and distance between roll axis and contact point of metal and roll, on interpenetrate plane, going through the maximal plug diameter.

Next were made experiments with various settings feed angle ($\beta = 10° \div 12°$) of barrel roll with constant advance and diameter of plug. Were selected the minimal advances and intermediate value of plug diameter, because achieved then big extension of external diameter.

The research was carried out on the samples obtained from steel tubes (C45) after complete annealing and skew rolling in Diescher's mill. The microhardness was examined by means of Vickers' method pursuant to the standard PN-ISO 6567-3, in Zeiss Jenn's metallographic microscope, and an instrument of H type was mounted on its handle. The measurement of microhardness included measurement of the diagonals of the square imprint made by a diamond indenter. The indenter affected the detail with the force of 0.1 N (10 g) for 10 seconds in ambient temperature. The diagonals were measured with accuracy of 0.2 μm. The microhardness was measured for transverse and longitudinal sections of the tubes. The microstructure was examined by means of Zeiss Axiovert 25 optical microscope, connected to the digital camera. Metallographic specimens were obtained by grinding with paper of final granulation being 1000 and by polishing with diamond paste. Finally, the samples were etched with 4% HNO_3 [14].

The potentiostatic method in the three-electrode system helped to estimate the influence of plastic working (skew rolling) onto the corrosion resistance. Three electrodes: reference electrode, (saturated calomel one), auxiliary electrode (polarizing one) made from platinic titanium and the examined sample were placed in 500 ml 5% H_2SO_4 solution, and 500 ml 3.5% NaCl solution. During the experiment the solutions were stirred and located in ambient temperature. The measurements were carried out with potentiometer of EP 21 type. The area of the samples was 1 cm^2. Polarization curves i = f(E) in the scope of anode and cathode potential were made. The curves in the scope of ±150 mV of the corrosion potential were recorded. The sudden change in the potential was 10 mV per minute. In order to determine the corrosion current the ELFIT [15, 16] program was applied.

3. Experimental results

Influences of geometrical parameters and space settings of working tools on modification powers parameters in piercing – spreading process was shown on Fig. 3. On the basis of graph (Fig. 3a), follows that during reducing plug advance, roll-separating force is rising, however value of metal pressure on piercing plug insignificantly decreasing. From data showed on Fig. 3b results that while are used bigger value of piercing plug diameter, the roll-separating force and value of pressure metal on piercing plug grow. Comparing data from measurements (collected on Fig. 3c and Fig. 3d) results that power values of pressure are decreasing during feed angle increasing.

Dependence of piercing plug advance, feed angle and plug diameter on twisting parameters in piercing and spreading process on Figs. 4÷6 have to observed. Lateral torsion angle ω_{tx} and longitudinal torsion angle Ψ_{lx} achieve minimal values with advance m = 40 mm, plug diameter $d_g = 46$ mm and feed angle $\beta = 12°$. Metal twisting decreases when are applied bigger values of feed angle. Larger values of advance and smaller values of piercing plug diameter and also larger feed angles decrease intensity of torsion level. Therefore, one may conclude that size, shape and position of working tool in rolling crack make increasing resistance of plastic metal flow and reduction of power values, drawing metal into the rolls. Thus, using larger values of external diameters and smaller piercing plug advances makes increases values of longitudinal and lateral torsion angle.

On the basis of experimental researches of piercing-spreading process, follows that basic parameters having influence on spreading value are: diameter and position of piercing plug in deformation area and feed angle of barrel roll. Was defined the maximal spreading of pipe external diameter d_t = 74.4 mm, for process parameters: diameter d_g = 52 mm and advance m = 16 mm of piercing plug. Received results lets concluding that larger values of piercing plug diameter and smaller advance make expanding reaching 25% (expanding ratio; $\rho_r = 1.25$).

After the metallographic experiments had been carried out by means of the optical microscope, the influence of deflection parameters of the piercing and spreading process in the skew Diescher's mill onto the microstructure of the tube was estimated.

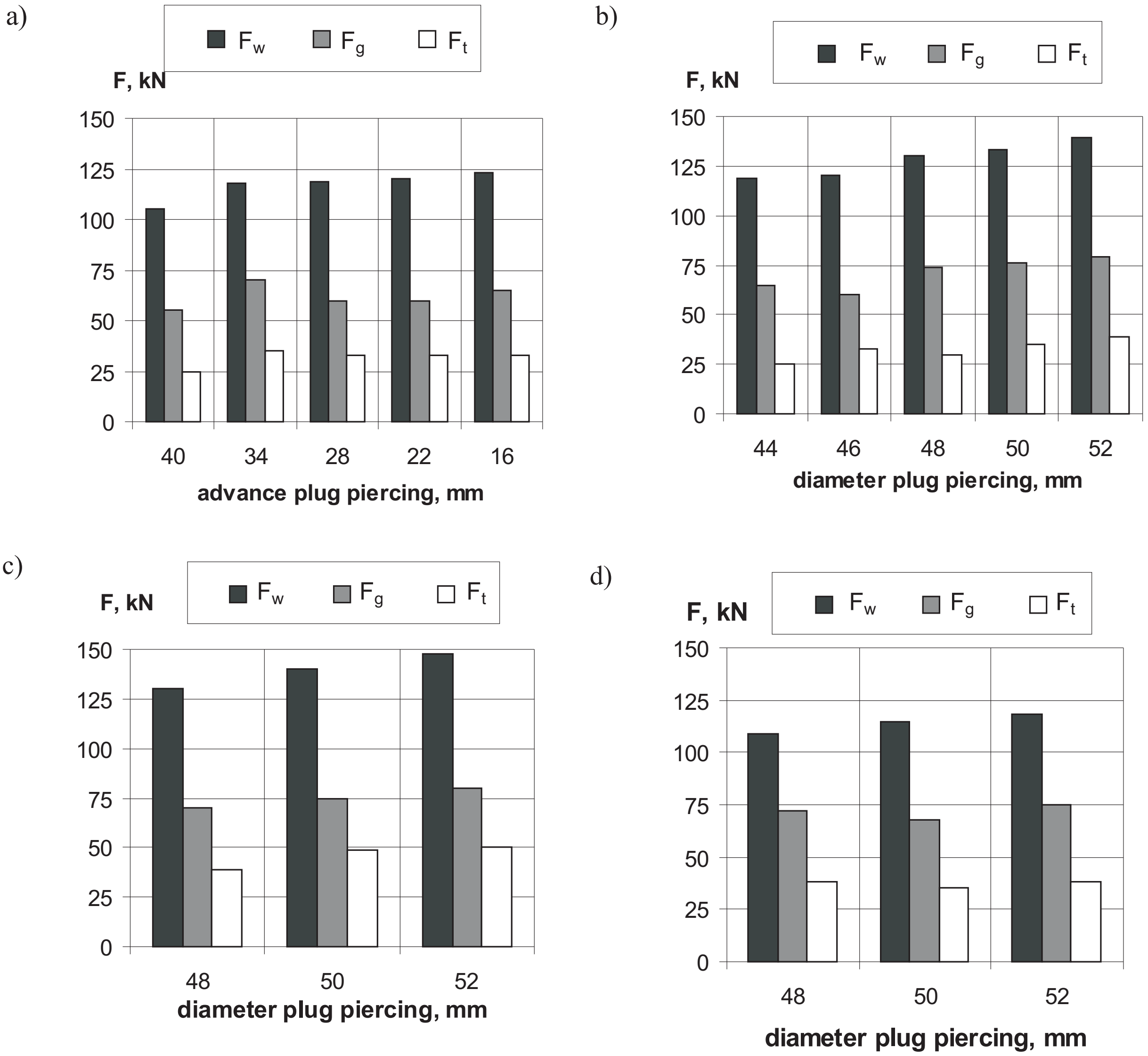

Fig. 3. Powers parameters piercing and spreading process, were: F_w, F_g, F_t – roll, plug and disc guide force: a) m = 40÷16 mm, d_g = 46 mm; b) m = 22 mm, d_g = 44÷52 mm; c) m = 16 mm,β = 10°; d) m = 16 mm, β = 12°

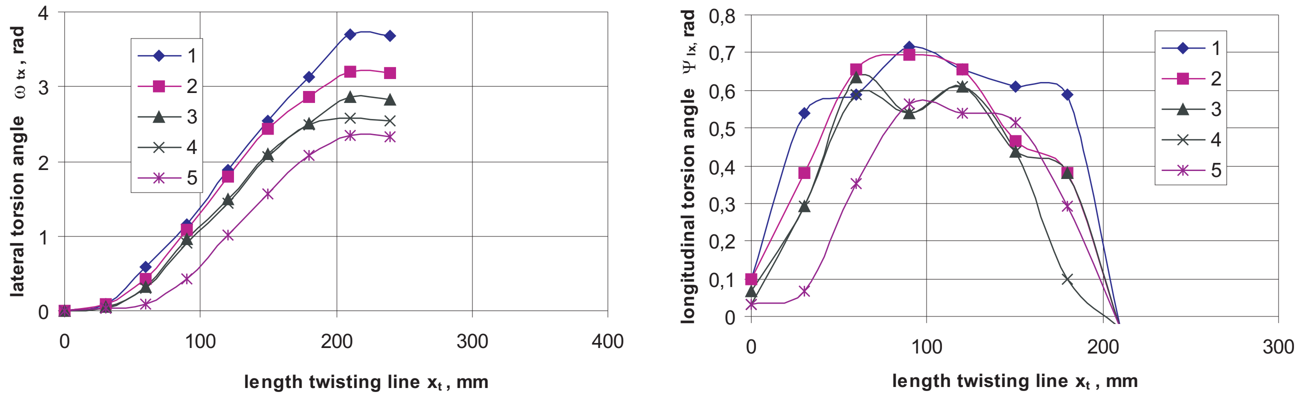

Fig. 4. Dependence twisting parameters piercing and spreading process from length pipe for d_g = 46 mm, β = 10° and variable advances plug piercing m: 1 – 16 mm, 2 – 22 mm, 3 – 28 mm, 4 – 34 mm, 5 – 40 mm

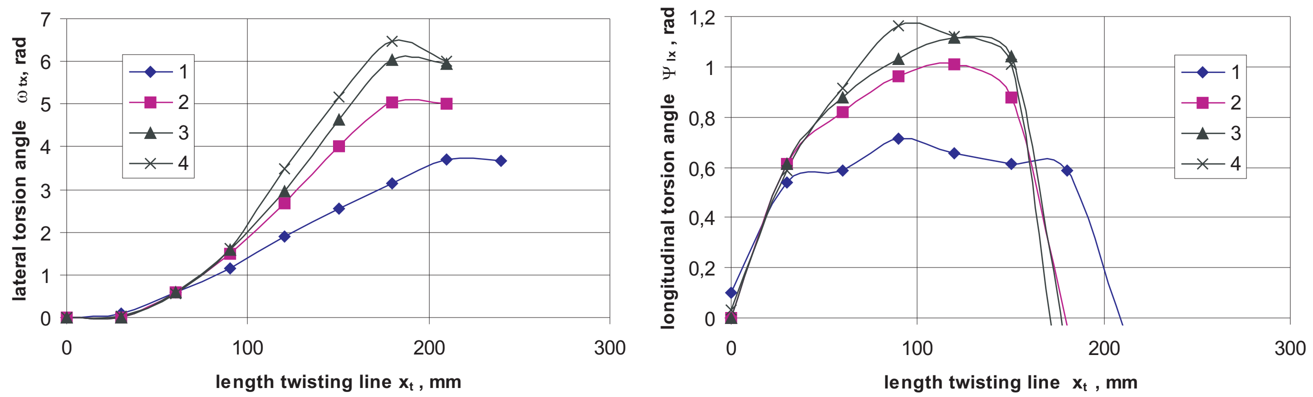

Fig. 5. Dependence twisting parameters piercing and spreading process from length pipe for m = 16 mm, β = 10° and variable diameter plug piercing d_g: 1 – 46 mm, 2 – 48 mm, 3 – 50 mm, 4 – 52 mm

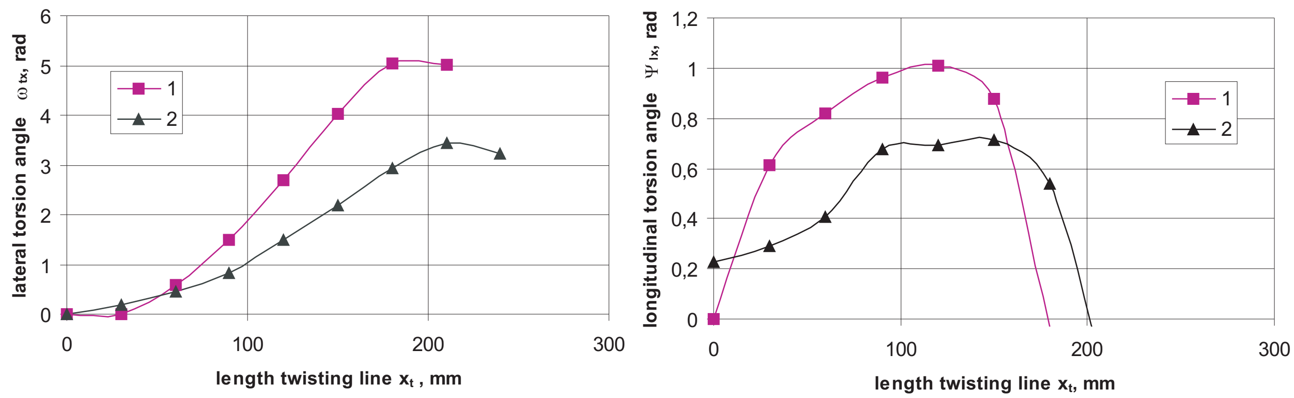

Fig. 6. Dependence twisting parameters piercing and spreading process from length pipe for m = 16 mm, d_g = 48 mm and variable feed angle β: 1 – 10°, 2 – 12°

Fig. 7 shows the microstructure of the tubes obtained in the piercing and spreading process for various values of the piercing head diameter. Ferrite and pearlite grains are located at a uniform rate on the transverse section in the external, middle and internal part of sample no 1 (Fig. 7.). Samples no 2 and 3 in the internal part of the transverse section (Fig. 7) show the grains of ferrite and pearlite are distributed at a uniform rate. The microstructure of both samples on the transverse section in the middle part demonstrates a substantial predomination of pearlite, whose grains are big, especially in sample no 2. In case of sample no 1, where the exposure is m = 32 mm and the piercing head diameter is d_g = 48 mm, the ferrite and pearlite grains are distributed at a uniform rate on the cross section tube.

The microstructure of samples no 16 and 17 was presented in the Figure 8. In case of sample no 17 (Fig. 8.) a bigger protruding of the piercing head was applied. However, sample no 16 (Fig. 8.) demonstrates bigger grains in comparison to sample no 17.

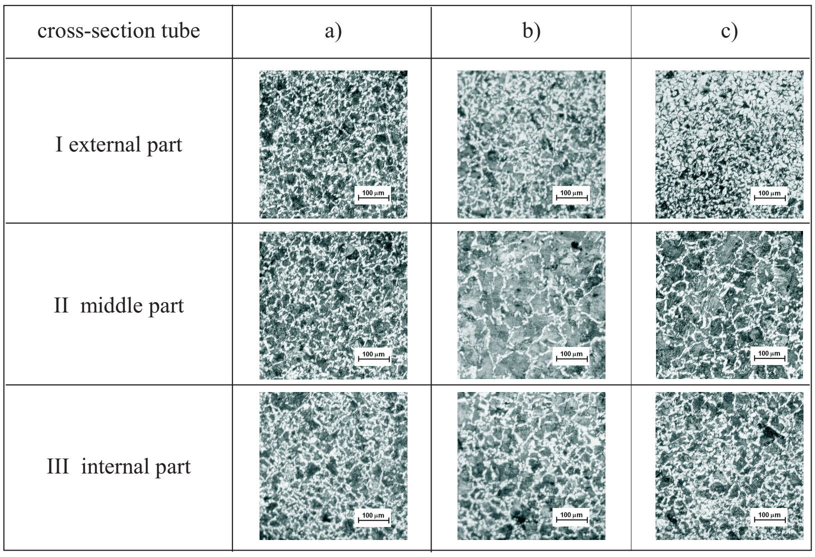

Fig. 7. Microstructure of the samples for variable plug piercing diameter (d_g): a) sample no 1 d_g = 48 mm; b) sample no 2 d_g = 50 mm; c) sample no 3 d_g = 52 mm; etched with 4% HNO_3

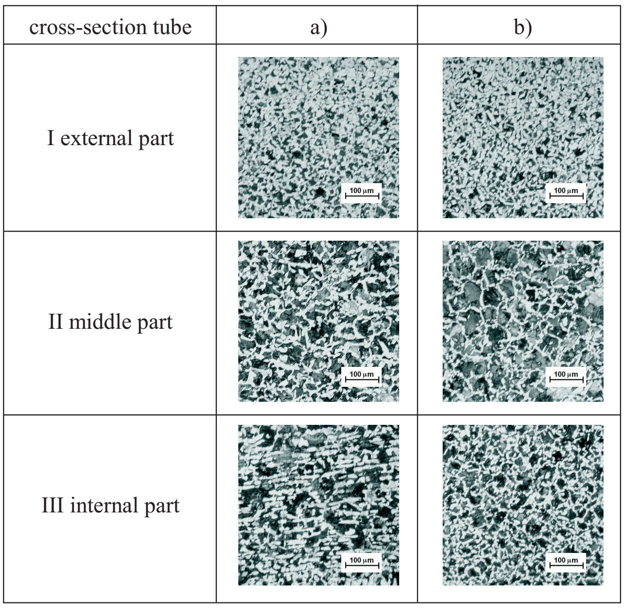

Fig. 8. Microstructure of the samples for variable advance plug piercing (m), barrel type roll pass design: a) sample no 16 m = 16 mm; b) sample no 17 m = 40 mm; etched with 4% HNO_3

On the transverse section of the external part there are distinct changes in the structure of both samples. On the external part of the tube a considerable decarburizing occurred, that means less pearlite was visible.

Distinct changes also occurred on the transverse section in the internal part of the tube, where orientation of the ferrite grains could be noticed for sample no 16. It was probably affected by a little value the piercing head protruding. In the middle part of sample no 16 a slight orientation of grains is noticeable, as well, though in minor degree. Sample no 17 in this part shows predomination of pearlite grains, which are bigger than the pearlite grains of sample no 16 (Fig. 8.).

The influence of the piercing head diameter on the microhardness of the tube is presented in the figure (Fig. 9.). In case of the piercing head diameter d_g = 48 mm, the external part of the tube is harder. The hardness diminishes when moving towards the internal part of the tube. Increasing the piercing head diameter up to d_g = 50 mm results in increased hardness of the internal part of the tube and slight decrease in the other two parts. Sample no 3, which was obtained from the tube pierced with a piercing head of d_g = 52 mm diameter shows the greatest hardness in the internal part. Almost the same hardness appears in the middle part of the tube. The changes in the microhardness, which can be observed in Fig. 9, prove direct influence of the piercing head diameter on the microhardness of the tube, particularly, onto its internal part, where the piercing head directly works during the piercing and spreading process.

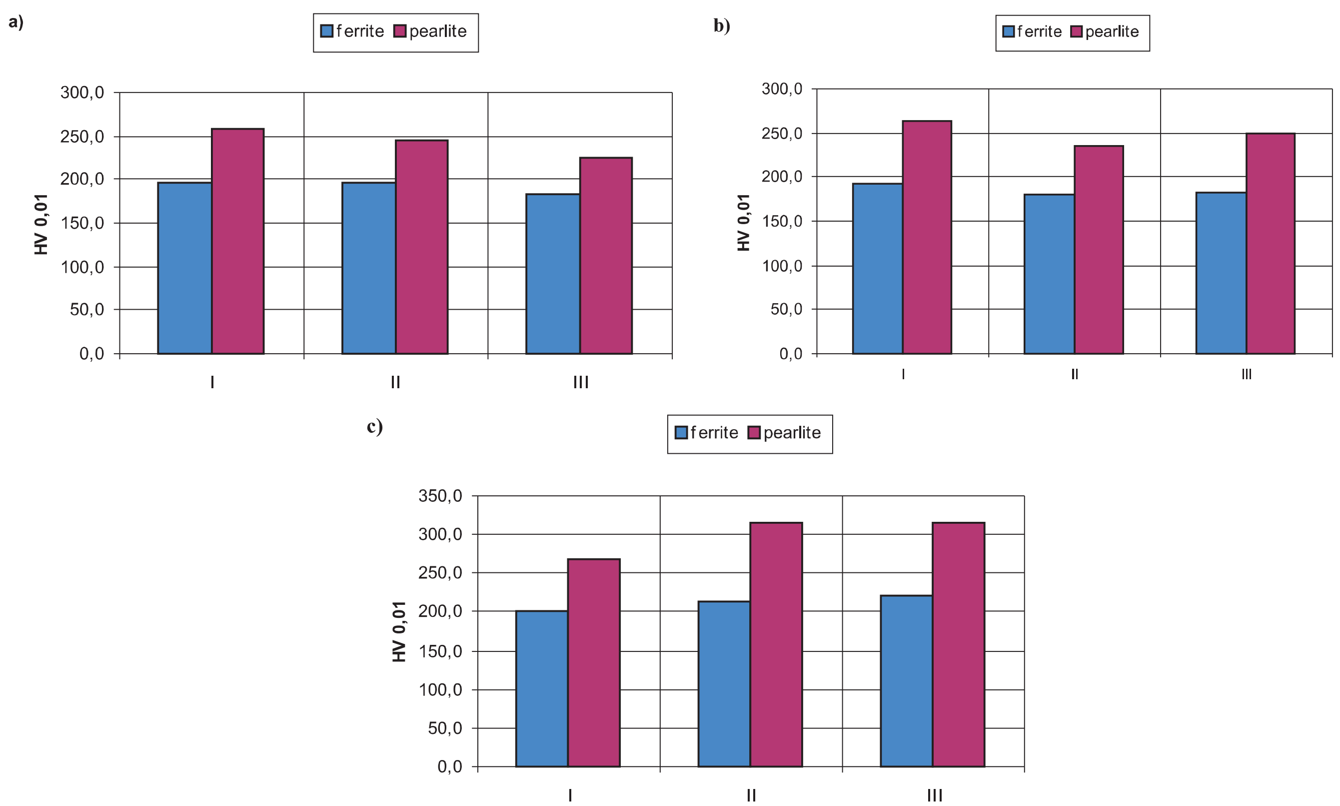

Fig. 9. Microhardness of the samples for variable plug piercing diameter (d_g): a) sample no 1 d_g = 48 mm; b) sample no 2 d_g = 50 mm; c) sample no 3 d_g = 52 mm; I – external part, II – middle part, III – internal part cross-section tube

The influence of the piercing head protruding (m) beyond the cylindrical part of the roll during roll barrel pass design is presented in Figure 10. For sample no 16 (m = 16 mm), the external layer of the tube has got the greatest hardness. The hardness diminishes when moving towards the internal part. In case of sample no 17 (m = 40 mm), microhardness increases in every part; and the internal layer of the tube obtains the greatest hardness, while the external part – the least. So this is contrary to the situation of sample no 16. Thus it can be stated that increasing of the piercing head protruding (m) affects increasing of the hardness of the tube from the internal side during roll barrel pass design.

Whereas, during the conical roll barrel pass design increasing of the piercing head protruding (m) affects adversely. Most probably this results from a different distribution of forces.

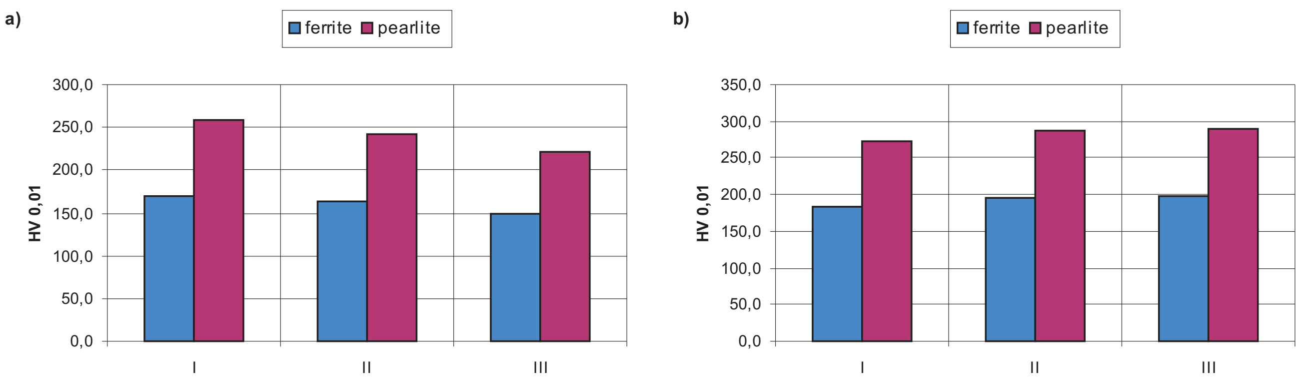

Fig. 10. Microhardness of the samples for variable advance plug piercing (m), barrel type roll pass design: a) sample no 16 m = 16 mm; b) sample no 17 m = 40 mm; I – external part, II – middle part, III – internal part cross-section tube

After the electrochemical examination had been carried out, density of the corrosion current was calculated by means of 'Elfit' program, for the samples after complete annealing and skew rolling. The corrosive environments were: 5% H_2SO_4 solution and 3.5% NaCl solution. It can be observed that the corrosion current for the samples after skew rolling, both in the artificial sea water and in the solution of sulfuric acid, is higher than the corrosive current jest of the samples after complete annealing. In NaCl solution the corrosive current is twofold greater, and in H_2SO_4 solution – threefold greater. This is to conclude that there appears faster corrosion of the samples, which underwent plastics working. Figure no 11 show curves of polarization in those solutions. In NaCl solution no phenomenon of transpasivity occurs because the chloride ions destroy the passive layer at the moment of formation, thus enabling its formation. The corrosive process in this solution takes place on the cathode only. The process of cathode depolarization occurs, as oxygen takes part in it [17, 18]. This is to conclude that steel will mostly corrode in strongly oxygenated waters. On the basis of the obtained results it can be stated that sea water is less favorable environment than the sulfuric acid as far as corrosion is concerned.

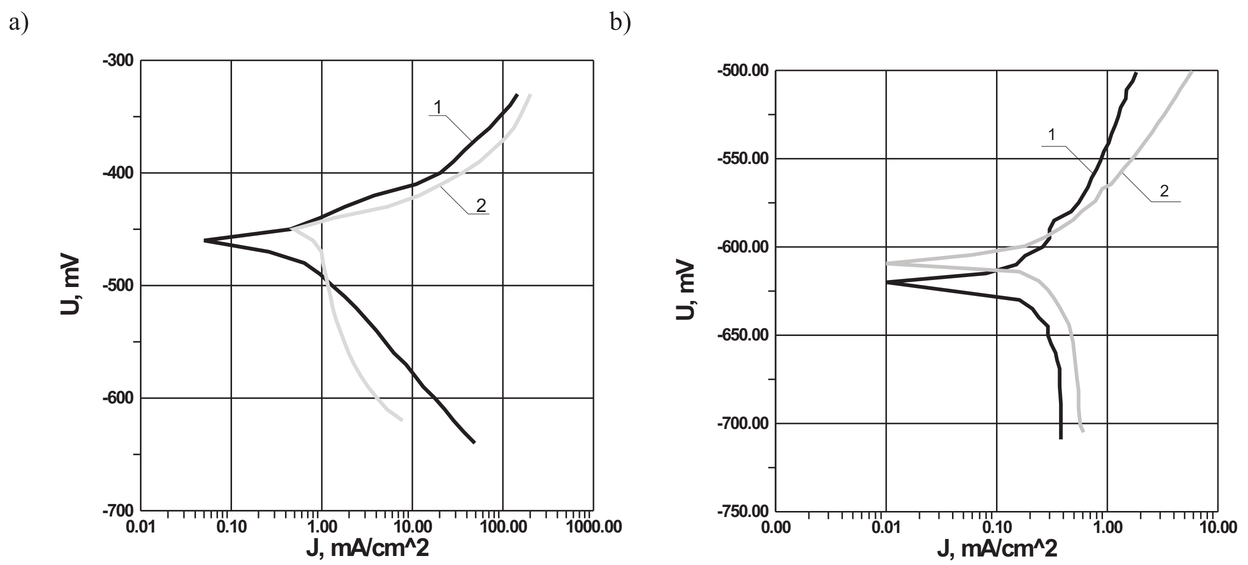

Fig. 11. Potentiostatic polarization curves for 1 – full annealing sample and 2 – pipe subjected to skew rolling mill in range ±150 mV from potential corrosive in: a) electrolytic solution of 5% H_2SO_4 and b) in sea water [17, 18]

In result of the microstructure observation by means of the optical microscope it can be noted that skew rolling clearly affects the size, shape and distribution of ferrite and pearlite grains. The experiments prove that the piercing and spreading process of the tubes influences microhardness of particular structural components, as well.

The value of microhardness of particular layers of the tube depend on selected parameters of the deflection area. In comparison to the insert material (non-alloy steel after complete annealing) the steel ferrite grains after the plastic working show distinct increase of microhardness, sometimes twofold. By contrast, microhardness of pearlite grains slightly increases, and sometimes the increase is very little. When using the conical roll pass design no orientation of grains was noticed. Whereas for roll barrel pass design directed deformation of the ferrite grains is visible. Therefore, it can be concluded that the conical roll pass design is more favorable to form the structure of the tube in comparison to roll barrel pass design of the working rolls. Density of the corrosive current determines the corrosive resistance of the material. The electrochemical experiments show that the samples obtained by skew rolling are less resistant to corrosion, because the value of the corrosive current is much higher than in case of the samples after complete annealing.

To become the maximal value of expanding, it is necessary to control advance and plug diameter, in such way setting up the minimal advance and maximal value of plug diameters. Along with increasing of plug diameter and decreasing of advance and feed angle, the force pressure on rolls increase. However, pressure forces on piercing plug grow, while parameters: diameter and advance of plug and roll feed angle are larger. Twisting parameters reaching minimal values while are used larger feed angles. So, favorable is to apply feed angles with larger values.

4. Conclusions

- The roll pass design and positioning of the piercing plug in the strain area has substantial influence on expansion external diameter pipes, forcing and twisting parameters in piercing and spreading process in Diescher's mill.
- On the basis of experimental researches of piercing and spreading process, follows that basic parameters having influence on spreading value are: diameter and position of piercing plug in deformation area and feed angle of barrel roll.
- The piercing and spreading process has considerable influence onto the microstructure and electrochemical resistance of the tubes.
- No essential influence of the geometrical parameters on the microhardness of particular layers of the tube was found.
- The most uniform distribution of ferrite and pearlite grains on the transverse and longitudinal sections were obtained for sample no 1, with the protruding value of m = 32 mm and the piercing head diameter d_g = 48 mm for the conical roll pass design.
- Change in the piercing head diameter slightly affects the microstructure of the tube.
- Protruding of the piercing head affects changes in the microstructure of the tube, for conical roll pass design with smaller protruding (m = 8 mm) there appear greater pearlite grains in the internal part of the tube, while for barrel roll pass design with smaller values of the piercing head protruding (m = 16 mm) orientation of the ferrite grains may be observed.
- With bigger value of the feed angle ($\beta = 12°$) decarburizing of the internal layer of the tube occurs.
- The samples which underwent the process of skew rolling have got greater microhardness of particular structural phases in comparison to the sample after complete annealing.
- For the samples after the skew rolling density of the corrosive current is twofold or even threefold bigger than the value of corrosive current density for the samples after complete annealing. This means that the tubes will corrode faster both in sea waters and sulfuric acid.

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