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THE RESEARCH OF INFLUENCE SIZE STRAIN AND NUMBER OF DRAWS ON DIMENSIONAL ACCURACY OF SEAMLESS TUBES MADE OF STEEL E235 AND E355

BADANIE WPŁYWU WIELKOŚCI ODKSZTAŁCENIA I LICZBY CIĄGÓW NA DOKŁADNOŚĆ WYMIAROWĄ RUR BEZ SZWU WYKONANYCH ZE STALI E235 I E355

The die drawing process is used as a final drawing operation, especially in the production of precise tubes of smaller diameter, while the advantage of the mentioned technology is a reduction of the drawing force and thereby also the decrease of the risk of possible tube rupture during the drawing process. The paper is focused on the research of the influence of the strain size and the method drawing process on the final thickness of the wall and the outer diameter of the tube during die drawing. The sinking drawing experiment was performed by single-pass and two-pass drawing technology to the final tube diameter Ø12 mm without inter-operational annealing.The output of the paper are bar graphs that allows to compare the influence of the strain size and the method of tube drawing technology (single-pass and two-pass) on the dimensional accuracy of the final Ø12 mm tubes made of E235 and E355 steel. The advantage of the single-pass drawing technology when achieving the required wall thickness within the prescribed tolerance (±10 %) would be a reduction of the number of draws.It was found that only in one case of the two-pass drawing technology of E355 steel tube production, the permitted positive tolerance of the tube wall thickness was slightly exceeded, in the case of increasing the reduction (size strain R) from 24 % to 32 %.

Keywords: *sinking drawing process, precise tubes, single-pass technology, two-pass technology, reduction, wall thickness*

Proces ciągnienia przy użyciu matrycy stosowany jest jako ostatnia operacja ciągnienia, szczególnie przy produkcji precyzyjnych rur o mniejszych średnicach, przy czym zaletą wspomnianej technologii jest zmniejszenie siły ciągnienia, a tym samym również zmniejszenie ryzyka ewentualnego pęknięcia rury podczas procesu ciągnienia. Praca skupia się na badaniu wpływu wielkości odkształcenia i metodzie ciągnienia na ostateczną grubość ścianki i średnicę zewnętrzną rury podczas ciągnienia przy użyciu matrycy. Eksperyment ciągnienia swobodnego przeprowadzono technologią ciągnienia w jednym ciągu i w dwóch ciągach do końcowej średnicy rury Ø12 mm bez wyżarzania międzyoperacyjnego. Wynikiem pracy są wykresy słupkowe, które pozwalają porównać wpływ wielkości odkształcenia oraz metody ciągnienia rur (w jednym ciągu i w dwóch ciągach) na końcową dokładność wymiarową rur Ø12 mm wykonanych ze stali E235 i E355. Zaletą technologii ciągnienia w jednym ciągu przy osiągnięciu wymaganej grubości ścianki w ramach określonej tolerancji (±10%) byłoby zmniejszenie liczby ciągów. Stwierdzono, że tylko w jednym przypadku ciągnienia w dwóch ciągach rur ze stali E355 dopuszczalna dodatnia tolerancja grubości ścianki rury została nieznacznie przekroczona, tzn. w przypadku zwiększenia gniotu R z 24% do 32%.

Słowa kluczowe: *proces ciągnienia swobodnego, rury precyzyjne, technologia ciągnienia w jednym ciągu, technologia ciągnienia w dwóch ciągach, gniot, grubość ścianki*

1. INTRODUCTION

Cold tube drawing is one of the most frequently used method for seamless tube manufacturing, which are widely used especially in the engineering industry. The desired tube diameter can be made by one or more tube manufacturing operations. Theoretical principles of cold tube drawing technology are described in the works [1–4]. The tube drawing is carried out in a simple drawing tool called “drawing die”, which consists of three parts: (1) the inlet part (i.e. reduction part), (2) calibration part (i.e. cylin-

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drical part) and (3) outlet part. The accuracy of the required diameter of the drawn tube depends mainly on the calibration (i.e. cylindrical) part of the drawing die.The tool geometry therefore is an important process parameter of cold tube drawing and affects not only the dimensional accuracy of the tubes but also the energy intensity of the manufacturing as well as the tool life [5, 6].

The geometry and dimensional accuracy of cold drawn tubes are also affected by other technological and process parameters such as the plastic strain degree, deformation rate, force and temperature conditions, friction conditions and the method of lubrication. Computer simulations using FE Method for the process of optimizing technological parameters are clearly of great importance for the flawless production of tubes [7–10].

The simulation software available on the market enables a relatively fast implementation of a large number of alternatives to FEM analysis of the cold tube drawing process with various combinations of process and technological parameters. In this way, FEM simulations make it possible to predict the possible effects of parameters on the dimensional accuracy of drawn tubes. Numerical simulation is therefore an important tool for monitoring the correct plastic flow of material in the drawing tool during cold drawing of the tube. There are many articles in which the authors investigated the effects of technological parameters on the process of cold tube drawing using FEM simulation. The results published in the works [11–14] are a great contribution to the development of cold tube drawing technology.

2. MATERIALS AND METHODOLOGY OF EXPERIMENT

2.1. DESCRIPTION OF THE SEMI-FINISHED PRODUCT AND THE TYPE OF STEELS FOR THE EXPERIMENT

Inlet tubes with outer diameter of Ø18 mm and Ø16 mm (in both cases wall thickness of 2 mm) were used for the cold tube drawing experiment in laboratory conditions. The inlet tubes were drawn to the required outer diameter of Ø12 mm in two ways: by (1) single-pass and (2) two-pass drawing technology. In the case of single-pass technology, one drawing die with an outer diameter of Ø12 mm was used, while the required diameter of the tube Ø12 mm was achieved per single draw by drawing from the initial diameter Ø18 mm and Ø16 mm. In the case of two-pass technology, two drawing dieswere used (with an outer diameter of Ø14 mm and Ø12 mm). Inlet tubes with outer diameter of Ø18 mm and Ø16 mm were drawn in the single-pass to a tube diameter of Ø14 mm and in the second-pass to a final tube diameter of Ø12 mm without inter-operational annealing.

The inlet tubes used in the experiment were supplied as cold drawn tubes. Tubes with a length of 3 m were cut by saw to the required length of 500 mm. One end of each 500 mm length tube was rotary swaged to a diameter of Ø11 mm. The tube will be gripped and drawned at the swaged end through the drawing die.

The dimensions of theinlet tube is shown in Fig. 1.

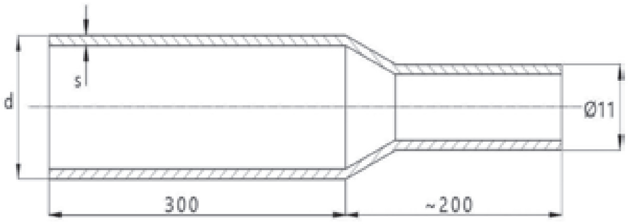

Fig. 1. The dimensions of the inlet tube; (*d* = Ø18 mm; Ø16 mm; *s* = 2 mm)

Rys. 1. Wymiary rury wlotowej; (*d* = Ø18 mm; Ø16 mm; *s* = 2 mm)

The inlet tubes are made of ferritic-pearlitic steel of classes E235 and E355, which are low-carbon and low-alloyed. These steels are suitable for the production of seamless tubes by cold drawing technology and are mainly used in the production of tubes for pressure, hydraulic and pneumatic circuits.

The mechanical properties of E235 steel are as follows: Yield stress Re = 235 MPa, tensile strength Rm = (340–440) MPa, elongation A_{min} = 24 %. The mechanical properties of E3555 steel are as follows: Yield stress Re = 355 MPa, tensile strength Rm = (490–630) MPa, elongation A_{min} = 22 %. The inlet used in the experiment were annealed in protective atmosphere (heat treatment marking "+N", EN10305-1). Chemical composition of low-carbon steels E235 and E355 according to EN10305-1 is given in Tab. 1.

Table 1. Chemical composition of tested steels [wt %]

Tabela 1. Skład chemiczny badanych stali [% mas.]

Steel	C	Si	Mn	P	S
E235	0.170	0.350	1.200	0.025	0.025
E355	0.220	0.550	1.600	0.025	0.025

2.2. SHAPE AND DIMENSIONS OF THE SPECIAL FIXTURE FOR TUBE DRAWING EXPERIMENT

For the purposes of the laboratory experiment, a special fixture was designed and manufactured to perform the technological experiments of the drawing of seamless steel tubes. The universal hydraulic tensile testing machine EU 40 was used tube drawing through the die, which is used in static mechanical tests of materials (pressure and tensile test).

The nominal force of the machine is 400 kN with the usable load range of 0–400 kN. The fixture for tube drawing is shown in Fig. 2.

The fixture was structurally designed for clamping in the working space of the universal hydraulic

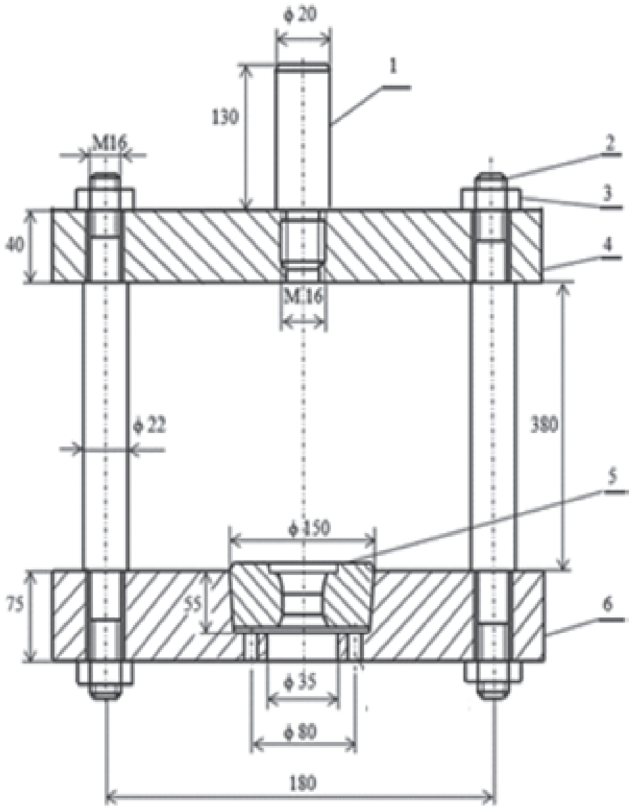

Fig. 2. The fixture used for the cold tube drawing experiment: 1 – slamping shank, 2 – post, 3 – nut, 4 – clamping plate, 5 – drawing die, 6 – base plate

Rys. 2. Uchwyt użyty do eksperymentu ciągnienia na zimno: 1 – trzpień zaciskowy, 2 – słupek, 3 – nakrętka, 4 – płyta zaciskowa, 5 – wykrojnik, 6 – płyta podstawy

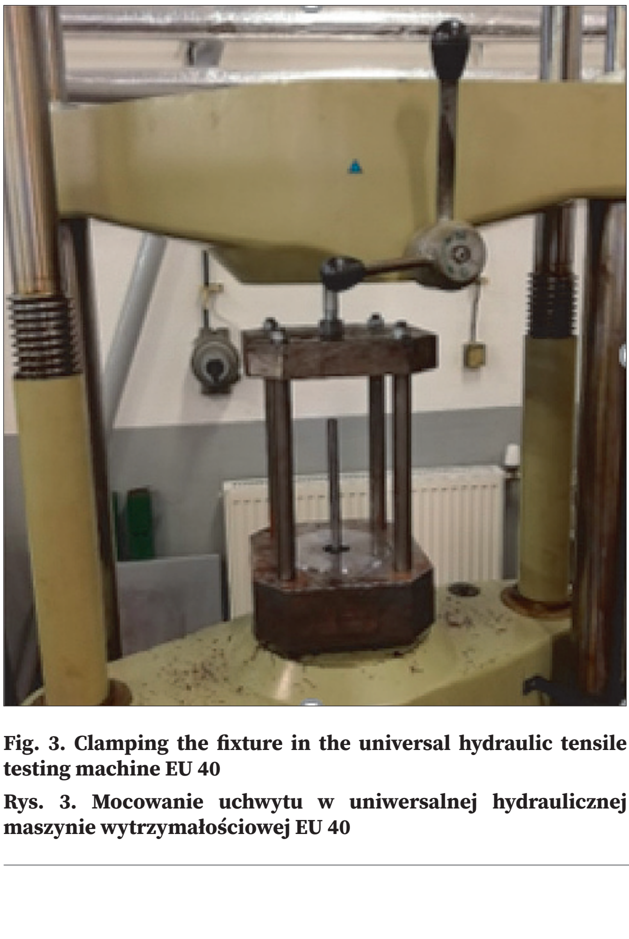

Fig. 3. Clamping the fixture in the universal hydraulic tensile testing machine EU 40

Rys. 3. Mocowanie uchwytu w uniwersalnej hydraulicznej maszynie wytrzymałościowej EU 40

tensile testing machine EU 40. The principle of clamping the fixture in the testing machine is documented in Fig. 3. The drawing speed of the tube was 60 mm/min and "Molykote HTF Dispersion" lubricating oil was used to reduce the effect of friction during the tube drawing through the drawing die.

The shape of the tube before and after drawing is shown in Fig. 4.

Fig. 4. The shape of the tube before and after drawing

Rys. 4. Kształt tuby przed i po ciągnieniu

3. RESULTS OF EXPERIMENT

Before each tube drawing process (single-pass and two-pass drawing process), measurements of the outer and inner diameters of the inlet tubes were performed and the tube wall thickness before drawing was also determined. Similarly, even after the tube draws were performed, the outer and inner diameters of the drawned tubes were measured.

The ZEISS Center Max coordinate measuring machine were used to measure tube diameters. Based on the measured tube diameters, the tube cross-section and tube wall thicknesses were calculated. From the cross-sections, the values of strain degree were calculated and the wall thicknesses were used to calculate the wall thickness change of the tube before and after drawing.

The measurement results for single-pass drawing technology are shown in Tab. 2, 3 and the measurement results for two-pass drawing technology are shown in Tab. 4, 5. Graphs were then constructed from the measured and calculated results. The graph of the resulting change in the tube wall thickness is shown in Fig. 5 and the graph of the outer diameter of the tubes after drawing is shown in Fig. 6. Bar charts shows the influence of the reduction size (size strain) and the production technology (one-pass, two-pass) on the achieved accuracy of the dimensions of the final tubes (outer diameter of Ø12 mm) made of steel E235 and E355. Reduction *R* [%] describes different size strain during analysed drawing technology variants. The graphs are also important for comparing the observed changes in thicknesses Δ*s* and the values of diameters of drawn tubes made of the investigated steels.

Table 2. Table of measured dimensions of tube and calculated values for drawned tubes of outer diameter of Ø12 mm (single-pass drawing technology; E235

Tabela 2. Zmierzone wymiary rury i obliczone wartości dla rur ciągnionych o średnicy zewnętrznej Ø12 mm (technologia ciągnienia jednoprzebiegowego; E235

Steel E235	Sample no.	Outer tube diameter D_0 [mm]	Inner tube diameter d_0 [mm]	Outer tube diameter after drawing D [mm]	Inner tube diameter after drawing d [mm]	Wall thickness s_0 [mm]	Wall thickness after drawing s [mm]	Wall thickness differences Δs [mm/%]	Reduction R [%]
Tube diameter [mm] Φ16	7	16.015	11.931	11.986	7.771	2.042	2.108	0.065 / 3.1	27.0
	8	16.013	11.942	11.987	7.761	2.036	2.113	0.077 / 3.7	26.6
	9	16.020	11.951	11.997	7.654	2.035	2.173	0.139 / 6.8	24.9
Tube diameter [mm] Φ18	1	18.000	13.945	11.978	7.781	2.028	2.099	0.071 / 3.5	35.9
	2	18.032	13.977	11.999	7.658	2.028	2.171	0.143 / 7.0	34.2
	3	18.028	13.971	11.984	7.798	2.029	2.093	0.065 / 3.2	36.2

Table 3. Table of measureddimensions of tube and calculatedvalues for drawned tubes of outer diameter of Ø12 mm (single-pass drawing technology; E355)

Tabela 3. Zmierzone wymiary rury i obliczone wartości dla rur ciągnionych o średnicy zewnętrznej Ø12 mm (technologia ciągnienia jednoprzebiegowego; E355)

Steel E355	Sample no.	Outer tube diameter D_0 [mm]	Inner tube diameter d_0 [mm]	Outer tube diameter after drawing D [mm]	Inner tube diameter after drawing d [mm]	Wall thickness s_0 [mm]	Wall thickness after drawing s [mm]	Wall thickness differences Δs [mm/%]	Reduction R [%]
Tube diameter [mm] Φ16	7	16.026	11.963	12.015	7.650	2.0315	2.1825	0.1510/7.43	24.518
	8	16.032	11.969	12.021	7.670	2.0315	2.1755	0.1440/7.09	24.693
	9	16.029	11.950	12.006	7.661	2.0395	2.1725	0.1330/6.52	24.008
Tube diameter [mm] Φ18	1	18.001	13.958	12.004	7.584	2.0215	2.2100	0.1885/9.32	32.994
	2	17.999	13.954	12.017	7.598	2.0225	2.2095	0.1870/9.25	32.937
	3	18.001	13.953	12.014	7.586	2.0240	2.2140	0.1900/9.39	32.904

Table 4. Table of measured dimensions of tube and calculated values for drawned tubes of outer diameter of Ø12 mm (two-pass drawing technology; E235)

Tabela 4. Zmierzone wymiary rury i obliczone wartości dla rur ciągnionych o średnicy zewnętrznej Ø12 mm (technologia ciągnienia jednoprzebiegowego; E235)

Steel E235	Sample no.	Outer tube diameter D_0 [mm]	Inner tube diameter d_0 [mm]	Outer tube diameter after drawing D [mm]	Inner tube diameter after drawing d [mm]	Wall thickness s_0 [mm]	Wall thickness after drawing s [mm]	Wall thickness differences Δs [mm/%]	Reduction R [%]
Tube diameter [mm] Φ16	10	16.013	11.947	12.001	7.787	2.033	2.107	0.074 / 3.6	26.6
	11	16.010	11.938	12.002	7.660	2.036	2.171	0.135 / 6.6	24.9
	12	16.015	11.948	12.001	7.690	2.034	2.156	0.122 / 6.0	25.3
Tube diameter [mm] Φ18	4	18.030	13.975	12.004	7.702	2.028	2.151	0.123 / 6.0	34.6
	5	18.028	13.973	12.006	7.717	2.028	2.145	0.117 / 5.7	34.8
	6	18.031	13.975	12.005	7.704	2.028	2.151	0.123 / 6.0	34.7

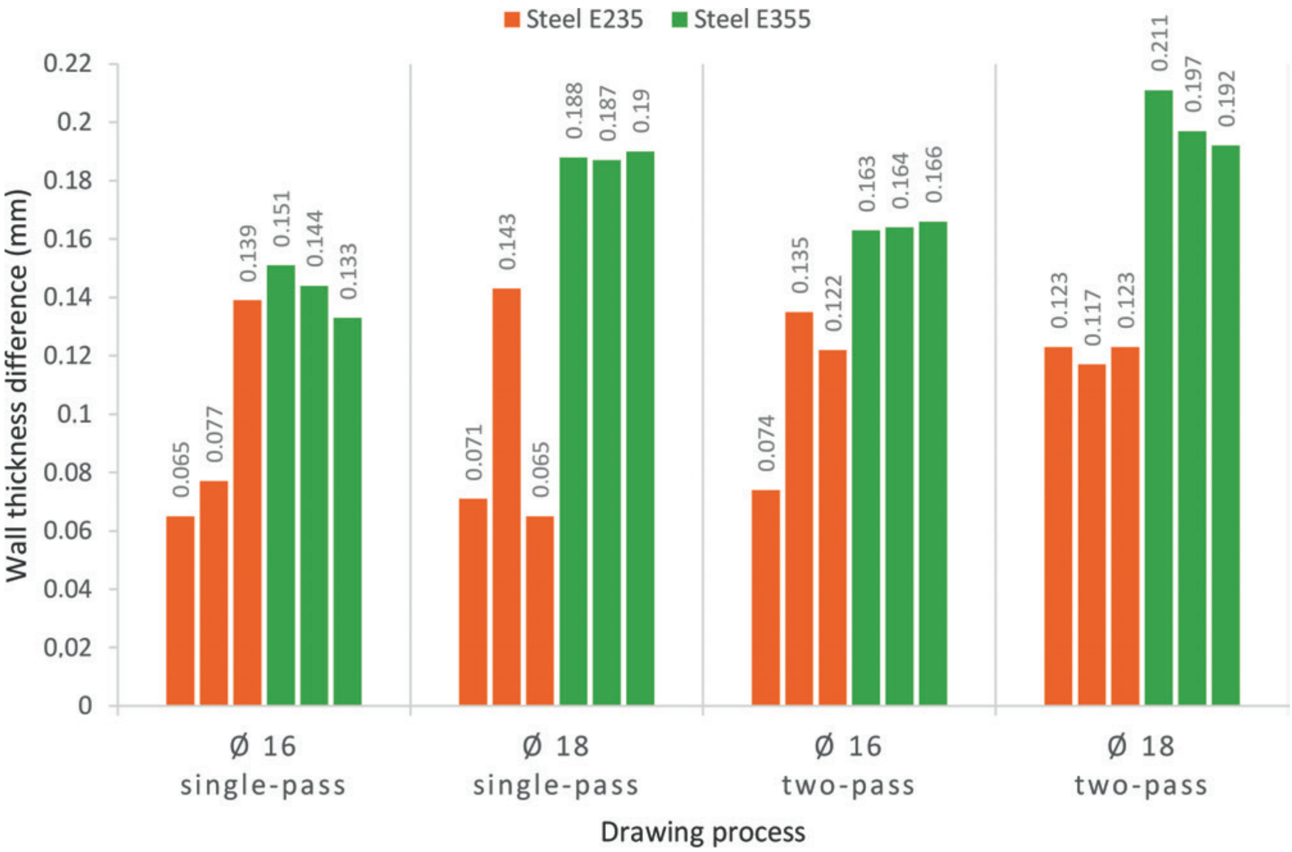

Fig. 5. Graphical dependence of the tube wall thickness change on the method of production (drawing technology)
Rys. 5. Graficzna zależność zmiany grubości ścianki rury od metody produkcji (technologia ciągnienia)

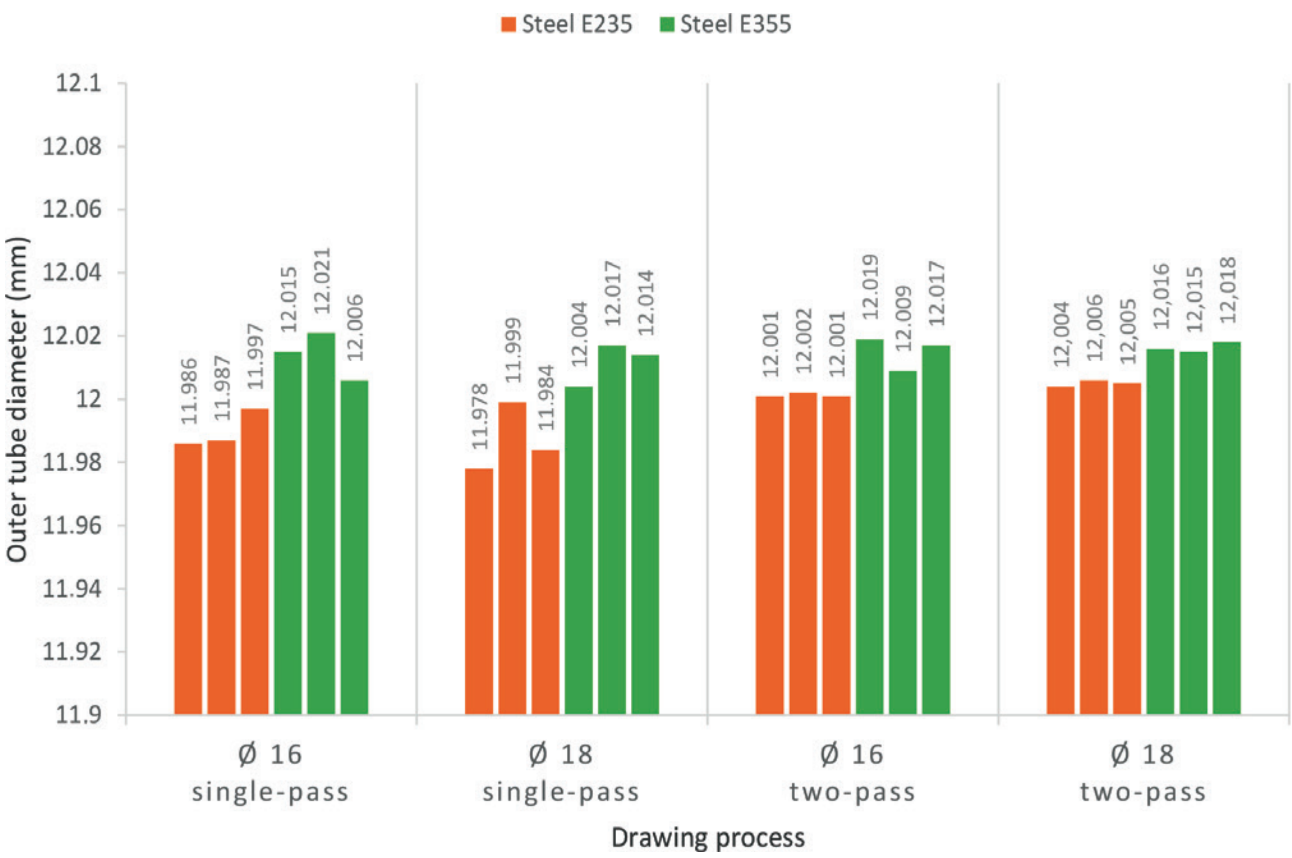

Fig. 6. Graphical dependence of the tube outer diameter on the method of production (drawing technology)
Rys. 6. Graficzna zależność średnicy zewnętrznej rury od metody produkcji (technologia ciągnienia)

Table 5. Table of measured dimensions of tube and calculated values for drawned tubes of outer diameter of Ø12 mm (two-pass drawing technology; E355)

Tabela 5. Zmierzone wymiary rury i obliczone wartości dla rur ciągnionych o średnicy zewnętrznej Ø12 mm (technologia ciągnienia dwuprzebiegowego; E355)

Steel E355	Sample no.	Outer tube diameter D_0 [mm]	Inner tube diameter d_0 [mm]	Outer tube diameter after drawing D [mm]	Inner tube diameter after drawing d [mm]	Wall thickness s_0 [mm]	Wall thickness after drawing s [mm	Wall thickness differences Δs [mm/%]	Reduction R [%]
Tube diameter [mm] Φ16	10	16.029	11.966	12.019	7.629	2.0315	2.1950	0.1635/8.05	24.167
	11	16.027	11.964	12.009	7.618	2.0315	2.1955	0.1640/8.07	24.220
	12	16.030	11.965	12.017	7.619	2.0325	2.1990	0.1665/8.19	24.112
Tube diameter [mm] Φ18	4	17.999	13.960	12.016	7.554	2.0195	2.2310	0.2115/10.47	32.352
	5	18.001	13.960	12.015	7.580	2.0205	2.2175	0.1970/9.75	32.713
	6	17.999	13.961	12.018	7.596	2.0190	2.2110	0.1920/9.51	32.793

4. SUMMARY

In the case of both investigated materials E235 and E355, the wall thickness increased in both the single -pass and two-pass drawing technology to the final tube's outer diameter of Ø12 mm. In the case of E355 steel with higher strength, the increase in wall thickness was more expressive than in the case of E235 steel with lower strength, both in single-pass and two-pass drawing technology.

With the increase in the reduction size (size strain) in both single-pass and two-pass drawing technology, there was a more significant increase in wall thickness after drawing. In the case of the E355 steel, when the reduction (size strain) was increased from 24% to 32% in one case with the two-pass drawing technology, the permitted positive wall thickness tolerance was slightly exceeded (+10%), which is unsatisfactory. Similar results were found in the case of monitoring the effect of reduction (size strain), number of drawings and material on the outer diameter of the tube after drawing. In the case of the outer diameter, however, this effect was significantly lower, as the outer diameter of the tube after drawing is given mainly by the diameter of the drawing die used.

Based on the results obtained when using drawing as the final operation, it is therefore more advantageous to use single-drawing technology with a smaller reduction (size strain) of up to 25 %, especially for materials with higher strength, as there is no risk of exceeding the permitted tube wall thickness tolerance.

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