EVALUATION OF THE POSSIBILITY OF DIAMETER REDUCTION IN MT 1020 STEEL TUBES BY ROLLING ON THE WPM-120 COLD PROFILE ECCENTRIC ROLLING MACHINE

MIŁEK Tomasz [1], KOPACZ Zenon [2]

[1]*Kielce University of Technology, Faculty of Mechatronics and Machine Design, Department of Applied Computer Science and Armament Engineering, Kielce, Poland, EU, tmatm@tu.kielce.pl*
[2] *Institute of Precision Mechanics, Warsaw, Poland, EU, zkopacz@imp.edu.pl*

Abstract

The paper presents experimental results of diameter reduction in tubes with the angle of flare $\alpha=30^0$. Tube diameter reduction was performed on the WPM-120 cold profile eccentric rolling machine. In the investigations, AISI MT 1020 (ASTM A513) steel tubes with the relative ratio $s_0/D=0.09$ were used. The appropriate values of the eccentric and feed were chosen for the experiment. The coefficient of necking for the samples was K=D/d=1.46 (where d - smallest diameter in reducing tubes after rolling, D - initial outer tube diameter). The evaluation of the quality of the samples obtained in the experiment was based on the measurements of cylindricity and the wall thickness distribution in the longitudinal section of reducing tubes. The measurements of cylindricity were taken with the ZEISS PRISMO navigator, a coordinate measuring machine. The results obtained in the experiment might be used as guidelines to develop a technological process for manufacturing such type of reducing tubes with the WPM cold rolling method. They could also be helpful while applying the method to industrial practice.

Keywords: Cold rolling, reducing tube, WPM-120 cold profile eccentric rolling machine, wall thickness distribution

1. INTRODUCTION

Different conventional methods of metal forming are employed while manufacturing pipe connections, including reducing tubes. When reducing tubes are formed, the diameter or cross-section of tubular blanks either decreases or increases [1-3]. In the first case, the following methods are used in industrial practice: necking; crimping of tubes in anvils with the use of steam-air hammers, pressing and upsetting performed by the machines, and also forming in a combined process of bending from sheets and welding [1,2,4-7]. As regards the other option, it is possible to obtain reducing tubes by using the bulge forming process which involves increasing the diameter or cross-section of tubular blanks. In conventional bulging methods, the following are used: steel or rubber punch dies, bulging fluid dies, where a liquid is used instead of a punch, and expanding segments drawn by a wedge mandrel [1,8]. A special type of tubular component processing is hydromechanic bulge forming, a type of hydroforming, which additionally employs internal bulging force [9].

In the 1970s, Professor Zdzisław Marciniak and Zenon Kopacz (Warsaw University of Technology, Poland) developed a cold rolling method which allowed forming cylindrical gears, involute splines and other circular profiles [10-15]. The involute splines were rolled accurately and the method found its way into industrial applications. The most essential features of the WPM method, distinguishing it from other known methods, involve the use of two circular segments as the tools and the adoption of a kinematics that allows one-directional rolling with a symmetrical system of forces relative to the axis of the rolled material. For rolling gears and splines, tools that had segments with internal toothing were used. In the case when the jaws with internal smooth rolling surfaces are used as the tools, it is possible to reduce the cross section of the shafts and tubes. The maximum initial diameter of shaft from medium steel to be reduced is 30 mm and tubes can have larger diameters depending on the tube wall thickness.

The consecutive stages of rolling in tube diameter reduction with the WPM method are presented in **Fig. 1**. The tube *1* has its diameter reduced when it rolls along the working surface of the tools 2 and 3 in the first stage of the work cycle (**Figs. 1 d,e,f**), whereas during the second stage, the tools move away from the material (**Figs. 1 a,b,c)** and the material shifts axially by the feed quantity. The reduced tube of the required length is gradually produced, which results from the consecutive working motions of the tools and the axial shifts of the rolled material.

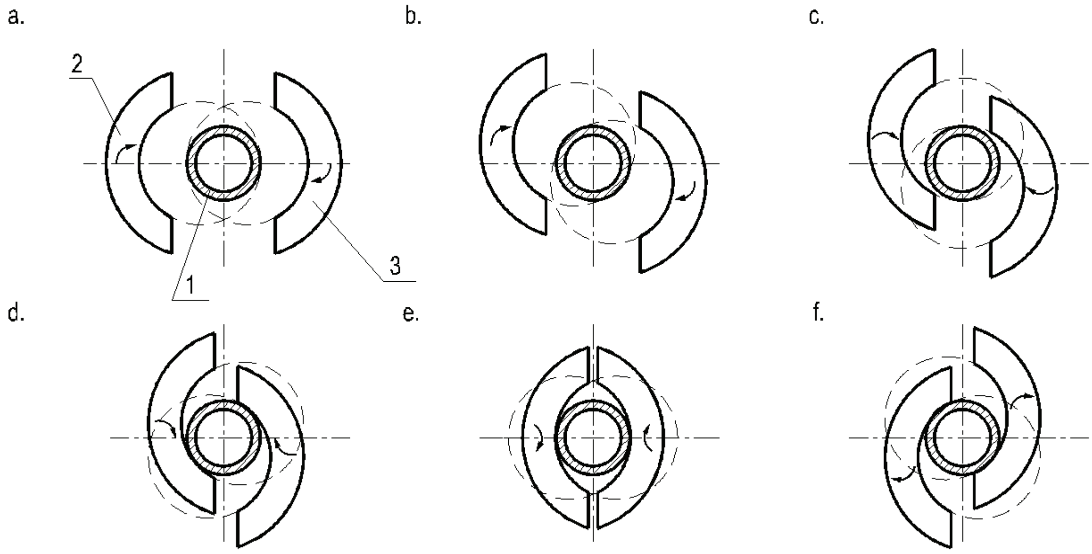


Fig. 1 The consecutive stages of rolling in tube diameter reduction with the WPM method

For necking, the reduction coefficient, defined in [2], is as follows:

$$K = \frac{D}{d} \qquad (1)$$

where: D - initial outer tube diameter, d - smallest diameter after the rolling of reducing tubes.

Most often, steel reducing tubes with outer diameters D=25÷508 mm and relative wall thickness s_0/D= 0.021÷0.920 (where: s_0 - tube wall thickness, D - tube diameter) are used in the construction of pipelines for power engineering. The coefficient of necking can range from 1.25 to 2.45 [4,5].

The stress condition that prevails in the necking area causes reduction in outer diameter, increase in wall thickness, and a slight pipe elongation [7].

The paper presents experimental results of diameter reduction in tubes made from MT 1020 (ASTM A513) steel with the angle of flare $\alpha=30^0$ and the relative ratio s_0/D=0.09. The coefficient of necking for the samples was K=1.46. The aim of experimental investigations was to evaluate of the possibility of reducing diameters of tubes made from AISI MT 1020 (ASTM A513) steel by rolling on the WPM-120 cold profile eccentric rolling machine. Evaluation of the quality of the samples obtained in the experiment was made on the basis of the measurements of the cylindricity and the wall thickness distribution in the longitudinal section of the reducing tubes.

2. METHODOLOGY

The material for experimental investigations were MT 1020 steel (ASTM A513) tube segments, whose outer diameter was D=34mm and the wall thickness s_0=3.25mm, (which corresponded to the relative thickness s_0/D= 0.09). The initial lengths of tube segments were 265 mm. The chemical composition of the investigated steel is presented in **Table 1**. Carbon and sulphur contents were determined using LECO CS 230 analyser. The mechanical properties of steel tubes used in the experiment are presented in **Table 2**.

Table 1 Chemical composition of MT 1020 steel [16, own research]

C	Mg	P	S
0.2081%[1]	0.3÷0.6%[16]	max. 0.035%[16]	0.006393%[1]

[1] LECO data

Table 2 The mechanical properties of MT 1020 steel [16]

Yield Strength, MPa, min.	Ultimate Strength, MPa, min	Elongation in 50mm, %,min
241	345	25

Tube diameter reduction was performed on the WPM-120 cold profile eccentric rolling machine. The view of the machine is presented in **Fig. 2**. The machine is located in Kielce, Poland, at Kielce University of Technology. The rolling of reducing tubes from pipes was performed with the tooling, the diagram of which is presented in **Fig. 3**. The tools were fitted to the WPM-120 machine. The tooling was setup for the angle of flare $\alpha=30^0$ and diameter 26 mm.

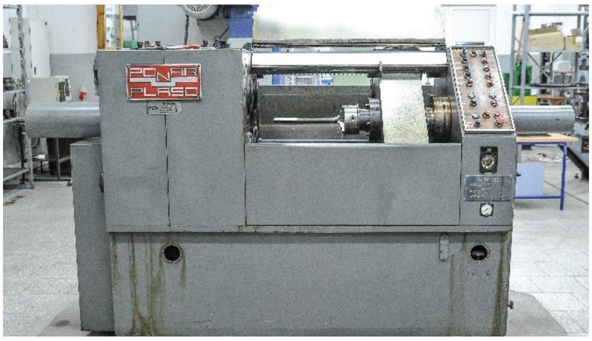


Fig. 2 View of the WPM-120 cold profile eccentric rolling machine

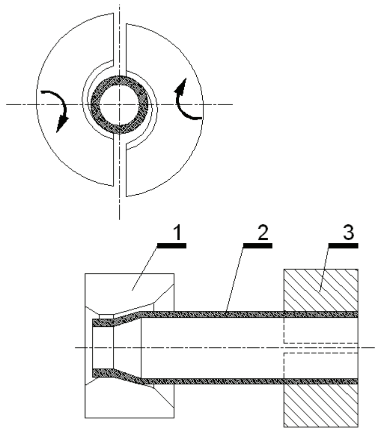


Fig. 3 The diagram of rolling by the WPM method, where: 1 - rolling tool, 2 - reducing tube, 3 - handle of the rolling machine feeder

The specification of WPM-120 cold mill is presented in **Table 3**.

Table 3 Specification of WPM-120 cold mill

Maximum diameter of splines that can be rolled	120 mm
Maximum diameter of splines rolled on a shaft more than 50mm long	75 mm
Maximum splines module	3 mm
Involute surface roughness	less than 1µm
Maximum feeder slide stroke	630 mm
Radial jaw pressure rating	12 tons
Working feed	25÷400mm/min
Approach and return rate	2 400 mm/min

The measurements of cylindricity were taken with a coordinate measuring machine, namely ZEISS PRISMO navigator, the measuring accuracy of which is up to 1µm.

3. EXPERIMENTAL RESULTS AND ANALYSIS

In the preliminary tests, experimental investigations into cold rolling were conducted for appropriate values of the eccentric and feed. Successful tests were carried out for eccentric e=1.161 mm and feed p=25mm/min. The diameter of the reduced part of tubes was 24.3 mm and the length was approx. 85 mm. The coefficient of necking for the samples was K=1.46 and the elongation ratio was λ= 1.958 ($\lambda=A_0/A$, where A_0 - cross- sectional area of the tube before rolling, A- cross-sectional area of the reducing tube). Examples of experimentally rolled steel reducing tubes are presented in **Fig. 4**.

a) b)

Fig. 4 Examples of experimentally rolled MT1020 steel reducing tubes at s_0/D=0.09 and K=1.46 ratios, where: a) reducing tube, b) longitudinal section of the reducing tube

Fig. 5 shows the results of measurements of cylindricity in the reduced segment of the steel reducing tube. The measurements were taken on 70 mm length of the sample. The result was 0.3250 mm, which represents a deviation of the diameter of the reduced tube segment from an ideal cylinder with an averaged diameter.

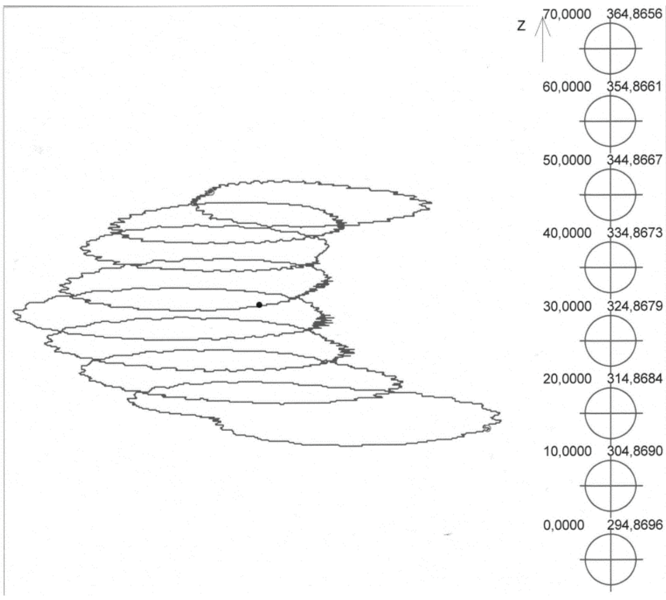
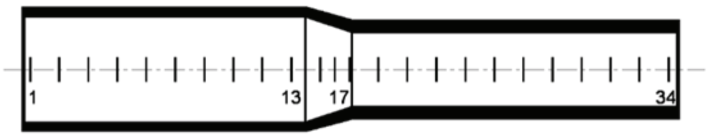


Fig. 5 The results of the measurements of the cylindricity of experimentally rolled MT1020 steel reducing tubes at s_0/D=0.09 and K=1.46 ratios

The analysis of wall thickness distribution in the longitudinal sections was conducted for reducing tubes with the angle of flare $\alpha=30^0$ and relative ratios s_0/D=0.09. Exemplary distributions, together with the spacing of the measurement points are presented in **Fig. 6**. Measured thicknesses s were referred to the initial thickness s_0 by means of the relative ratio s/s_0. The wall thickness in the cylindrical part of the reducing tube (measurement points 1÷12) does not change, or the wall is slightly thickened by max. 4%. In the zone of the cylindrical part transition into the reduced cone (measurement points 13-17), gradually increasing thickening of the wall occurs from point 13 by max. 10% to point 17 by max. 60 %. In the reduced part of the reducing tube (measurement points 18-31) the wall is thickened by max. approx. 65 %. In the vicinity of the front portion of the reduced part (measurement points 32-34), gradually decreasing thickening from 56 % to 33 % is found.

a)



b)

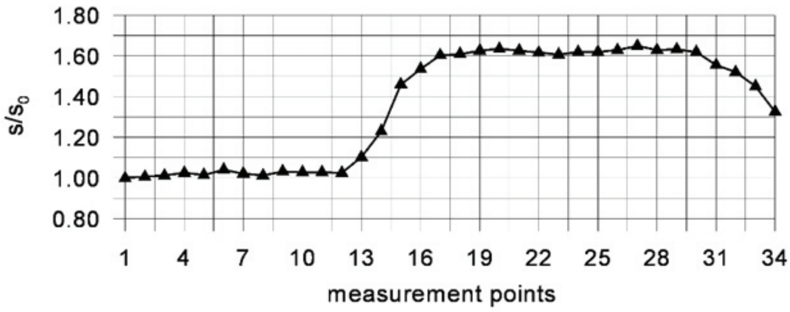


Fig. 6 The wall thickness distribution in the longitudinal section of the rolled reducing tube from MT1020 steel at s_0/D=0.09 and K=1.46 ratios,
where: a) spacing of measurement points, b) the wall thickness distribution graph

4. CONCLUSIONS

On the basis of investigations carried out into cold rolling of MT 1020 steel reducing tubes with the angle of flare $\alpha=30^0$ and the relative initial tube thickness s_0/D=0.09, it can be stated as follows:

1) It is possible to conduct cold rolling of steel reducing tubes by WPM-120 machine for appropriate values of the eccentric and feed. That was confirmed by successfully performed tests for ratios K=1.46 and λ= 1.958, for the length of the tube reduced part of approx. 85 mm. At those parameters, it was possible to receive the cylindrical part of the reducing tube without any defects. Further rolling resulted in the crack formation in this part.
2) The analysis of the results of the wall thickness distribution in the longitudinal sections of the reducing tubes and the measurements of the cylindricity of reduced part indicates the technological usefulness of the method for reducing tube forming, especially when there is a need to obtain reducing tubes with highly thickened walls. The maximum wall thickening was found in the zone of the reduced part of the reducing tube and amounted to approx. 65 %.
3) The results obtained in the experiment could be helpful while applying the method of cold rolling of reducing tubes to industrial practice. It is necessary to continue investigations into reducing pipe forming at different reduction ratios and various types of steel.

REFERENCES

[1] LANGE, K. *Handbook of metal forming.* McGraw-Hill, Inc. USA,1985
[2] ROMANOWSKI, W. P. *Handbook of Cold Working*, Wydawnictwa Naukowo-Techniczne Warsaw (1976), (in Polish).

[3] HASHMI, M.S.J. Aspects of tube and pipe manufacturing processes: Meter to nanometer diameter, Journal of Materials Processing Tech., 2006, Vol. 179, Issue: 1-3, pp. 5-10.

[4] CHAŁUPCZAK, J., PACANOWSKI, J., MIŁEK, T. Ocena możliwości wykonania zwężek rurowych metodą obciskania oraz walcowania na walcarce profilowej mimośrodowej WPM-120. *Rudy i Metale Nieżelazne.* 1998, Vol. 45, No. 10, pp. 486- 490.

[5] CHAŁUPCZAK, J., PACANOWSKI, J., MIŁEK, T. Badanie możliwości i dobór parametrów technologicznych przy walcowaniu wewnętrznym rur oraz zwężek rurowych na mimośrodowej walcarce WPM-120*. Rudy i Metale Nieżelazne,* 2000, Vol.45, No. 10-11, pp.552-555.

[6] ZIÓŁKIEWICZ, S. CZARTORYSKA, I. GRONOWSKI, W. Investigation of the process of pipe end diameter reduction by the method of necking. *Obróbka Plastyczna Metali,* 2008, No.19, pp. 21-27. (in Polish)

[7] KNAP, F., KRUZEL, R., KRAKOWIAK, M. Conical pipe envelope formation process. *Journal of Materials Processing Technology*, 2003, Vol. 139, Issue: 1-3, pp. 164-169.

[8] MIŁEK, T. Experimental investigations into one-sided and two-sided bulge forming of steel reducing tubes. Steel Research International, special edition. *14th International Conference Metal Forming 2012*, pp. 543-546.

[9] MIŁEK, T. Experimental research on hydromechanical bulge forming of pipe connections. Metal Forming 2008 Conference *Steel Research International*, Special Edition, 2008 Vol. 1, pp. 280-287.

[10] MARCINIAK, Z., KOPACZ, Z. WPM and WPMR transverse cold rolling processes. *1st International Conference on Rotary Metal-Working Processe*s. London, 1979.

[11] KOPACZ, Z. Profile rolling of involute splines. *Metalurgia and Metal Forming* 1977*, 9th Plenary Meeting of International Cold Forging Group (ICFG*. Paris 1976.

[12] MARCINIAK, Z., KOPACZ, Z. *New rotary metalworking processes developed in Poland*. Stratford upon Avon, UK, 1982.

[13] MARCINIAK, Z., KOPACZ, Z*. Faconnage des profils a froid a froid au myen de machoires a surface d'action concave.* Formage et Traitements des Metaux. 45, Paris 1973, 45 p.

[14] KOPACZ, Z., RYBKA, J. Neuartige Kaltzwaltzmethode, Technische Rundschau Nr 10/1973, Bern.

[15] MARCINIAK, Z., CHODAKOWSKI, A., KOPACZ, Z. Neue Verfahren zum palstischen Kaltumformen von Maschinen-teilen, VDI-Z Nr 8/1973, Dusseldorf.

[16] Standard Specification for Electric-Resistance-Welded Carbon and Alloy Steel Mechanical Tubing, Designation: A513-07, ASTM International, USA.