# MEASUREMENT OF AXIAL FORCE ON A CROSS-ROLLING MILL

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**Abstract**

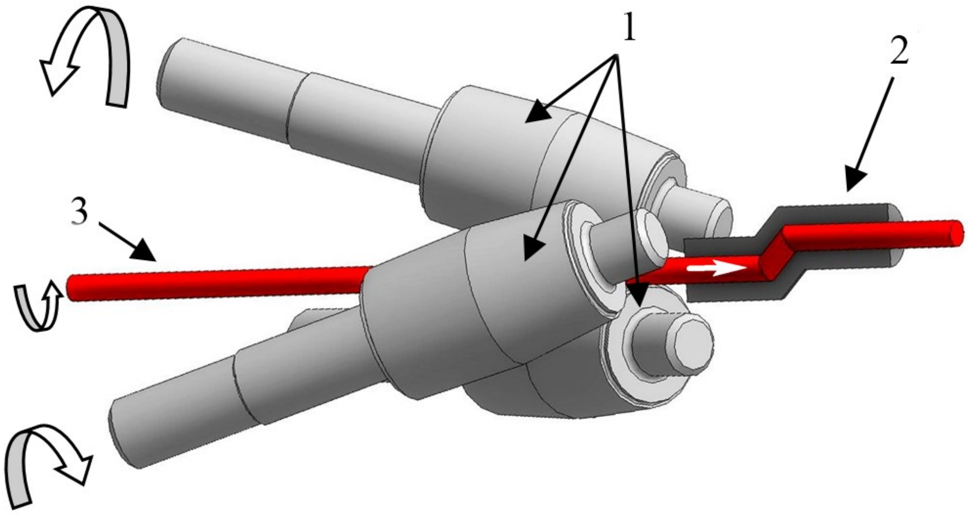
The present paper presents an experimental verification of the typical values of axial forces for each setting three-roll cross-rolling mill. We tested the influence of transport angle and diameter billet on the axis force. Sufficient magnitude of this force allowed the smooth flow of metal through the piercing plug. Experimental work was carried out on a laboratory rolling mill with three-roll arrangement 120° around the circumference of the billet. Rolling was carried out using a special measuring mandrel. The technological parameters were selected as follows: speed of work rolls 100 rpm, transport angle 6°, toe angle 0°, temperature 1000°C, reduction of the diameter 5 and 10%. Sufficiently large reserve of the axial force was necessary to prevent blinded tube making, which decreased the production cycle and thus also capacity of production. The transport angle has the primary effect on magnitude of the axial force, which for the given calibration work rolls shows the possibilities and limitations of the technology with such rolls.

**Keywords:** Physical modelling, axial force, experimental equipment, three-roll mill

## 1. INTRODUCTION

It is known that present metal materials for the traditional method of processing have coarse-grained and/or sub-grained structure. At the same time, that its ultrafine-grained (UFG) and nanostructural (NS) condition with grains size less than one micron and special condition of borders can considerably (by 2-3 times) increase the durability of technically pure metals and by 1,5-2 times – for alloys in combination with rather high plasticity [1,2].

Use of three-roll mills continues in the development process, as evidenced by research on their use for the technology which enables to obtain in forming piece UFG microstructure using intensive plastic deformation (**Fig. 1**). Combination cross-rolling and equal-channel angular pressing (ECAP) allows realization of stress-strain state with intense movement of the surface of the material at cross-rolling in a first process step and the integration intense shear deformation angular extruding with torsion of the second part of the process. These processes create good conditions for the formation of UFG microstructure in the sample of circular cross section of unlimited length. Implementation and putting commissioning of this process and its industrial use to obtain high-quality round bars using by continuous extrusion. The transition between the different shaped profiles can be dealt with changing the extruder die and distance between the rolls, which is faster and easier than changing the roll passes. This is advantageous for small-scale production, where frequent changes are common rolled products [3, 4]. Mapping the parameters affecting the axial force in a wider area allows finding the limits of use of technology. Describing the three-roll mill is not primarily intended for ECAP, but the principle is the same technological process. It is equipment usable primarily for experimental work of punching operation, and also for elongation hollow billets.




**1 – conic rolls; 2 – stepped ECAP matrix; 3 – bar**

**Fig. 1** Scheme of combined process of skew rolling & ECAP [3]

## 2. EXPERIMENTAL PART

Experimental work was carried out on laboratory cross-rolling mill with three-roll arrangement 120° around the circumference of the billet (**Fig. 2**). Rolling was carried out using a special measuring mandrel. This facility is located in MATERIAL & METALLURGICAL RESEARCH Ltd., Ostrava (MMR), detailed description of the experimental equipment is presented in [4,5].

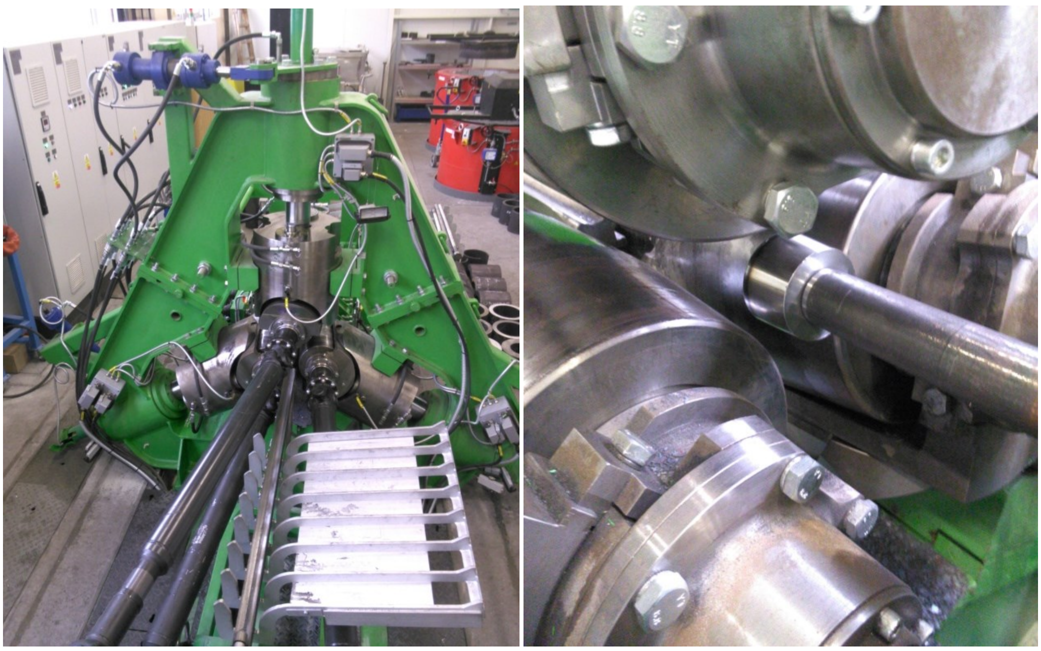


**Fig. 2** Laboratory cross-rolling mill (MMR)

Other laboratory equipment used for these experiments is located at the workplace Karaganda State Industrial University (KSIU) and designed by Moscow Institute of Steel and Alloys (MISA) [6]. It is a device that is smaller and easier to use than devices MMR, for these experiments is fully sufficient (**Fig. 3**).

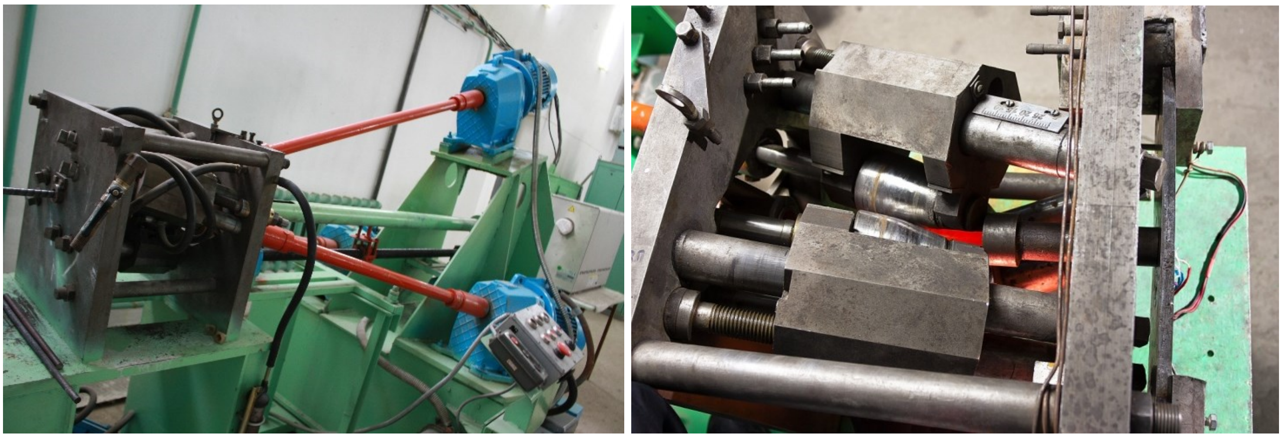


**Fig. 3** Laboratory equipment in Karaganda State Industrial University

The aim of the experiment was to measure the maximum axial forces exerted on special measuring mandrel, its verification by finite element method (FEM) simulation and compare the results with other laboratory equipment. For the experiment in MMR was used usual type of structural steel with 0,18 % C). The technological parameters were selected as follows: speed of work rolls 100 rpm, transport angle 12°, toe angle 0°, temperature 1000°C, reduction of the diameter 5 and 10 %, diameter billet ($D_0$) 55 and 68 mm, the diameter of the cylinders ($D_V$) 240 mm (**Table 1, Fig. 4**). For the experiment in KSIU on the MISA device was also used structural steel with 0,14-0,22% C. The technological parameters were selected as follows: transport angle 18°, toe angle 12°, temperature 1000°C, reduction of the diameter 6 and 12 %, diameter billet ($D_0$) 25, 20 and 16 mm, the diameter of the cylinders ($D_V$) 71 mm (**Table 1, Fig. 4**).

**Table 1** Measured values of axial forces

| **MMR device** | | | | **MISA device** | | | |
|---|---|---|---|---|---|---|---|
| e = 10% | | e = 5% | | e = 16% | | e = 6% | |
| **($D_v/D_0$)** | **F, kN** | **($D_v/D_0$)** | **F, kN** | **($D_v/D_0$)** | **F, kN** | **($D_v/D_0$)** | **F, kN** |
| 3,5 | **101,5** | 3,5 | **67,0** | 2,8 | **44,4** | 2,8 | **48,0** |
| 3,5 | **98,8** | 3,5 | **74,7** | 2,8 | **44,4** | 2,8 | **44,7** |
| 3,5 | **100,2** | 3,5 | **59,2** | 2,8 | **47,4** | 2,8 | **42,8** |
| 3,5 | **83,6** | 3,5 | **71,9** | 2,8 | **41,4** | 2,8 | **44,0** |
| 4,3 | **72,9** | 4,3 | **45,5** | 3,6 | **42,0** | 3,6 | **46,6** |
| 4,3 | **82,6** | 4,3 | **51,9** | 3,6 | **39,9** | 3,6 | **38,0** |
| 4,3 | **66,2** | 4,3 | **53,0** | 3,6 | **40,5** | 3,6 | **45,6** |
| 4,3 | **88,9** | 4,3 | **52,9** | 3,6 | **36,3** | 3,6 | **44,6** |
| | | | | 4,4 | **22,1** | 4,4 | **20,0** |
| | | | | 4,4 | **19,2** | 4,4 | **18,7** |
| | | | | 4,4 | **17,9** | 4,4 | **26,4** |
| | | | | 4,4 | **23,2** | 4,4 | **20,7** |

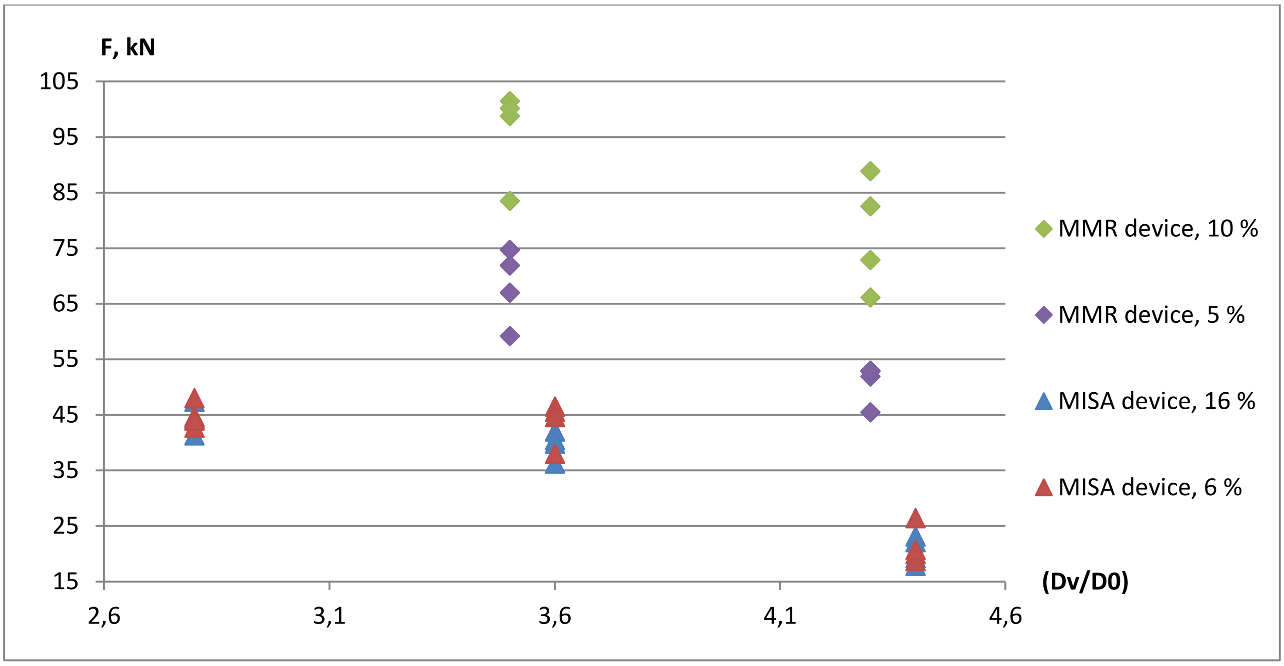



**Fig. 4** The plot of the axial forces on the Dv/Do

Furthermore, for 55 mm diameter billets with a 10 % reduction by diameter made using finite element method (FEM) simulation software FORGE NxT 1.0. Result axial forces in these cases ranged 25 to 30 % of the real measured values (MMR). For comparison FEM analysis and laboratory experiment is useful to know the conditions forming, respectively in this case, the contact area between the rolls and the billet. In a laboratory experiment, it was possible for comparable experiments only measure the approximate length of the contact area (deformation zone). It had a length of from 70 to 80 mm (**Fig. 4**). For the FEM analysis can be determined more accurately the contact zone. The length of the contact zone was 30 mm and the total contact area between all the rolls and the billet was 600 mm$^2$ (**Fig. 5** and **Fig. 6**). From the above it can be concluded that the flow of metal will, in fact, other than the FEM analysis shows.

**Fig. 4** Rolling with visible deformation zone (e=10%; $D_V/D_0$=4,3)

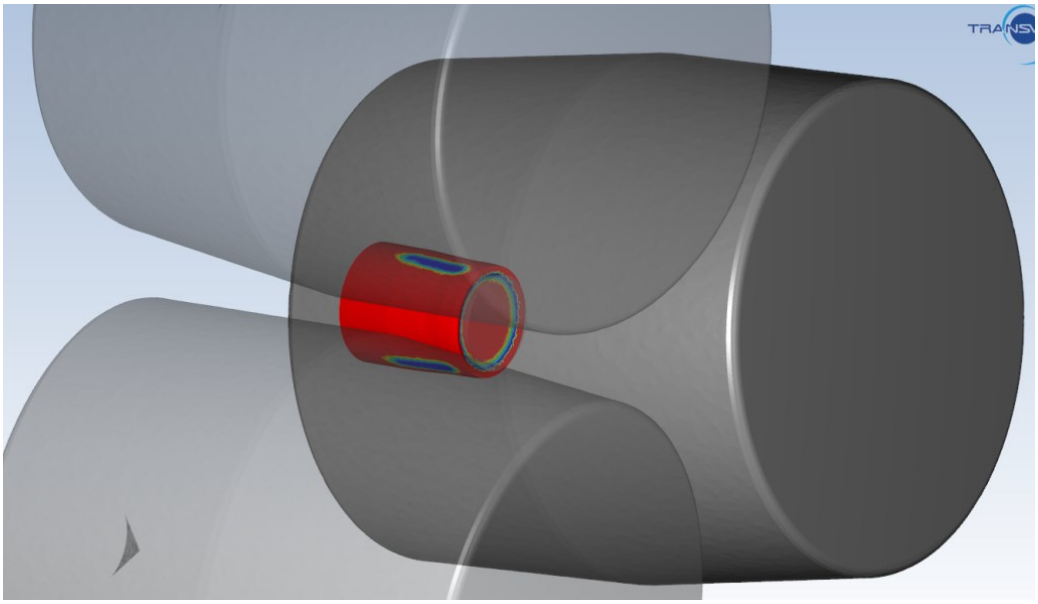


**Fig. 5** Contact area between the cylinder and billet

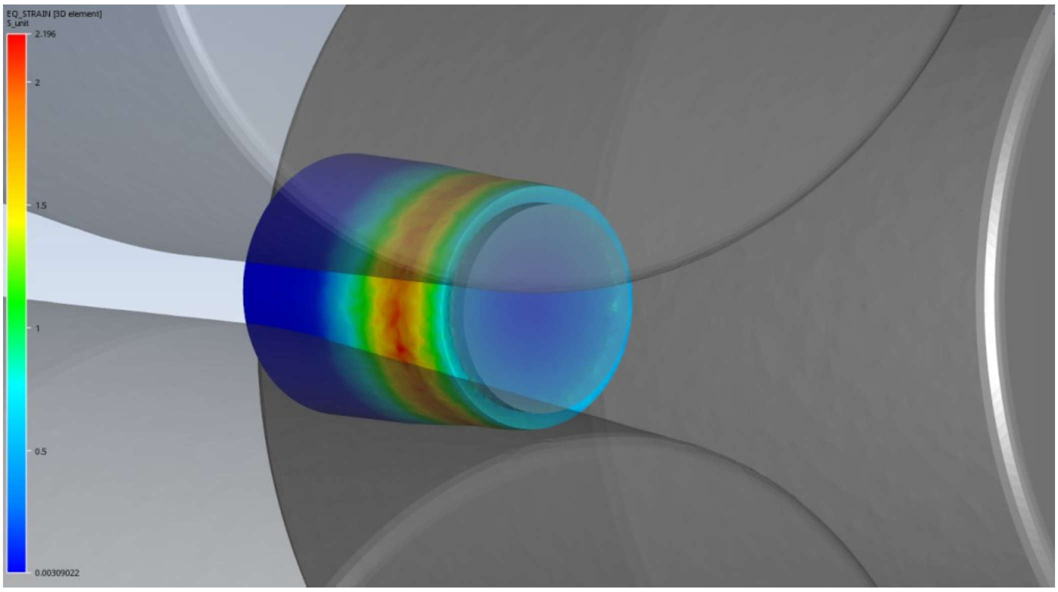



**Fig. 6** Strain on the billet during rolling

Similar experiments were also performed on the MISA device in KSIU (Kazakhstan) (**Fig. 3**). For the experiment were chosen three different diameters of billets. Specifically were selected diameters of 25, 20 and 16 mm. The dimensions of the cylinders were 71 mm and reduction by diameter 6 and 16 % (**Table 1**). The result of FEM analysis for this case, obtained by the software package DEFORM-3D 10.2, corresponded to about 30-40 % of the real measured values.

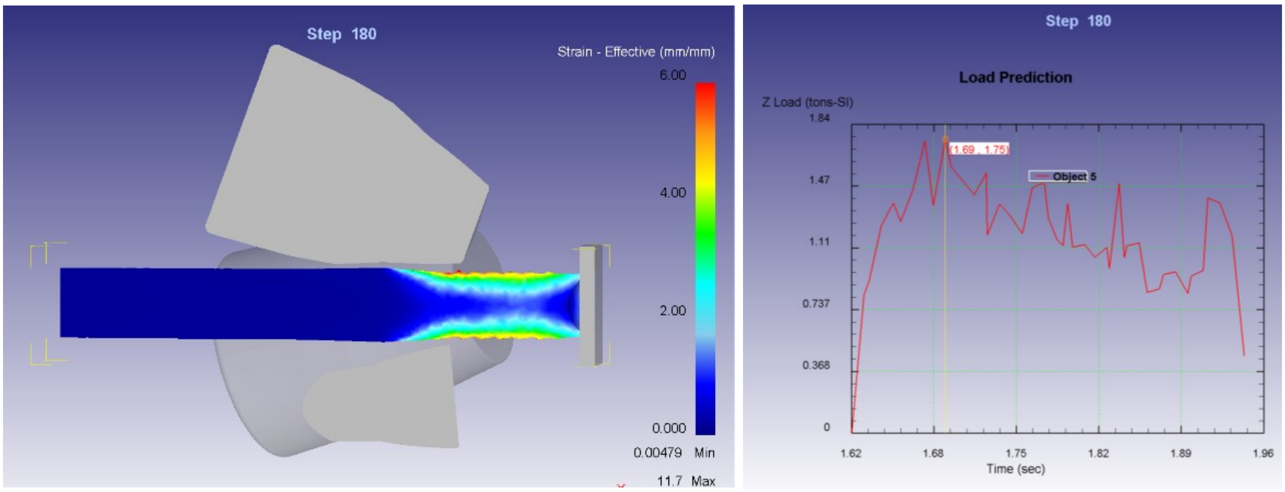



**Fig. 7** FEM analysis by KSIU (for e=16%; $D_V/D_0$=2,8)

## CONCLUSION

Using three roll mills as the primary phase of the ECAP method seems to be promising for future industrial use. This experiment measured the axial force according to the diameter of the billet and its deformation in order to verify the size of this force for the subsequent extrusion operation. The result of this experiment was considerable discrepancy between FEM simulations and physical measurements. This contradiction recorded on both workplace. As the main reason seems to be that the real deformation zone (ie also measured axial force) is much larger than the FEM analysis has shown. Metal flow during physical modelling and FEM analysis has will be different.

## ACKNOWLEDGEMENT

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