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**Jan VALÍČEK, Marta HARNIČÁROVÁ, Petr HLAVÁČEK, Sergej HLOCH,
Michal ZELEŇÁK, Wojciech KACALAK, Czesław ŁUKIANOWICZ,
Leon KUKIEŁKA**

INFLUENCE OF LONGITUDINAL COLD ROLLING ON THE SURFACE TOPOGRAPHY OF LOW CARBON STRUCTURAL STEEL FOR ENGINE PARTS

Abstract

The paper presents a method of surface evaluation of steel strips formed by longitudinal cold rolling using the rolling mill DUO 210 SVa. The experiments were performed on samples of low carbon structural steel in order to determine the impact of grain size of material with respect to technological parameters, particularly with respect to the reduction and rolling force. Surface roughness of the steel strips was measured at three areas by an optical profilometer MicroProf FRT. Consequently, these three results were mutually compared.

Nomenclature

v_{roll}	rolling speed [m·s^{-1}]
h_0	initial strip thickness [mm]
h_1	final thickness after the pass [mm]
Δh	thickness reduction [mm]
l_d	deformation zone length [mm]
R_m	ultimate tension strength of structural steel [MPa]
$R_{p0,2}$	yield stress point [MPa]
R_a	surface profile roughness parameter – average roughness [μm]
Fv	rolling force [N]
S_d	surface deformation in the cross section [mm^2]
Q_{Fv}	forming factor [-]
h_s	medium height of rolled sheet [mm]

INTRODUCTION

Continual cold rolling is an important process in metallurgical industry. Its performance directly affects quality of the final product. This process is considered to be a very complex system as it includes also a number of multi-disciplines such as: computing technique, automatic control, mechanics, and materials engineering and more. Any correctly designed renovation of the system can bring a great financial benefit for the company regarding improvement of performance, quality and overall competitiveness on the market [1÷7].

Intensive hardening of metal with the increase of total strain is a typical feature of cold forming, which consists of an elastic and plastic part. There is a plastic deformation presented with the cold rolling, which does not take place simultaneously in the entire volume of the metal similar to some direct processes (die forging, pressing), but only in its relative small part, called the zone of deformation. The plastic deformation is caused by the motion of dislocation and their density. The dislocation motion occurs when the critical slip stress is crossed, which means a permanent displacement of atoms that remain unchanged also after the effect of external active forces. Within the slip motion of dislocations by a crystal lattice, there is a plenty of obstacles in the way of moving free dislocations that hinder the movement and increase the value of critical slip stress. This results in a gradual strengthening of the formed metal with the decrease of its plastic properties. Within the slow course of dehardening processes (with very low deformation temperatures), this leads to the total exhaustion of plasticity and to the formation of cracks.

1. CURRENT STATE OF THE PROBLEM

The rolling process is a continuous process in which a wrought material is being deformed between the rotating operating rolls under the conditions of prevailing all – round pressure. The rolled material is being deformed, the height is being reduced, the material is being extended and expanded at the same time, and also the speed is being changed, which produces the rolled material from the rolling mill.

The rolling process is carried out mainly by heat but also by cold. Hot forming takes place above the recrystallisation temperature with such a high speed that the hardening caused by forming already disappears during or after the forming process. The forming temperature is above 70% of the material melting temperature. The material is not being hardened and the forming forces can be ten times smaller than during the cold forming. The texture may or may not arise, but the surface is poor due to scaling, moreover, the grain is being thicker, which is a problem for other technological operations in term of the quality. The process is relatively slow and expensive, but on the other hand it leads to the removal of cracks, bubbles, etc.

Cold forming (forming below the recrystallisation temperature when the forming temperature is below 30% of the melting temperature of the formed material), leads to hardening of the material. This hardening increases the mechanical properties (ultimate strength and yield point) while the ductility decreases. It is possible to retrieve ability of deformation by heating of the metal; the metal again acquires the ability to be plastically formed. High dimensional accuracy, surface quality (there are no scales there) and improved properties by hardening are considered as an advantage. The necessity to use heavy forming forces, irregular hardening and reduced ductility of material are considered as a disadvantage. A rolled product is the result of this process. The rolling can be divided into longitudinal, transverse and oblique according to the direction of rolling, position of operating rolls in respect of the place through which the material passes, the rolls axis location considering the rolled material and also according to the deformation process. The rolling can produce a great number of semi-products of various shapes. Among the basic belong profiles, sheet metals, wires, pipes [1÷7].

Today, the goal of the development of the metallurgical process is in searching of the shortest, the most economical, environmentally friendly and sustainable way to transform raw materials into the final products. After 1980, there was another increase in production and consumption of steel, particularly in the automotive industry, building industry, and in the household appliance industry [8÷9].

2. EXPERIMENTAL SET UP

2.1. Material

An initial material of the plastic deformation tests, using the method of longitudinal cold rolling in order to monitor the impact of technological parameters on the surface topography and especially in relation to the reduction of material, were the steel strips of low carbon structural steel PN EN 10263-2:2004 with the strength of R_m = 370 MPa and the yield stress of $R_{p0,2}$ = 225 MPa. The original size of the sample was 72 × 33 × 1.6 mm. The chemical composition of the steel strips is shown in Table 1.

Tab. 1. Chemical composition of low carbon steel measured [%]

Fe	C	Mn	Si	P	S	Cr	V	Cu	Al	Co	B
99.620	0.0228	0.1928	0.0117	0.0081	0.0053	0.0209	0.0014	0.0275	0.0562	0.0075	0.0004

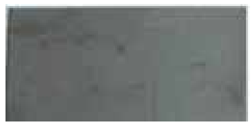
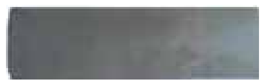
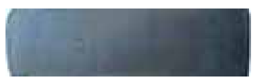
Source: Own study.

Chemical analysis was performed by a glow discharge optical emission spectrometer LECO GDS 750. This device allows to perform the quantitative chemical analysis of metals and alloys, based on the measurement and subsequent evaluation of the intensities of selected spectral lines of the determined elements. It is a simulation device, i.e. determination of all elements runs simultaneously. The device is equipped with the channels to determine 28 elements. They are: Mg, Al, Cu, B, Mo, Cd, Ni, Fe, Mn, Na, C, S, P, As, Si, Zn, Ti, Co, Ta, V, Cr, Pb, Sb, Bi, Sn, Nb, Zr and W. The analysis of this device depends on the calibration using reference materials with a known advanced content of elements.

2.2. Plastic deformation

Due to the effect of plastic deformation during cold rolling, there were made four rolled stocks with the different reductions in accordance with the technological parameters listed in Table 2. The steel strips *b, c, d, e* were rolled by the rolling mill DUO 210 SVa and once rerolled at the speed of rolls v_{roll} = 0.703 m·s^{-1} used. The original sample *a* did not pass through the rolling mill due to the mutual comparison of samples.

Tab. 2. Technological parameters of the created samples

Steel strips marking	h_0 [mm]	h_1 [mm]	Δh [mm]	Picture
a	1.6	1.6	-	
b	1.6	1.2	0.4	
c	1.6	1.1	0.5	
d	1.6	1.0	0.6	
e	1.6	0.8	0.8	

Source: Own study.

2.3. Metallography

Metallographic investigation was performed on the prepared samples due to a structural analysis. The metallographic sections were performed in the perpendicular direction to the longitudinal axis of the sample. The inverted microscope GX51 was used for metallographic examination in order to reflect a light with the maximum magnification of 1000×. Figure 1 illustrates the microstructure for the initial material and material after cold rolling by the rolling mill DUO 210 SVa, where there was a grain refinement in the longitudinal direction by approximately 55.6%.

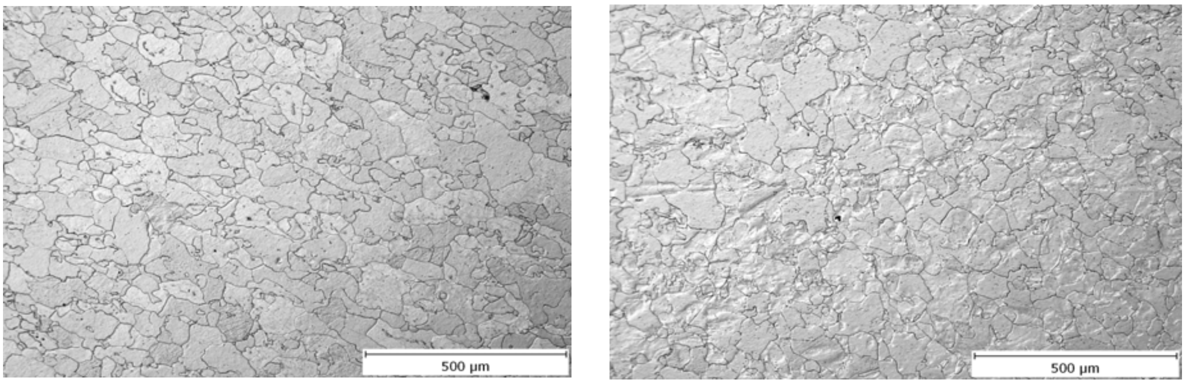


Fig. 1. The microstructure of the initial material and material after cold rolling by the rolling mill DUO 210 SVa with a reduction in thickness of 0.8 mm

Source: Own study.

Where can be observed some ferrite grains and at the grain boundaries tertiary cementite (grooves and lines of bright golden color give an impression of twin boundaries) and a small amount of non-metallic inclusions (providing a high purity). Given that the carbon content is 0.0228%, perlite excludes. In Table 3, there are shown the measured grain sizes from the metallographic section in order to find a link between the grain size and plastic deformation, that occurred while longitudinal cold rolling.

Tab. 3. Overview of the grain sizes determined from the metallographic section

Samples	Average grain size in the longitudinal direction [μm]	Average grain size in the vertical direction [μm]
a	36.1	40.4
b	15.8	15.4
c	24.1	18.9
d	42.4	48.2
e	16.0	24.5

3. RESULTS AND DISCUSSION

3.1. Results from the optical profilometer Microprof FRT

The steel strips created by the longitudinal cold rolling were measured in three areas by the optical profilometer MicroProf FRT. Figure 2 shows in which points the surface topography of steel strips was measured because of the different deformation of the material. The first region reflects the input region of steel strip entering into the rolling mill and its surface topography in this region. The second region presents the middle part of material and the third region represents the end of material. 3D surface topography for the measured regions was obtained by the optical profilometer.

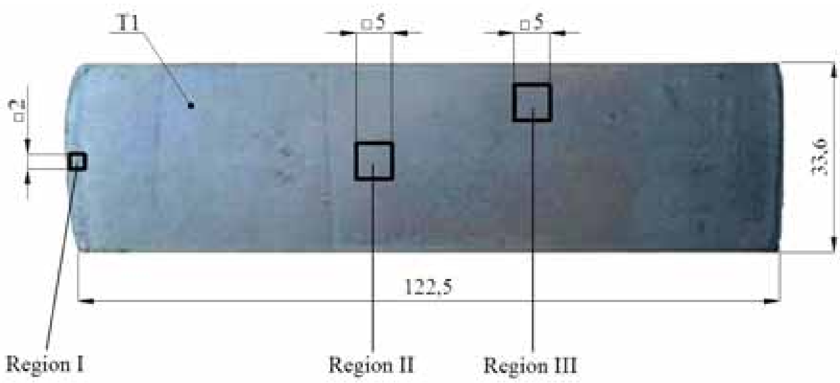
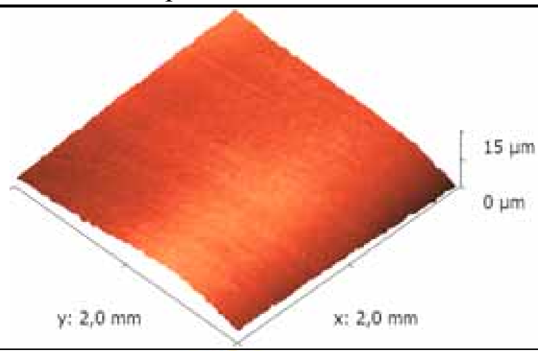
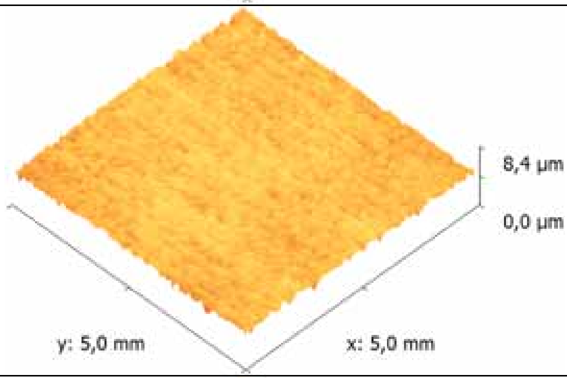
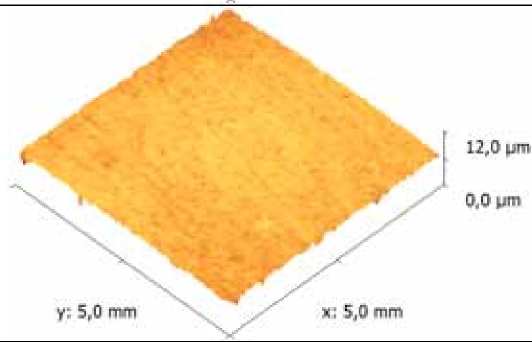


Fig. 2. Illustration of the area topography measurement with the reduction in thickness of 0.6 mm
Source: Own study.

The data measured by the optical profilometer MicroProf FRT were analyzed by the program Gwyddion. By means of this program the data of the surface irregularities of steel strips at the measured areas were obtained. In Table 4, there is a detailed view of 3D regions of the steel strip *d* with the reduction 0.6 mm.

Tab. 4. Detailed view of 3D regions of the steel strip *d*

Region I	
Region II	
Region III	

Source: Own study.

The data of the surface roughness created by longitudinal cold rolling are for individual reductions in thickness Δ*h* are presented in Table 5 (mean arithmetic deviation of the surface profile *Ra,* root mean square deviation of the profile *Rq*, and the greatest height of profile parameter *Rz*).

Tab. 5. Appropriate standardized parameters of the surface texture evaluation for each sample and region

Steel strips marking		a	b	c	d	e
	Δh [mm]	-	0.40	0.50	0.60	0.80
Region I	Ra [μm]	-	0.34	0.33	0,18	0,21
	Rq [μm]	-	0.48	0.43	0.24	0.28
	Rz [μm]	-	3.01	2.545	1.45	2.24
Region II	Ra [μm]	0.72	0.35	0.44	0.22	0.13
	Rq [μm]	0.97	0.49	0.58	0.29	0.19
	Rz [μm]	6.86	3.29	3.71	2.10	1.77
Region III	Ra [μm]	0.71	0.43	0.39	0.25	0.16
	Rq [μm]	0.96	0.59	0.57	0.34	0.23
	Rz [μm]	7.05	3.95	5.28	2.52	2.14

Source: Own study.

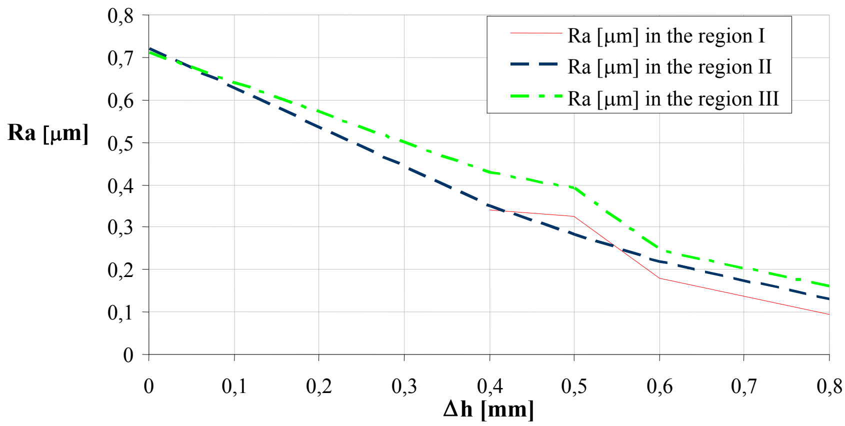


Fig. 3. Graphical illustration of the arithmetic mean deviation of the surface at three measuring regions

Source: Own study.

Based on the obtained data the chart was created (Fig. 3), which shows the best quality (the lowest values of the mean arithmetic deviation of the surface profile parameter *Ra*) of the steel strips in the first region, except for the steel strip *e.* The highest roughness (the highest values of the mean arithmetic deviation of the surface profile parameter *Ra*) of the steel strips was in the third measured region, except for the steel strip *c.* The surface roughness in the implicit expression is given as follows: $Ra = f\,(Fv,\ Q_{Fv},\ b,\ v_{roll},\ n_{roll}/min)$. It is necessary to search for the links between the technologies used and the final quality of the surface.

Using the Gwyddion program, there were analyzed the measured regions of individual samples. The measured regions were divided in 10 equidistant measuring lines with a distance of 0.2 mm in the first region for the steel strips *a, b, c, d* with the dimensions of 2×2 mm (see Fig. 2) and for the steel strip *e* with the dimensions of 4×5×4.5 mm with a step of 0.45 mm, in the second and the third region with the dimensions of 5×5 mm with a step of 0.5 mm. The measuring lines were perpendicular to the rolling direction. From each measuring line, there was obtained a signal in itself bearing information about the distribution of surface elevation fluctuations (Fig. 4).

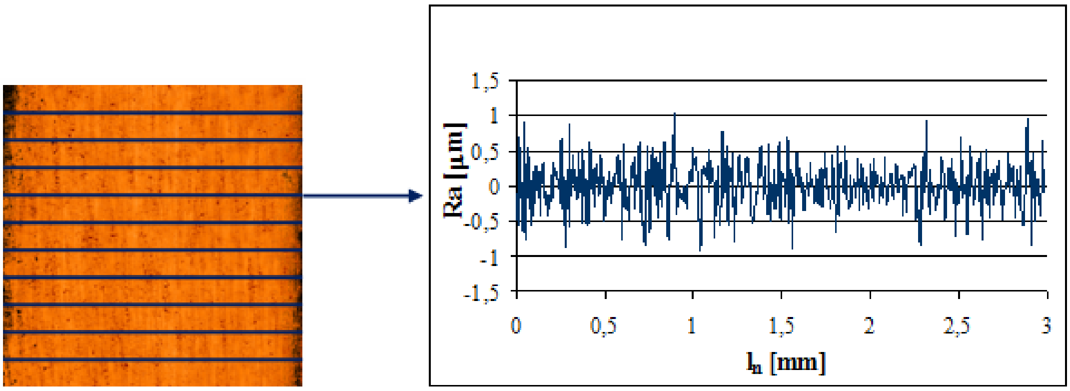


Fig. 4. The measured regions on the sample with the reduction in thickness of 0.6 mm in 10 equidistant lines with a distance of 0.5 mm from which the signals of the surface roughness were obtained

Source: Own study.

3.2. Link between the reduction in thickness *Δh*, surface roughness *ra* and rolling force *FV*

The surface quality can be demonstrated on the rolling force used, that is defined as the vertical component of the resultant force of the rolled metal onto the working roll. In our case, it has been moving in the first area from 26.039 kN to 42.962 kN, calculated by the formula:

$$Fv = Rp_{02} \cdot S_d \cdot Q_{Fv} \tag{1}$$

$$Q_{Fv} = \frac{l_d}{h_s} = \frac{2 \cdot \sqrt{R \cdot \Delta h}}{h_1 + h_0}. \tag{2}$$

In the Table 6, there are given the parameters for calculation the rolling force Fv and the shape factor Q_{Fv}. The shape factor characterizes the influence of the medium stress acting on the contact surface of the rolled metal with the roll within the zone of deformation on the size of the rolling force. The rolling factor has an integrated character in term of the material stress intensity with an impact on the performance of the rolling mill (the ratio of mass to time), economy of process (the ratio of currency to mass) and therefore on the rolling speed v_{roll}.

Tab. 6. Parameters for the calculation of the rolling force *Fv*

Steel strips	Δh [mm]	l_d [mm]	h_s [mm]	Q_{Fv} [mm]	Fv [N]
a					
b	0.4	12.9615	2.8	4.6291	26038.7
c	0.5	14.4914	2.7	5.3672	30190.4
d	0.6	15.8745	2.6	6.1056	34343.9
e	0.8	18.3303	2.4	7.6376	42961.7

Source: Own study.

The greater rolling force we use, the higher the reduction in thickness is (Fig. 5) and also the smoother surface of the rolled stocks.

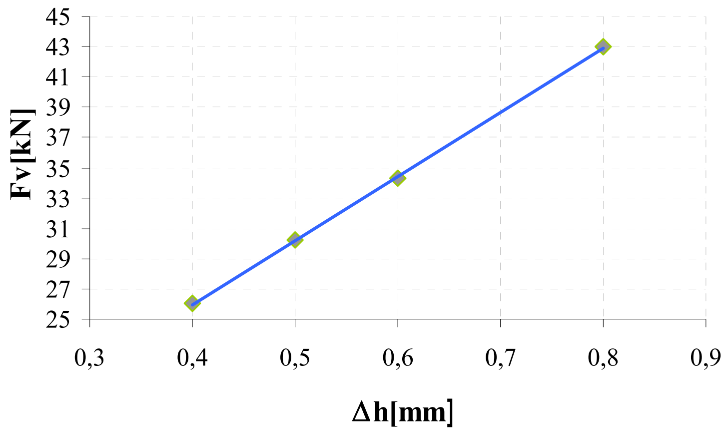


Fig. 5. Link between the rolling force *Fv* and the reduction in thickness *Δh*
Source: Own study.

CONCLUSIONS

The paper presents the results obtained from the surface topography created by cold rolling of low carbon structural steel PN EN 10263-2:2004. The presents results show the link between the rolling force *Fv*, the individual reduction in thickness *Δh,* and the surface roughness *Ra* of the rolling mill DUO 210 SVa.

Due to the plastic deformation that occurs during cold rolling, the grain refinement occurs. In the experiment carried out, the original grain decreased during the reduction in thickness of 0.8 mm of more than 55%. The mean stress acting on the contact surface of rolled metal with the roll in the zone of deformation affects the size of the rolling force *Fv*. The larger the rolling force is, the smoother surface of the rolled products appears. But on the other hand, the rolling force *Fv* increases, when increasing the frictional force that is accompanied by an increase in energy consumption and a reduction in the lifetime of the roll.

We can ascertain that understanding the surface quality is very important for both the producers and customers. Understanding the surface quality can affect the technological process of cold rolling in any manufacturing company. Further research within this issue concerns a comprehensive assessment of the complex process conditions, surface quality and also the economy and optimization of technological production cycle obtained by cold rolling.

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WPŁYW WALCOWANIA WZDŁUŻNEGO NA TOPOGRAFIĘ POWIERZCHNI STALI NISKOWĘGLOWEJ STOSOWANEJ W BUDOWIE SAMOCHODÓW

Streszczenie

Artykuł przestawia metodę oceny zmian struktury geometrycznej powierzchni części stalowych po walcowaniu wzdłużnym na zimno na walcarce typ DUO 210 SVa. W badaniach zastosowano stal niskowęglową stosowaną w budowie samochodów w celu określenia zależności pomiędzy wielkością ziarna struktury metalograficznej i parametrami technologicznymi procesu walcowania, w szczególności relacji zmniejszenie wysokości próbki – siła walcowania. Chropowatość powierzchni mierzono w trzech obszarach na profilografometrze typ MicroProf FRT. Otrzymane trzy wyniki porównano.

***Authors**:*

Assoc. Prof., Ing., PhD. **Jan Valíček** – Institute of Physics, Faculty of Mining and Geology VŠB-TU Ostrava, Czech Republic

Ing. **Marta Harničárová** – Faculty of Manufacturing Technologies, Technical university of Košice with a seat in Prešov, Slovak Republic

Ing. **Petr Hlaváček** – Institute of Physics, Faculty of Mining and Geology VŠB-TU Ostrava, Czech Republic

Assoc. Prof., Ing., PhD. **Sergej Hloch** – Faculty of Manufacturing Technologies, Technical university of Košice with a seat in Prešov, Slovak Republic

Ing. **Michal Zeleňák** – Institute of Physics, Faculty of Mining and Geology VŠB-TU Ostrava, Czech Republic

Prof. Ing., DSc. **Wojciech Kacalak** – Koszalin University of Technology, Poland

Assoc. Prof. Ing., DSc. **Czesław Łukianowicz** – Koszalin University of Technology, Poland

Prof. Ing., DSc. **Leon Kukiełka** – Koszalin University of Technology, Poland