Copper strip electroplastic rolling

Victor Lyashenko

D. Sc. In engineering, professor
Kremenchuk Mykhailo Ostrohradskyi National University
Pervomayskaya st. 20, Kremenchug, 39600, Ukraine

Elena Kobilskaya

Candidate of Physical and Mathematical Sciences,
Associate professor
Kremenchuk Mykhailo Ostrohradskyi National University

Aleksandr Aniskov

Senior teacher
State Higher Educational Institution
"Kryvyi Rih National University", Ukraine

Abstract
In the paper, the continuous and pulse electric current impact on copper strip physical and mechanical properties when electroplastic and ordinary rolling is investigated. The strip resistivity by electric current is studied. Different methods of continuous and pulse current carrying to plastical deformation zone were considered. It appears that sliding contacts arrangement for electric current carrying before and after deformation zone is the most efficient method.

Key words: ROLLING, CONTINUOUS AND PULSE CURRENT, ELECTRICAL, PHYSICAL AND MECHANICAL PROPERTIES

Introduction

At the present day, the work on development of new generation energy-saving production technology of current-carrying conductors with better physical and mechanical properties is carried out in the world practice. These technologies are based on pulse electric current processing of movable strip and wire along with plastical deformation processes. This processing is called electroplastic working of metal and alloy (EPW)[1]. The strip and wire after EPW are used in nuclear-power engineering, aerospace equipment, high-speed electric transport, production of cabling and wiring products.

Purpose and objectives of research

The purpose of the paper is determining of different thickness copper strips optimum EPW parameters and current pulses carrying to deformation zone optimum pattern on the experimental researches basis. This allows obtaining the maximum strip stretching in the direction of rolling, comparing the physical and mechanical properties, structural changes after electroplastic rolling and ordinary rolling without current.

The material and results of researches

On experimental rolling mill, the following researches have been conducted.

1. The choice of current pulses and continuous carrying to deformation zone available petterns was given:

a) current carrying from roll to roll through the strip, which undergoes deformation, with rolling mill deformation rolls including into electric circuit (Fig. 1);

b) current carrying before and after deformation zone by means of sliding contacts without deformation rolls including into electric circuit (Fig. 2);

c) current carrying by the mixed pattern, where one sliding contact is carried to strip and another one to rolling mill deformation rolls (Fig. 3).

2. Optimum length of current zone effect for patterns 2 and 3 was determined.

3. The investigations of samples electric current resistivity were conducted.

Samples of several copper strip of M1 grade production runs were taken. From three to eight transitions with single reduction 10-12% were performed. When strip rolling with current carrying, the rolling direction by transitions was not changed. The strip check samples without current were rolled as well as with current. After each transition, the sample stretching was measured and physical and mechanical properties measurements were performed. The obtained results are shown in Table 1.

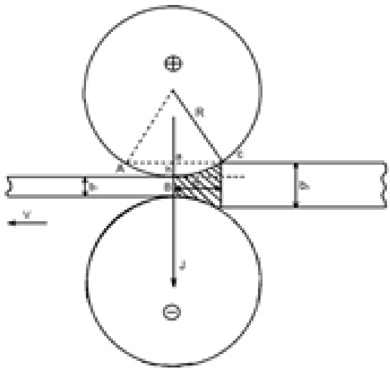

Figure 1. Electric current carrying to strip through rolls

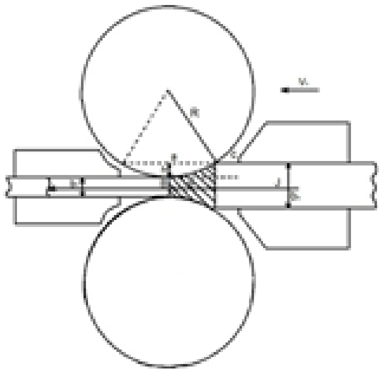

Figure 2. Electric current carrying to strip by means of sliding contacts

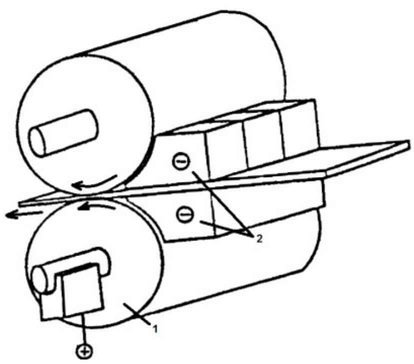

Figure 3. Electric current carrying to strip by sliding contact and deformation roll

Continuous and rectified alternating pulse currentof various pulse recurrence frequency was used for investigation of current effect on 200 microns in thickness copper strip plastic and other properties for pattern 1. After each transition, samples physical and mechanical properties were studied. The investigation results are shown in Table 1.

Table 1 shows that rolling direction deformation is increased by 12% under the continuous current effect for pattern 1 and it is increased by 13% under the pulse current effect. The increasing of transitions number to 20 with the same single reductions under both continuous and pulse current effect showed that the strip lengthening is 5-6% by the continuous current rolling and it is 8-10% under the pulse current effect.

The current effect researches for pattern 2 were conducted as follows. Only central part of sample was investigated while its ends were not considered since the electric circuit was broken when strip being out current effect zone at the frontend and backend of the process. After seven transitions, strip sample stretching effect was from 8% (when continuous current effect) up-to-12% (when pulse current effect). Moreover when continuous current carrying, the current carrying polarity (minus polarity to deformation zone and plus polarity after it) is also of great importance. After 25 transitions with the same single reductions, the lengthening effect was 15-20% when continuous current and 20-25% when pulse current. The processing parameters were I=20A for continuous current and I=700 Amp, F=80 Hz, $\tau \approx 1\text{-}5 \cdot 10^{-4}$s for pulse current.

The researches of current carried for pattern c) effect showed that the strip stretching was 6-9%, which is comparatively less than for patterns 1 and 2.

The strip mechanical properties were checked by strength testing machine P-05 and microhardness tester PMT-3. The strength testing machine was equipped with auxiliary devices for strip testing: force measure device 500N, instrument rack with control unit. The measurements percentage error was 5-7%.

The electric resistance was measured by the four-contact method. For the purpose, continuous current of I=1μAmp was passed through the sample from strip and its voltage loss was measured by digital voltmeter. The strip sample resistance and current resistivity were calculated according to Ohm's law by formula $\rho = \frac{U \cdot S}{I \cdot l}$, where U, S, l – voltage, strip cross section area and its length. The temperature resistance coefficient was not considered when measurement. The main error source was thermoelectric EMF, which was not more than 5%.

The electrical and physical properties measurements results of strip strength and current resistivity when various processing conditions are given in Table 2. The physical and mechanical properties measurement error always was about 5%.

Table 1

Condition	Sample param.	1st transition	2nd transition	3rd transition	4th transition	5th transition	6th transition	7th transition	Current effect
Pattern 1									
Without current	Length, mm Thickness, mm	l_1=200 h_1=0.18	l_2=241 h_2=0.13	l_3=275 h_3=0.1	l_4=321 h_4=0.08	l_5=368 h_5=0.06	l_6=435 h_6=0.05	l_7=520 h_7=0.04	$\frac{l_I - l}{l} \times 100\%$
Cont. current	$I = 12$ Amp	l_1=200 h_1=0.15	l_2=250 h_2=0.11	l_3=304 h_3=0.09	l_4=347 h_4=0.07	l_5=410 h_5=0.06	l_6=475 h_6=0.05	l_7=580 h_7=0.04	12%
Pulse current	$I_m = 330$ Amp $\tau = 10^{-2}$ s	l_1=220 h_1=0.13	l_2=240 h_2=0.1	l_3=280 h_3=0.085	l_4=320 h_4=0.07	l_5=382 h_5=0.06	l_6=460 h_6=0.05	l_7=590 h_7=0.04	13%
Pattern 2									
Without current	Length, mm Thickness, mm	l_1=175 h_1=0.15	l_2=192 h_2=0.13	l_2=220 h_2=0.11	l_2=245 h_2=0.09	l_2=300 h_2=0.07	l_2=425 h_2=0.06	l_7=510 h_7=0.045	$\frac{l_I - l}{l} \times 100\%$
Cont. current	$I = 20$ Amp	l_1=175 h_1=0.15	l_2=195 h_2=0.13	l_2=222 h_2=0.11	l_2=255 h_2=0.09	l_2=325 h_2=0.07	l_2=462 h_2=0.06	l_7=550 h_7=0.045	8%
Pulse current	$I_m = 500$	l_1=175 h_1=0.15	l_2=195 h_2=0.13	l_2=230 h_2=0.11	l_2=260 h_2=0.09	l_2=347 h_2=0.07	l_2=475 h_2=0.06	l_7=570 h_7=0.045	12%

	Amp $\tau = 3 \cdot 10^{-4}$ s								
Pattern 3									
Without current	Length, mm Thickness, mm	l_1=100 h_1=0.15	l_1=110 h_1=0.12	l_1=140 h_1=0.08	l_1=170 h_1=0.05	l_1=216 h_1=0.04	—	—	$\frac{l_t - l}{l} \times 100\%$
Cont. current	$I = 25$ Amp	l_1=100 h_1=0.15	l_1=110 h_1=0.12	l_1=140 h_1=0.08	l_1=187 h_1=0.05	l_1=230 h_1=0.04	—	—	6%
Pulse current	$I_m = 600$ Amp $\tau = 10^{-4}$ s	l_1=100 h_1=0.15	l_1=115 h_1=0.12	l_1=150 h_1=0.08	l_1=195 h_1=0.05	l_1=236 h_1=0.04	—	—	9%

From Table 2 we can see that the most significant samples properties changes were in case after simple rolling. Hardness, current resistivity and strength characteristics were sharply increased. This fact is well-known. It is usually linked to the significant increasing of dislocations number and decreasing of their mobility. As Table 2 data show, the continuous as well as pulse current flow when strip rolling affects significantly their final physical properties. The hardness and yield point was reduced and percentage stretching was increased comparing with simple rolling (Fig. 4)

The electrical and physical properties measurements results of copper strip samples strength and current resistivity.

Table 2

Condition	Current resistivity, $\rho \times 10^{-8}$, Ohm·m	$\sigma_c \left[\frac{kg}{mm^2}\right]$	$\sigma_s \left[\frac{kg}{mm^2}\right]$	Microhardness HV	Percentage stretching, $\frac{\Delta l}{l} \cdot 100\%$
Without rolling	1.85	20	33	120	2.5
After simple rolling	3.6	35	44	170	2.1
Continuous current rolling	2.9	30	45	122	2.2
Pulse current rolling	2.00	29	44	110	2.3

Here σ_c – yield point, σ_s - ultimate tensile strength.

The physical and mechanical properties measurements data of copper strip different parts for different carrying current patterns are given in Tables 3, 4, 5.

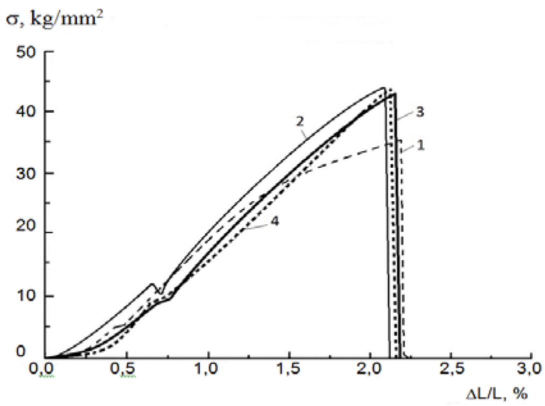

Figure 4. 1 – initial copper sample; 2 – copper rolling without current; 3 – copper rolling with continuous current; 4 – copper rolling with pulse current

The electrical and physical properties measurements results of samples after current carrying for pattern from roll to roll.

From the Table 3 we can notice that yield point is reduced at average by 10% and ultimate tensile strength by 18% when continuous current and by 12% and 23% when pulse current as the result of current carrying from roll to roll. Current resistivity is reduced by 21% and 34% when continuous and pulse current respectively.

Table 3

Condition	Current resistivity, $\rho \times 10^{-8}$, Ohm·m	$\sigma_c \left[\frac{kg}{mm^2}\right]$	$\sigma_s \left[\frac{kg}{mm^2}\right]$	Percentage stretching, $\frac{\Delta l}{l} \cdot 100\%$
Without rolling	1.85	20	33	0.5
After simple rolling	3.64	33	44	0.1
Continuous current rolling	2.88	30	36	0.6
Pulse current rolling	2.4	29	34	0.59

The electroplastic rolling data after current carrying for pattern 2 before and after mill rolls are shown in the Table 4.

From the Table 4 we can see that yield point is reduced at average by 21% and ultimate tensile strength by 16% when continuous current and by 16% and 14% when pulse current as the result of current carrying before and after mill rolls. Current resistivity is reduced by 6% and 10% when continuous and pulse current respectively. After 20 transitions the current boundary was reduced by 12-14%.

Table 4

Condition	Current resistivity, $\rho \times 10^{-8}$, Ohm·m	$\sigma_c \left[\frac{kg}{mm^2}\right]$	$\sigma_s \left[\frac{kg}{mm^2}\right]$	Percentage stretching, $\frac{\Delta l}{l} \cdot 100\%$
Without rolling	1.85	20	33	0.5
After simple rolling	1.22	38	50	0.4
Continuous current rolling	1.15	30	42	0.7
Pulse current rolling	1.11	29	43	0.63

This goes to prove that current carrying when rolling facilitates the rolling process by energy expenditures reducing. Such effect can be explained by interaction of dislocations and conduction electrons, as consequence their mobility increasing and their coupling energy reduction.

As the result of different copper strip samples parts experimentation, it was discovered that current boundary is reduced at average by 10-15% while ultimate tensile strength by 15% when continuous current and by 20% when pulse current as the result of electroplastic rolling when current carrying from roll to roll for pattern 1. The significant strip electric current resistivity reduction was noticed. In particular cases the current resistivity was reduced by 25-30%. After 20 transitions the copper strip thickness was 30 microns.

When current carrying to deformation zone by means of sliding contacts for pattern 2 yield point was reduced by 30-50% when continuous current and by 20-25% when pulse current. After 20 transitions the yield point was reduced by 10-15%.

The same physical and mechanical properties improving results were obtained by combined carrying of continuous as well as pulse current for pattern 3.

Thus, electroplastic rolling affects significantly the physical and mechanical properties improving comparing with simple rolling. At that, strip rolling process energy expenditures are reduced. The most significant copper strip mechanical properties changes towards strength reduction and ductility increasing are in process when current carrying by patterns 2 and 3.

Conclusions

The continuous and pulse current effect on copper strip physical and mechanical properties determination researches were conducted.

1. Continuous and pulse current carrying to deformation zone optimum pattern was found out.

2. It was shown that samples percentage stretching and yield point are increased and

ultimate tensile strength is reduced by 15-20% under pulse current.

3. It makes sense to develop the industrial mill for copper strip EPW and implement it into one of the specialized company.

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