PHYSICAL MODELLING OF THE SEAMLESS MICRO-ALLOYED STEEL TUBES PRODUCTION DEPENDING ON THE DIFFERENT TEMPERATURES AND RPM SPEEDS OF THE WORKING ROLLS

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Abstract

The paper presents laboratory physical modeling of the seamless tubes production, specifically the first step of the Mannesmann production process, the so-called punching. A "Universal rolling mill" at MATERIAL & METALLURGICAL RESEARCH Ltd. was used for experiments. The experimental material was micro-alloyed steel. The tests were carried out at four different heating temperatures and at different rpm speeds of the working rolls. The other settings of the rolling mill remained the same. In terms of the geometrical parameters, the biggest necking of the punched sample (preferably at both ends) was observed with increasing temperature and strain rate. The torque decreased with increasing temperature and with lower speed of working rolls. The punching time and the total current power consumption decreased with increasing temperature and with a higher deformation rate.

Keywords: Laboratory physical modelling, punching, seamless tubes, micro-alloyed steel, temperature, rpm speeds of the working rolls

1. INTRODUCTION

At present, research on forming processes in the field of seamless tube production goes along two lines. The first is mathematical modeling, including numerical simulations, and the second is physical modeling. The mathematical modelling is currently booming but its results are highly dependent on the setting of boundary conditions, including the definition of the contact between the tool and the blank and the mesh settings. Mathematical modeling can always be considered as an approximation of the process, or ideally as a complement to physical modeling. Research of the cavity formation complex process in the billet during axial rolling of seamless tubes (Mannesmann punching method) seems to be more suitable using a laboratory physical modelling. The paper focuses on the physical modeling of the rolling process of low-alloy seamless tubes on a laboratory rolling mill in MATERIAL & METALLURGICAL RESEARCH Ltd. based in Ostrava (CZ) [1-6].

2. EXPERIMENTAL PART

A series of 16 punching tests with variable heating temperature and variable rpm speeds of the working rolls were performed on a Mannesmann's laboratory rolling mill. The heating temperatures in the range of 1240 – 1300 °C in steps of 20 °C and the rolls speeds of 60 rpm and 120 rpm per minutes were used. Tests were performed twice to eliminate process deviations. Niobium micro-alloyed steel was used for experiment, see **Table 1**. Samples with a diameter of 70 mm and length of 190 mm with a conical bore on the front circular side for better guidance of the punching mandrel were made of continuously cast billet with a diameter of 410 mm (**Figure 1**). A punching mandrel of 38 mm diameter was used for punching, the feed angle was set to 4 °, the forming angle was 1 ° (opening on the inlet side - narrowing) and the material removal was 9 mm. These experimental conditions were chosen with regard to the requirements of the industrial partner.

Table 1 Chemical composition of the studied steel micro-alloyed by niobium (wt. %)

C	Mn	Si	P	S	Cu	Ni	Cr	Mo	V	Ti
0.17	1.1	0.19	0.016	0.006	0.03	0.04	0.2	0.006	0.002	0.001
Alc	**W**	**Nb**	**B**	**N**	**Sn**	**H**	**As**	**Co**	**Sb**	
0.028	0.01	0.025	0.0005	0.0109	0.003	0.00011	0.002	0.003	0.003	

Figure 1 Test samples with a diameter of 70 mm and a length of 190 mm with a conical hole

All punched samples were measured (**Figure 2**), specifically their minimum and maximum lengths, diameter in the front, middle and back of the samples (measured at two points around the circumference with a 90° rotation), see **Table 2**. Based on the measured values, the elongation and narrowing values in the front, middle and back of each punched sample were calculated (**Table 3**). The total punching time, the values of the torque, the pressing forces acting on the work roll, the forces acting against the punching mandrel and the current were also measured (**Table 3**). From these values, the maximum and average values were calculated, as well as the total current consumption for punching out the individual samples (**Table 4**).

Figure 2 Punched samples

Table 2 Rpm, temperature, minimum and maximum length, measured diameters in two locations for the front, middle and back of all tests performed

no [-]	RPM [min^{-1}]	temperature [°C]	min.length [mm]	max.length [mm]	ϕfront1 [mm]	ϕfront2 [mm]	ϕmiddle1 [mm]	ϕmiddle2 [mm]	ϕback1 [mm]	ϕback2 [mm]
1	120	1300	340	344	66.62	66.71	67.33	67.25	66.56	66.3
2	120	1300	338	341	66.85	66.68	67.89	67.84	66.65	66.6
3	60	1300	323	327	67.57	67.74	69.19	69.47	67.89	67.95
4	60	1300	325	331	66.95	67.22	68.2	68.35	68.01	67.71
5	120	1280	343	345	66.85	67.09	67.15	67.04	66.11	66.09
6	120	1280	337	344	67.08	67.04	67.68	67.66	66.36	66.7
7	60	1280	324	328	67.21	67.09	68.92	68.96	67.98	68.13
8	60	1280	300	303	66.75	66.88	71.77	71.88	72.35	72.42
9	120	1260	320	323	67.84	67.89	69.2	68.86	67.69	67.84
10	120	1260	318	321	67.69	67.62	69.3	69.51	69.66	69.74
11	60	1260	312	315	68.46	68.54	70.15	70.23	70.03	69.94
12	60	1260	285	288	68.28	68.34	72.29	72.43	74.32	74.57
13	120	1240	330	332	67.94	67.88	68.2	68.37	66.95	66.66
14	120	1240	317	321	67.39	67.53	69.94	69.91	69.67	69.64
15	60	1240	313	317	68.13	68.16	69.85	69.77	69.14	68.88
16	60	1240	304	307	68.84	68.7	70.71	70.74	70.16	70.09

Table 3 Calculated elongation value; % of front, middle and back narrowing values; total sample punching time

no [-]	elongation [-]	narrowing front [%]	narrowing middle [%]	narrowing back [%]	time [s]
1	1.80	4.76	3.87	5.10	7.5
2	1.79	4.62	3.05	4.82	7.6
3	1.71	3.35	0.96	2.97	11.9
4	1.73	4.16	2.46	3.06	11.8
5	1.81	4.33	4.15	5.57	8.2
6	1.79	4.20	3.33	4.96	8.1
7	1.72	4.07	1.51	2.78	12.2
8	1.59	4.55	-2.61	-3.41	11.9
9	1.69	3.05	1.39	3.19	7.7
10	1.68	3.35	0.85	0.43	7.7
11	1.65	2.14	-0.27	0.02	11.6
12	1.51	2.41	-3.37	-6.35	11.6
13	1.74	2.99	2.45	4.56	8.6
14	1.68	3.63	0.11	0.49	8.2
15	1.66	2.65	0.27	1.41	12.2
16	1.61	1.76	-1.04	-0.18	13.7

Table 4 Measured and calculated values of torque, axial forces acting on the punching mandrel, pressing forces acting on the working rolls, electric current and electric energy consumption

no [-]	max. torque [Nm]	mean torque [Nm]	max. axial force [kN]	mean axial force [kN]	max. press. force [kN]	mean press. force [kN]	max. electricity [A]	mean electricity [A]	current consumption [As]
1	4392	3255	16.99	13.98	103.96	89.15	91.51	72.11	1082
2	4501	3289	16.09	13.55	104.55	89.94	93.42	73.2	1113
3	4249	3057	17.01	13.51	101.66	86.4	88.65	67.37	1603
4	4390	3176	18.27	14.24			92.31	69.3	1635
5	4955	3572	18.15	14.91	110.74	93.05	103.52	78.43	1286
6	5105	3524	18.04	14.34	110.52	93.66	103.3	76.9	1246
7	4506	3256	19.47	15.28	106.63	89.97	96.76	71.3	1740
8	4498	3007	19.05	15.35	108.53	90.08	93.59	66.53	1583
9	4776	3551	19.09	15.13	109	93.94	100.89	77.89	1200
10	4742	3565	19.7	15.56	109.49	95.79	100.33	78.15	1204
11	4956	3383	20.03	15.54	110.13	92.07	104.21	73.68	1709
12	4825	3012	22.06	16.87	109.81	90.59	101.08	66.86	1551
13	5119	3862	20.38	16.01	111.51	97.92	105.92	83.72	1440
14	5142	3680	20.19	16.1	110.82	96.7	106.82	80.16	1315
15	5440	3639	20.93	15.93	112.26	93.96	107.1	78.27	1910
16	5318	3776	20.45	15.31	109.44	93.74	105.2	79.95	2191

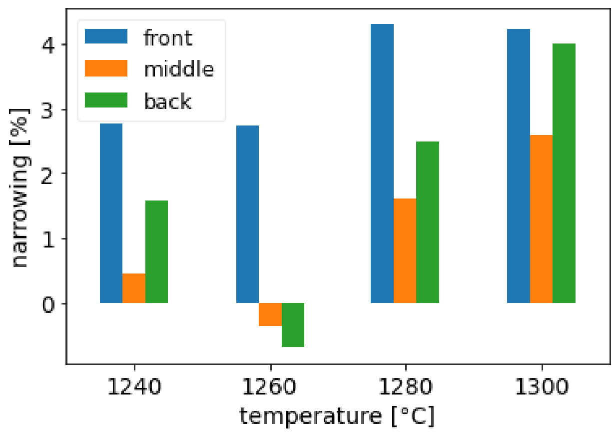

Figure 3 Dependence of narrowing on temperature for front, middle and back of punched samples

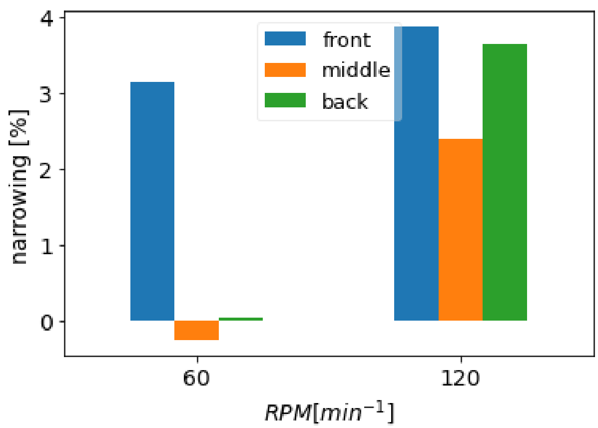

Figure 4 Dependence of narrowing on the speed of work rolls for the front, middle and back of punched samples

The measured and calculated values were further analyzed graphically in **Figures 3-9**. **Figures 3 and 4** show the temperature dependence and rpm for the front, center and back of the punched samples. A negative value means expansion. There is a clearly visible trend of increasing rates of narrowing with increasing temperature and rpm. **Figure 5** shows the narrowing for each sample for the front center and back. **Figure 6** shows the effect of rpm and heating temperature on the overall elongation of the punched samples. There are evident the increasing rate of elongation with increasing temperature and rpm with the exception of 1260 ° C. The dependence of current consumption on rpm and temperature is shown in **Figure 7**. The result is a trend of decreasing current consumption with increasing temperature and higher rpm. **Figures 8 and 9** show the effects of rpm and temperature on the maximum and average axial force acting on the punch and, on the forces, acting on the work rolls. In this case, the effect of rpm is insignificant, the forces increase slightly with higher rpm. As the temperature increases, the axial and pressing forces are slightly lower.

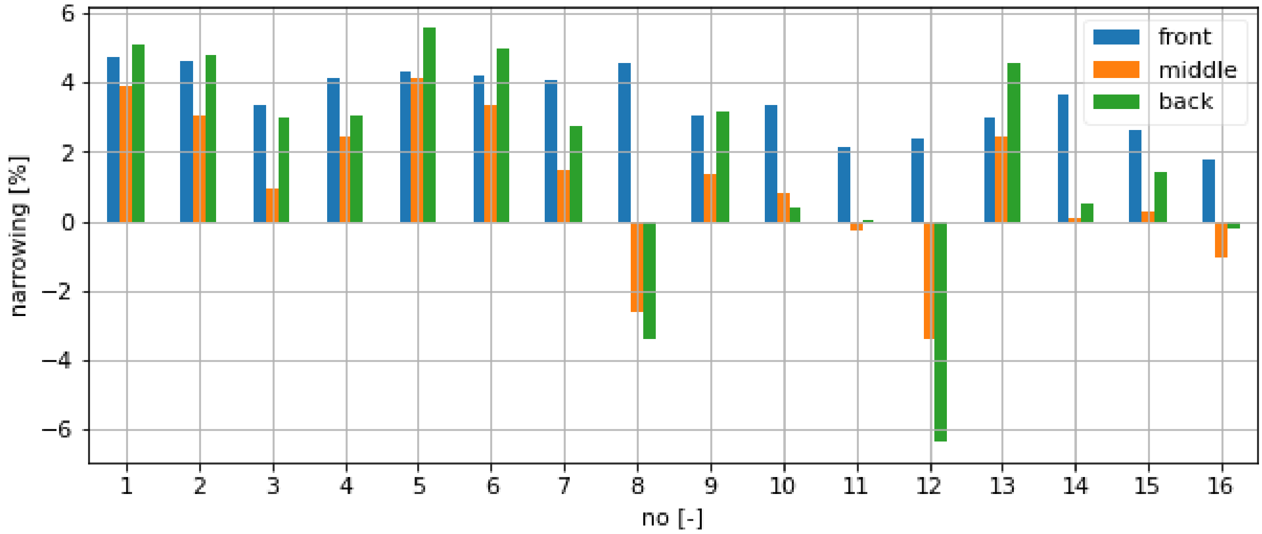

Figure 5 Narrowing at the front, middle and back of all tests performed

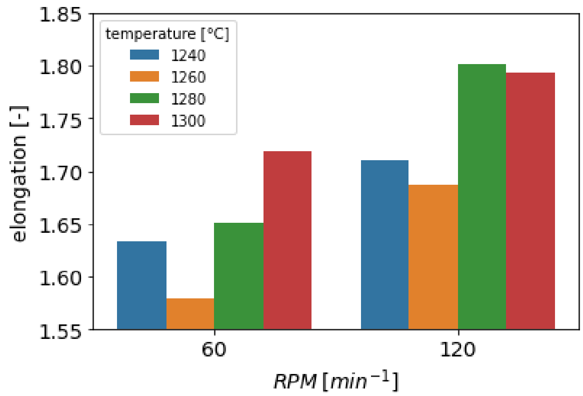

Figure 6 Rolling elongation depending on speed for different temperatures

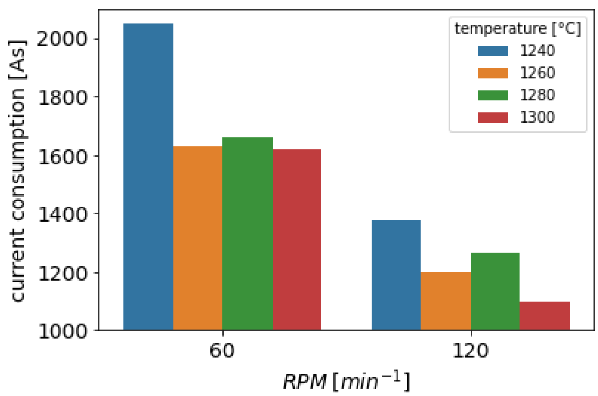

Figure 7 Current consumption depending on speed for different temperatures

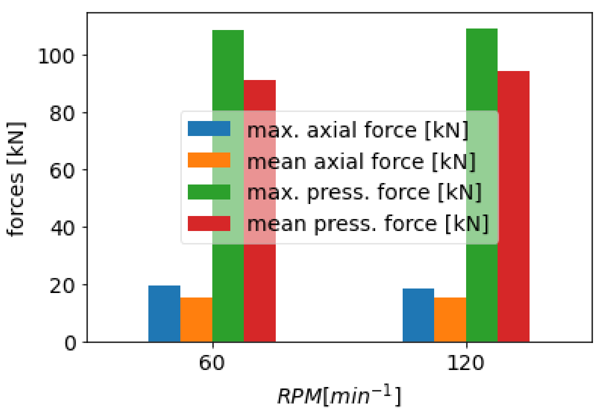

Figure 8 Axial and pressing forces depending on speed of working rolls

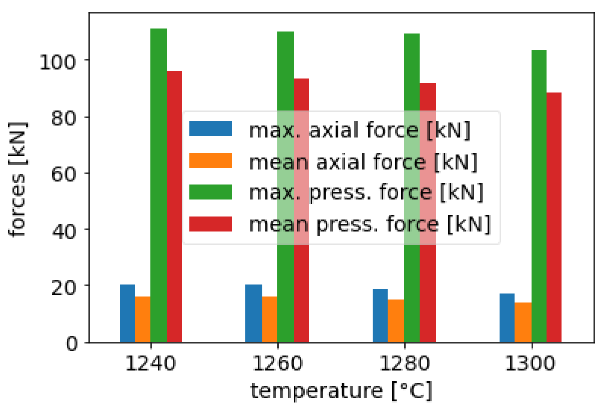

Figure 9 Axial and pressing forces depending on the heating temperature

3. CONCLUSION

The presented article summarizes the findings from punching of niobium micro-alloy steel. The result of the work was the mapping of trends of measured and calculated values of the punching process, where the heating temperature and rpm were chosen as variables. The lower current consumption appears to be a significant obtained data in tests performed at 120 rpm, when the current consumption required for punching full semi-finished products decreased by approx. 40%, the effect of heating temperature was not so significant. With increasing temperature and rpm, elongation and narrowing increased. Other significant trends are shown above. The use of a laboratory punching mill for physical simulations in order to investigate the dependence and trends between individual quantities seems to be the optimal use of this unique device. The findings will be further supplemented by other steel grades in order to compare the final parameters among other materials. The aim of the tests is primarily to imitate real industrial knowledge from the production of seamless tubes on a laboratory scale, with the aim of transferring laboratory results into industrial practice.

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