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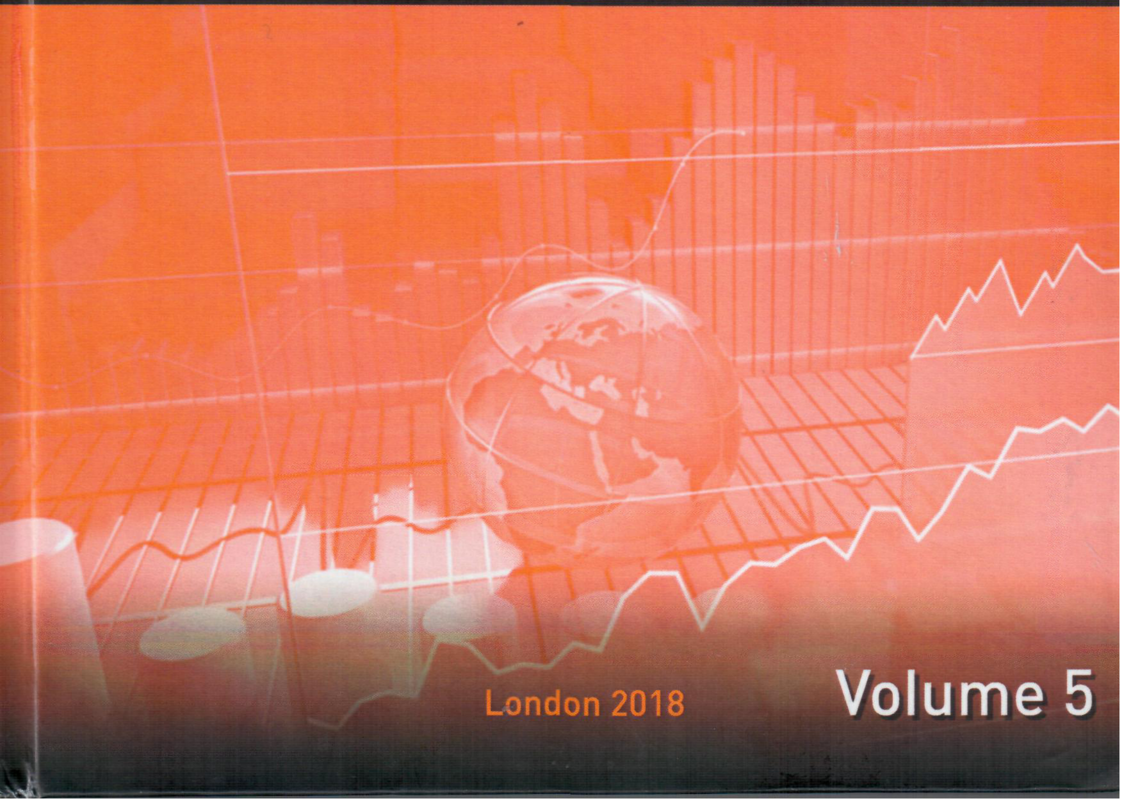

London 2018

Volume 5

SCIENTIFIC DEVELOPMENT AND ACHIEVEMENTS

volume 5

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First Edition: 2018
A catalogue record for this publication is available from British Library.

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ISBN 978-1-9993071-0-3
Includes bibliographical references and index.

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DEVELOPING OF MANUFACTURING TECHNOLOGY FOR HOT ROLLING COILS (STEEL GRADE S355MC) AT THE WIDE-STRIP ROLLING MILL 1700

Introduction. Widely known advantages of the rolled product manufacturing with the use of thermo-mechanical controlled process (TMCP). Increase in the customer demand for the products, which are manufactured in compliance with the abovementioned technology, makes domestic producers to master their production. The product mix, which can be manufactured, directly depends on the producer's equipment characteristics and composition, in other words, it is important to preliminary make technical and technological assessment of the potential for TMCP technology implementation into production. Indeed, the operating conditions in the companies manufacturing rolled products [1] can be a very important factor for increasing competitiveness of steel products in European markets. It should be noted that the domestic hot rolling coil mills were constructed much earlier than the thermomechanical rolling technology was widespread. Therefore, this technology and products are not designed and shall be implemented in a phased manner.

Problem definition. The paper objective is to develop manufacturing technology for hot rolling coils up to 6×1500 mm (steel grade S355MC) in accordance with EN 10149-2 at PJSC ILYICH IRON & STEEL WORKS OF MARIUPOL (Mariupol), without equipment upgrading.

Review of recent studies and publications. The diffusion of the thermo-mechanical controlled process (TMCP) technology in the world commenced during the 1960's of the last century [2]. In our country, this technology was introduced 10 years later [3]. During the period of implementation, TMCP technology has evolved, and relevant equipment has also undergone significant changes [4-6]. Currently, this production practice presents the greatest potential and is constantly developing.

Nowadays, TMCP is used to manufacture the rolled products for various structures and construction, pressure vessels, pipelines of plates and coils. The results of its intensive study are presented in many papers of the international authors [4-18].

If earlier TMCP was predominantly used to manufacture the rolled products from low carbon steel grades [14, 15], steels, in which the carbon content is 0.40% [19], have become more widely used recently. The development devoted to the in-depth study of strengthening processes and additional properties of the steels with carbon content from 0.06% and below [9, 11, 16, 20, 21] has been further evolved. Of particular interest is the study of the impact of various cooling rates on the structure and properties of the rolled products [12, 22], when using TMCP, which demonstrates the influence of significant increase in properties with the cooling velocity enhancement.

The existing technologies make it possible to manufacture the rolled products with a yield strength of up to 800 MPa and above. However, processing of materials with new, higher levels of properties creates new challenges that need to be further explored [13, 16].

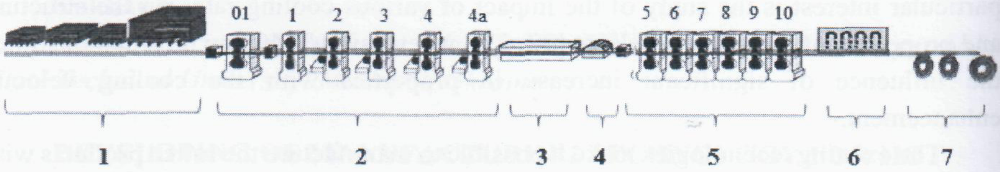
At the same time, in addition to the development of technology and in-depth study of its impact on new properties of the rolled products, the trend aimed at forecasting technology implementation results through the simulation of microstructure development and mechanical properties proposed, for instance, by the authors [7, 8] has gained prevalence.

Among the many scientific papers, which address TMCP technology introduction, the critical issue remains the combination of objectives with the level of strength properties of the product mix, which must be mastered on the existing equipment that has certain limited technical capabilities. However, optimal combination between the chemical composition of steel, the technology potential and the obtained strength properties of the rolled products should be taken into account in order not to manufacture too expensive final product.

The development of TMCP technology for manufacturing hot rolling coils with a section of 6×1500 mm (steel grade S355MC) for the rolling mill 1700, without upgrading at this stage, is a crucial task that will enable to produce the coils from the most common steel grade and meet the needs of the enterprise key customers.

Statement of basic materials. The existing equipment of the rolling mill 1700 currently consists of four reheating furnaces, of which three are of pusher type. The mentioned three furnaces have been revamped to heat the slabs up to 250×1550×6200 mm. One walking-beam furnace (Stein Heurtey, France) may heat the slabs up to 250×1600×10500 mm. 250 mm thick slab is used for production only in case of reduction at the slabbing mill. The roughing train includes one two-high stand No. 01 (roughing scale breaker) and 5 four-high stands (1-4, and 4a), of which four are universal ones (2-4, and 4a). There are also installed heat-saving shields, rotary shears. The finishing train includes 6 four-high stands (5-10), accelerated cooling unit, which in turn consists of 14 sections and 3 coils, of which two may wind the coils weighing up to 9 tonnes, and one, the latter in the rolling direction, may wind the coils weighing up to 27 tonnes. It is worth noting that 7 descalers with a pressure of 80-140 atm are installed at the rolling mill.

Layout of the main equipment of the rolling mill 1700 is shown in Fig. 1.



1 – reheating furnaces;
2 – roughing train;
3 – heat-saving shields;
4 – rotary shears;
5 – finishing train;
6 – accelerated cooling units;
7 – coilers.

Figure 1. Flowchart: the main equipment of the rolling mill 1700

According to the project and applicable technology, the rolling mill produces hot rolling coils weighing up to 9 tonnes, having a thickness of 1.5-9 mm, width of 1000-1530 mm, depending on the product mix, of steel grades from 08ps (according to GOST 1050) to 09G2S (according to GOST 19281), S355 of all categories in accordance with EN 10025-2 and another similar product mix limited to the tensile strength of no more than 590 MPa.

During the production using TMCP technology, the principal difference is the low level of chemical elements that provide for the strength properties of the rolled products (comparison is given in Table 1).

Table 1 Comparison of the values for the products, which are manufactured under different process conditions

Standards	Technology*	Steel grade	Values / Chemical composition						
			C max., %	Mn max., %	Nb max., %	V max., %	Ti max., %	CE max.	KV-20 min., J
EN 10025-2	AR; N[2]	S355J2	0.20	1.60	-[1]	-[1]	-[1]	0.45	27
EN 10025-4	TMCP	S355ML	0.14	1.60	0.05	0.10	0.05	0.39	47
EN 10149-2	TMCP	S355MC	0.12	1.50	0.09	0.20	0.15	-	-

* AR – hot-rolled; N – as normalized rolled; TMCP – as TMCP rolled;

[1] – it is allowed to use elements;

[2] – prevailing condition of the rolled products according to this standard.

Thus, the major difference of the requirements for rolled products manufactured using TMCP is the lower level of the chemical elements in comparison with other methods, and also the addition of microalloying elements. In total, such changes provide for excellent complex of mechanical properties.

For the production of pilot batch of hot rolling coils (6×1500 mm, steel grade S355MC) in accordance with EN 10149-2, the heat has been melt with the following chemical composition (see Table 2).

Table 2 Chemical composition of pilot batch (steel grade S355MC)

Heat	Mass fraction of chemical elements, %											
	C	Mn	Si	S	P	Cr	Ni	Cu	V	Al	Ti	Nb
255634-2	0.11	1.36	0.03	0.007	0.019	0.04	0.01	0.01	0.004	0.037	0.022	0.030

Nb and Ti are used as chemical composition elements, which make it possible to monitor the grain sizes during the austenitization and rolling, and also changes in the properties owing to carbonitride strengthening.

Based on the chemical composition (Table 2), the target thermomechanical values of the rolling process [2, 23] are calculated, the observance of which, in the future, will provide the necessary complex of mechanical properties in accordance with EN 10149-2 (see Table 3).

Table 3 Thermomechanical values of the rolling process

Parameter	Unit	Parameter value
Slab reheat temperature	°C	1260 ± 20
Heat time	hours-minutes	≤ 2-00
Rolling temperature behind the stand 4a	°C	≥ 1040
Rolling temperature behind the stand 10	°C	810-860
Coiling temperature	°C	580-630
Number of sections, which are used for accelerated cooling	pcs.	8-14
Cooling rate	°C/s	45-55

In order to obtain the process parameters necessary for TMCP introduction, the target temperature and deformation conditions were calculated preliminary (see Table 4) [24].

The slab with a section of 250×1550 mm, previously reduced to 140×1500×5395 mm, has been used as a semi-finished product.

According to these calculations, the operating constraints for the equipment of the roughing and finishing trains were not exceeded, which makes it possible to apply these temperature and deformation conditions for the production of pilot batch of the rolled products.

It should be noted that, when calculating, the required temperature level behind the stand 10 was achieved owing to the rolling speed adjustment for the metal in the finishing train.

The pilot batch of hot rolling coils with a section of 6×1500 mm (steel grade S355MC, heat 255634-2) in accordance with EN 10149-2 and EN 10051 was produced according to the calculated conditions. During production, the deformation conditions were partially adjusted from the calculated ones, including by the process control automation, resulting in changing main motor load distribution by the stands, Fig. 2. Changing actual deformation conditions during the rolling from the target (calculated) ones, Fig. 2, did not result in the overloads of the main motors by stands.

Table 4 Temperature and deformation conditions for coil rolling (6×1500 mm, steel grade S355MC) at the mill 1700

Stand No.	Values					
	Thickness*, mm	Temperature, °C	Calculated rolling force, MN×100	Maximum allowed rolling force, MN×100	Rolling rate, m/s	Motor power, kW
0**	140					
01	120	1260	707.3	800	0.85	1343.5
1	90	1237	1217.0	2500	1.26	3758.8
2	60	1213	1508.2	2500	1.36	5046.3
3	42	1178	1260.1	2000	1.78	4676.5
4	32	1138	1039.2	2000	1.78	2907.3
4a	28	1074	722.3	2000	2.89	2129.9
5	22	934	1736.5	2400	1.36	3846.4
6	16	916	1772.1	2400	1.87	4714.1
7	12	898	1346.9	2000	2.67	3619.8
8	10	876	1460.3	1800	3.38	4575.2
9	8	856	1274.1	1700	4.27	4127.9
10	6	834	994.1	1500	5.70	3343.1

* thickness after pass

** initial data

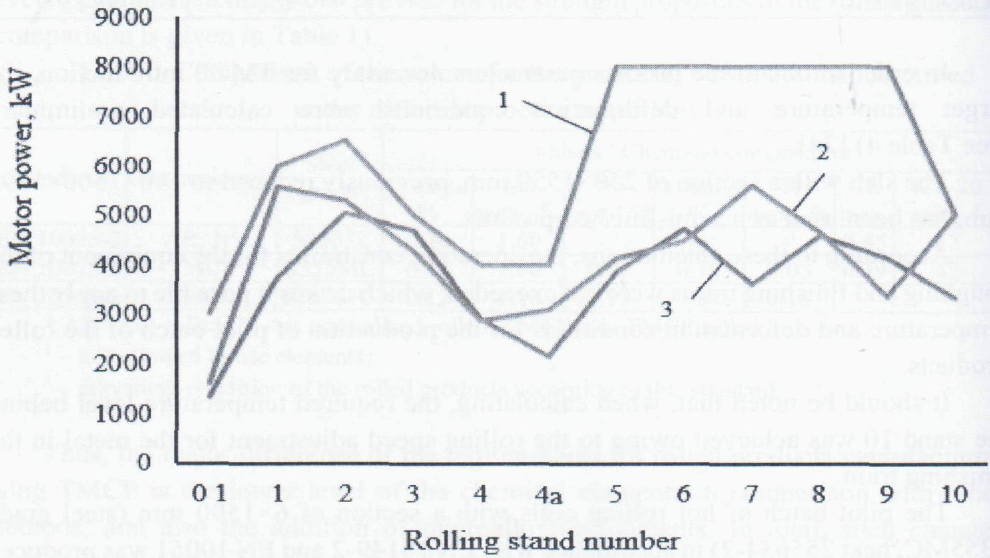


Figure 2. Power of the main motors by stands: (1) allowed, (2) actual, (3) calculated

After rolling, the coils were processed at the accelerated cooling unit, see Fig. 1. Actual thermomechanical parameters of the pilot batch production are shown in Table 5.

Table 5. Actual thermomechanical values of the rolling process

Parameter	Unit	Parameter value
Slab reheat temperature	°C	1260-1280
Heat time	hours-minutes	2-12
Rolling temperature behind the stand 4a	°C	1105-1117
Rolling temperature behind the stand 10	°C	880-887
Coiling temperature	°C	623-644
Number of sections, which are used for accelerated cooling	pcs.	14
Cooling rate	°C/s	60.2

Comparison of the target and actual data according to the average metal temperatures behind the stands 4a, 10, and coiling temperatures are shown in Fig. 3.

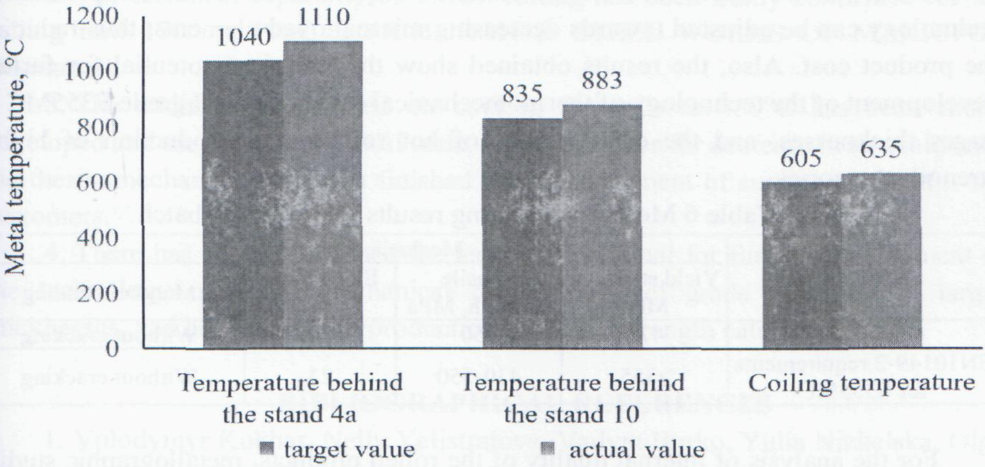


Figure 3. Comparison of target and actual metal temperatures based on the process operations

In fact, the obtained thermomechanical parameters are slightly higher than the target ones, which is associated with the regulation of parameters during the rolling, and also the technology refinement. It is worth mentioning that in order to obtain the necessary mechanical properties, increase in the rolling finishing temperature at the stand 10 and the coiling temperature were compensated by using maximum number of cooling sections, which has contributed to increase in the cooling rate of the rolled products.

The coils were undergone the additional controlled air cooling to 450°C, which was carried out using industrial aerators [25, 26]. After this technological operation, the coils were taken to the warehouse for final ambient cooling.

The technology of additional controlled air cooling of the rolled products following the thermomechanical rolling is specially developed for the production of this pilot batch. The deployment of this technology made it possible to reduce the thickness of air scale, which is intensively built up once the rolling is finished and up to 450°C, with typical air cooling.

Analysis and discussion of the results. The quality analysis of the obtained results was carried out based on the mechanical tests and metallographic research.

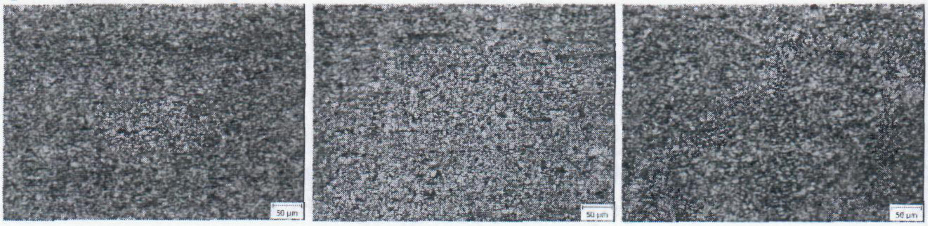
The samples for evaluation of mechanical properties from coils of the pilot batch were taken after the final cooling. The mechanical testing results are shown in Table 6.

The results of the mechanical tests are fully in line with the requirements described in EN 10149-2 for steel grade S355MC. It should be said that the test results obtained are at the upper level of the standard requirements. Thus, the production technology can be adjusted towards decreasing microalloyed elements, thus reducing the product cost. Also, the results obtained show the technical potential for further development of the technology of thermomechanical rolling of steel grade S355MC in larger thicknesses, and the development of hot rolling coil production of higher strength categories.

Table 6 Mechanical testing results for coil pilot batch

Heat No.	Mechanical properties			
	Yield strength, MPa	Tensile strength, MPa	Elongation, %	Mandrel bending
255634-2	475	550	30	Without cracking
EN10149-2 requirements for S355MC	≥355	430-550	23	Without cracking

For the analysis of internal quality of the rolled products, metallographic studies of the samples from coils (heat 255634-2) were carried out. The microstructure of the samples is shown in Fig. 4.



surface axis surface

Figure 4. Microstructure of samples (heat 255634-2) after etching, × 200

The obtained microstructure of the rolled products is ferrite-pearlitic, where ferrite grain number is 9, 10, and banding is 1 point.

The difference in the ferrite grain size between the axis and the surface does not exceed one number, and the metal has almost the same banding across the cross section.

Such a state of microstructure in thickness of the rolled product and banding shows that the desired result during the thermomechanical rolling and a sufficiently effective, for this product mix, cooling of the rolled products in thickness have been achieved. In order to determine whether the rolled products in larger thicknesses can be manufactured, taking into account the cooling capabilities of the equipment, further development study is required.

CONCLUSION

1. The developed technology and the produced batch of hot rolling coils (6×1500 mm, steel grade S355MC) are fully in line with EN 10149-2.

2. The technical capability of TMCP rolling has been firstly confirmed for the rolling mill 1700 at PJSC ILYICH IRON & STEEL WORKS OF MARIUPOL (Mariupol).

3. The additional controlled air cooling for coils to 450°C has been firstly developed and used on an industrial scale, which provides for decrease in air scale once the thermomechanical rolling is finished and improvement of surface quality for the customers.

4. There has been established the technical potential for further development of the technology of thermomechanical rolling of steel grade S355MC in larger thicknesses, and hot rolling coil production of higher strength categories.

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Scientific development and achievements

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First Edition: 2018
A catalogue record for this publication is available from British Library.

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ISBN 978-1-9993071-0-3
Includes bibliographical references and index.

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This research was partially supported by PO "Center of European Enterprises". We thank our colleagues from Center of European Enterprises who provided insight and expertise that greatly assisted the research, although they may not agree with all of the conclusions of this paper.

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