Improving of preventive management for flat rolling products quality indices

V V Kukhar1,*, O H Kurpe1, A H Prysiazhnyi1, O A Khliestova1, V A Burko1, E Yu Balalayeva1, N Yu Yelistratova1

1 Pryazovskyi State Technical University, Universytetska str., 7, Mariupol, 87555, Ukraine

*Corresponding author’s e-mail: kvv.mariupol@gmail.com

Abstracts. Based on the combination of ISO and Lean system tools, the methodology of continuous optimization of technology and quality improvement of rolled steel has been improved. To assess the condition and determine the production level to set limits to process indices the use of colored markers was suggested. The improved flat rolling quality control methodology is based on the use of Deming cycle and includes the use of such analysis tools as Fishbone (Ishikawa) diagram, Pareto principle, distribution diagrams, 3σ rules and Shewhart control charts. For the first time, differentiated corrective solutions for plate steel which is produced with different levels of process stability and quality indices are suggested. The inspection was carried out with the data from the mechanical properties of flat steel products 14 mm thick from K60 steel, produced by thermo-mechanical controlled process on a plate mill 3600. Introduction of the methodology allowed to reduce the standard deviation of yield strength, tensile strength and percentage elongation after fracture of the studied rolled products by 44%, 31% and 46%, respectively, indicating an overall increase in technology stability and quality indices and implementation of an effective tool for their preventive control.

1. Introduction

For proper functioning and achieving development of an enterprise or a company, the product quality system must be implemented in all process areas [1–5], starting with raw materials supply and ending with the processes of working with the consumers (customers) [6–8], and can be combined with the production system [9–12]. The analysis of enterprises operation showed that their quality system operates only in the field of technology, and the use of this system in other areas that interact with technology is only formal. Therefore, further improvement of approaches to preventive product quality control and their systematic use in all process areas of production is a relevant problem.

The analysis of data [6, 9–13] allowed us to conclude that to solve this problem it is effective to combine the quality system ISO 9000, ISO 9001 with the tools of the Lean production system. This is a system of organization and control of product development, production, relationships with suppliers and consumers, when products are manufactured in strict accordance with consumer demands and with lower losses [13–16]. In particular, one of the approaches provided by the ISO 9001 quality system and can be used to solve the problem is the use of "Risk-oriented thinking" [9, 12, 13, 17–19]. Its essence is that an organization must perform a risk assessment, i.e. identify factors that may cause deviations of its processes and quality control system from planned results, and develop actions towards the risks to prevent adverse effects, based on available data on manufactured products and its quality indicators. At
the same time, it is necessary to plan how to integrate and implement actions into the processes of the quality control system of an organization and evaluate their effectiveness, i.e. the Deming cycle or PDCA cycle should work – “Plan”, “Do”, “Check”, “Act” [6, 16, 20–22].

Among the tools of the Lean production system which should be used in combination with the ISO 9001 quality system, we can note the following [13, 16, 21–24]: (a) benchmarking, which is to compare indicators, results, quality indices, etc. with similar industries, manufacturers in order to find the best experience; (b) Ishikawa diagram, as a graphical way to study and determine the most significant cause-and-effect relationships between factors and consequences in the studied problem; (c) Pareto principle – an empirical rule according to which for many events 80% of the consequences are caused by 20% of the causes. At the same time, the analysis of the experience metallurgical enterprises showed that they do not fully use the methodology, which would be based on a combination of ISO quality systems and Lean production system, which complicates the improvement of technology and product quality. Therefore, the aim of the paper is to provide the necessary quality indicators of flat rolling products (on the example of heavy plate steel) based on the combination of the ISO and Lean systems principles.

2. Research methodology
The improved rolling quality control methodology is based on the use of the Deming (PDCA) cycle and includes the establishment, determination of process indices values that affect product quality, their control, accumulation, processing and improvement mechanisms, Fig. 1. The proposed methodology is applied to products that have passed the stage of development and are produced on an industrial scale. In order to control the production process and ensure the quality of flat rolled sheet steel, it is necessary to install and control the appropriate process parameters by the Lean tools. After establishing a list of process indices, it is necessary to determine their values, which can be established based on analysis of similar products production, statistical processing of available information, research, published sources.

![Figure 1. The methodology example of rolling quality control in the PDCA cycle.](image-url)
rolling quality indices, establishing the restrictions in accordance with 3σ or 6σ rules, depending on the process. Restrictions should up to existing regulations or stricter. On the second step of processing the accumulated statistical data it is necessary to build distribution charts for each of the established process indices that affect this rolling quality parameter, and set limits that ensure the required quality production. It is recommended to use colored markers to visually assess the condition and determine the levels of process when setting restrictions on process indices. In particular, the red marker can be used when the process index deviates from the limits that ensure receiving needed quality index of rolled products in accordance with the standard (this means a violation of the process). The yellow marker can be used when the process index deviates from the limits that provide increased requirements set within the quality control system, while this indicator of rolling quality is still within the standard (this means that the process needs attention). The green marker should be used when the process index meets the limits of the increased requirements for the rolling quality, and the process is stable. Using this approach within the combination of ISO and Lean systems allows not only to stabilize the process and improve product quality, but also to reduce production costs by applying restrictions on obtaining overly high quality levels. For example, consistently obtaining the average requirement level of mechanical properties indices of flat rolling (sheet metal) for the main pipelines allows saving micro-alloying elements during steelmaking.

To monitor the result and control compliance with the established restrictions on process indices there can be used direct control by an employee of the quality control department at the place of fixing the process index, visualization (control) of process indices or automatic process control system. Shewhart control charts are also widely used, which are graphs of sampling indices change, usually the average value and standard deviation, which is calculated in the process of data collection. Obtaining information on deviations allows for managing the future of such products in accordance with the requirements of ISO 9001. Thus, products produced in batches, for each unit of which all parameters are within the green marker, is considered appropriate. If the individual units of the batch have parameters that are within the yellow marker, then additional quality control is assigned to these units. Products with yellow markers are considered appropriate only after the additional control results confirmation. In case when individual units of the party have parameters that are within the red marker, the products, if not agreed with the Customer, are considered non-compliant.

3. Results and discussion

Below is an assessment of the proposed methodology effectiveness in order to establish the current level of quality and areas of improvement of such quality indices as yield strength σy, tensile strength σuts and percentage elongation after fracture δ in the production of plate made of pipeline steel grade K60 (API 5L Standard), 14 mm thickness, that was produced with thermo-mechanical rolling with accelerated cooling on the mill 3600 at PJSC "AZOVSTAL IRON & STEEL WORKS" (Mariupol, Ukraine). The list of process indices that affect the level of these quality parameters is determined by practical data. This list includes the chemical composition with the elements that affect to the mechanical properties of the steel (C, Mn, Nb, V, Mo, Cr, Ni, Cu), as well as temperature of rolling in start in roughing stand (TRSr), the temperature of the second stage rolling start in roughing stand, which is due to recrystallization inhibition start (TRI), temperature of the rolling start and finish in finishing stand (TRF, TRFR), controlled cooling start and finish temperature (TCS, TCF) [25–29].

To determine the process indices that affect the studied quality parameters, Pareto diagrams were constructed for each parameter. The basis for constructing Pareto diagrams is the value of reliability of approximation $R^2$ and the value of Pearson’s correlation coefficient (by module), which were obtained when determining the relationship between each quality parameter and process index. Fig. 2, for example, shows Pareto diagrams constructed for the yield strength σy. For the data set used in the calculations, the critical value of the Pearson’s correlation coefficient is 0.17 for the significance level $p = 0.05$ (see Fig. 2(b)). Process indices which Pearson’s correlation coefficient towards the corresponding rolling quality parameter is less than 0.17 are not significant.
Table 1 shows the process indices, which according to the results of statistical data processing are set as significant. Actions to improve the technology and the rolling quality were developed only for significant process indices, and insignificant indices were left at the level set by the technological process. In accordance with the proposed methodology for rolling quality control there were also constructed distribution diagrams for these quality parameters of rolled thick sheets and heavy plates. Fig. 3, for example, shows distribution of the rolling yield strength. The analysis of the constructed diagrams established that the distribution of the yield strength has cases of obtaining results below the required regulatory standard and level with minimum required regulatory standard. In relation to the distribution of temporary resistance, there are also cases of obtaining lower than the regulatory standard of requirements. The distribution of percentage elongation after fracture has a significant number of cases obtaining results below the regulatory standard of requirements, which indicates the instability of the process to obtain this quality parameter of sheet steel.

**Table 1.** Parameters those are significant in determining the appropriate rolling quality index.

| Parameter | Pearson’s correlation value according to the rolling quality indices |
|-----------|---------------------------------------------------------------|
| TRI       | $\sigma_{ys}$ | $\sigma_{uts}$ | $\delta$ |
| V         | 0.316           | 0.379           | -        |
| TCS       | -0.224          | -0.334          | -        |
| Ni        | -0.213          | -0.219          | -        |
| Mo        | -0.196          | -               | -        |
| Cu        | -0.188          | -0.202          | -        |
| C         | 0.178           | 0.246           | -        |
| TCF       | -               | -0.241          | 0.412    |

**Figure 2.** Distribution diagram of the reliability of approximation (a) and the Pearson’s correlation coefficient (b) on the indices that affect the yield strength of rolled products made of K60 grade steel.

To stabilize the rolling technology and improve the rolling quality on studied parameters, the restrictions were set and the process levels determined, using color markers presented in Table 2. In order to obtain the required level of technology indices according to the established limits of rolling quality parameters in studied data set, using filters only those data which corresponded to the stable level of the process (indicated by the green marker in Table 2) were kept and their limits set. Filtration was started with the most unstable quality parameter, which in this case is the specific elongation. The list of significant process indices for all three parameters of sheet quality was the same. When setting yellow and red markers and the corresponding levels of the process, the values of Pearson’s correlation in terms of rolling quality parameters were taken into account (see Table 1). Determining the limits of violation of the rolling technology (marked with a red marker in Table 2) was carried out according to the data that meet the limits of regulatory requirements for plate steel quality parameters. It should be
noted that the quality of originally developed (basic) technology plays an important role in using the proposed methodology to establish the levels of process.

In the studied case the wrong basic technological process of plate steel thermo-mechanical rolling was developed, it did not allow to obtain the required mechanical properties parameters of rolled products by accelerated cooling, which can be seen in negative correlations of cooling indices. The desired level of plate steel properties was achieved mostly through the rolling process indices. After establishing levels of process indices (see Table 2) required to obtain stable quality parameters of plate steel, the diagrams of yield strength, tensile strength and specific elongation of the metal were constructed. Fig. 4 shows an example of the diagram of the yield strength distribution of rolled products 14 mm thickness, made of K60 grade steel for the green level process.

| Table 2. Restrictions on process indices and rolling quality parameters. |
|-----------------------------------------------|
| Quality parameter/process index | Process levels | violations of the process | needs attention | stable | needs attention | violations of the process |
|-----------------------------------------------|
| Yield strength, (σₚₒ), MPa | <505 | 505–510 | 511–570 | 571–580 | - |
| Tensile strength, (σₚₛ), MPa | <590 | 590–600 | 600–660 | 661–710 | >710 |
| Elongation after fracture, % | <22 | 22.0–22.4 | 22.5–25.0 | 25.1–26.0 | - |
| TRI, °C | <876 | 876–908 | 909–1008 | - | >1008 |
| V, % | <0.055 | 0.056–0.059 | 0.06–0.08 | - | >0.08 |
| TCS, °C | <717 | 718–720 | 721–737 | - | >737 |
| Ni, % | - | - | 0–0.29 | - | >0.29 |
| Mo, % | - | - | 0–0.07 | - | >0.07 |
| Cu, % | - | - | 0–0.28 | - | >0.28 |
| C, % | - | - | 0.08–0.11 | - | >0.11 |
| TCF, °C | <541 | 542–595 | 596–640 | - | >640 |

Figure 3. The initial distribution of the yield strength of 14 mm thick rolled products made of K60 grade steel.

Figure 4. Distribution of the yield strength of 14 mm thick rolled products made of K60 grade steel for the green level of the process.

The analysis of obtained results showed that the green level process provides the parameters of plate steel mechanical properties that are within the regulatory requirements. At the same time, the standard deviation along the yield strength, tensile strength and specific elongation of rolled products decreased by 44%, 31% and 46%, respectively, indicating an overall increase in technology stability.
4. Conclusion
The methodology of product quality control was improved and performed the efficiency evaluation of its application according to the conditions of obtaining plate steel with thickness of 14 mm and above from steel of K60 strength grade on a plate mill "3600". The results of this assessment showed that suggested methodology allows to obtain the mechanical properties parameters of plates that are in line with the regulatory requirements, as well as to control the level of these indices to obtain economic benefit, combining the ISO and Lean systems.

References
[1] Backman J, Kylönen V and Helaakoski H 2019 IFAC PapersOnLine 52(13) 1174-1179
[2] Grudziń D and Hamrol A 2016 International Journal of Information Management 36(4) 599-606
[3] Su H-C, Kao T-W and Linderman K 2020 European Journal of Operational Research 283(2) 530-540
[4] Kukhar V, Kurpe O, Klimov E, Balalayeva E and Dragobetski V 2018 International Journal of Engineering & Technology (UAE) 7(4.3) 35-39
[5] Artiukh V, Mazur V and Butyrin A 2018 Advances in Intelligent Systems and Computing 692 212-219
[6] Martinez-Costa M, Choi T Y, Martinez J A and Martinez-Lorente A R 2009 Journal of Operations Management 27(6) 495–511
[7] Dragobetski V, Naumova E, Shapoval A, Shlyk S and Moloshkan D 2019 Proc. Int. Conf. on Modern Electrical and Energy Systems (MEES 2019)(Sept. 23-25, 2019, Kremenchuk, Ukraine) 506-509
[8] Konstanciak E, Budzik R and Waszkielewicz W 2003 Metalurgija 42(2) 123-127
[9] Antsev V Yu, Vitchuk N A and Miroshnikov V V 2017 Procedia Engineering 206 950-957
[10] Markov O E, Gerasimenko O V, Shapoval A A, Abdulov O R and Zhynnikov R U 2019 International Journal of Advanced Manufacturing Technology 103(5-8) 3057-3065
[11] Orlov G A and Orlov A G 2020 Solid State Phenomena 299 693-698
[12] Liu C and Sun Y 2009 Proc. 2nd Int. Conf. on Future Information Technology and Management Engineering (FITME 2009) (Dec. 13-14, 2009, Sanya, China) 77-80
[13] Priede J 2012 Procedia – Social and Behavioral Sciences 58 1466-1475
[14] Kukhar V, Grushko A V and Vishchak I V 2018 Solid State Phenomena 284 408-415
[15] Kukhar V, Balalayeva E, Prysiazhnyi A, Vasylevskiy O and Marchenko I 2018 MATEC Web of Conferences 178 02003
[16] Silva A J V 2015 Proc. 2nd Int. Conf. on Computer, Intelligent and Education Technology (CICET 2015) (Apr. 11–12, 2015, Guilin, China) 823-826
[17] Popova L, Yashina M, Babynina L, Ryzhakova A, Yefremova N and Andreev A 2019 Quality – Access to Success 20(170) 58-63
[18] Hunchenko O 2019 International Journal of Recent Technology and Engineering 8(2) 5787-5790
[19] Kukhar V, Yelistratova N, Burko V, Nizhelska Y and Aksionova O 2018 International Journal of Engineering and Technology(UAE) 7(2.23) 216-220
[20] Emelianova D, Kluchareva N, Kolesnichenko-Yanush S and Yakovlev A 2020 E3S Web of Conferences 164 10013
[21] Badea D M, Stanciu V M, Constantin P, Stefânescu G and Tănăsescu F T 2010 Quality – Access to Success 11(1-2) 33-39
[22] Garza-Reyes J A, Torres R J, Govindan K, Cherrafi A and Ramanathan U 2018 Journal of Cleaner Production 180 335-348
[23] Djapic M, Popovic P and Lukic L 2019 IOP Conference Series: Materials Science and Engineering 682 012017
[24] Kohl H and Neumann K 2020 ZWF Zeitschrift Fuer Wirtschaftlichen Fabrikbetrieb 115(1-2) 27-30
[25] Kurpe O, Kukhar V, Klimov E, Chernenko S and Balalayeva E 2020 Lecture Notes in Mechanical Engineering (Advances in Design, Simulation and Manufacturing II, DSMIE-2019) 418-429
[26] Kurpe O, Kukhar V, Klimov E and Prisyažnij A 2018 Solid State Phenomena 291 63-71
[27] Artiukh V, Kukhar V, and Balalayeva E 2018 MATEC Web of Conference 224 01036
[28] Efremenko V G, Zurnadzhi V I, Chabak Y G, Tsvetkova O V and Džherenova A V 2017 Material Science 53 67-75
[29] Smirnov E N, Smirnov A N, Sklyar V A, Belevitin V A, Eron’ko S P and Pivovarov R E 2018 Steel in Translation 48(6) 381-387