Improving the Quality of Rolled Metal Products Using a Set of Quality Management Statistical Methods

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Abstract. In the face of the increasing need of shaped and bar iron for buildings and installations construction, production of modern domestic vessels at one of the Kuzbass metallurgical enterprises, mastering the production of hot-rolled bulb bars made from high-quality structural steel, which is based on existing technology, has begun. To ensure the production quality, control quality techniques for "asymmetric bulb bar" experimental rolled steel made from A32 and D32 steel grades is proposed. It enabled us to identify the systemic and most significant unsatisfactory features in production process, to develop measures to eliminate them and prevent possible defects in mass production of rolled products. These techniques are based on the application of quality management statistical methods. The implementation of a quality control techniques and recommended measures to prevent possible defects made it possible to improve the quality of metal, ensure production stability and competitiveness in the metal market.

1. Introduction, relevance and research objective
Improving the quality of products is an important condition for improving the efficiency of production process and the services provided, which is a decisive factor in determining the product competitiveness. Improving the technical level and production quality determines the pace of scientific and technological progress and the growth of production efficiency in general, has a significant impact on economic development, the competitiveness of goods and services.

The purpose of this scientific work is to improve the quality of manufactured metal products, namely hot-rolled bulb bars made from steel grades A32 and D32 [1], by improving the quality control methods using quality management statistical methods [2, 3].

To achieve this purpose, the following tasks were performed:
▪ requirements for structural steel used in shipbuilding were formulated;
▪ production technology of rolled metal at a metallurgical enterprise was studied;
▪ quality control of rolled metal was carried out on the basis of the existing techniques for quality control of finished steel;
▪ the most significant deviations using statistical methods of quality management were identified;
▪ corrective actions were developed for identified non-conformities.

An integrated approach to achieving this purpose made it possible to identify weaknesses in the production technological chain and to develop measures to prevent the occurrence of possible defects.
2. Experimental research
Quality level assessment included the following steps:
- selection of a list of quality indicators and justification of its necessity and sufficiency;
- selection or development of methods for determining the values of quality indicators;
- selection of indicator basic values and initial data for determining the quality of the analyzed production;
- determination of actual values of quality indicators and the comparison with basic indicators;
- comparative analysis of options for possible solutions and finding the best one;
- feasibility demonstration of recommendations for a managerial decision.

Rolled metal products validation testing procedure
The initial (control) testing procedure is standard. It is designed for structural steel used in shipbuilding, in accordance with GOST 21937 for steel grades in accordance with GOST 52927. The list of controlled parameters includes the following tests: pull test (GOST 1497), blow-bending test (GOST 9454), sensitivity to hardness ageing (GOST 9454, GOST 7268), chemical analysis (GOST 18895, GOST 22536.0 - GOST 22536.5, GOST 22536.7-GOST 22536.10), steel chemical inhomogeneity test (sulfur segregation according to GOST 10243), grain size test (GOST 5639) [4].

In general, samples and test procedures should meet the requirements of the “Rules for technical supervision of the construction of ships and the manufacture of materials and products for ships” and the requirements of the “Rules for the classification and construction of ships”.

Test samples were made from rolled samples in accordance with the requirements of standards and procedures for each type of test. Testing of rolled samples was carried out by competent personnel using calibrated equipment, in a laboratory that has passed the assessment of the state of measurement and received a “Certificate of Measurement Status”. The test results were tabulated and processed using statistical methods.

Application of statistical methods for processing quality control data
To conduct a statistical analysis of the metal-roll process, a set of the following tools was selected:
- Checklist [5];
- Pareto Chart [6];
- Ishikawa Diagram [7];
- SWOT analysis [8].

The main stages of the statistical analysis included:
- checklist development and filling;
- Pareto chart construction to identify the most dangerous types of defects in metal;
- indicating cause-effect relations through the Ishikawa diagram;
- analysis of strengths and weaknesses in the production of rolled products (SWOT analysis).

3. Results and discussion
Checklist development and filling.

The checklist is a form for recording and counting data collected as a result of observations or measurements of controlled indicators over a specified period of time. The following information has been taken into account and reflected in this checklist:
1. Name of object.
2. Data logging table.
3. Control area.
4. Surname and position title of the employee registering data.
5. Date.
6. Observation period.

The monitoring results are given by the study example of five batches of rolled products, which are presented in Table 1. The control sampling was made of 5 batches, the total tonnage of manufactured products was 295.965 tons.

As a result of monitoring above parameters over three months, the following results were obtained: manufactured defected products amounted to 16.618246 tons.

Table 1. Checklist

| Name of object | The production process of "asymmetrical hot-rolled bulb bars for shipbuilding" rolled products |
|----------------|------------------------------------------------------------------------------------------|
| Control area   | Long product rolling mill                                                                 |
| Responsible controller | QC inspector                                                                 |
| Control time   | 10-00  14-00  08-00  09-30  10-00                                                     |
| Defect name    | Batch 1 Batch 2 Batch 3 Batch 4 Batch 5 Quantity, tons                                      |
| camber (curvature) | 2,03  0,80123  1,25001  0,950140  1,4301  6,47                                         |
| curl           | 1,6317  0,907265  0,90401  0,975850  1,15  5,5                                        |
| strip geometry deviations | 0,95  0,610254  1,3125  0,730000  0,84  4,4                                    |
| rolled blister | 0,13  0,0003  0,0001  0,000025  0,0011  0,13                                     |
| contamination  | 0,0001  0,000025  0,000014  0,000010  0,0009  0,000158                                |
| ripple marking | 0,003  0,00001  0,000015  0,000008  0,0001  0,00312                                   |
| prints         | 0,0013  0,000045  0,000025  0,00001  0,0001  0,0013                                |
| size           | 0,00012  0,000014  0,000025  0,000003  0,0006  0,0001                                |
| Total defect   | 16,61                                                   |
| Total production | 295,96                                                |

Pareto Chart construction to identify the most dangerous types of defects in rolled metal products

To visualize the considered factors in decreasing order of importance, we used a statistical tool - the Pareto Chart.

The Pareto Chart construction is divided into two stages - filling the source data table (Table 2) on the basis of information obtained from the control sheet and The construction of the Pareto diagram is divided into two stages - filling out the source data table (Table 2) on the basis of information obtained from the control sheet and constructing the column diagram itself and the cumulative curve (Fig. 1).
Table 2. Data table to construct a Pareto Chart

| No | Controlled parameter | Number of exposed nonconformances | Accumulated amount of nonconformances | Percentage of each nonconformance | Accumulated percentage |
|----|----------------------|-----------------------------------|---------------------------------------|----------------------------------|------------------------|
| 1  | camber (curvature)   | 6,471                             | 6,47129                               | 38,940                           | 38,94088               |
| 2  | curl                 | 5,568                             | 12,0401                               | 33,510                           | 72,45118               |
| 3  | strip geometry deviations | 4,442                              | 16,4828                               | 26,734                           | 99,18537               |
| 4  | rolled blister       | 0,1305                            | 16,6134                               | 0,785                            | 99,97086               |
| 5  | contamination        | 0,0001                            | 16,6135                               | 0,0009                           | 99,97181               |
| 6  | ripple marking       | 0,0031                            | 16,6166                               | 0,0187                           | 99,9906                |
| 7  | prints               | 0,00139                           | 16,6180                               | 0,0083                           | 99,998                 |
| 8  | size                 | 0,00016                           | 16,6182                               | 0,0010                           | 100                    |
|    | Total                | 16,618                            | 100                                   |                                  |                        |

Figure 1. Pareto Chart

After constructing the Pareto Chart, “ABC analysis” was carried out, the main defects that are in risk zone A and, therefore, have a strong influence on the process are identified. Defects that are in B and C zones are insignificant and were not subject to detailed analysis in the framework of this study [9].

The following defects are in zone A: camber (the defect's appearance was 38.94%), curl - 33.5% and strip geometry deviations - 26.7%. These defects are especially dangerous and
cause great financial damage directly to the manufacturer and affect the safety of finished ships made by customers.

In this regard, these defects were further investigated using the Ishikawa Diagram, that is, a visual review of the cause-effect relationships between the object of analysis and the factors influencing it.

Indicating cause-effect relations through the Ishikawa diagram

To indicate the main causes of rolled steel defects, the Ishikawa Diagram (“fish skeleton”) was constructed. The analysis made it possible to identify the main causes of each defect type, namely, camber, curl and geometry deviations.

The camber defect makes the largest percentage of getting into zone A (38.94%) and, therefore, causes the greatest damage to the process under study.

From the diagram it follows that the main causes of camber defect are:

- staff qualifications;
- operating procedures;
- quality of raw materials;
- technological preparation for production.

Analysis of strengths and weaknesses in the production of rolled products (SWOT analysis).

At the final stage, using the SWOT analysis (Table 3), weaknesses and strengths in the production of rolled products were revealed [10].

Table 3. SWOT analysis

| Strengths                                      | Weaknesses                                  |
|------------------------------------------------|---------------------------------------------|
| The flexibility of production technology.     | Organization of a sales system.             |
| The condition of the equipment.               | Order processing speed.                     |
| The quality of the finished product.          | Brand fame.                                |
| The range of products, the ability to meet    | Return on equity.                           |
| individual needs.                             | Relations with local authorities.           |
| The competence of the staff.                  |                                             |

Opportunities                                                                 Threats

| The growing demand for customized products   | Sales dip in the market.                    |
| and services in the Russian and foreign      | Activation of competitors.                  |
| markets.                                     | The increase in customs duties (export /    |
| The growth of solvency of market customers. | import).                                   |

Based on the SWOT analysis, measures were developed to improve the rolled steel quality, including:

1. Regular monitoring and preventive maintenance of equipment.
2. Development of personnel motivation policies, moral and material incentives.
3. Scheduling staff development (training every three years). Upgrading work methods and technologies.
4. Drafting work instructions on the manufacturing processes.
5. Updating of documented instructions and procedures for the production of rolled steel (production methods and technologies).
6. Strengthening of the incoming quality control of raw materials. (verified suppliers, raw material certificates availability, test reports, raw material chemical composition control).
7. Continuous monitoring of the rolled steel production process.
8. Periodic replacement of outdated equipment (moral and physical depreciation).
9. Compliance with the production environment standards (lighting, humidity, temperature).
10. Compliance with the rules, regulations and instructions in the rolled steel production.

4. Conclusions
As a result of the research:
1. The methodology for quality control of the "asymmetric bulb bar" experimental rolled steel was developed, which includes methods of control and statistical quality analysis.
2. A statistical analysis of the experimental rolled steel quality control was carried out using the following quality tools: checklist, Pareto Chart, Ishikawa Diagram, SWOT analysis.
3. As a result of the implementation of the quality control methods, the main defects in the rolled steel production were revealed - camber, curl and geometry deviations.
4. On the basis of statistical analysis, cause-effect relations were indicated, make it possible identify the basic causes of defects.
5. Using the SWOT analysis, the strengths and weaknesses of the process were identified, corrective and preventive actions aimed at improving the quality of rolled metal products were developed.

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