QUALITY ASSURANCE OF THE ROOF BOLTING REINFORCING MESH WELDED JOINTS BY MEANS OF PRODUCTION ROBOTIZATION

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Nowadays, production robotization is one of the key directions of industrial enterprises' development all over the world. According to Ernst&Young, more than 40% of manufacturing companies are now actively investing in robotization and automation of production processes. The market for industrial robots is actively growing in Russia as well, at a rate of 30-50% annually.

The advantages of industrial robots implementation for manufacturing companies are obvious. First of all, it reduces the cost of production and increases output. However, the question arises **- what is the benefit of robotized production for the consumer company**? Does it make sense for a consumer company to look for such technological solutions from a manufacturing company when sourcing suppliers to provide the goods for its production needs?

Stability Is a Mark of Craftsmanship. Or the Result of Robotized Production Processes

One of the results of industrial robots implementation is a high degree of repeatability of technological operations. Indeed, the robot never experiences fatigue, nor is it affected by factors in the production environment. And when auxiliary processes are properly organized, the production robotization can provide a predictable, stable outcome of production processes.

As part of its product quality assurance program, OKS LLC has implemented the ABB robotics system for welding the reinforcing meshes intended for roof boltings. It consists of three manipulators. Two manipulators are designed to control movements of the welding arc relative to the reinforcement, another one to move the reinforcement into and out of the welding area.

The **REINFORCING MESH** is a critical part of the roof bolting, as it directly takes up the loads from the fixed roof and transmits them to the anchor bolts. **In many respects it is the strength of the reinforcement's welded joints that determines the bearing capacity of the roof bolting as a whole; in case of failure of these joints, the roof may collapse.** Therefore, for a mining enterprise, stable quality indicators of the welded joints are an important issue to which it is advisable to pay attention when choosing a manufacturer of roof bolting.

For quality management in terms of ensuring the stability and predictability of the performance characteristics of the product, methods of statistical process control are widely used [1-9].

According to the basic principles of this concept, the best quality is ensured by a production process that has minimal variability in results.

The methodology of statistical process control is based on the assumption that the causes due to which the performance characteristics of the product may deviate from a given value can be divided into "accidental" and "special" ones [10-12].

By "accidental" causes (uncontrolled, general, internal, natural) we mean causes of accidental nature arising from variations in the parameters of a normally occurring process, that is, such a process that ensures the performance characteristics of the product in a given range.

Under "special" causes (systematic, special, controlled, unnatural) we mean the causes that lead to a significant deviation in performance characteristics of the product, and these causes can be identified and eliminated.

If the change in performance characteristics of the product is due to accidental causes only, the process is considered statistically controllable, and allows guaranteed output of products of a given quality, the indicators of which are within a given range.

One of the main tools for implementing statistical process control is Shewhart control charts, which visually represent the values of a certain characteristic relating to the distribution of values taken by the monitored indicator of the product; this characteristic is obtained from a certain sampling of products. The control chart establishes a central line corresponding to a given value of the product indicator and statistically defined upper and lower control limits. The process is considered statistically controllable if all values of the evaluated characteristics fall within the range between the lower and upper control limit, and there are no systematic patterns in the data location on the control chart relative to the center line. A characteristic out of the tolerable value range is a signal for identifying the causes of the process not meeting the prescribed requirements.

To determine initial parameters of the control charts used to monitor the stability of process indicators, the strength of the welded joints made in the reinforcing mesh by means of manual, resistance and robotized welding was studied in the premises of OKS LLC.

When designing a control chart, an important issue is the accuracy of determining the central line and the control limits. To define reliable parameters of the control chart, a preliminary research into the distribution of the product quality indicators is necessary (stage 1) [12].

This paper examines welded joints made by manual arc welding (K3-Rp according to GOST 14098-2014, hereinafter manual welding), mechanized arc welding using a robotics system (K3-Mp according to GOST 14098-2014, hereinafter robotized welding) and resistance welding (K1-Kt according to GOST 14098-2014).

Manual and robotized welding was performed in carbon dioxide medium on a semi-automatic machine. Robotized welding is performed on an ABB robotics system (Fig. 1).

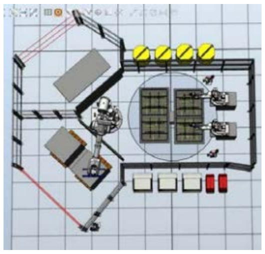


Fig. 1. General view of the robotics system installed in the premises of OKS LLC.

Welded joints produced with resistance welding are formed by the flow of welding current through the weld junction zone of the reinforcement bars.

To implement statistical process control in the premises of OKS LLC, $\overline{X}$-□ control charts are going to be used, which are based on the assessment of mean values and sample standard deviations of the indicator sampling.

In order to establish the initial parameters of the control charts, reinforcing meshes were made of 12mm diameter reinforcing steel (rebar AIII-A400C according to GOST 5781-82) by three welding methods, and cross-shaped specimens were cut out of them to test the welded joints for shear. A total of 30 samples were obtained for each welding method.

Next, the obtained samples were tested for shear on the PM-50M test rig according to GOST R 57997-2017, and the maximum force that the joint can withstand was assessed.

After that, for each of the welding methods, the mean value based on the distribution of the values taken by the force at failure, $\overline{P}$, the sample standard deviation *s* value, the upper □$_{CL}$ and lower □$_{LC}$ control limits were calculated for both control charts representing mean values and those representing sample standard deviations.

After determining the parameters of the control charts, additional studies were conducted to assess the adequacy of the initial values obtained. For this purpose, additional samples were used (14 specimens in each sample), including specimens made by robotized welding.

The distributions of the forces at failure for various welding methods are shown in Fig. 2.

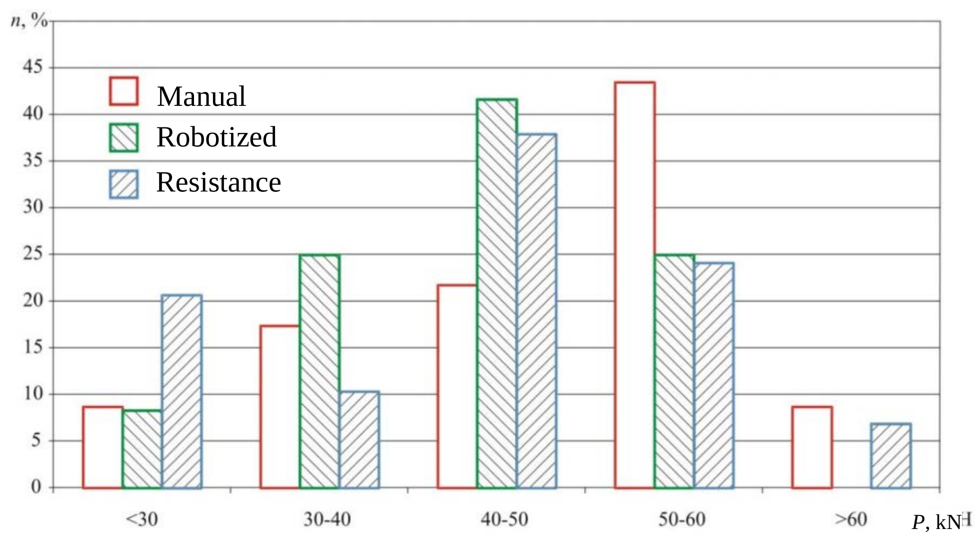


Fig. 2. Distribution of values taken by the forces at failure in welded joints, *P*, where □ is the fraction of specimens in the sample falling into the corresponding force interval

The analysis of the obtained results shows a significant influence of the welding method chosen on the distribution of the welded joints' strength characteristics. Thus, the strength distribution for manual welding has a distinct asymmetry, with the mean value of the sample biased towards higher values. Such deviation from the normal distribution may indicate the presence of external causes of strength decrease; the scatter of strength values in this case cannot be attributed to purely random, unrelated factors.

The distribution for resistance welding does not correspond to the normal pattern, either, and is bimodal. In this case, one of the maximum values falls in the low value range (up to 30 kN) of force at failure in welded joints.

The distribution for robotized welding is the closest of the methods considered to a normal distribution, with a negligible number of low-strength specimens. It should be noted that the use of control charts is recommended for processes whose values are distributed in a manner close to the normal distribution. The obtained values of the control chart parameters are given in Table 1.

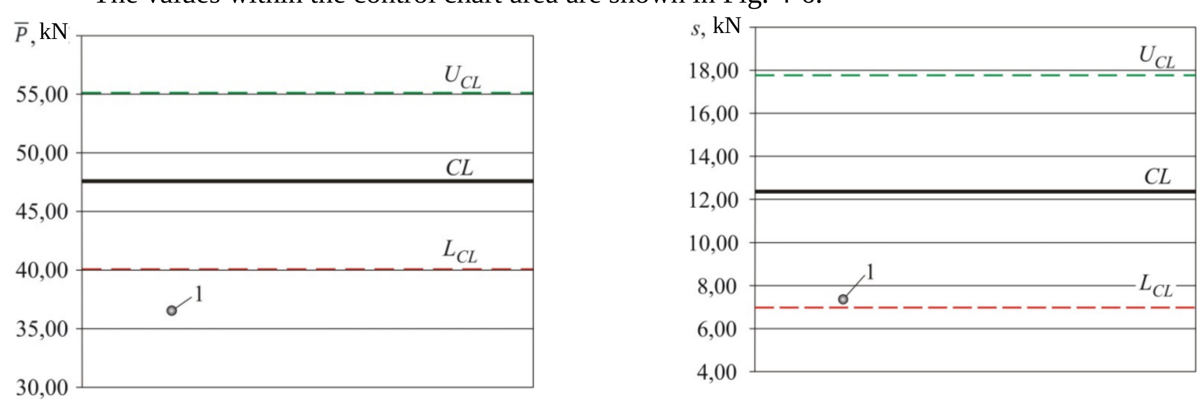
Table 1

Values of the control charts parameters

Welding method	Control chart of the mean values			Control chart of sample standard deviations		
	$\overline{P}$	U_{CL}	L_{CL}	s	U_{CL}	L_{CL}
Manual	47.65	55.16	40.13	12.40	17.80	7.01
Resistance	42.72	50.37	35.07	12.62	18.11	7.13
Robotized	42.24	48.05	36.43	9.59	13.76	5.42

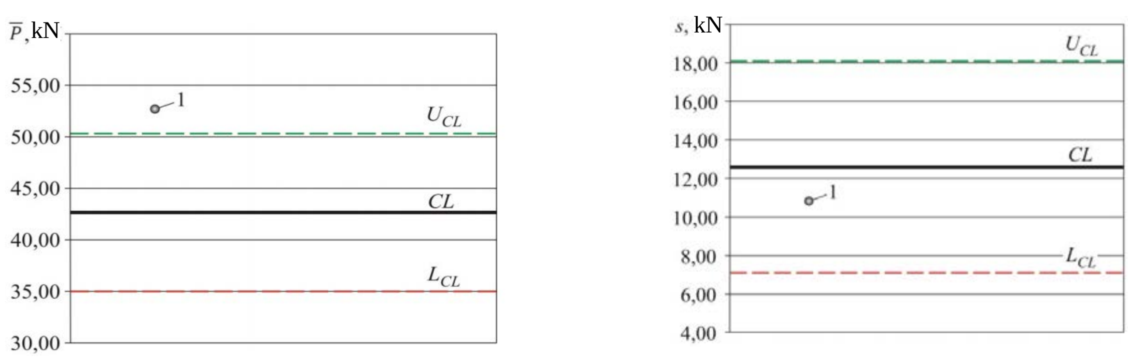
The results show that the sample standard deviation for manual and resistance welding is comparable, exceeding 12 kN. The sample standard deviation for robotized welding is minimal at 9.59 kN. This indicates less variability in the strength values when making reinforcing meshes using the robotics system, and therefore more predictability in the quality of roof bolting as a whole.

The values within the control chart area are shown in Fig. 4-6.



a) b)

Fig. 4. Control charts for manual welding, 1 - position of the indicator characterizing the additional sample distribution: a) - mean values; b) - sample standard deviations



a) b)

Fig. 5. Control charts for resistance welding, 1 - position of the indicator characterizing the additional sample distribution: a) - mean values; b) - sample standard deviations

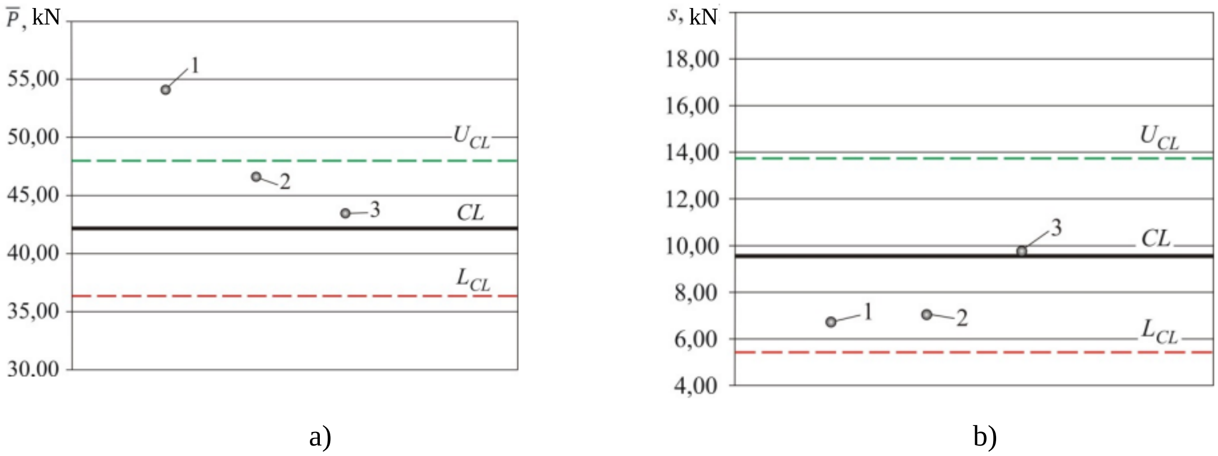


Figure 6. Control charts for robotized welding, with numbers indicating the values of the strength distribution for additional samples produced with the use of welding wire:1 - ESAB AristoRod; 2 and 3 - WS Weldeship; letters indicate control cards types: a) - representing mean values; b) — representing sample standard deviations

The mean value of the additional samples produced by resistance welding also does not fall within the originally defined range, this value is larger than the upper control limit. The sample standard deviation falls within the defined range of the corresponding control chart. Despite the fact that the mean strength value of the additional sample is higher than the original value obtained, no conclusion can be made on the possibility of consistently obtaining such strength values. Taking into account the significant number of low-strength welded joints during the initial definition of the control chart parameters, it is necessary to conduct additional research on how the characteristics of welded joints obtained by resistance welding are formed.

The mean value of the additional samples produced by robotized welding (series 2 and 3 in Fig. 6) falls within the defined range, even though the width of the latter is much narrower than the width of the defined range for manual and resistance welding. The sample standard deviation also falls within the defined range. The proximity that the values of the additional sample 3 demonstrate with respect to the initially defined values of the control chart is noteworthy. This indicates the stability of the robotized welding process and allows us to draw a preliminary conclusion about the adequacy of the initially obtained parameters of the control charts for robotized welding.

The mean value of the additional sample 1 produced by robotized welding is higher than the upper control limit, with the sample standard deviation being at the lower end of the control chart's defined range. This mean value is due to the use of the ESAB AristoRod welding wire and is not indicative with respect to the instability of the robotized welding process. For statistical control of the robotized welding process using this welding wire, it is advisable to repeat step 1 of defining the initial control chart parameters.

To summarize the above, the following conclusions can be made:

1. For welded joints made by robotized welding, the sample standard deviation value is 22% lower than for those made by manual and resistance welding, which means there is less variation in strength values for robotized welding compared to manual and resistance welding.

2. It has been found that for robotized welding, the characteristics relating to the distribution of the strength values of the specimens from additional samples fall within the initially defined ranges of the control charts, which indicates the stability of the robotized welding process and the possibility of using the initial parameters of the control charts.

3. When using ESAB AristoRod welding wire for robotized welding, the mean strength value is 28% higher than the mean strength value when using WS Weldeship welding wire, and also higher than the upper control limit value of the control chart representing mean values for robotized welding.

Thus, the robotization of industrial processes is an effective way to improve production. And not just for the manufacturer of a particular piece of equipment. The experience of implementing the industrial robotics solutions by OKS LLC shows that it is also an opportunity for the consumer company to be confident in the quality of purchased products.