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APPLICATION OF SELECTED METHODS AND TOOLS FOR IMPROVING THE PIPE PRODUCTION PROCESS WITH WELDED PROBES

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Purpose: Welding is one of the most commonly used methods of joining parts in the manufacturing industry. Unfortunately, during the welding process, a phenomenon in the deformation of the welded part occurs. With the required high geometrical accuracy, deformations negatively affect the ability of mounting a given part (Ferenc, 2007). The article presents a method of minimising pipe deformations with welded probes.
Design/methodology/approach: The paper focuses on welding – method of joining metal parts and using selected quality management methods and tools (Wolniak, and Skotnicka, 2011).
Findings: The cause of defective products was found.
Practical implications: It has been developed a tool that minimizes the deformation of the welding process. The amount of defective products was minimized from 100% to 2% in the analyzed case.
Originality/value: The presented methods can be used in production processes in which welding is used.

Keywords: welding process, FMEA, minimisation of inconsistent products.

Category of the paper: technical paper, case study.

1. Introduction

Pipes with welded probes are used in the production of car exhaust systems. They connect the engine-mounted catalysts to the rear exhaust system. Such a system is called Cold End. It is responsible for the final purification of exhaust gases and examination of exhaust gases with sensors and acoustics. In the car it connects to the Hot End, which is mounted directly to the engine (Fig. 1).

The welded probes perform the function of sockets, screwed to which are temperature and exhaust gas sensors during assembly of the car.

The tolerance of the dimensions of the part, tapered to the very limit, causes the resulting deformation of the welding process to affect the efficiency of the production line.

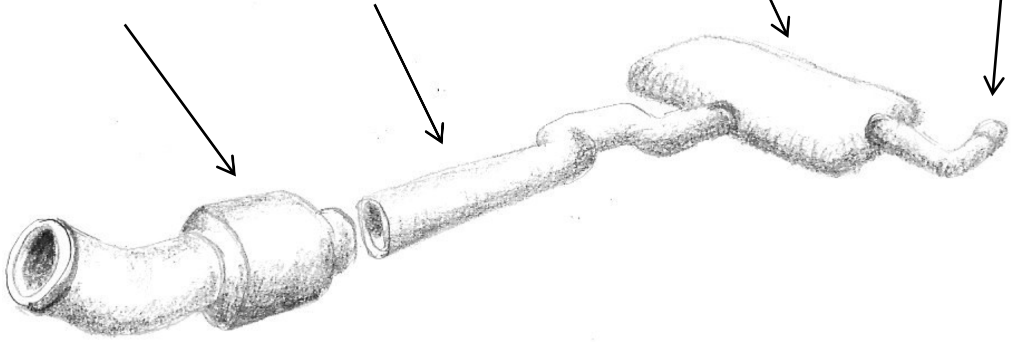

Figure 1. Diagram of parts included in the Cold End system. Based on: Wróbel K.: Analiza i doskonalenie procesu produkcji rur z wspawanymi sondami. Praca magisterska obroniona na Wydziale Organizacji i Zarządzania Politechniki Śląskiej pod kierunkiem dr inż. Krzysztofa Michalskiego, Zabrze 2020.

2. Identifying the causes of inconsistencies

Application of the Run at Rate method at such workstations as: 1. welding pipes with the robot, 2. tightness test and calibration, and 3. inspection of geometry and packaging, revealed that the bottleneck of the process is workstation 2. The area was indicated as necessary for improvement. Table 1 shows a comparison of the real time of performing activities with the quickest possible time of their performance without any disruptions. "Quickest possible CT" has been empirically measured.

Table 1.
Summary of cycle times measured during run at rate

Position	Average CT during R@R [min]	Quickest possible CT [min]	Comments
1	2.2	2.08	2 pcs/cycle
2	1.65	1	
3	1.65	0.83	

A line balance was also made, taking into account the cycle time of 1 piece. Figure 2 presents a graph.

Figure 3 shows the Pareto Chart, summarising the losses observed during run at rate at station 2.

Based on the run at rate analysis, the largest cause of line losses was determined – recalibration of the pipe. The next step is to analyse the reasons for the recalibration. This was done using the Ishikawa diagram (Fig. 4).

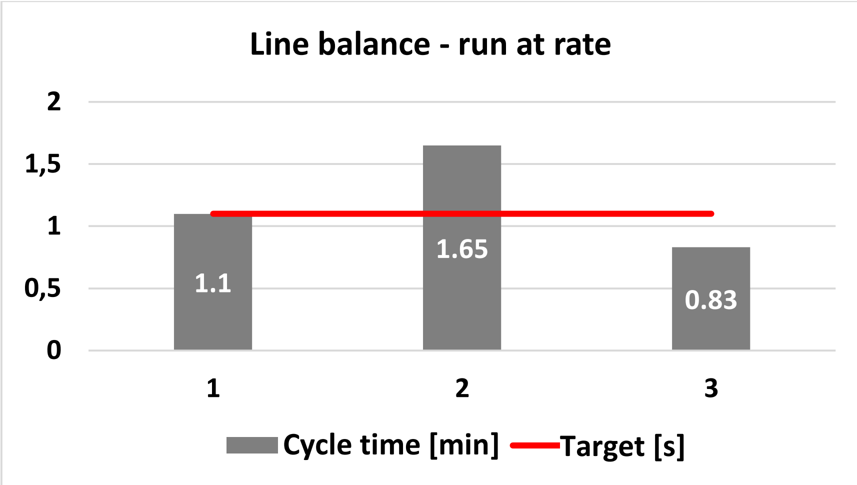

Figure 2. Line balance during run at rate.

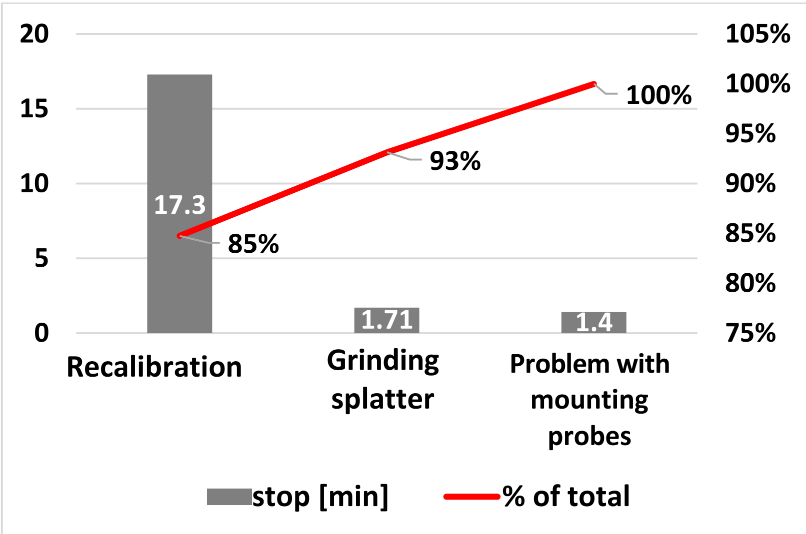

Figure 3. Pareto Chart of losses during run at rate.

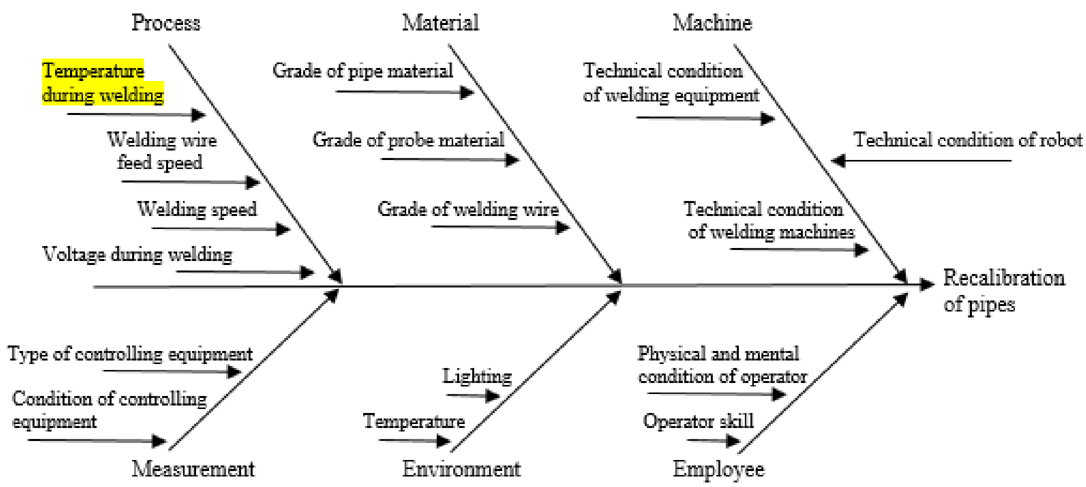

Figure 4. Ishikawa diagram of reasons for recalibration.

The heat generated during the welding process was defined as the biggest reason for the recalibration, which results in welding deformations of the pipe.

The FMEA analysis of the recalibration of the pipes was then carried out (Table 2).

Table 2.
FMEA recalibration analysis

Required function / required process	Potential effects of the defect	Weight	Potential reasons for (mechanical) defects	Occurr-ence	Current control		Detect-ability	RPN	Recommended action	Results of actions				
					Prevention	Detection				Action taken	Weight	Occurr-ence	Detect-ability	RPN
Inconsistent pipe inlet diameter	Customer complaint - lack of ability to mount pipe	6	Unsuitable welding programme parameters	9	Specification of parameters	-	2	108	Blocking the possibility of changing parameters to unauthorised persons	consistent with recommen-dations	6	1	2	12
Inconsistent pipe inlet diameter	Customer complaint - lack of ability to mount pipe	6	Inadequate technical condition of welding equipment and robot	7	Yearly inspections	-	2	84	Implementing the TRM system at the workstation	consistent with recommen-dations	6	4	2	48
Inconsistent pipe inlet diameter	Customer complaint - lack of ability to mount pipe	6	Inadequate control and measuring equipment	6	-	-	2	72	Control list with allowed control equipment	consistent with recommen-dations	6	2	2	24
Inconsistent pipe inlet diameter	Customer complaint - lack of ability to mount pipe	6	Inadequate condition of control and measuring equipment	6	-	-	2	72	List of KP equipment with specific verification frequency	consistent with recommen-dations	6	1	2	12
Inconsistent pipe inlet diameter	Customer complaint - lack of ability to mount pipe	6	welding deformations	10	-	-	2	120	Making a calibrating tool that works in the opposite direction to the deformation	consistent with recommen-dations	6	1	2	12
Inconsistent pipe inlet diameter	Customer complaint - lack of ability to mount pipe	6	too little operator skills	4	induction training of employees	-	2	48	Creating a skill matrix for each of the operators. Only a sufficiently trained employee may work in the position	consistent with recommen-dations	6	1	2	12

An FMEA analysis was performed for all significant, defined causes of the recalibration of pipes.

The highest RPN (Risk Priority Number) index was given to welding deformations because it concerns 100% of manufactured pipes.

The second biggest RPN factor is the use of unsuitable welding parameters, as shown in the Ishikawa analysis, the welding speed and wire feed speed affect the amount of deformation.

Other causes of recalibration were also analysed, such as inadequate technical condition of welding equipment and the robot – this has little effect on the process, but it can lead to a worsening of the problem.

Attention was also paid to the possibility of using inadequate or damaged control and measuring equipment.

3. Solution development

A literature analysis was carried out which describes the problems of deformations of pipes in the welding process and the solutions obtained in this field (Hyrcza-Michalska, and Grosman, 2007; Goss et al., 2012; Jany, 2009; Pilarczyk et al., 2011; Słania, 2012; Juffy, 1962; Fortain, 2009). A process improvement solution was then developed: the proposed corrective action is the implementation of a tool that nullifies the effects of deformation, working in the opposite direction to welding actions. In order to design it, 30 pipes were measured to determine in which direction and how repeatedly the welding deformations propagate. Measurements were made immediately after the cooling phase, before calibration. The pipes were measured in two axes X and Y.

This allowed to define the dimensions of the calibration tool, whose task will be to calibrate the pipe from the X and Y axes in the opposite direction to the effect of strain.

The standard expansion tools used in calibrators have a round shape. They are made of a cylinder divided into eight segments. In the centre of the cylinder is a milled hexagonal hole for a pin. A calibrator is a machine that uses oil as a medium for working. The pin is moved back and forth by means of a hydraulic actuator, which, moving deeper and deeper into the groove of the barrel, increases its diameter. These types of equipment are not, however, adapted to calibrate oval shapes.

As a precautionary measure, in the case of using unsuitable welding parameters, blocking the ability to change welding parameters to unauthorised employees is recommend.

Implementation of TPM (Total Productive Maintenance) at workstations would correct the inadequate technical condition of welding equipment and the robot. Appropriate instructions on how to check the technical condition and define the frequency of inspections will eliminate these causes. In the case of using inadequate or damaged control and measuring equipment, creating a list of such equipment and determining the required frequency of its verification is recommended. The occurrence of these inconsistencies may lead to the omission of the inconsistent product, the use of an appropriate control method is of great importance, especially if a situation occurred such as the one on the analysed line – a very high percentage of inconsistent products.

4. Making a calibration tool

The basic corrective action for inconsistent products was the creation of pipe calibration tool. The expansion tool, designed to improve the production process of pipes with welded probes, will work in the same way as a standard calibration tool but it will have an oval shape. The following figure (Fig. 5) provides an overview of the dimensions of the tool before and after expansion against the background of the dimensions of the pipe.

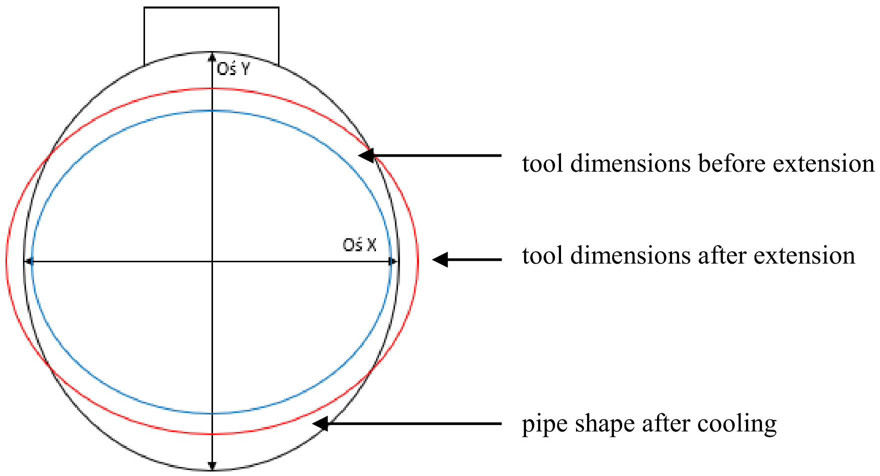

Figure 5. Sketch of the tool dimensions before and after expansion with respect to the pipe contour.

The functioning principle of this tool is to extend the pipe in the X axis beyond the permissible diameter. This is to reduce the dimension in the Y axis (the material will be 'pulled' in the direction of the X axis) and to increase the dimension in the Y axis (direction of forces working on the material of the pipe presented in Fig. 6).

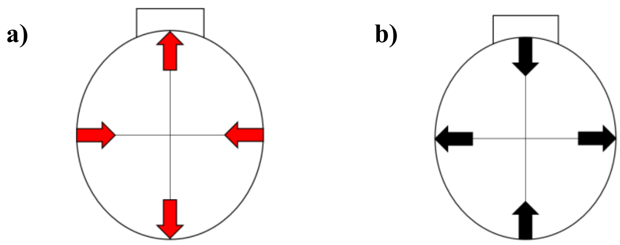

Figure 6. Direction of a) welding deformations on the pipe material during cooling, b) forces on the pipe material during expansion with an oval tool.

After such an operation, the pipe will have a reduced oval shape, however, its dimensions will still be inconsistent. Therefore, the second step will be the tapering of the pipe, also made on the calibrator. This time a standard round tool will be used, which is designed to finally reduce the dimensions in the X and Y axis to the ones required. The operating principle is to insert the pipe inside the tool, after starting the calibrator, the diameter of the tool decreases to the specified size, causing the pipe to be calibrated to a smaller size, maintaining the round shape of the tool. This type of tool could not be used before because the dimensional difference in the X and Y axes was too large, it is impossible to make a tapering tool with the necessary range of operation. To reduce the dimension in the Y axis, hammering was used. After using an oval calibration tool that reduces the difference in dimensions in the X and Y axes, it is possible to use such a tool.

A picture of the tapering tool is shown in Figure 7.

Figure 7. Tapering tool.

5. Implementation of the tool

The first stage of implementation was the design and making of the tool. For the first attempts, it was decided to make the tool with a non-hardened metal. The purpose of this was to leave the possibility of later grinding the tool segments in the event that the assumed dimensions did not fulfill their function. Using the tool in such a condition on several dozen pieces during the first implementation is safe for its general condition, it will not wear out. However, it is not allowed to produce more pipes using unhardened tools, which can lead to tool breakage and a general change in geometry, which would entail reincurring relatively high costs.

The first attempts proved to be successful, dimensions specified on the basis of previous process analysis and dimensions of pipes after cooling correspond to the assumptions. Pipes calibrated with an oval tool increase the diameter in the X axis and decrease in the Y axis in accordance with the expected, desired effects of this operation. This only makes it possible to calibrate the pipe automatically, using a new, oval expansion and standard tool for tapering. This eliminated the need for manual hammering and accelerated the entire process at this workstation.

6. Verification of results

After completing the tool and installation on the line, run at rate was again performed at the tightening test and calibration workstation. The hammering operation has been completely eliminated. The need for one recalibration did not drastically affect the cycle time because the calibration is now only automatic, which is faster than manual hammering.

The line balance, after implementing the changes, is presented in Figure 8.

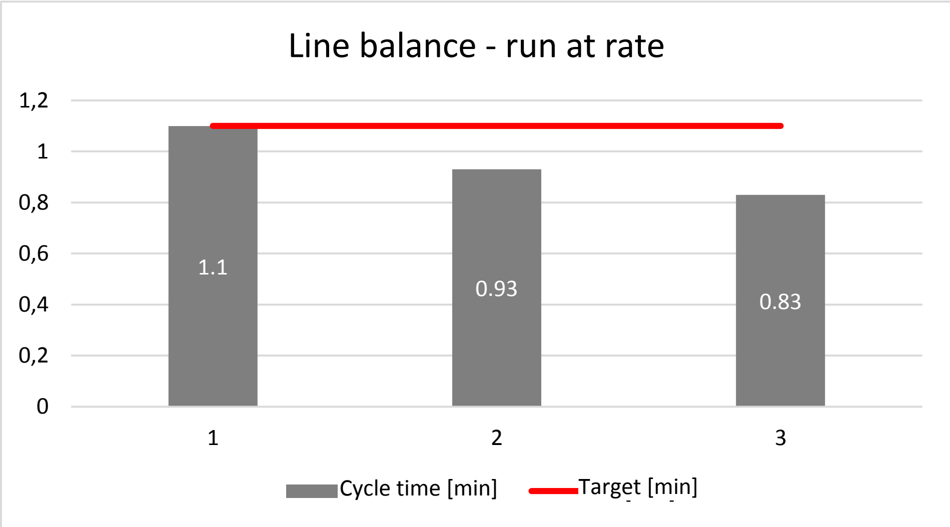

Figure 8. Line balance after implementing the tool.

The elimination of additional manual hammering operations has increased the line's efficiency. The table below (Table 3) compares the efficiency of the production line and the level of pipe calibration rework (repair) before and after the implementation of corrective actions.

Improvement of the production process allowed to increase the efficiency of the line by 49%.

Table 3.
Comparison of efficiency and rework before and after the implementation of FMEA corrective actions

	Cycle time [min]	number of pcs./1 change	% pipe repair after calibration
Before improvement	1.65	273	100
After improvement	1.1	409	2

Figures 9 and 10 show in turn: line balance before and after improving the process, and the number of pieces produced per shift before and after the implementation of the tool.

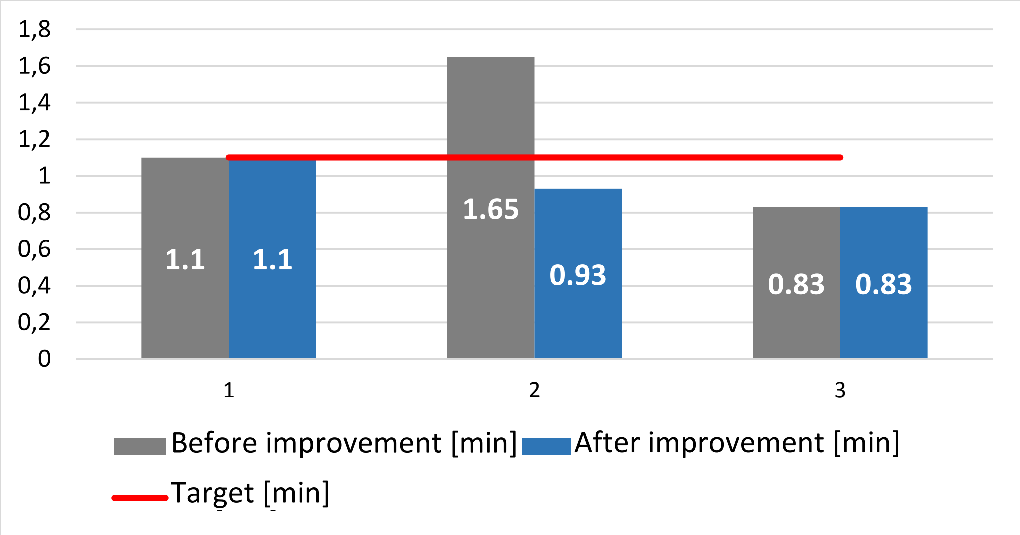

Figure 9. Line balance before and after improving the process.

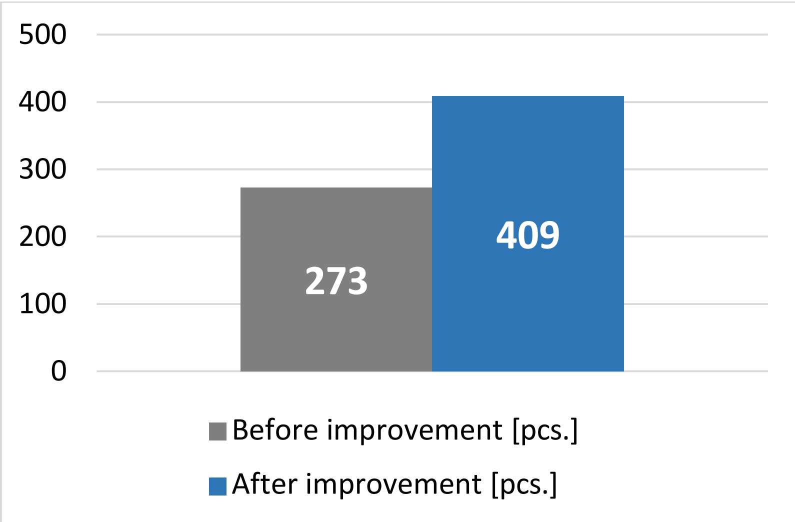

Figure 10. Number of pieces produced per production shift before and after improvement.

The level of additional pipe calibration repair from 100% has been levelled to 2%.

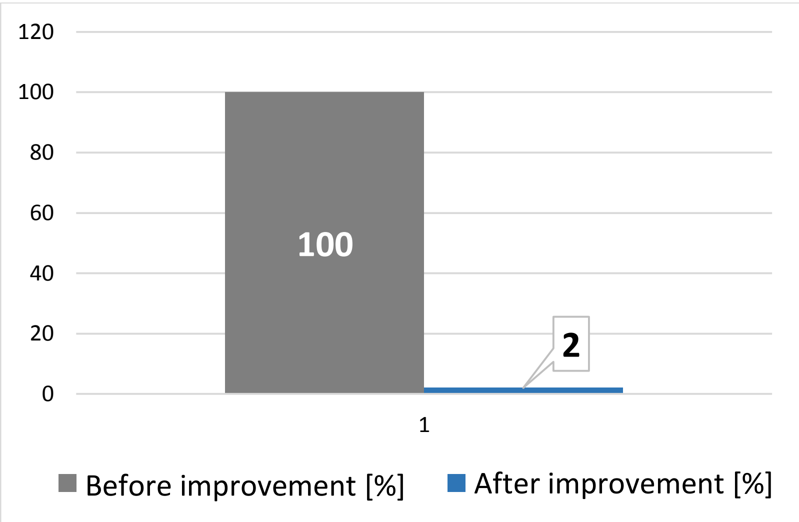

Figure 11. Diagram of the recalibration percentage of the pipe at workstation 2 before and after improving the process,

7. Summary

The welding process is a special process, its control and improvement are difficult due to its operating principle (Pilarczyk, 2017). Deformation and welding stress will always accompany production lines using this method of bonding materials (Madej, 2019; Messler, 2004). Depending on the geometry and grade of materials combined, their negative effects will be more or less visible (Rhodin, 2012; Božičković et al., 2012). The article presents the methods of analysing such production lines and the methodology for nullifying the effects of welding deformations. First of all, the directions of their operation should be determined, and then technical auxiliary measures should be designed and implemented, there will most often be additional tools that change the geometry of the welded product and the selection of the appropriate welding method.

Therefore, the presented solutions and methods of analysis can be adapted to the vast majority of production lines, not only in the automotive industry, but in every industry using welding.

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