IOP Conf. Series: Materials Science and Engineering **400** (2018) 022051 doi:10.1088/1757-899X/400/2/022051

Joining methods in car body construction

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Abstract. Growing requirements from customers for quality and safety, also strictive emissions limits caused for automobile manufacturers researching for new solutions and materials. The development of the automotive market is associated with the enrichment of societies and, consequently, increased demands. Modern production systems meet needs of corporations. However, automation and robotization of traditional production methods or assembly are not always sufficient [4]. In order to improve the quality of products and reduce costs at the same time, it is very important to carefully analyze each stage of production. The key step in designing a new car model to enter the market is choosing the right method to join the elements into a whole body. The random car body consists of 4,000 spot welds, 13 meters of welds, 90 meters of glue [9]. Most of the car body elements are sheet metal with a thickness of less than three millimeters. The aim of the study to present various methods of joining car body parts and to compare their strength in an analytical way and using the finite element method. Particular attention has been given to the clinching, which becomes a cheaper and more flexible alternative to resistance spot welding.

1. Introduction

Considering problem concerns the integration of a new model to the produced series of cars. The existing production line is adapted to the production of one of the known models of panel vans in various length and height versions. The manufacturer also plans to introduce this model in the eleven-person minibus version [5,6]. For reasons such as travel comfort and safety requirements, a few changes related to the construction of the car body should also be set. These include changes in the side walls shape (adding windows), adding next doors and changes in the shape of the roof due to the necessity to implement the emergency exit. The subject concerns the connection of roof cross members to the frame of the hatch located in the roof. It was decided to combine them using special adapters figure 1. The production profile should be changed in the least intrusive way to existing devices, control programs and be able to flexibly adapt to current needs [2, 3].

The frame of the hatch will be connected to the intermediate parts by spot welding. The horizontal orientation of the parts and the chamfering of the pipes allow the process to be carried out automatically without major problems. Introducing this process into the existing production plan enables adaptation of the existing empty, two-story cell intended for the introduction of the future model. The proposal for the arrangement of devices in the adapted space is presented below figure 2. Both elements will be delivered above the roof height using special, vertical conveyors [5,11]. The frame is taken directly from the conveyor, while the cross-member must be transported to the other end of the cell on the horizontal conveyor. Then robots equipped with grippers ensuring repeatability of the geometry position, connect elements to the rest of the body. Docked grippers ensures the

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positions accuracy of the car parts at least at the level of 0.1 mm. The retooled robots equipped with welding guns perform the resistance welding process. After the process, the bodywork leaves on the skid conveyor.

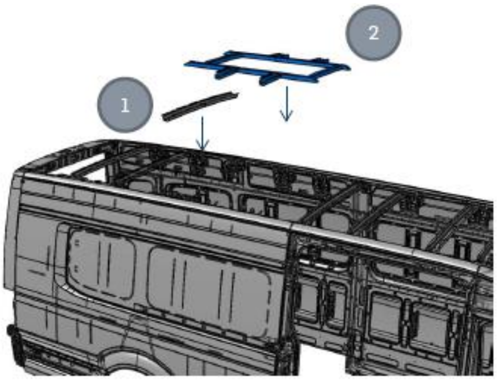

Figure 1. Marked: 1. Cross member. 2. Frame of the hatch.

On the other hand, it is problematic to connect the adapter part with the hatch frame. The Q feeder must already contain roof members assembled with adapters. The appropriate joining method should be chosen, which will meet the strength requirements and the costs of its introduction will not be high. Strength verification will be carried out using the analytical method as well as the computer finite element method. The methods considered are:

- spot welding,
- clinching,
- electric arc welding,
- riveting,
- adhesive joining.

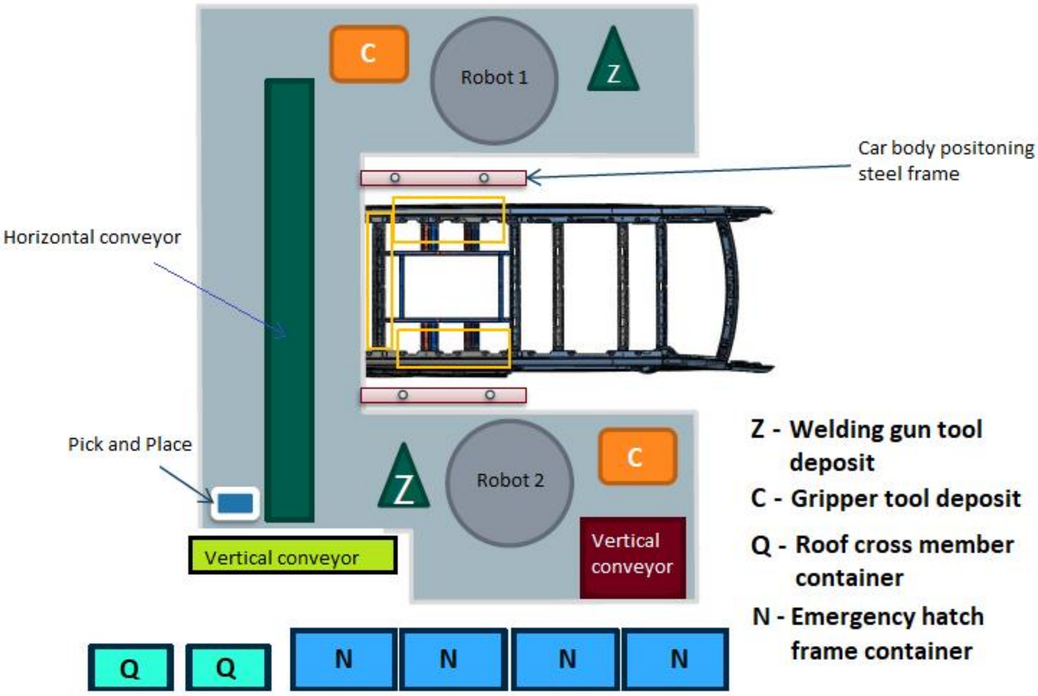

Figure 2. Proposal of layout in a cell intended to integrate the line for introducing of a new model [3].

2. Analysis of selected connection methods – analithycal calculations

This connection will work under the weight of the emergency frame. The shear force is symmetrically distributed over four elements connecting the frame with the two roof cross members. The weight of the element is 86 N. This gives a static load of 21.5 N per one adapter, figure 3.

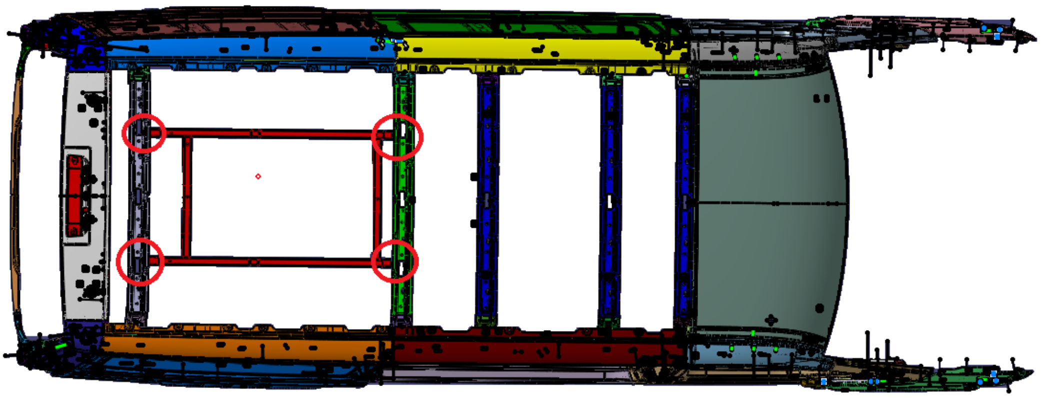

Figure 3. Marked areas where the gravity of the manhole cuts the adaptation elements.

All strength calculations must be based on the principle that the actual stresses must be less or at most equal to the allowable stresses. The yield strenght of this material is taken as the basis for the selection of acceptable stresses for plasticity materials. In this case, it is steel with the yeld strenght of 275 MPa and tensile strenght of 500 MPa. In order to obtain more certainty, a safety factor is introduced. The joint will work only under the weight of the manhole, so the calculations will apply to static loads. For steel with constant loads its value for shear loads is assumed to be in the range of 2.5-3. Due to the degree of responsibility, it was taken value of 3. So for steel with a yield strenght of 275 MPa, for which the stress value will be calculated will be 92MPa.

2.1. Arc welded connection

The calculations will be carried out for welds in the areas marked below, figure 4. Welding in the direction perpendicular to the modeled welds would be impossible because of the size of the MIG / MAG electrode.

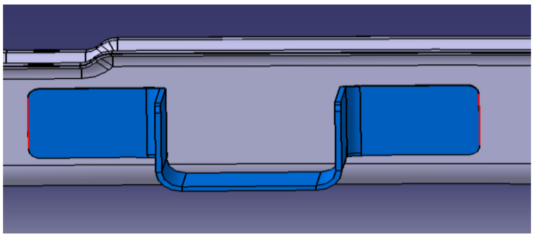

Figure 4. Marked locations of welds.

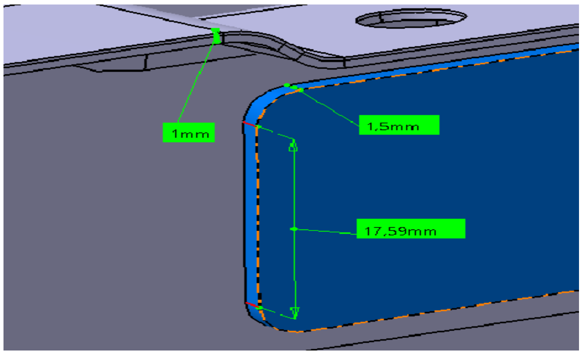

Figure 5. Determining dimensions the size of the weld.

For the designed size of the weld figure 5, the size of a one active cross-section area is A = 12.3 mm2. Permissible stress for this connection is 64 MPa.

2.2. Spot welded connection.

The reengineering involved welding in four points on one element, figure 6. The PN-EN 74-1: 2006 standard defines the parameters of spot welds in relation to the thickness of the sheets. For class A welds (electronic control welder, adjustable welding conditions, hydraulic or pneumatic clamping of electrodes) for given sheet thicknesses, their diameter is 5 mm. According to the table contained in the standard, the breaking force of one weld is 2400 N.

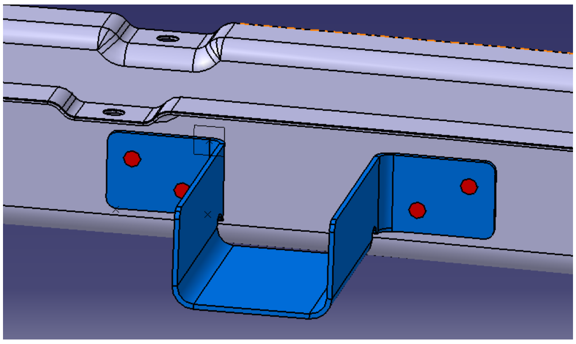

Figure 6. Adapter welded with roof cross member.

2.3. Riveted connection

The riveted connection is also designed as a four-point connection. Precisely at the same points it was planned to use blind rivets (DIN 7337) with a diameter of 5 mm, figure 7. In strong joints it is use to imply the diameter of rivets as doubled sum of the joint thickness. In addition, according to the design recommendations, the minimum distance of the rivet axis from the edge of the sheet should be e = 1.6d. In connection with this guideline, an 8 mm gap from the edge was kept, figure 8.

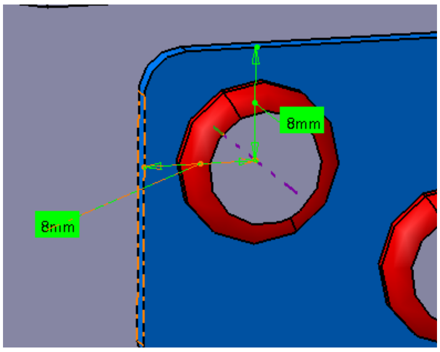

Figure 7. Fulfilled condition of the distance from the edge.

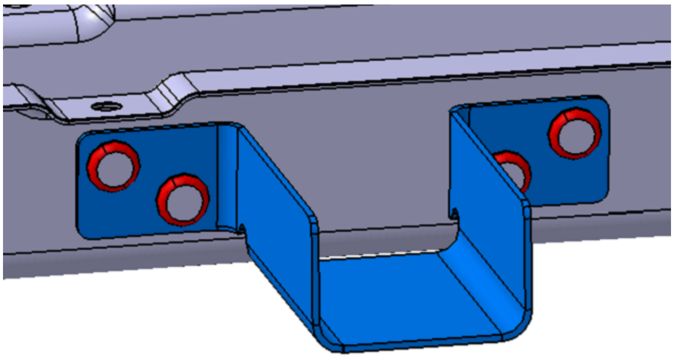

Figure 8. Riveted connection model.

For standardized St2N rivets materials tensile strength is from 340 to 420 MPa. In the case of ordinary joints, the lower value of the allowable shear stress is k_t = 80 MPa. The calculation of the riveted connection requires, additionally to taking into account also a check of the strength of the surface pressure of the rivet and joining elements.

2.4. Adhesive connection

Usually, testing adhesive joints, connections are made in the laboratory to simulate structural joints. There are substrates of the same materials, the same adhesive and the same curing cycle are used. Then, strength and other mechanical properties are measured. In the production of presented car's body some elements are combined using a two-component adhesive based on epoxy resin with an activator. The adhesive has a density of about 0.98 g/cm3. The manufacturer declares a shearing strength of 22 ± 2 MPa (according to ASTM D 3039). Temperature resistance ranges from -55° to + 120°C. The optimum thickness of the adhesive is 0.05 - 0.2 mm. The thicker layer reduces the strength of the connection, because its destruction occurs through cohesive damage (shearing of the adhesive itself). Designing adhesive connections, it should be remembered that the joint should be subjected to shearing forces only. The presence of a normal stresses causing tearing significantly reduces the properties of the connection.

2.5. Clinching

The calculations for the clinched connection were only analyzed using the finite element method. They were modeled according to the of clinch joints used in the production of another vehicle belonging to the same corporation, figure 9. The most important parameters determining the strength of the connection are:

- narrowing p: determines the strength of the shear joint; if the p value is too low, the material from the stamp side breaks in the thinnest place,
- overlap z: determines the strength of the transverse tensile joint called plucking, because in the case of normal force the joint is usually disconnected, without violating the material from the side of the punch and die.

Having the parameters p, z and an information on the geometry of the pneumatic Press, using the Generative Shape Design module, a 3D model of the joint was designed, figure 10.

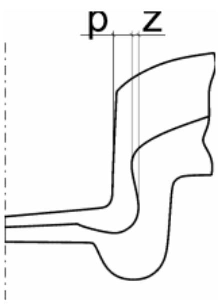

Figure 9. Basic parameters of the clinched joint.

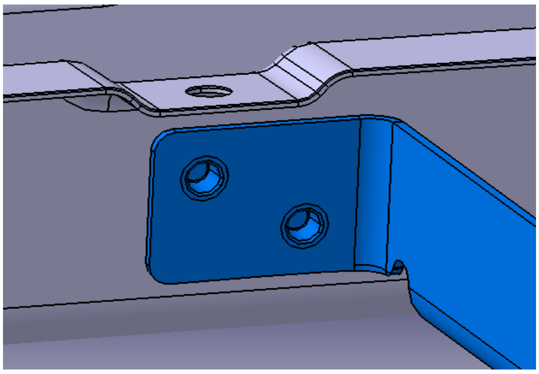

Figure 10. View of the clinched connection model from the punch side.

Additional geometrical features of the clinched joint are shown in figures 11 and 12.

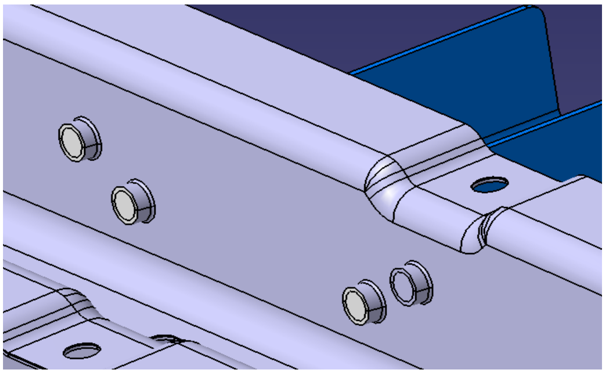

Figure 11. View of the clinched connection model from the die side.

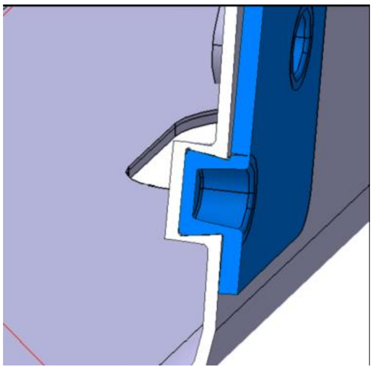

Figure 12. Cross-section of a clinched joint model.

2.6. Results summary

The results of analytical calculations clearly indicate that the permanent load applied to the connection is many times lower than the joint strength. However, it can be seen that the rivet connection is several times more resistant to this type of stress. It should also be taken into account that during many years of vehicle using, various situations may arise in which the joint would be loaded with dynamic, impact and thermal loads.

The percentage of joint loading for particular connection methods was:

- Arc welding: 1.35%
- Spot welding: 0.9%
- Riveting: 0.22%
- Adhesive joining: 3.95%.

The more difficult issue is the strength calculation of the clinched joint. It depends on the dimensions and construction of this joint. The main difficulty is, first of all, the lack of a clearly defined method of calculating this kind of joints. Statistical results show that the static shear strength is smaller than the arc or spot welded joint. Fatigue strength is compared. The calculations were made only by the finite element method.

3. Calculations by the method of finished elements

Strength calculations were performed using the finite element method in the CATIA V5 application in the General Structural Analysis module. The issue was considered for a static issue. Mesh parameters were left as default. Depending on the size of the elements, the program selected the size of finite elements. As the boundary conditions, the cross member has been fixed in places where it will actually be welded to the side walls of the vehicle. Strength calculations were carried out for two cases - a load of 21.5N and for a load twenty times greater (possibly occurring during a road collision). The results presented include stresses and displacements. The force has been set as distributed on the surface where the frame is positioned. Also included was the gravity of Earth equal to 9.82 m / s^2.
List of results of the carried out tests, (table 1 and table 2):

Table 1. Maximum displacement values under two assumed loads in millimetres.

Load	Arc welding	Spot welding	Riveting	Adhesive	Clinching
21.5 N	0.48	0.188	0.223	0.17	0.118
430 N	9.6	3.22	3.39	3.4	1.41

Table 2. Maximum stress values under two assumed loads in MPa.

Load	Arc welding	Spot welding	Riveting	Adhesive	Clinching
21.5 N	76.1	41.5	109	260	122
430 N	1562	804	166	416	237

4. Optimization and method selection

On the basis of the carried out strength tests, the optimization of the choice of method was also taken into account the technological issue. By technological aspects it is understood in this case the ease and cost of introducing an of every method without affecting the existing production profile. From the point of view of production planning, the combination of these two elements is sufficient time to carry out these operations manually. This is because the bottleneck is created at this point in the process due to the time the elements are delivered by the feeders. The size of the planned series makes it possible to refuse the full automation of the process without necessity of employing a new worker. It is much

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cheaper to learn an employee and reorganization of work than purchasing and programming a third robot [1, 8, 10]. Therefore, technologically, it will also be possible to construct a device that does not take up too much space to carry out the required operations. For example, a manual gun takes up much more space than a riveting tool. Each of the optimization criteria was rated on a scale from 1 to 10. In the case of strength criteria 1, was the worst result and the best was 10. For technological features, the assessment was made by subjective value assignment. The following factors were used for the optimization criteria with the same weight [2, 7]:
K1 – Maximum displacement at the load of 21.5N. K2 – Maximum displacement at the load of 430N. K3 – Maximum stress at the load of 21.5N. K4 – Maximum stress at the load of 430N. K5 – The cost of the method introducing. K6 – The difficulty of the method introducing. K7 – Safety of the service. K8 – Required qualification of the worker, table 3.

Table 3. Maximum stress values under two assumed loads in MPa.

	Arc welding	Spot welding	Riveting	Adhesive	Clinching
K1	1	8	7	8	10
K2	1	8	8	8	10
K3	8	10	5	1	5
K4	1	5	10	8	10
K5	7	4	9	6	1
K6	3	7	10	9	1
K7	1	2	8	10	5
K8	1	5	10	10	5
$\overline{X}$	**2.875**	**6.125**	**8.375**	**7.5**	**5.875**

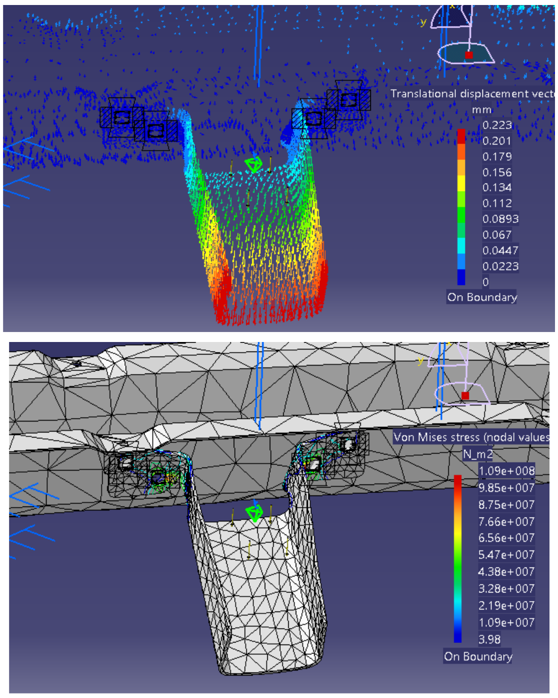

Figure 13. View of the clinched connection model from the die side.

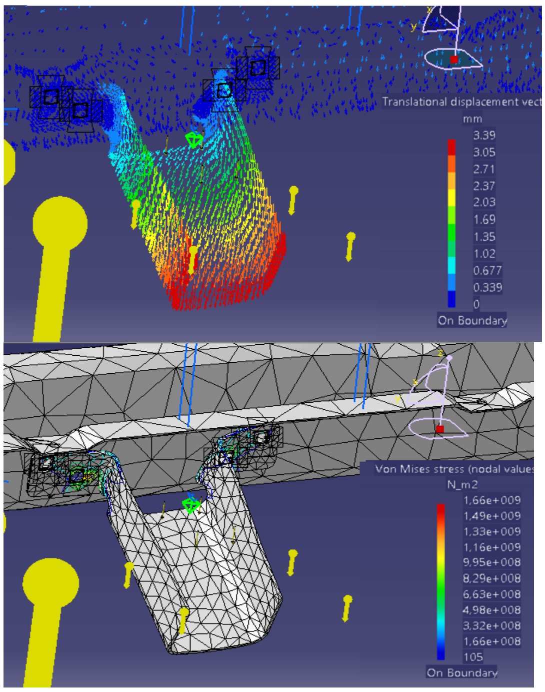

Figure 14. Cross-section of a clinched joint model.

The FEM results regarding displacements and stresses for a selected rivet connection are shown in figures 13 and 14.

5. Conclusions

Despite the fact that durability tests speak clearly for the use of clinching or gluing, due to the characteristics of the existing production line, it was decided to use traditional joining methods. The plant does not have adequate equipment to carry out this type of method, and their purchase would be beneficial when it will be introducing of a new model and production profile will be completely changed. The purchase of specialized equipment for the need to make several joints with compared to the entire body structure has no economic justification. The roof cross member geometry would force the use of custom designer welding guns in the case of a spot weld using. This solution generates problems related to the need for the construction of a specific welding equipment the production of which would prove unprofitable. The welded or riveted connection seems more technological [2]. However, the welded joint showed the greatest deflection during the strength analysis. The most rational way seems to be riveting the considered elements. What is more manual welding of thin-walled requires the skill of a welder. Manual drilling and riveting devices are definitely safer, easier to use and cheaper than welding machines. The optimization shows that the elements should be connected by riveting. The developed results, however, give an idea of the strength parameters of the other types of joint and encourage to include another model when new production is planned. Special attention should be taken to the simulation results for gluing and clinching, i.e. the most modern methods. When implementing the next generation of the model, the introduction of these methods may prove to be expedient not only technically, but also economically.

The analysis shows that joining the considered details by riveting is the most reasonable. The shape of details, strength properties, and a relatively low cost of integration this method are the main arguments for adopting this assumption. The issue under consideration shows that not always modern methods and automation are optimal solutions, even in a modern factory.

6. References

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