AUTOMATION OF SHIELDING GASES WELDING PROCESS - WELDING ROBOT VERSUS HUMAN

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Summary
The aim of the work was to determine which fusion welds are of higher quality and have better mechanical properties – those made by an experienced welder or by an industrial robot. Comparative tests have been performed for butt welds made in the down hand position by means of string and weave beads. Test joints made of S235JR steel has been welded. Metal active gas welding has been used. The joints have been put to the visual and penetrative tests. The results of tensile test of transverse test pieces, Charpy impact test and Rockwell hardness test have been compared. Conclusions have been formulated.

Keywords: manual welding, robotization of welding, tests of welded joints

1. Introduction
Welding is one of the most frequent methods used for joining metals. It is at the same time described as a dirty, dusty and dangerous process. It involves such phenomena as: splinters, slag, gases and radiation. Due to the fact that joint production is time-consuming and it often entails the necessity to work in a limited area, the welder’s organism is exposed to long-term harmful influence of ultraviolet radiation and poisonous fumes.
In order to reduce the harmful effect of the above-mentioned factors on a human organism, along with the industrial development and particularly with the implementation of advanced electronics in machines, new welding technologies as well as devices fully or partially automating the welding process have been developed [1, 2]. Although automatic welding machines replaced the welder in the process of making welds, their work still requires the presence of a man. Thus, the natural consequence of technological progress is aiming at complete replacement of human by machines. Therefore, industrial robots have been dominating as automatic welding machines for umpteen years. They are produced both as welding robots and universal robots which are later adjusted for welding.

Automation and particularly robotization of the welding process brings a lot benefits. These include: moving man away from work in dangerous and difficult conditions, training costs reduction, increasing production efficiency, eliminating the risk of defects resulting from tiredness, better production repeatability and joints quality, reducing the wear of welding materials and increasing the control of the welding process. The above-mentioned factors are arguments for implementing the robotized welding system. The argumentation is presented in papers [3-5].

The dominating technology applied in the process of joining metals is shielding gases welding with the use of consumable electrodes (methods: MIG – metal inert gas welding, MAG – metal active gas welding), both in the case of welding robots and automatic welding machines [6, 7]. Thanks to numerous advantages, including universal character of both methods, shielding gases welding enables joining various metals and alloys both in workshop and assembly conditions, in all positions. However, due to the fact that welding is a multi-parametric process, producing a joint correctly requires taking into account many factors such as:

- The shape of the joint, the thickness and the type of the welded material;
- Fitting accuracy and the distance between the edges of the joined elements;
- The position in which welding will be performed.

The quality of the weld and stability of the welding process will be conditioned by the ability to choose the following parameters correctly:

- The type of current, its polarity and intensity;
- Arc voltage;
- Shielding gas composition;
- The speed of electrode feeding;
- The distance of the nozzle mouth from the material and its angle of inclination;
- Welding speed;
• The movement of the electrode relative to the joint i.e. the type of welding bead.

In the case of manual welding, all the parameters are chosen by the welder on the basis of his experience and are dependent on his manual skills. Additionally, they may be modified during the process of making a joint in order to correct possible deviations and errors.

During welding performed on the robotized stand, particular process parameters and the relationship among them are chosen on the basis of the programme controlling the work of the robot and a welding machine. Therefore, the realization of welding, where open-loop control is applied, requires thorough preparation of elements and a high repeatability of dimensions.

The attempt of experimentally checking which fusion welds have better quality and mechanical properties, those made by an experienced welder or those made by a robot, was taken in this work. Moreover, the aim was to determine how far the precision performed by a robot influences joint quality.

2. Preparing elements for welding

The tests were performed for butt welds made in down hand position. Sheet metal plates made of S235JR steel with dimensions of 5x150x350 mm were chosen for welding elements. The dimensions of the joined elements were chosen according to PN-EN ISO 15614-1 [8]. On the basis of the standard PN-EN ISO 9692-1 [9] (which contain the guidelines concerning preparation of the joints for welding), the distance between the joined elements was assumed to be 6 mm. It was determined that the edges of the elements will not be scarfed. A copper backing bar was used along the whole length of the gap between the elements (Fig. 1). The elements were mechanically cleaned before welding.

3. The course of tests

Comparative tests whose aim was to determine which welds have better quality and mechanical properties, those made by a man or by a robot, were performed with MAG method. The FRONIUS TPS-4000 type welding machine was used. CORGON (Ar 82% + CO₂ 18%) gas and G3Si1 (φ 1.2 mm) copper-plated solid wire were used for welding.

First, a qualified welder with 20 years experience chose the parameters of welding machine work by trial method. Next, he welded test joints trying to make a weld in the shortest time possible. The welder applied string bead welding and next welding with weaving. During the welding process the time of making welds was measured.
Fig. 1. The view of metal plates prepared for welding (before making the positional weld)

The information obtained from the welding process performed by the welder (Table 1) were used to programme an industrial robot and a welding machine installed on it [10]. Next, Kawasaki FA 06E type, six-axis industrial robot made test joints with the string and weave bead method. The same parameters of welding machine work as during welding performed by the welder were used. Programming the robot, the attempt to maintain the same nozzle position as the one applied by the welder was made. In the case of weave bead welding, the frequency and the amplitude of the nozzle mouth movement were chosen on the basis of observing the movements performed by the welder.

Table 1. Information obtained during the welding process performed by the welder

<table>
<thead>
<tr>
<th></th>
<th>Bead type</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Welding parameters</strong></td>
<td>String</td>
<td>Weave</td>
</tr>
<tr>
<td>Welding current</td>
<td>135</td>
<td>125</td>
</tr>
<tr>
<td>Welding load voltage</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>Speed of welding wire feeding</td>
<td>2.6</td>
<td>2.32</td>
</tr>
<tr>
<td>Distance of nozzle mouth from material</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Nozzle angle of inclination</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Welding time</td>
<td>155</td>
<td>200</td>
</tr>
<tr>
<td>Welding speed</td>
<td>13.5</td>
<td>10.5</td>
</tr>
</tbody>
</table>

After the test joints had been made, they were put into non-destructive tests (visual and penetrative). Next destructive tests (tensile test of transverse test pieces, impact Charpy test and the Rockwell hardness test) were also performed [11].

Visual and penetrative tests were done on the entire joints. The test pieces for other tests were taken from the test joints in the way described in the standard PN-EN ISO 15614-1 [8]. Next, they were prepared for other tests according to the requirements of appropriate standards.
Test pieces for tensile test were prepared according to standard PN-EN 895 [12]. Two test pieces were made for each joint.

For Charpy impact test on the basis of the standard PN-EN 10045-1 [13], six V-notch test pieces with dimensions of 5x10x55 mm were prepared for each joint.

For Rockwell hardness tests, one test piece was prepared for each joint in accordance with the requirements of the standard PN-EN ISO 6508-1 [14].

Visual tests were performed based on standard PN-EN 970 [15] with the use of a magnifying glass, slide caliper and weld gauge. The heights of weld faces were determined with the use of a weld gauge (Fig. 2). A slide caliper was used to measure their width (Fig. 3). The measurement was performed along each joint in ten points in an equal distance from one another.

Fig. 2. Weld faces heights

Fig. 3. Weld faces widths
Penetrative tests described in standard PN-EN 571-1 [16] were performed with the use of a set of chemical agents. They consisted in cleaning the weld by means of a remover, applying a dye penetrant for 30 minutes, removing the dye penetrant and applying a developer. A test was performed after 30 minutes of developing.

The tensile test of transverse test pieces was performed in accordance with the rules included in the standard PN-EN ISO 6892-1 [17]. A „Fritz Heckert” tensile testing machine was applied for the tests. The test pieces after the tensile test (with the visible break points) are shown in Fig. 4. The forces applied to break the joints are presented in Fig. 5.

![Fig. 4. The view of test pieces after the tensile test](image)

Impact test was performed with the use of a Charpy pendulum machine with the initial energy of 300 J. For each set of test pieces, average energy used for breaking was determined (Fig. 6). Figure 7 shows test pieces taken from the joints (made with the string bead method) after the impact test.

![Fig. 5. Forces applied to break the test pieces during the tensile test](image)
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Fig. 6. Average values of energy used for breaking the test pieces during the impact test

Fig. 7. Test pieces after the impact test: a) welder – the weld made with the string bead, b) robot – the weld made with the string bead

Hardness test was made with Rockwell method in the following scales:
• B – for the weld;
• C – for the heat-affected zone (HAZ).

The averaged results of hardness test in the HAZ area and along the face and root of the weld are compared in Fig. 8a and 8b.

Fig. 8. Average hardnesses: a) RC for HAZ, b) RB for the face and root of weld
4. Results analysis

On the basis of the visual and penetrative tests, it was concluded that:

- In the case of the weld made with the string bead by the welder (Fig. 9), there is visible porosity and the bead is irregular from the side of the weld face. The face of weld is low. However, there are significant differences in its height (Fig. 2). From the root side, there is visible clear fusion of the weld only in one of the sheet metal plates. Numerous penetrant flaws observed during penetrative tests prove the weld discontinuity.

- In the case of the weld made with the weave bead by the welder (Fig. 10), the face is high with clearly visible fusion into the edge of the sheet metal plate. The differences of the face height are significant (Fig. 2). From the root side, the weld is uniformly fused into both edges of the metal. There are a few discontinuities observed on the joint. However, they are much smaller and less frequent than in the case of the joint made with the string bead.

Fig. 9. The weld made by the welder with the string bead: a) detailed view, b) the result of penetrative test

Fig. 10. The weld made by the welder with the weave bead: a) detailed view, b) the result of penetrative test
• In the case of the weld made with the string bead by the robot (Fig. 11), the bead is very regular from the face side, the face is low, and there are no pores and no lacks of the filler metal. The root is regular with clear visible fusion zone of both edges of the metal plates. During penetrative tests, there were no penetrant flaws, i.e. there were no visible any indications of defects. Therefore, the weld is devoid of any discontinuities.

![Fig. 11. The weld made by the robot with the string bead: a) detailed view, b) the result of penetrative test](image)

• In the case of the weld made with the weave bead by the robot (Fig. 12) both the face and the root were made with high precision. The weld was put down uniformly without any pores or lacks. The face of weld is low. There are no significant differences in the face height along the whole joint (Fig. 2). The weld is devoid of any discontinuities.

![Fig. 12. The weld made by the robot with the weave bead: a) detailed view, b) the result of penetrative test](image)
On the basis of the following tests, where the test pieces taken from the joints were being destroyed, it was determined that:

- During tensile test of transverse test pieces, the biggest force was applied to break the joints made by the robot with the string bead. Only a little less force was necessary to failure of the joints made with the weave bead (Fig. 5). In both cases, breaking of each test piece occurred in the distance of 1.5 to 2 cm from the joint on the parallel part of the test piece. Whereas in the case of welds made by the welder, the breaks occurred in the weld junctions, which proves weak joining of the elements (Fig. 4).

- Performing the Charpy V impact test, the biggest energy was necessary for breaking joints made with the weave bead by the robot. Whereas the smallest force was necessary for breaking joints made with the string bead by the welder (Fig. 6). None of the test pieces made with the weave bead by the robot was broken, and the crack point in five test pieces was the middle part of the weld. Out of the six test pieces made with the string bead by the robot, only one was broken. The crack point was always the middle part of the weld (Fig. 7b). Two test pieces were broken and the next four were not in the case of the weld made with the weave bead by the welder. The crack point was always in the middle of the weld. All test pieces were broken and the break occurred where the weld was joined to material in the case of the joint made with the string bead by the welder (Fig. 7a).

- Hardness of the weld reaches much smaller values than the hardness of the joined material. In the case of welds made by the robot with both string and weave bead, hardness measured along the face and the root of the weld is almost on the same level. However, in the case of welds made by the welder, there are significant hardness fluctuations along the root and relatively good uniformity along the face (Fig. 8b).

5. Summary and conclusions

In order to determine which of the welds have better quality and better mechanical properties – those made by a man or by an industrial robot, comparative tests for butt welds made in the down hand position with the use of MAG method have been performed. Tests have been performed on test joints with significant distance between the edges of the joined elements. String and weave bead welding have been performed.

On the basis of the visual and penetrative tests, it has been claimed that the welds made by the industrial robot were produced with higher accuracy and precision than those made by the man. The weld faces are regular and lack welding discontinuities. Therefore, they are of high quality.

Taking into account the place where the test pieces were broken during the tensile test, one can conclude that the joints made by the welder are incorrect
because the break of each test piece occurred in the place of contact of the weld and the joined element, which proves inadequate joint penetration of the edges.

The highest impact resistance was determined during the impact (Charpy) test for test pieces taken from the joint made with the weave bead method by the robot. Slightly lower values were observed for test pieces taken from the joint made by the robot by mean of string bead.

The results obtained from the research show that the joints made by an industrial robot have better mechanical properties than those made by a man, which in turn results in durability and safety of the welded construction.

Even though the welds made by a robot are much better than those made by a man, robotization of welding stands should be performed really carefully [18]. First of all we should to take into account profitability of the stand [19]. Robotization of welding stands is profitable only in the case of the large-lot production. However, in the case of small-lot production, the cost of the industrial robot and the welding equipment may be much higher than profit [20, 21].

References


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