1. Introduction

In case of steel constructions a few things are very important. One of them are plastic properties of the construction. Properties of the construction it means properties of material of components and properties of connection between components. In case of welded constructions plastic properties of welds are also very important, for example shock, overload [1, 2]. Plastic properties of welds depend on a few things (welding method, parameters of welding process, welding binder, etc.). Moreover, construction durability and safety maintenance under different conditions depend on plastic properties.

In case of welded steel constructions plastic properties depend on structure of weld metal deposit (WMD). Beneficial phase is acicular ferrite (AF). High content of AF is a guarantee of high plastic properties. Safety maintenance of welded construction is effect of proper values of these parameters [3÷8]. Welding with micro-jet cooling is a new interesting way to improve plastic properties of welds. High amount of AF in WMD appears during welding with micro-jet cooling. Amount of AF is higher than in ordinary welding method (e.g. MIG). This fact influences positively on improve plastic properties of welds. This paper describes the influence of welding with micro-jet cooling on plastic properties of the weld in comparison to weld made by ordinary welding method. Additionally, comparison was done for different number of micro-jet streams. Cooling medium was gas (argon). Fact of material heating and cooling influence on structure and properties [9÷14]. Erichsen cupping tests and bending tests were carried out. Figures 1 and 2 present apparatus for welding with micro-jet cooling.

Fig. 1. Apparatus for welding with micro-jet cooling
2. Experimental procedure

Two kinds of samples were made for investigations: samples for Erichsen cupping tests and samples for bending tests. For both kinds of investigations following type of samples were made:

- samples without weld,
- samples with weld made by MIG method,
- samples welded with MIG method with micro-jet cooling with one jet,
- samples welded with MIG method with micro-jet cooling with two jets,
- samples welded with MIG method with micro-jet cooling with three jets.

Argon was chosen as shielding welding gas and as a gas (cooling medium) for micro-jet cooling. The diameter of stream in micro-jet injector was always 40 µm. Samples were welded with different number of micro-jet stream (one, two and three). The main data about parameters of welding were shown in table 1. Figure 3 shows arrangement of jets.

A typical weld metal deposit had chemical composition which was shown in table 2. One type of low alloy S355J2G3 steel was used in investigations. The thickness of the test sample always was 3 mm.

**TABLE 1**

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Diameter of wire</td>
<td>4 [mm]</td>
</tr>
<tr>
<td>2.</td>
<td>Standard current, Voltage</td>
<td>220 [A], 24 [V]</td>
</tr>
<tr>
<td>4.</td>
<td>Shielding welding gas</td>
<td>Ar</td>
</tr>
<tr>
<td>5.</td>
<td>Micro-jet cooling gas</td>
<td>Ar</td>
</tr>
<tr>
<td>6.</td>
<td>Cooling gas pressure</td>
<td>0.4 [MPa]</td>
</tr>
<tr>
<td>7.</td>
<td>Diameter of micro-jet cooling stream</td>
<td>40 [µm]</td>
</tr>
</tbody>
</table>
| 8.  | Number of tested micro-jet cooling jet      | 1 (A)  
2 (B + C)  
3 (A + B + C)  
Situated in equilateral triangle with sides 6 mm (fig. 3) |

**TABLE 2**

<table>
<thead>
<tr>
<th>No.</th>
<th>Element</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>C</td>
<td>0.08 [%]</td>
</tr>
<tr>
<td>2.</td>
<td>Mn</td>
<td>0.79 [%]</td>
</tr>
<tr>
<td>3.</td>
<td>Si</td>
<td>0.39 [%]</td>
</tr>
<tr>
<td>4.</td>
<td>P</td>
<td>0.017 [%]</td>
</tr>
<tr>
<td>5.</td>
<td>S</td>
<td>0.018 [%]</td>
</tr>
<tr>
<td>6.</td>
<td>O</td>
<td>380 [ppm]</td>
</tr>
<tr>
<td>7.</td>
<td>N</td>
<td>85 [ppm]</td>
</tr>
</tbody>
</table>

First investigation was Erichsen cupping tests. In order to determine changes in the plastic properties comparison of depth of the indentation for weld was done. Tests were done with the standard [15]. Investigation points were situated in place of weld. Idea of Erichsen cupping tests was shown in figure 4.
Second investigation was bending test. In order to determine changes in the plastic properties comparison of bend for samples without and with weld was done. Tests were done with the standard [16]. Places of bending were situated in place of weld. Figures 5 and 6 describe methodology of bending test.

![Bending Test Diagram](image1.png)

**Fig. 5.** The way of the calculation of the successive bends of sample [16]

![Bending Test Diagram](image2.png)

**Fig. 6.** Idea of bending tests [16], a – thickness of sample, h – distance from the track to the sample clip, r – radius of support, y - the closest point of contact with the sample clip to sample

### 3. Results and discussion

Figure 7 shows example of samples after Erichsen cupping tests and figure 8 shows the results obtained in that investigations. For all kind of test sample five trials were done. The results are the average of five trials. The higher value of Erichsen cupping index was observed for samples without weld. It was about 13.2 mm. For welded samples that values were smaller than for samples without weld. For samples welded by MIG method this value was about 10.1 mm. Samples welded with MIG method and micro-jet cooling with one jet achieved value about 12.1 mm. Samples welded with MIG method and micro-jet cooling with two jets achieved value about 13.0 mm. Samples welded with MIG method and micro-jet cooling with three jets achieved value about 12.2 mm. It could be observed that welding with micro-jet cooling improves results in comparison to ordinary welding method, but very important thing is number of jets. In this case the best results were achieved for welding with micro-jet cooling with two jets. It should be told that for all cases with micro-jet cooling results were better than for ordinary MIG welding method.

![Erichsen Cupping Test Examples](image3.png)

**Fig. 7.** Example of sample after Erichsen cupping tests; a) – sample without weld, b – wimple with weld

![Erichsen Cupping Test Results](image4.png)

**Fig. 8.** Results of Erichsen cupping tests
First part of this investigation was from first bend to number of bend to appearance first material discontinuities. The best results were achieved for test sample without weld and for cases of welding with micro-jet cooling with two and three jets. The worse result were achieved for samples which were made with ordinary MIG welding method without micro-jet cooling. Use of micro-jet cooling for welding influences positively on results of bending test, during first part of that investigations.

Second part of this investigation was from number of bend to the appearance of the first material discontinuities to number of bends to cracks of sample. In this case the situation is little different. The best results were observed for not welded sample. The worse result were observed for test samples welded with using standard MIG method without micro-jet cooling. Application of micro-jet cooling for welding influences positively on results of bending test, during second part of that investigations. It could be observed that welding with micro-jet cooling improves results in comparison to ordinary welding method. In that cases results are similar to result for non welded samples.

Figures 9 and 10 show the results obtained in bending tests. For all kind of test sample five trials were done.

During the study it was found that very important is number of nozzles that produce streams of cooling medium. Too large number of jets degrades performance of micro-jet cooling. The reason for this may be an interaction between streams of coolant and interrelation disruption the flow of coolant.

4. Conclusions

This work introduced Erichsen cupping tests and bending tests as a measure of the plastic properties for welded samples. An innovative welding process with micro-jet cooling influences positively on plastic properties of the weld. It could have influence on another aspect in welding. The investigations of Erichsen cupping tests and bending tests have been carry out. On the basis of this investigations it is possible to deduce that:

- micro-jet cooling could be treated as an important element of MIG welding process,
- micro-jet technology in welding could improve plastic parameters of welds,
- different number of micro-jet cooling jet influences on weld parameters, but too large number of jets is not the best solution,
- the best results for Erichsen cupping tests were achieved with use of two micro-jet cooling jets,
- the best results for bending tests were achieved with use of two micro-jet cooling jets.

REFERENCES


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