

## MECHANICAL PROPERTIES OF PLUG WELDS AFTER MICRO-JET COOLING

New technology of micro-jet welding could be regarded as a new way to improve mechanical properties of plug welds. The main purpose of that paper was analyzing of mechanical properties of plug welds made by MIG welding method with micro-jet cooling. The main way for it was comparison of plug welds made by MIG welding method with micro-jet cooling and plug welds made by ordinary MIG welding method. It is interesting for steel because higher amount of acicular ferrite (AF) in weld metal deposit (WMD) is obtained in MIG welding method with micro-jet cooling in relation to ordinary MIG welding method. This article presents the influence of the cooling medium and the number of micro-jet streams on mechanical properties of the welded joint. Mechanical properties were described by force which is necessary to destroy weld joint.

*Keywords:* welding, micro-jet cooling, plug welds, plastic properties

### 1. Introduction

Plug welded joints are very popular in steel structures. The geometrical dimensions of these connections are very small, but these connections have a very big load capacity. This kind of welds is suitable especially in hard maintenance conditions of welded constructions [1]. The basic method for making these connections is a resistance spot welding and laser welding [2]. The main parameters of resistance spot welding process is the current welding, pressing force of the electrodes and current flow time. Geometrical parameters of this process are the thickness of the welded plate and the diameter of the electrodes. The connection between the components is achieved through the implementation of many single points of welding. The mechanical properties of a single point are very important because of the mechanical properties of the whole components connection.

An example of use of a large number of welded point connections is the passenger car body (fig. 1). In these case mainly resistance welding is used, but laser welding could be found. Manufacturers use for this automated production lines with industrial robots. Industrial robots are equipped with welding resistance device or laser welding device. A great number of metal stampings consists on the car body. Stampings are joined by spot welding. These connections ensure properly strength of the car body. This is closely related to the passive safety of the vehicle. During car body reparation connections made with resistance spot welding or laser welding are replaced by welded joints. Usually MIG welding method is used in these cases.

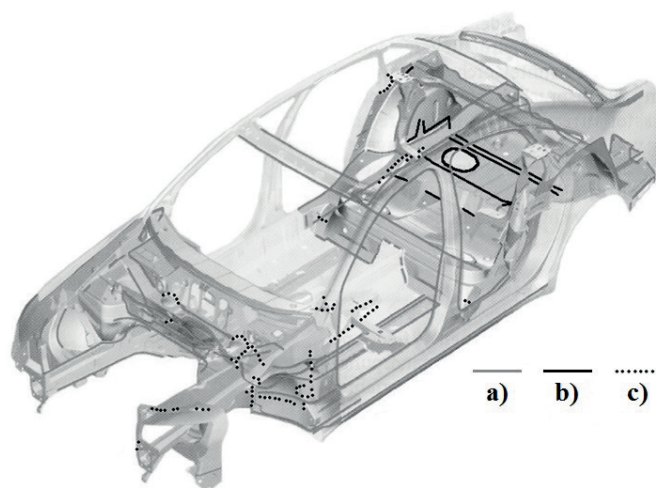


Fig. 1. Car body with different kinds of welded joints [3]; a) resistance spot welding, b) laser welding, c) MIG welding

Replacement of resistance welded joint by plug welded joint made by MIG welding method may adversely affect on the strength parameters of this connection. This may result in a decrease of the level of vehicle passive safety [4]. It is very important to ensure adequate strength of the plug welds made by MIG method which replaced the original connection. It has been researched that the correct execution of plug weld with using MIG welding method creates some difficulties. It has been shown that they relate to the strength of the welded joint. This situation can be improved through the use of micro-jet cooling.

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## 2. Welding with micro-jet cooling

Using of micro-jet cooling for plug welding is a very interesting solution. This solution introduces a forced cooling of plug weld immediately after welding. It allows to obtain interesting results in terms of the properties of the plug welded joint. Using of micro-jet cooling give possibility of steering of plug weld structure and properties of the plug weld. Result of it is high amount of AF in WMD. High amount of acicular ferrite influences positively on mechanical properties of plug weld [5, 6, 7]. Higher amount of AF in WMD can be obtain with welding with micro-jet cooling in comparison to traditional welding method. Amount of AF depends on parameters of micro-jet cooling process. These parameters are connecting with cooling intensity.

The intensity of the cooling is dependent on several parameters of the micro-jet cooling process [8, 9]. Main parameters are the type of cooling medium and the number of cooling streams. These parameters influence on mechanical properties of plug welds.

## 3. Experimental procedure and samples

In order to evaluate mechanical properties of the welded joints investigations have been carried out. During investigations the forces necessary to destroy of the plug welds were observed. Results were compared for plug welds made

by traditional MIG welding method and for plug welds made by MIG welding method with using micro-jet cooling.

Two variables were very important during samples preparation. The first was kind of cooling medium and the second was number of micro-jet streams. Parameters of welding for samples preparation are corresponded with these variables. Argon was chosen as shielding welding gas. Argon, helium and nitrogen were chosen as a micro-jet cooling medium. The diameter of stream in micro-jet injector was always 50  $\mu\text{m}$ . Pressure of cooling medium was always 0.5 MPa. Samples were welded with different number of micro-jet streams (1, 2 and 3). The main data about parameters of welding were shown in table 1.

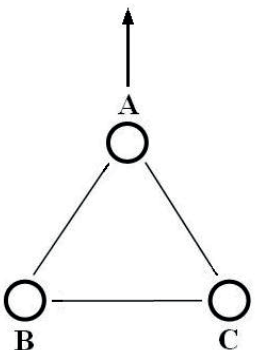
In the literature, there is a division of plug welds made by welding methods with the consumable electrode. These joints are divided as follows [10]:

- joint with hole – round hole or oblong hole is made in the outer sheet; the joint is formed with binder filling into the hole; the edges of the hole may be straight or angled in order to better melting,
- joint without hole – joint is formed by complete melting of the outer sheet and partial melting of the inner sheet without making a hole in outer sheet.

In investigation one kind of joints which were described above was used. Samples with plug welds with hole were made for tests. This kind of samples was shown in figure 2.

Parameters of welding process

TABLE 1

No.	Parameter	Value
1.	Diameter of wire	0,8 mm
2.	Standard current, Voltage	220 A; 24 V
4.	Shielding welding gas	Ar
5.	Micro-jet cooling gas	Ar, He, N <sub>2</sub>
6.	Cooling gas pressure	0.5 MPa
7.	Diameter of micro-jet cooling stream	50 $\mu\text{m}$
8.	Number of tested micro-jet cooling jet; arrow indicates direction of movement	1 (A) 2 (B + C) 3 (A + B + C) 

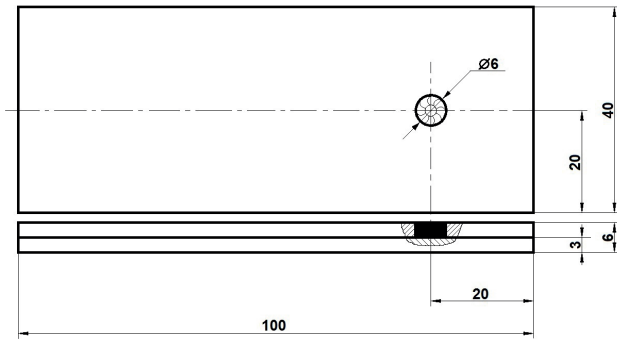


Fig. 2. Sample used in investigations

The samples have been made with S355J2G3 steel. Chemical constitution and mechanical properties of this steel have been shown in table 2 and table 3.

TABLE 2  
Chemical constitution of steel used in investigation

No.	Chemical element	Content [%]
1.	C	max 0.2
2.	Mn	1.00 ÷ 1.5
3.	Si	0.2 ÷ 0.55
4.	P	max 0.04
5.	S	max 0.04
6.	Cr	max 0.3
7.	Ni	max 0.3
8.	As	max 0.08
9.	Cu	max 0.3

TABLE 3  
Mechanical properties of steel used in investigation

No.	Property	Value
1.	Yield stress [MPa]	355
2.	Tensile strength [MPa]	510 ÷ 680
3.	Elongation, $A_{80}$ [%]	18

Investigations have been carried out with using test stand WDW-100E [11] which is presented in figure 3. Maximum tensile force corresponds with mass 10 Mg.

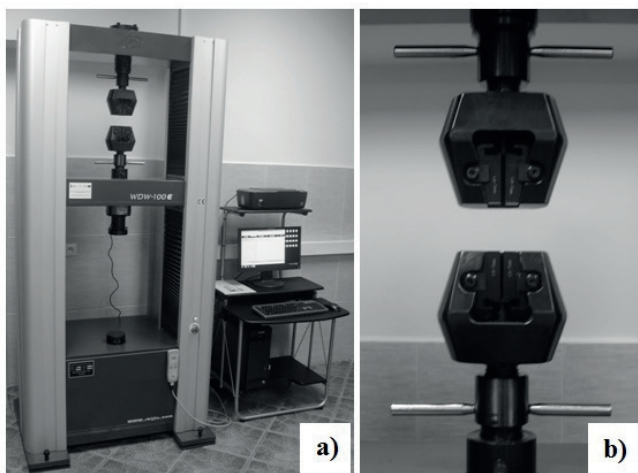


Fig. 3. Test stand WDW-100E; a) global view, b) holders for samples

The samples after welding have been formed in order to allow their installation in the test stand. Figure 4 presents sample preparation and manner of mechanical test.

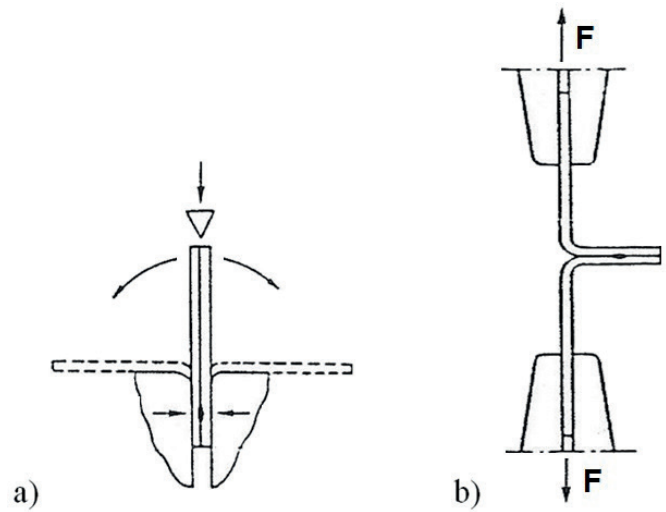


Fig. 4. The sample preparation (a) and manner of mechanical test (b); F – tensile force [12]

#### 4. Results and discussion

Welding with micro-jet cooling technology was done with different kind of cooling medium and different number of micro-jet streams. Welds made by traditional MIG welding method and welds made by welding with micro-jet cooling technology were compared. The investigations have been carried out for all kind of samples. Figure 5 shows examples of the curves of the tensile force for different kinds of samples. In figure 6 average maximum tensile force was presented for all cases of samples. It means for different cooling medium and for different number of micro-jet streams. The results are the average of five tests.

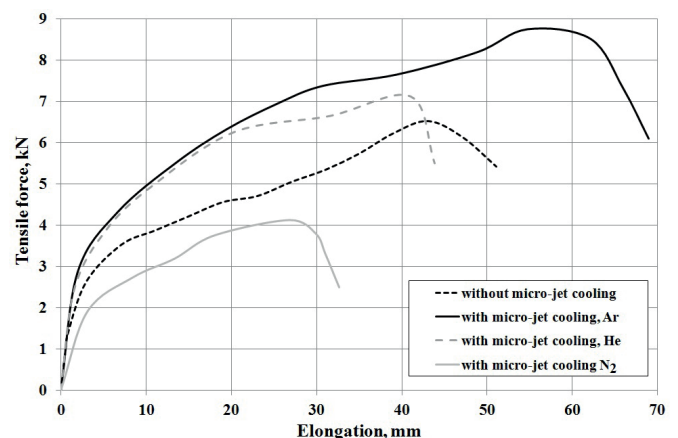


Fig. 5. Examples of investigation results

In the case of the tensile force it must be noted that using micro-jet cooling with argon and helium influences positively on results. Maximum tensile force was observed for samples welded with micro-jet cooling with argon. The value of tensile force for samples welded with micro-jet cooling with helium

was smaller, but it was still higher than for samples welded by traditional MIG welding method. The worst results were obtained for samples which were welded with micro-jet cooling with nitrogen. In this case using of micro-jet cooling influences negatively on results. In this case, the results are worse than for conventional MIG welding method.

A similar situation was in the case of the elongation. It must be noted that using micro-jet cooling with argon also influences positively on investigation results. Maximum value of elongation was obtained for samples welded with micro-jet cooling with argon. Values of elongation for samples welded with micro-jet cooling with helium and for samples welded with conventional MIG welding method were similar. The lowest values of elongation were observed for samples welded with micro-jet cooling with nitrogen.

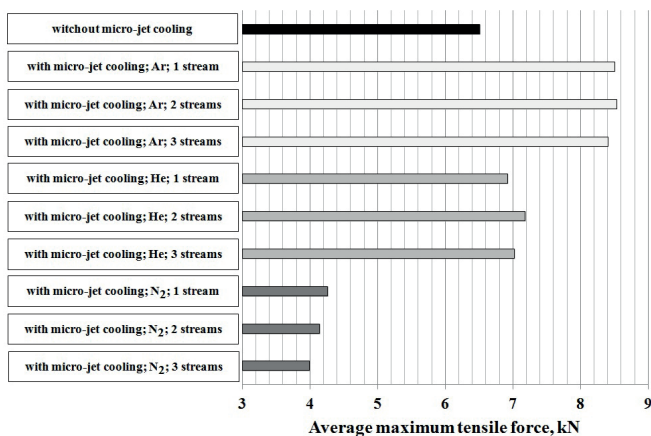


Fig. 6. Investigation results for different kind of samples

Comparison of average maximum tensile force shows that using of micro-jet cooling for welding influences on mechanical properties of the welded joints. The influence is different for different kind of cooling medium and for different number of micro-jet streams.

Average maximum tensile force for samples welded without micro-jet cooling achieved value about 6.5 kN. Using micro-jet cooling for welding effects different value of average maximum tensile force.

In the case of samples welded with argon as a micro-jet medium the average maximum tensile force was higher than for samples welded without micro-jet cooling. Average maximum tensile force for samples welded with micro-jet cooling with argon achieved value about 8.5 kN. For argon as a cooling medium average maximum tensile force increased about 30% in comparison to samples welded without micro-jet cooling. Using of micro-jet cooling with argon for welding influent positively on mechanical properties of the welded joints. This influence is very significantly.

In the case of samples welded with helium as a micro-jet medium the average maximum tensile force was higher than for samples welded without micro-jet cooling. It should be noted that results for argon were higher than values for helium. Average maximum tensile force for samples welded with micro-jet cooling with helium achieved value about 7.0 kN. For helium as a cooling medium average maximum tensile force increased about 7% in comparison to samples welded without micro-jet cooling. Using of micro-jet

cooling with argon for welding influent positively on mechanical properties of the welded joints, but it is not very significantly.

The lowest values of average maximum tensile force were observed for samples welded with nitrogen as a micro-jet medium. Average maximum tensile force for samples welded with micro-jet cooling with nitrogen achieved value about 4.2 kN. For nitrogen as a cooling medium value of average maximum tensile force achieved only 65% of value for samples welded without micro-jet cooling. Using of micro-jet cooling with argon for welding influent negatively on mechanical properties of the welded joints. This negative influence is very significantly.

In the case of different number of micro-jet streams during investigation different results were observed. Differences were not significantly and results were not unequivocal.

For argon the best results were observed for two micro-jet streams and the worst results were observed for three micro-jet streams. Differences between results for one micro-jet stream and two micro-jet streams were very small.

In the case of helium as a cooling medium the best results were observed for also for two micro-jet streams. The worst results were observed for one micro-jet stream. Differences between observed results were bigger than for results for argon.

Only for nitrogen situation was unequivocal. The bigger number of micro-jet stream, the less value of average maximum tensile force. For one micro-jet stream the biggest value of average maximum tensile force was observed and for three micro-jet streams the lowest value of average maximum tensile force was observed.

## 5. Conclusions

In this investigations plug welds were made by new method of welding (welding with micro-jet cooling) were compared with welds made by ordinary welding method. New method of welding is very promising and capable of industrial application, mainly due to the significant improvement of weld properties and quality.

This work introduced comparison of mechanical properties of samples welded with micro-jet cooling and without micro-jet cooling. Three different cooling mediums (argon, helium, nitrogen) were used for micro-jet cooling of welds immediately after welding. Moreover, different number of micro-jet streams (1, 2, 3) were used for micro-jet cooling. On the basis of investigations it is possible concluded that:

- micro-jet cooling with suitable cooling medium could be treated as an important element of improving MIG welding process results,
- micro-jet technology in welding with suitable cooling medium could improve mechanical properties of welds,
- argon and helium could be treated as an micro-jet gases in welding process,
- nitrogen could not be treated as an micro-jet gas in welding process,
- the number of jets during micro-jet cooling has influence on the welding process, but in this case this influence is not significant and is not unequivocal.

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