DYNAMIC LOAD AND THE PLASTIC DEFORMATION OF WELDS MADE WITH MICRO-JET COOLING

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Abstract

Steel construction needs to present high plastic properties especially during dynamic load. It is necessary for impact conditions. The way to improve of plastic properties of welds is welding with micro-jet cooling. It is a innovative method of welding. After welding with micro-jet cooling the microstructure of weld presents the high content of acicular ferrite in weld metal deposit. It allows to obtain a high values of the plastic properties. In this paper influence of the micro-jet streams number and the kind of cooling gas on plastic deformation of welds was presented. The aim of the paper is comparison of plastic properties of welds made with and without micro-jet cooling.

Keywords: Welding, micro-jet cooling, dynamic load, plastic properties

1. INTRODUCTION

Micro-jet cooling is one of forced cooling methods. This method of cooling could be used to cooling of weld immediately after welding and it allows o minimize of heat transfer to welded elements. The heat is absorbed by the cooling medium [1, 2, 3]. **Figure 1** presents changes of weld temperature during welding with and without micro-jet cooling.

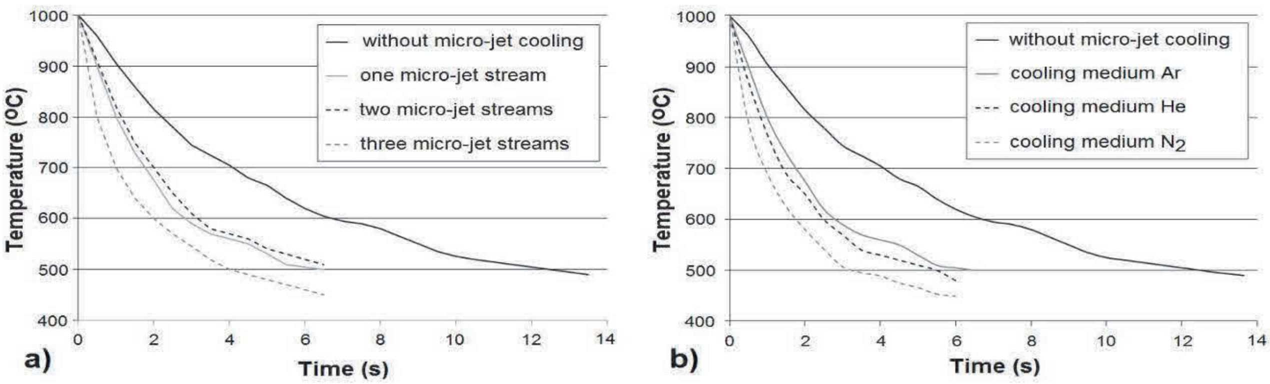


Figure 1 Changes of weld temperature during welding with and without micro-jet cooling; a) for different number of micro-jet streams, cooling medium: Ar; b) for different micro-jet cooling medium, number of micro-jet streams: 1

Using of micro-jet cooling for welding influences on microstructure of weld metal deposit (WMD). Goal of this is fact of obtain high amount of acicular ferrite (AF) in WMD. It corresponds with mechanical properties of welds. The higher amount of AF is present in WMD, the higher values of weld plastic properties are observed. Using of micro-jet cooling for welding allows obtain welds with better mechanical properties in comparison to ordinary welding method. The percentage of AF in WMD and the plastic properties of the weld can be controlled by several variables, e.g.: type of cooling medium, the number of micro-streams. In standard MIG welding process high amounts of grain boundary ferrite (GBF) and side plate ferrite (SPF) fractions were usually gettable. In welding with micro-jet cooling these fractions were not dominant because time of GBF and SPF formation has been reduced and it is too short to formation of great amount of GBF and SPF. It allowed reduce amount GBF and SPF with increase the amount of AF in WMD [1, 2]. Different types of cooling medium and different number of micro-jet streams have different effects on the intensity of cooling.

A interesting method to analyze the behaviour of welded components under impact load is calculation of restitution coefficient R. This coefficient describes the absorption of impact energy. It describes which part of impact energy is recovered during the second phase of impact (during reflection). For full plastic impact R = 0, and for full elastic impact R = 1 - during real impact 0 < R < 1 [4]. Coefficient of restitution R can be determined by several methods. One of ways to restitution coefficient calculation is experimental procedure. During experimental procedure four pendulum heights and two different mass were used. It allowed obtain several impact energies to calculate the coefficient of restitution (equations 1 to 4).

$$M = \frac{m_2}{m_1} \tag{1}$$

$$\lim_{m_2 \to \infty} M = \lim_{m_2 \to \infty} \frac{m_2}{m_1} = \infty \tag{2}$$

$$R = \frac{1}{M} + \frac{1+M}{M}\sqrt{\frac{h_2}{h_1}} \tag{3}$$

$$\lim_{M \to \infty} R = \lim_{M \to \infty} \frac{1}{M} + \frac{1+M}{M}\sqrt{\frac{h_2}{h_1}} = \sqrt{\frac{h_2}{h_1}} \tag{4}$$

where: m_1 - mass of pendulum, kg; m_2 - sum of specimen mass, test stand mass and foundation mass, kg; h_1 - height of pendulum drop, m; h_2 - height of pendulum reflect, m.

2. EXPERIMENTAL PROCEDURE

Test stand and specimens after tests were shown in **Figure 2**. The test procedure has been done on single-blow impact testing machine with modified pendulum. Mass of test stand was about 700 kg and mass of pendulum was 20 kg. Test stand has been fixed to the base (foundation), i.e. $m_2 \to \infty$. During investigation two heights have been registered: height of pendulum drop (h_1) and height of pendulum reflect (h_2).

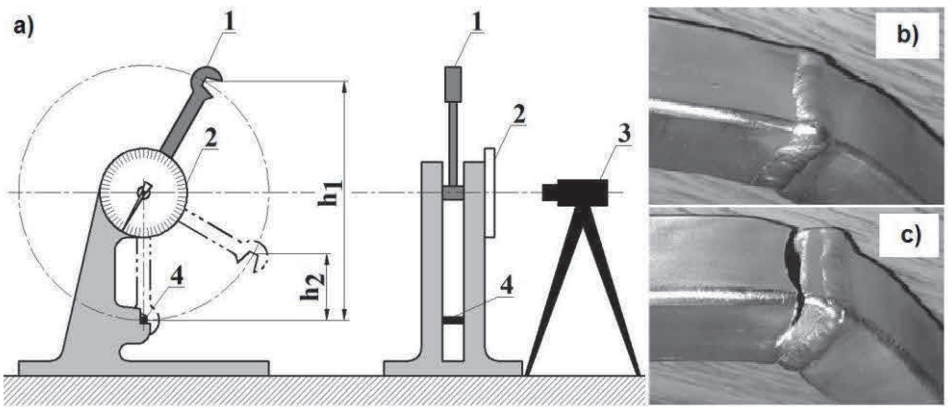


Figure 2 Detail of experimental procedure (a) and welded specimens after investigations: b) specimen welded with micro-jet cooling, c) specimen welded without micro-jet cooling; 1 - pendulum, 2, 3 - registration device, 4 - specimen

During the test procedure, the pendulum has been dropped from height h_1. In moment of impact pendulum has maximum kinetic energy and the specimen was deformed by pendulum. After that the pendulum returned to height h_2. During the test, the specimen was supported at the ends, and the impact force was positioned in the middle length of the specimen. Pendulum height h1 was from 0.91 m to 1.61 m and impact energy was from 178.5 J to 315.9 J.

3. SPECIMENS

Specimens have been made with S235JR steel. This is a grade of steel on steel constructions and it is one of the most popular steel grade of steel. This steel had following mechanical properties: yield stress 235 MPa, tensile strength 380 ÷ 520 MPa and Elongation A_{50} 16 %. **Figure 3** shows welded specimens used during investigations.

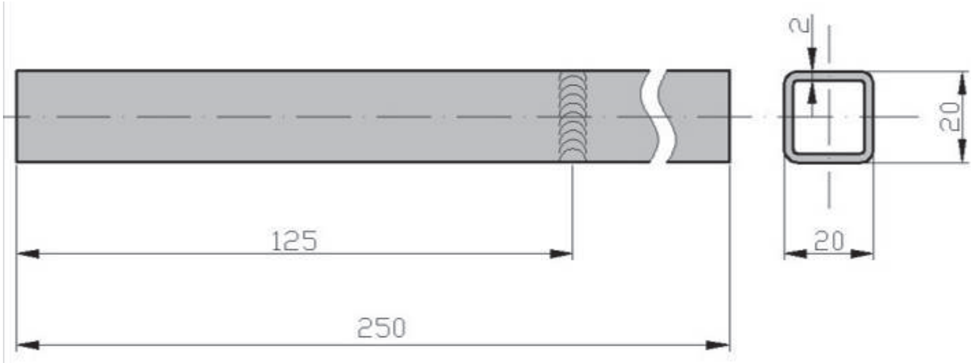


Figure 3 Dimensions of the specimen

Two parts of investigations were planned. In the first part influence of number of micro-jet streams on plastic properties of welds was tested. In the first part cooling medium always was Ar. In the second part of investigations influence of cooling medium kind on plastic properties of welds was tested. In the second part of investigations number of micro-jet streams always was 1. All welded specimens were welded with MIG welding method (Metal Inert Gas).

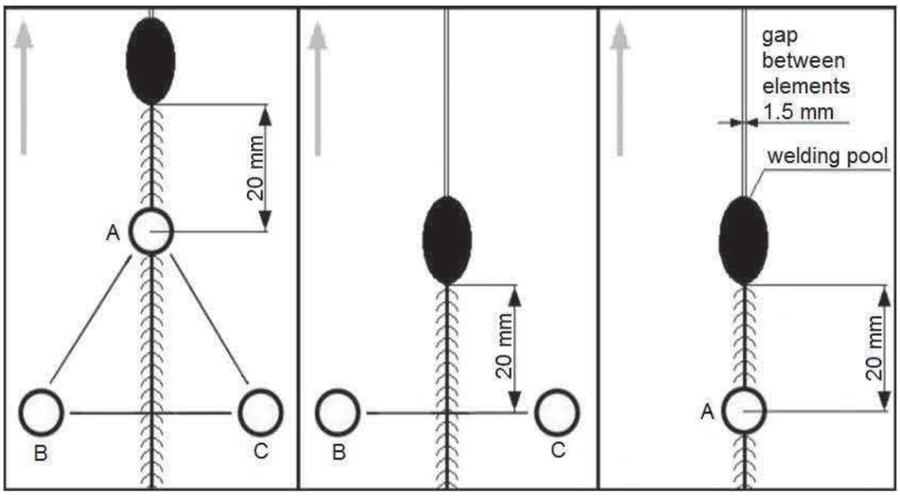
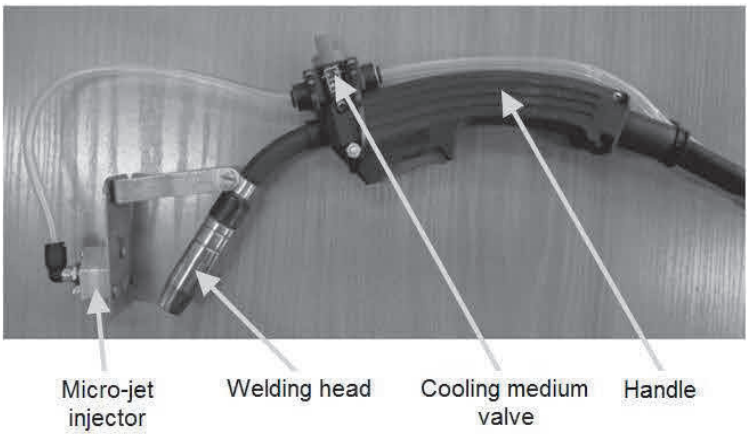


Figure 4 Top view of localization of the micro-jet cooling stream jets (A, B+C, A+B+C - 3 cases); the grey arrows indicates the movement direction; micro-jet cooling streams fall perpendicular to the welded steel plates at points A, B and C

For the first part of investigations five types of specimens were made. It means: specimens without weld, specimens welded with traditional MIG method (without micro-jet cooling) and specimens welded with MIG method with using micro-jet cooling by one, two and three micro-jet streams. Different number of micro-jet streams allows obtain different cooling conditions and different cooling intensity. For the second part of investigations five types of specimens were made. It means: specimens without weld, specimens welded with traditional MIG method (without micro-jet cooling) and specimens welded with MIG method with using micro-jet cooling with different cooling mediums (Ar, N_2, He). Different properties of used cooling mediums allow obtain different cooling conditions and different cooling intensity. **Figure 4** shows arrangement of micro-jet streams. The main data about parameters of welding process were shown in **Table 1**. After welding specimens for metallographic investigations were prepared. After showing the metallographic structure measurements of the volume fraction of individual phases were made. Grid method had been used for this purpose. A net was applied to the structure. The number of nodes falling on a given phase relative to the total number of nodes in the grid describes the volume share of a given phase in structure.

Different amount of AF appeared in WMD after application of micro-jet cooling for welding. In all tested cases there were observed also MAC phases (self-tempered martensite, retained austenite, carbide). Acicular ferrite with percentage above 70 % was gettable only after Ar micro-jet cooling. For micro-jet cooling with He amount of AF in WMD was about 60%. In case if N_2 amount of AF was similar to the case of welding without micro-jet cooling. The high amount of MAC phases was especially gettable for N_2 as micro-jet cooling medium (about 5 ÷ 7%) and it was greater than for standard MIG welding (3 %). For welding with micro-jet cooling with He amount of MAC phases was about 4 ÷ 5%. The lowest amount of MAC phases in WMD was obtained for welding with micro-jet cooling by Ar.

Table 1 Parameters of welding process

Parameter	Value / Description
Diameter of wire and electrode classification	1.2 mm; G2Si1 / ER70S-3
Standard current and voltage	220 A; 24 V
Shielding welding gas	Ar
Kind and pressure of micro-jet cooling gas	Ar, He, N_2; 0.5 MPa
Diameter of micro-jet cooling stream	40 µm
Number of tested micro-jet cooling stream	1 (A); 2 (B + C); 3 (A + B + C) Situated in equilateral triangle with sides 6 mm (**Figure 4**).
Weld geometry and number of passes	butt weld; gap 1.5 mm; 1 pass
Device for welding with micro-jet cooling	

4. RESULTS AND DISCUSSION

Different kinds of specimen (with and without welds) were tested and compared. The computations have been carried out with five level impact energy and velocity. The results show the average and standard deviation of the five tests. **Figure 5** shows the permanent angle measured in order to evaluate the plastic strain after the impact.

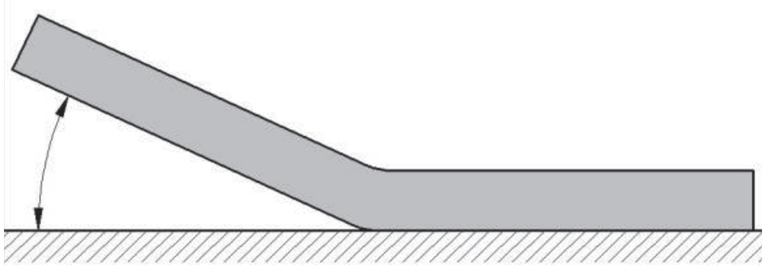


Figure 5 Detail of angle measure to evaluate the plastic deformation

The first part of investigations includes test for specimens made with different number of micro-jet streams. 1, 2 and 3 micro-jet streams were tested. **Figuire 6a** shows the evaluation of the restitution coefficient in function of the impact energy. The value of restitution coefficient has decreased when the impact energy has increased. These results do not depend on the type of specimen. Specimens without weld have had the largest values of restitution coefficient. The smallest value of restitution coefficient has been reached for specimens welded without micro-jet cooling. Specimens welded with micro-jet cooling with 1, 2 and 3 micro-jet streams reached intermediate values of restitution coefficient, but values for 2 micro-jet streams were the highest and values for 3 micro-jet streams were the lowest. **Figure 6b** shows results of plastic strain in function of the impact energy. The value of plastic strain has increased when the impact energy has increased. These results do not depend on the type of specimen. Specimens without weld have had the smallest values of plastic strain. The largest value of plastic strain has been reached for specimens welded without micro-jet cooling (with ordinary MIG welding method). Specimens welded with micro-jet cooling with 1, 2 and 3 micro-jet streams reached intermediate values of plastic strain. Values of plastic strain for 3 micro-jet streams were the lowest and values for 2 micro-jet streams were the highest. Generally, the greater value of impact energy, the greater differences in the test results for different kind of specimens can be awaited. Higher number of micro-jet cooling streams allows obtain a higher value of restitution coefficient and lower value of plastic strain. For low impact energy (178.5 J and 239.4 J) the results were very similar for all kind of specimens. But for higher impact energy (276.6 J, 306.1 J and 315.9 J) cracks were observed for specimens welded without micro-jet cooling. For specimens welded with micro-jet cooling, were not observed any cracks. Generally, the increase of the number of micro-jet cooling stream from 1 to 2 positively influence on the results. This effect is positive, but the influence is not significant. Reduction of plastic strain is a desirable property of micro-jet cooling application for welding.

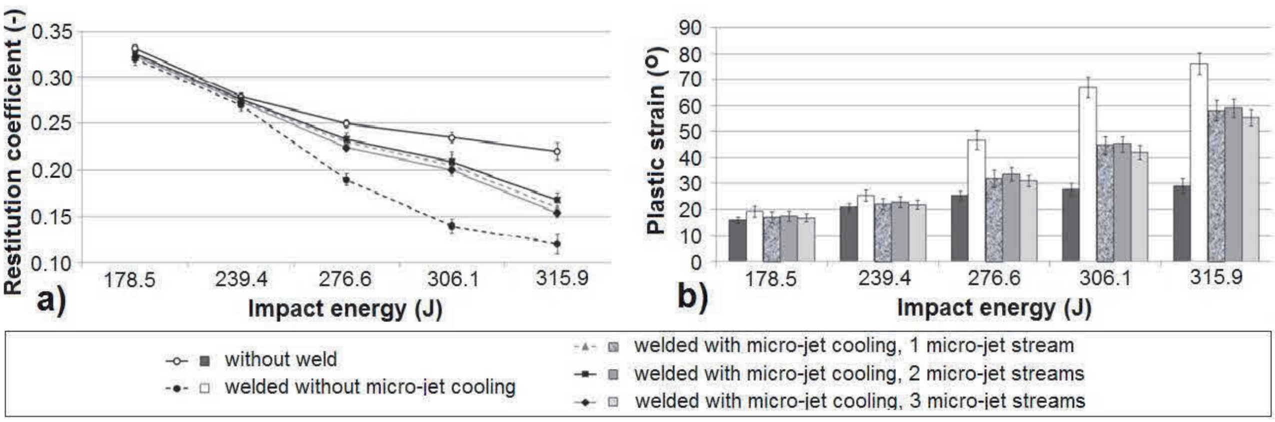


Figure 6 Evaluation of the coefficient of restitution (a) and plastic deformation of specimens (b) in function of the impact energy for different number of micro-jet streams

The second part of investigations includes test for specimens made with different kind of cooling medium. Ar, He and N_2 were tested. **Figure 7a** shows the evaluation of the restitution coefficient in function of the impact energy. The value of restitution coefficient has decreased when the impact energy has increased. These results do not depend on the type of specimen. Specimens without weld have had the largest values of restitution coefficient. The smallest value of restitution coefficient has been reached for specimens welded without micro-jet cooling. Specimens welded with micro-jet cooling reached intermediate values of restitution coefficient and values for Ar were the highest and values for He were the lowest. Values for N_2 were very similar for values obtained for specimens welded without micro-jet cooling. **Figure 7b** shows results of plastic strain in function of the impact energy. The value of plastic strain has increased when the impact energy has increased. These results do not depend on the type of specimen. Specimens without weld have had the smallest values of plastic strain. The largest value of plastic strain has been reached for specimens welded without micro-jet cooling. Very similar values were obtained for specimens welded with micro-jet cooling with N_2 and for specimens welded without micro-jet cooling. Specimens welded with micro-jet cooling with Ar and He reached intermediate values of plastic strain. Values of plastic strain for Ar were lower and values of plastic strain for He were higher. Generally, the greater value of impact energy, the greater differences in the test results for different kind of specimens can be observed. For low impact energy (178.5 J and 239.4 J) the results were very similar for all kind of specimens. But for impacts with higher energy (276.6 J, 306.1 J and 315.9 J) cracks were observed for specimens welded without micro-jet cooling. For specimens welded with micro-jet cooling with Ar and He, were not observed any cracks or fissures. Cracks were observed for specimens welded with micro-jet cooling with N_2. The best results were obtained for micro-jet cooling with He, but this effect is not significant. The worst results were observed for micro-jet cooling with N_2. Generally, using appropriate cooling medium for micro-jet cooling influence positively on the results can be seen. Based on the investigations, it can be noticed that the best choice as micro-jet cooling medium is Ar and the worst is N_2. Results obtained with N_2 are due to the presence of nitrides in the WMD.

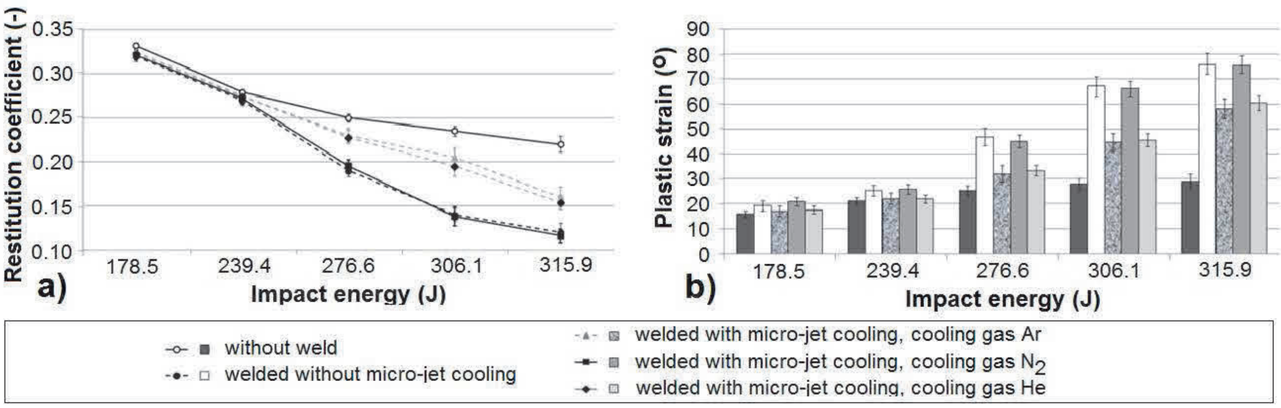


Figure 7 Evaluation of the coefficient of restitution (a) and plastic deformation of specimens (b) in function of the impact energy for different cooling mediums

5. CONCLUSIONS

It was observed that the value of restitution coefficient decreased when the impact energy increased. Minimum values of restitution coefficient have been reached for specimens welded without micro-jet cooling system. Low values of the plastic strain are presented by the specimens without weld. The highest plastic strain has been reached for specimens welded with traditional MIG method, without micro-jet cooling. The presence of the weld has affected the plastic properties of the element. Plastic properties of the weld in this case are poor. The reason for this is the appearance of the weld and heat affected zone (HAZ). It is observed that the use of micro-jet cooling with proper cooling medium for welding could influence positively on the plastic strain. Use of micro-jet cooling for welding causes a decrease in the plastic strain value and this protects against cracks.

This innovative welding process, using the micro-jet cooling shows good results. On the basis of investigation it is possible concluded that: micro-jet cooling is treated as an important element of welding process and it could improve plastic properties of the welds; Ar and He could be treated as a micro-jet medium for welding process; N_2 is not good for micro-jet cooling of welds; great number of micro-jet cooling streams has positively influence on plastic properties of the weld.

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