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IMPACT LOAD OF WELDS AFTER MICRO-JET COOLING

DYNAMICZNE OBCIĄŻENIE SPOIN CHŁODZONYCH MIKROJETOWO

Micro-jet cooling is an innovative method of forced cooling. It could be used to cooling after welding immediately. It allows to obtain welds with better properties in comparison to ordinary welding method. Favourable structure of weld metal deposit (WMD) with higher content of acicular ferrite (AF) could be obtained. These properties can be controlled by several variables (e. g. type of cooling gas, number of jets). Plastic properties are particularly important in case of impact load. This type of strength is very dangerous for the structure and for safety of users (ex. car body during car crash). This article presents the influence of the cooling gas and the number of jets on plastic properties of the weld joint for impact load. It is described by restitution coefficient and plastic strain.

Keywords: welding, micro-jet cooling, coefficient of restitution, plastic strain, dynamic conditions

Chłodzenie mikrojetowe to innowacyjna metoda wymuszonego chłodzenia. Może ona być wykorzystywana do chłodzenia spoin natychmiast po spawaniu. Umożliwia to uzyskanie spoiny o lepszych właściwościach w porównaniu do spoin wykonywanych w typowych metodach spawania. Powodem tego jest pojawienie się korzystnej struktury stopiwa o dużej zawartości drobnopłatkowego AF (acicular ferrite). Właściwości spoiny mogą być przy tym sterowane przez kilka zmiennych, takich jak rodzaju gazu chłodzącego oraz ilość chłodzących mikro strug. Właściwości plastyczne stopiwa są szczególnie ważne w przypadku obciążeń udarowych. Ten rodzaj wymuszeń jest bardzo niebezpieczny dla samej konstrukcji spawanej oraz dla bezpieczeństwa jej użytkowników (np. nadwozia samonośnego samochodu podczas wypadku samochodowym). Artykuł przedstawia wpływ rodzaju gazu chłodzącego i ilości mikro strug na własności plastyczne spoiny przy obciążeniach udarowych. Właściwości plastyczne zostały opisane przez współczynnik restytucji i odkształcenia plastyczne.

1. Introduction

In case of steel construction, especially in severe conditions, one of the most important issues are the material of construction and the joints between elements. In both cases plastic properties are very important. Many of construction elements are joined by welding. The high content of acicular ferrite (AF) in weld metal deposit (WMD) is a guarantee of high plastic properties. Correct values of AF are required to optimize the safety maintenance of welded construction [1, 2].

Using of micro-jet cooling is a very interesting method of welding technology. It introduces a rapid cooling immediately after welding. This allows to obtain interesting results in terms of the properties of the welded joint. Welding with micro-jet cooling can be considered as an efficient way to obtain a high content of AF in WMD and also to improve the properties of plastic welds, especially in hard maintenance conditions of welded constructions [3, 4, 5]. Generally, welds which were welded with micro-jet cooling have greater plastic properties than welds which were made by ordinary welding method. The reason is high amount of AF in welds which were welded

with micro-jet cooling. It has positively influence on improve plastic properties of the weld [6, 7, 8, 9].

The behavior of welded components during impact load is represented by the coefficient of restitution. This coefficient describes the way of impact energy absorption [10, 11]. Moreover, this coefficient describes what part of impact energy is recovered during reflect (second part of impact) and what part of impact energy is changed on plastic strain and elastic strain. Coefficient of restitution R was introduction by Newton. For entirely plastic impact $R=1$, but for entirely elastic impact $R=0$. In reality impacts have elastic-plastic character and $0 < R < 1$.

2. Experimental procedure

Coefficient of restitution can be calculate with using different methods or it can be determined during investigations. Usually, the results have a big distribution [12]. One of the way to do it is experimental method. In this method two height and two mass during free fall are registered (eq. 1 ÷ 4).

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

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

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

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

Where m_1 is mass of pendulum, m_2 is mass of sample, plus mass of test stand, plus mass of foundations, h_1 is height of pendulum drop, and h_2 is height of pendulum reflect.

Test stand (fig. 1), samples and impact conditions should have been selected before investigation. The test procedure have been carried out on single-blow impact testing machine with modified pendulum. Mass of test stand was 700 kg and the mass of pendulum was 20 kg. Test stand has been fixed to the foundation, so $m_2 \rightarrow \infty$. During investigation two height have been registered: height of pendulum drop (h_1) and height of pendulum reflect (h_2).

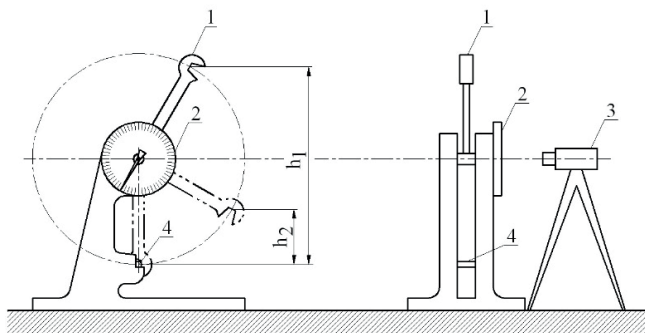


Fig. 1. Test stand: 1– pendulum, 2 and 3 – registration device, 4 – sample

During test pendulum has been dropped from height h_1 . Pendulum hit on sample. Sample has been deformed in depend on impact energy. Next pendulum reflected and returned to height h_2 . Values of impact energy and velocity of pendulum during impact has shown in table 1. Figure 2 show the way to plastic strain measurement.

TABLE 1
Impact conditions during investigations

No.	Height of pendulum drop (h_1), [m]	Impact energy, [J]	Impact velocity, [m/s (km/h)]
1.	1.61	315.9	5.6 (20.2)

2.	1.56	306.1	5.5 (19.9)
3.	1.41	276.6	5.3 (18.9)
4.	1.22	239.4	4.9 (17.6)
5.	0.91	178.5	4.2 (15.2)

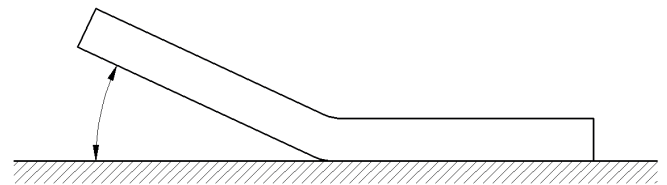


Fig. 2. Illustration of the way of plastic deformation measurement

3. Samples

The samples have been made with S235 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	0.17
2.	S	0.035
3.	P	0.035
4.	Si	0.10 ÷ 0.35
5.	Mn	1.40
6.	Cu	0.55
7.	Ni	0.12

TABLE 3
Mechanical properties of steel used in investigation

No.	Property	Value
1.	Yield stress [MPa]	235
2.	Tensile strength [MPa]	380 ÷ 520
3.	Elongation, A_{50} [%]	16

Five kinds of samples were made for investigation:

- samples without weld,
- samples welded with MIG method without micro-jet cooling,
- 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,

Figure 3 shows welded samples which were used in investigations, and figure 4 shows arrangement of jets.

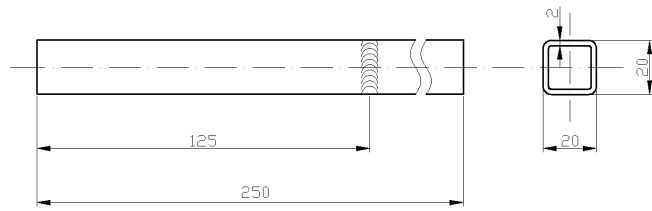


Fig. 3. samples which weld

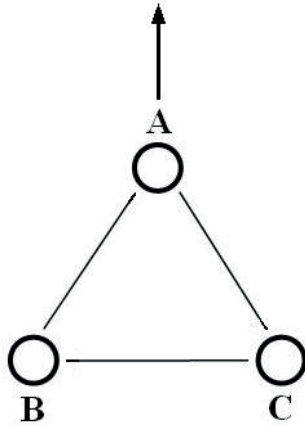


Fig. 4. Illustration of the micro-jet cooling jets location; arrow indicates the direction of movement.

Welding of samples has been done with micro-jet cooling, with argon as a micro-jet cooling gas. Argon was chosen because of no oxidizing potential [13]. The main data about parameters of welding process were shown in table 4.

TABLE 4

Parameters of welding process

No.	Parameter	Value
1.	Diameter of wire	1.2 mm
2.	Standard current	220 A
3.	Voltage	24 V
4.	Shielding welding gas	Ar
5.	Micro-jet cooling gas	Ar
6.	Micro-jet cooling gas pressure	0.4 MPa
7.	Diameter of micro-jet cooling jet	40 μm
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. 5).

Equipment for MIG welding with micro-jet cooling and test stand are presented in figure 5.



Fig. 5. Apparatus for welding with micro-jet cooling

4. Results and discussion

Welding with micro-jet cooling technology was done with different number of micro-jet cooling jets. Welds made with ordinary MIG method and with micro-jet cooling technology were compared. The computations have been carried out for five level impact energy/velocity. The results are the average of five tests.

Figure 7 shows the restitution coefficient as function of the impact energy for five kind of samples. It was observed that the restitution coefficient decreased with the impact energy increased. This situation did not depend on the type of sample. Samples without weld had the biggest values of restitution coefficient. The smallest value of restitution coefficient has been reached for samples welded without micro-jet cooling. It could be observed that the number of micro-jet jet influenced on the results. This effect is positive, however, this influence is not higher.

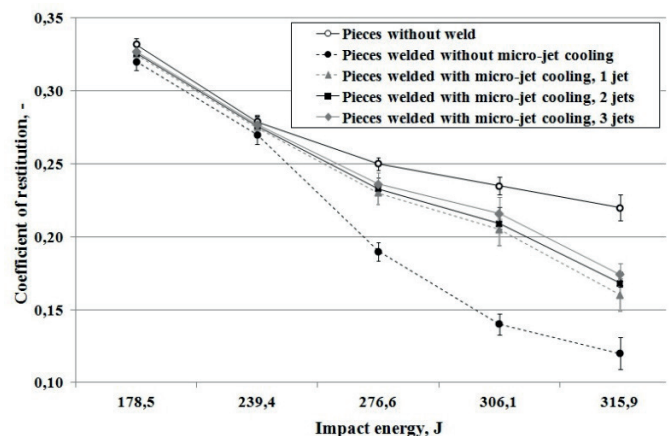


Fig. 6. Evolution of the coefficient of restitution in function of the impact energy for specimens with and without weld and with different number of micro-jet cooling jet

Figure 7 shows the plastic strain in function of the impact energy for five kind of samples. Plastic strain increased with the impact energy increased. Model samples without weld had the smallest plastic strain. The higher plastic strain has been reached for samples welded with ordinary MIG method

without micro-jet cooling. It was observed that using of the micro-jet equipment for welding process has positive influence on plastic strain.

For impact energy about 178.5 J and 239.4 J the results were very similar for all kind of samples. Thereafter for impacts with 276.6 J, 306.1 J, and 315.9 J cracks were observed for samples welded without micro-jet cooling. Specimens welded with micro-jet cooling did not show any cracks. It could be observed that the number of micro-jet cooling jet also influences on the results. The higher number of micro-jet cooling jet, the smaller plastic strain. Despite this positive effect this influence was not so great.

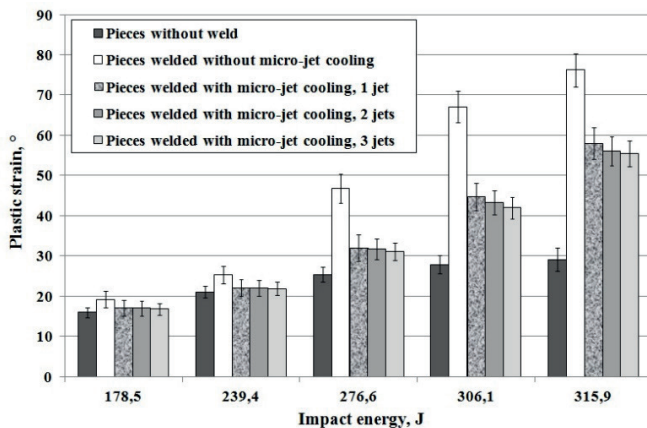


Fig. 7. Plastic deformation of samples after impact

5. Conclusions

This work introduced values of coefficient of restitution for welded samples with five level of impact energy and velocity. It was observed that the value of restitution coefficient decreased when the impact energy increased. Smallest values of restitution coefficient has been reached for specimens welded without micro-jet cooling.

Samples without weld shows the poor values of the plastic strain. The highest plastic strain has been reached for samples welded with ordinary MIG method without micro-jet cooling. It is observed that the use of micro-jet welding positive influences on plastic strain.

This innovative welding process with using the micro-jet cooling shows good results related with the welding plastic properties. It is very important especially during impact load. The investigations of coefficient of restitution and plastic strain have been carry out. On the basis of this investigations it is possible concluded 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,
- argon could be treated as an micro-jet gas in welding process,

- the number of jets during micro-jet cooling has influence on the welding process, i.e, increasing the micro-jet jets number influences on the weld cooling intensity, and consequently it influences positively on the plastic properties of the weld.

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