A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 59 2014 Issue 3
DOI: 10.2478/amm-2014-0155

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PLASTIC PROPERTIES OF FINE-GRAINED WMD AFTER MICRO-JET COOLING

WŁASNOŚCI PLASTYCZNE DROBNOZIARNISTEGO STOPIWA SCHŁODZONEGO MIKRO-JETOWO

Micro-jet welding is an innovative method of weld forced cooling immediately after welding. It allows to obtain weld with superior properties in comparison to conventional welding. The reason for this is to obtain a more favorable structure of the weld metal deposit (WMD) with much higher amount of acicular ferrite (AF). Different structures and mechanical properties of weld metal deposit were obtained by using various gases for cooling. The paper shows the relationship between the type of gas for micro-jet cooling and plastic properties of the weld joint. Coefficient of restitution and plastic strain were selected to describe changes of weld plastic properties for different micro-jet cooling gases. The tests were performed in dynamic conditions (impact).

Keywords: micro-jet cooling in welding, coefficient of restitution, plastic strain, dynamic conditions, metallographic structure, acicular ferrite

Spawanie z chłodzeniem mikrojetowym to nowatorska metoda spawania z wymuszonym chłodzeniem spoiny bezpośrednio po spawaniu. Pozwala ona na uzyskanie połączeń spawanych o właściwościach lepszych w porównaniu do spawania tradycyjnego. Przyczyną tego jest uzyskiwania korzystniejszej struktury stopiwa z większą zawartością drobnoziarnistego ferrytu (acicular ferrite – AF). Dzięki zastosowaniu różnych gazów do chłodzenia spoiny, można uzyskiwać różne struktury stopiwa i właściwości mechaniczne. W artykule przedstawiono zależność pomiędzy rodzajem gazu do chłodzenia mikrojetowego, a własnościami plastycznymi połączenia spawanego. Jako wielkości opisujące własności plastyczne wybrano współczynnik restytucji i odkształcenie trwałe. Testy przeprowadzono w warunkach dynamicznych.

1. Introduction

Welding with micro-jet cooling (micro-jet welding) it is a new technology of welding. It could be regarded as a new way to get high content of AF in weld metal deposit (WMD) and to improve plastic properties of welds [1-6]. During micro-jet welding higher amount of AF in WMD is observed than in traditional welding method [7-12]. The reason of it is high amount of AF has positively influencing improvement of plastic weld properties [12-17].

Coefficient of restitution R was discovered by Newton. This coefficient describes the way of impact energy absorption and describes what part of impact energy is recovered in second part of impact (during reflect). Moreover, restitution coefficient describes what part of impact energy is used to plastic strain and elastic strain. For entirely plastic impact R = 1, but for entirely elastic impact R = 0. In reality impacts have elastic-plastic character and 0 <R <1 [1-6]. That way of impact describe is used often for car accidents (Fig. 1).

2. Mathematical groungs of restitution coefficient

Coefficient of restitution can be calculated in a few various ways. Usually research results have a big distribution [1, 5]. Experimental procedure in which are registered two height and two mass during free fall are described by equations 1-4.

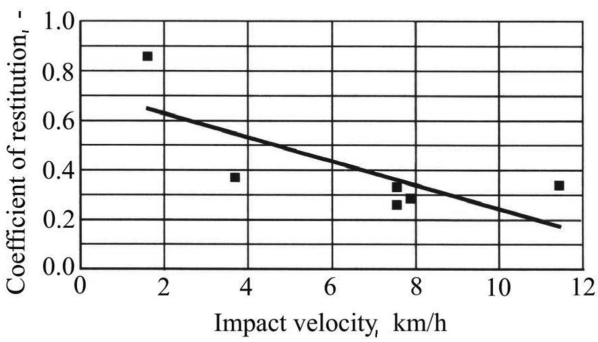

Fig. 1. Value of restitution coefficient in depends on impact velocity [1]

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$$M = \frac{m_2}{m_1} \quad (1)$$

$$\lim_{m_2\to\infty} M = \lim_{m_2\to\infty} \frac{m_2}{m_1} = \infty \quad (2)$$

$$R = \frac{1}{M} + \frac{1+M}{M}\sqrt{\frac{h_2}{h_1}} \quad (3)$$

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

where:

m_1 – mass of pendulum, kg,

m_2 – mass of test piece + mass of test stand + foundations, kg,

h_1 – height of pendulum drop, m,

h_2 – height of pendulum reflect, m.

3. Experimental procedure

At the beginning of the investigation three very important things should have been selected, ie test stand, test pieces and impact conditions. The investigation have been carried out on single-blow impact testing machine (Charpy pendulum machine). This machine has modified form of pendulum. Mass of test stand was about 700 kg. Additionally machine was fixed properly to the foundations ($m_2 \to \infty$). The mass of pendulum was 20 kg (m_1). During investigation two heights have been registered: height of pendulum drop (h_1) and height of pendulum reflect (h_2). The test stand is shown in Fig. 2.

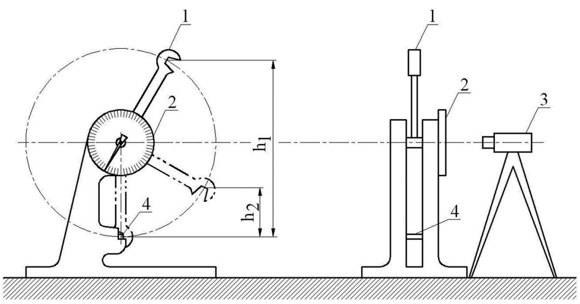

Fig. 2. Test stand, 1 – pendulum, 2 and 3 – registration device, 4 – test piece

All test pieces have been made from S235 steel. Chemical constitution and mechanical properties of this steel have been shown in Table 1 and Table 2.

TABLE 1

Chemical constitution of steel used in investigation [8]

Chemical element	C	S	P	Si	Mn	Cu	Ni
Content, %	0.17	0.035	0.035	0.10÷0.35	1.40	0.55	0.12

TABLE 2

Mechanical properties of steel used in investigation [8]

Property	Yield stress, MPa	Tensile strength, MPa	Elongation A_{50}, %
Value	235	380÷520	16

Five different types of samples were prepared for investigations. There were test pieces without weld and welded test pieces:

- test pieces without weld,
- test pieces welded with MIG method without micro-jet cooling,
- test pieces welded with MIG method with micro-jet cooling (cooling gas Ar),
- test pieces welded with MIG method with micro-jet cooling (cooling gas N_2),
- test pieces welded with MIG method with micro-jet cooling (cooling gas He).

Figure 3 shows welded test piece used in investigations. Table 3 presents parameters of welding process.

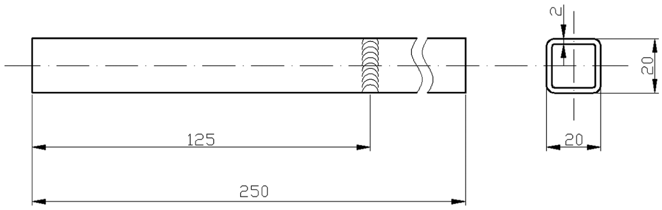

Fig. 3. Welded test piece

TABLE 3

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.	Gas pressure	0.4 MPa
7.	Diameter of jet	40 m
8.	Number of jets	1

During test pendulum has been drop from height h1 and has hit into test piece. Test piece has been deformed. Deformation is depend on impact energy. Next pendulum has reflected and returned to height h2. Height of reflection is depend on impact character and test piece parameters. The larger plastic strain, the less reflection. In Table 4 have been shown value of impact energy and velocity of pendulum during investigation. Figure 4 shows the way to plastic strain measurement.

TABLE 4

Impact conditions during investigations

Height of pendulum drop (h_1), m	1.61	1.56	1.41	1.22	0.91
Impact energy, J	315.9	306.1	276.6	239.4	178.5
Impact velocity, m/s, (km/h)	5.6 (20.2)	5.5 (19.9)	5.3 (18.9)	4.9 (17.6)	4.2 (15.2)

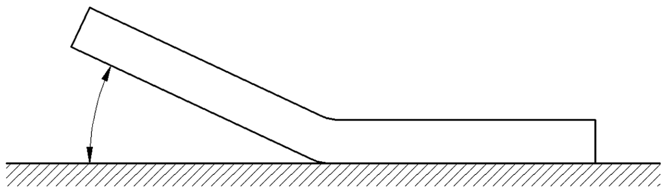

Fig. 4. The way of plastic strain measurement

4. Results and discusion

This work has introduced value of coefficient of restitution for dynamic impact to welded test pieces. Moreover, the plastic strain of different test pieces were observed. The tests have been done for five levels of impact energy from 178.5 J to 315.9 J (and velocity from 4.2 m/s to 5.6 m/s). Figure 5 shows plastic strain in depend on impact energy for five kind of test pieces. Figure 6 shows value of restitution coefficient in depend on impact energy for five kind of test pieces. All results are average from five tests.

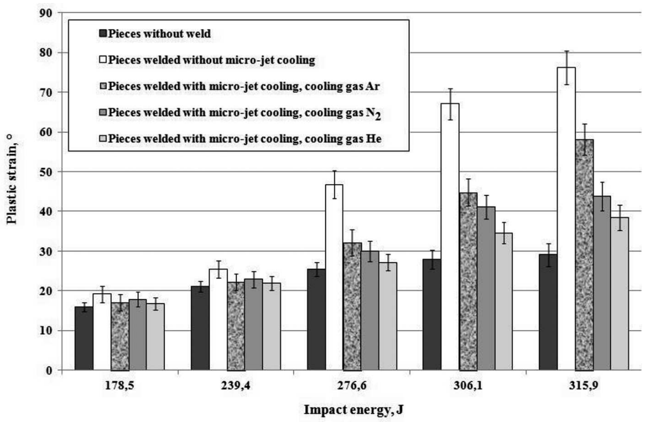

Fig. 5. Plastic strain of test pieces after impact

Plastic strain increased when impact energy increased. Model pieces without weld have had the smallest plastic strain for all impact energies. The biggest plastic strain has been reached for test pieces welded with ordinary MIG method without micro-jet cooling. That situation was for all impact energies.

Using of micro-jet welding positively influences on plastic strain. For tested micro-jet cooling gases, the best results (the slallest plastic strain) were obsreved for helium and the worst results (the biggest plastic strain) were obsreved for argon. Medium results were eved for nitrogen.

Value of restitution coefficient has decreased when the impact energy has increased. Test pieces without weld have had the biggest values. The smallest value of restitution coefficient has been reached for test pieces welded without micro-jet cooling. Test pieces welded with mitro-jet cooling achieved intermediate values. For test pieces welded with mitro-jet cooling in case of helium the best results were obserwed. This results were sililar to results achieved for test pieces without welds.

For impact energy about 178,5 J and 239,4 J results were very similar for all kind of test pieces. For impacts with energy 276,6 J, 306,1 J and 315,9 J cracks were observed for test pieces welded without micro-jet cooling. For test pieces welded with micro-jet cooling cracks were not observed (regardless of the type of cooling gas).

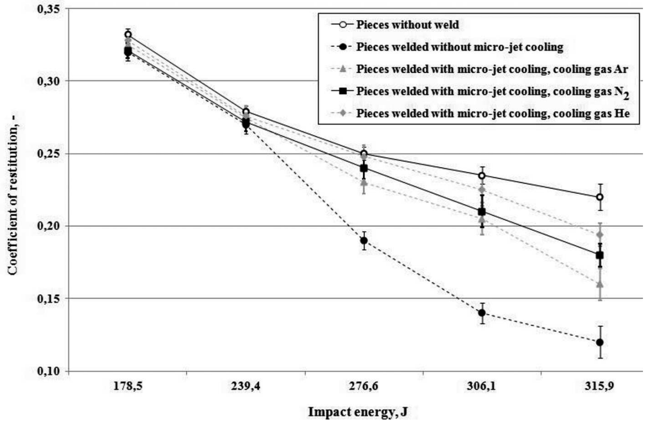

Fig. 6. Coefficient of restitution in depend on impact energy for test pieces with and without weld

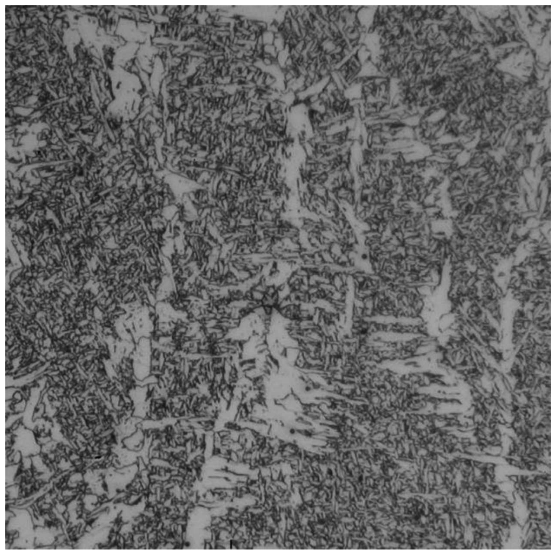

Fig. 7. Acicular ferrite in weld metal deposit which was done without micro-jet cooling, magnification × 200

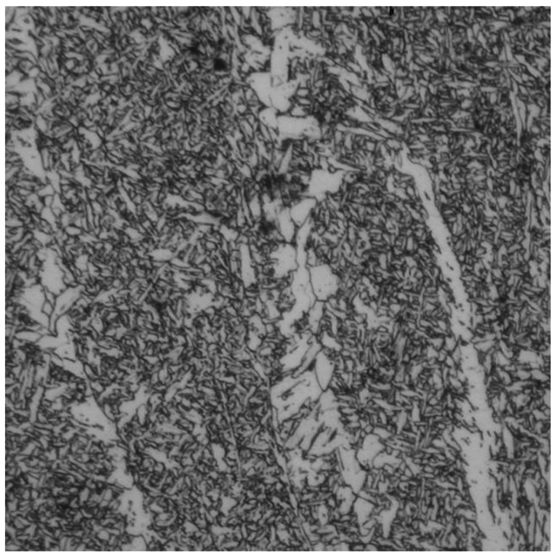

Fig. 8. Acicular ferrite in weld metal deposit which was done with micro-jet cooling (cooling gas Ar), magnification × 200

In order to explain the differences in the plastic properties of the weld metal deposit of tested joints, metallurgical studies were conducted.

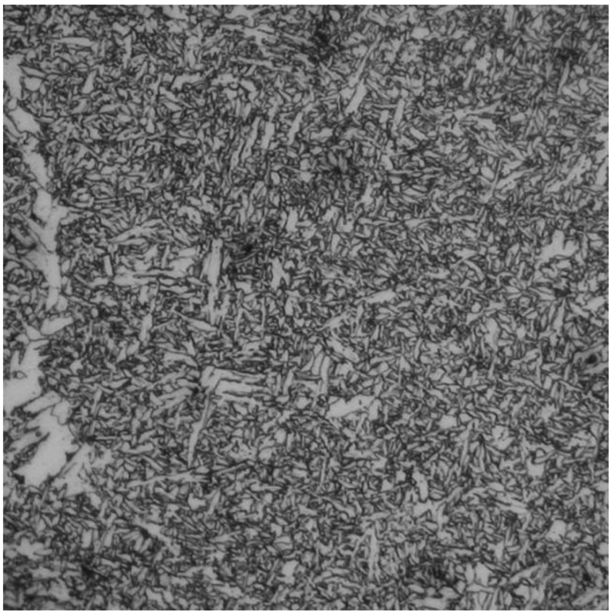

Fig. 9. Acicular ferrite in weld metal deposit which was done with micro-jet cooling (cooling gas N_2), magnification × 200

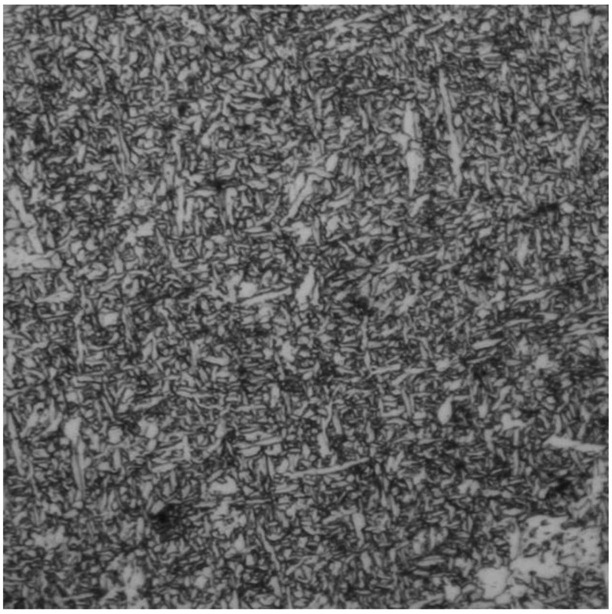

Fig. 10. Acicular ferrite in weld metal deposit which was done with micro-jet cooling (cooling gas He), magnification × 200

On the basis of metallographic examination can determine different ferrite content in the weld metal deposit. The differences are clear. Least of AF is in the weld metal deposit which was done without micro-jet cooling. Increased amount of ferrite was observed in WMD wchih was done with micro-jet cooling, regardless of cooling gas type. However, differences in the amount of ferrite can be observed for various cooling gases.

In the case of welds made with cooling the greatest amount of AF was observed for micro-jet welding with He as a coolong gas. The smallest amount was in WMD wchih was done with micro-jet welding with Ar as a coolong gas. Nitrogen represented intermediate values.

5. Summary and conclusions

The results of investigation shows that kind of cooling gas used for micro-jet cooling has clear influence on WMD parameters. Using of welding with micro-jet cooling has positivelly influence on plastic parameters of the weld. Selection fo cooling gas could be the one fo the ways to steering of the WMD structure and the properties of the welded joint.

Final conclusions:

a) micro-jet cooling could be treated as an important element of improve plastic properties of welded joints,
b) micro-jet cooling after welding can prove amount of ferrite AF, the most beneficial phase in low alloy steel WMD,
c) kind of cooling gas is very important for weld parameters,
d) choice of cooling gas could be one of welding with micro-jet cooling parameters.

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Received: 10 January 2014.