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FILLER MATERIALS FOR MAG WELDING WITH MICROJET COOLING FOR TRUCK FRAME REPAIRS

Summary. The goal of this paper is to analyse the mechanical properties of the weld steel structure of car body truck frames following MAG welding repairs using various filler materials. The main role of welding conditions is connected with filler materials, welding technology, stress state and temperature. In the paper, the properties of steel structures after MAG welding with microjet cooling are presented. Weld metal deposits (WMDs) were prepared by using various welding wires with different chemical compositions. A WMD with various nickel content was examined using three different welding wires; simultaneously, a WMD with varied oxygen content was examined using different gas mixtures for microjet cooling. In this study, the metallographic structure and impact toughness of welded joints were analysed in terms of welding parameters. The amount of acicular ferrite (AF) in WMDs, with various amounts of nickel and oxygen after welding, was tested. The various steel deposits were checked with the variable content of manganese and silicon, as well as nickel. Gas mixtures of argon and carbon dioxide were used for microjet cooling.
Keywords: MAG welding; cooling system; welded construction; trucks, transport

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1. INTRODUCTION

There is an increasing need for sheet steels with high-impact toughness for automotive applications, in order to reduce the body-in-white (BIW) weight. BIW refers to the stage in automobile manufacturing in which a car body's sheet metal components have been welded together. This is the stage before painting and before moving parts (doors, hoods and deck lids as well as fenders), the engine, chassis subassemblies or trims (glass, seats, upholstery, electronics etc.) have been assembled in the frame structure. For this reason, a large part of current sheet steel research is focused on the development of high-strength steels, by combining toughness, which is highly tensile, with good elongation and good impact, and innovative welding technologies [1-4].

The choice of alloying elements is highly important due to their influence on the microstructure and impact toughness. The largest contribution of the steel composition relates to the effect of alloying elements on the microstructure, which determines most of the mechanical properties of the final product. The influence of the chemical composition of steel WMDs on Charpy V impact properties has been carefully analysed over the last 15 years [8-10]. The influence of the steel alloying elements classifies them into two groups: carbide-forming elements and elements that do not form carbides. Generally, non-carbide-forming elements are simultaneously austenite stabilizers (i.e., they expand the austenite zone), while carbide formers are simultaneously ferrite stabilizers (i.e., they reduce the austenite zone). Mn and Co are treated as carbide formers, which are simultaneously austenite stabilizers. Ni, Cu are non-carbide formers, which are simultaneously austenite stabilizers. On the other hand, Mo, Cr, V, W, Ti, Nb and Zr are treated as carbide formers, which are simultaneously ferrite stabilizers. Si, P and Al are non-carbide formers, which are also ferrite stabilizers. An important role with regard to the tensile properties of WMDs is also played by oxygen and nitrogen. According to current opinion, there is an optimum percentage of some elements offering an optimal metallographic structure and properties with the highest impact [4,10].

Nitrogen, chromium and vanadium increase the strength of the joint, while at the same time having a negative effect on its tensile WMD properties. Silicon and manganese can be treated as neutrally acting elements on plastic properties of joints. The dominant view is that there is a significant influence on the impact toughness of steel welds in the case of such elements as nickel and oxygen. An amount in the range of about 1-2% nickel and 200-500 ppm for oxygen in the WMDs allows us to obtain high-impact toughness for the steel joint; but the reasons for such dependences are not definitively explained [10]. Nickel as the main non-carbide former and austenite stabilizer inhibits the formation of larger-size ferrite at the grain boundary, which favours the formation of much more beneficial AF. The effect of oxygen on good properties is most visible in the MMA welding process [4]; see Figure 1.

On analysing Figure 1, it is easy to deduce that the less oxygen there is in a WMD, the higher the impact toughness. It can also be observed that second-class WMDs' impact toughness (47 J at -20°C) corresponds to a content of no more than 350 ppm of oxygen in the WMD. In other welding processes, these values (optimal oxygen amount in a WMD) may be slightly different [4]. The oxygen content in a WMD has an influence on the formation of inclusions that favour the nucleation of AF. The special role of non-metallic inclusions, such as $MnO \cdot Al_2O_3$, TiO and TiN, on the AF formation is strongly underlined [4,11].

Microjet cooling, immediately after welding, offers a new opportunity to increase the amount of AF in the weld, which consequently has an effect on the impact toughness of the weld [9-10]. Microjet cooling leads to significant ferrite grain disruption, which, in connection with the optimal chemical composition, will give a perfect effect. Microjet cooling can lead to a reduction in unfavourable MAC phases (self-tempered martensite, retained austenite, carbide). Meanwhile, MAC phases reduce the impact toughness of the weld and should not be higher than 5% in WMDs [5,9].

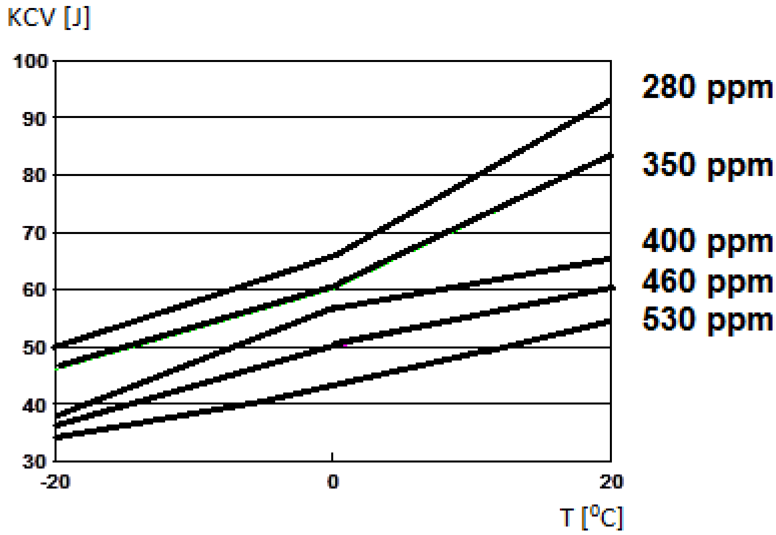


Fig. 1. The influence of oxygen on the impact toughness properties of the WMD [5]

2. EXPERIMENTAL PROCEDURE

The aim of the investigation presented below was to observe the common effect of nickel and oxygen on some properties of the MAG WMD, as well as assess the effect of nickel and oxygen on the mechanical properties of deposited metals and welds made in gas shields, involving various typical electrode welding wires used in automotive repairs (Table 1).

Table 1

The chemical compositions of various types of electrode welding wires

Wire	PN classification	EN classification	AWS classification	Main chemical composition
A	PN ISO 14341, 4Si1	EN ISO 14341, 4Si1	AWS A5.18, ER 70S-6	0.08% C; 0.6% Si; 1.3% Mn; 0.01% Ni
B	SPG1	EN 12536, OI	AWS A 5.2, R45	0.08% C; 0.3% Si; 1.1% Mn; 0.1% Ni
C	PN-88/M-69420 SPG4N	-	-	0.08% C; 0.3% Si; 1.1% Mn; 1% Ni

The WMD was prepared by the MAG welding process (shielding gas: Ar with 15% CO_2) involving microjet cooling with various gas mixtures of Ar and CO_2. The main parameters of microjet cooling were slightly varied:

- Cooling steam diameter was not varied (60 µm)
- Gas pressure was twice varied (0.5 and 0.6 MPa)
- Microjet gas mixtures were substituted (various gas mixtures of Ar and CO_2)

The basic material being researched was S355J2G3 steel (typical material for truck frames and car bodies). This typical WMD had a rather similar chemical composition in all tested cases after MAG welding using Wire A and staining various microjet cooling gas mixtures. The parameters of the welding process in all tested cases (for Wires A, B and C) are presented in Table 2.

Table 2

Parameters of the welding process

Arc voltage	28 V
Current	190 A
Diameter of tested wires	1.2 mm
Shielding gas	Ar with 15% CO_2
Microjet gas pressure	0.5 and 0.6 MPa
Microjet diameter	60 μm
Microjet gas mixtures	Ar Ar with 15% CO_2 Ar with 30% CO_2

In the main, welds produced via MAG welding with microjet cooling with various microjet gas mixtures were tested and compared. This typical WMD had various chemical compositions regarding welding wire choice and microjet gas mixture (Tables 3-4).

Table 3

Chemical composition of the WMD after MAG welding using Wire A

Element	Amount
C	0.09%
Mn	1.37%
Si	0.52%
P	0.014%
S	0.017%
O	290-380 ppm
N	60 ppm
Ni	0.01%

The use of microjet cooling after MAG welding using Wire A noticeably affected the oxygen content of the WMD (Table 4).

Table 4
Chemical composition of the WMD after MAG welding using Wire A

Gas mixture in microjet cooling micro-k	O amount, ppm
Ar	290
Ar with 15% CO_2	330
Ar with 30% CO_2	380

This typical WMD also had a similar chemical composition in all tested cases after MAG welding using Wire B and staining various microjet cooling gas mixtures (Table 5).

Table 5
Chemical composition of the WMD after MAG welding using Wire B

Element	Amount
C	0.09%
Mn	1.12%
Si	0.47%
P	0.012%
S	0.017%
O	280-370 ppm
N	60 ppm
Ni	0.1% Ni

The chemical composition of the tested deposits was similar (Tables 3 and 5). Both deposits had low nickel content. The use of microjet cooling after MAG welding using Wire B also clearly affected the oxygen content of the WMD (Table 6).

Table 6
Chemical composition of the WMD after MAG welding using Wire A

Gas mixture in microjet cooling micro-k	O amount, ppm
Ar	280
Ar with 15% CO_2	330
Ar with 30% CO_2	370

The typical WMD also had a similar chemical composition in all tested cases after MAG welding using Wire C and staining various microjet cooling gas mixtures (Table 7).

Table 7
Chemical composition of the WMD
after MAG welding using Wire C

Element	Amount
C	0.07%
Mn	0.7%
Si	0.42%
P	0.019%
S	0.013%
O	300-390 ppm
N	60 ppm
Ni	1.04%

The third deposit's (C's) chemical composition differed from the other two (A, B), mainly in nickel, whose content changed on a logarithmic scale (Wire A; 0.01% Ni; Wire B 0.1% Ni; Wire C 1% Ni). The use of microjet cooling after MAG welding using Wire C also noticeably affected the oxygen content in the WMD (Table 8).

Table 8
Chemical composition of the WMD after MAG welding using Wire C

Gas mixture in microjet cooling micro-k	O amount, ppm
Ar	300
Ar with 15% CO_2	360
Ar with 30% CO_2	390

The AF amount regarding the microjet cooling parameters (gas mixture composition and gas pressure) was precisely analysed. In all tested cases, MAC phases (self-tempered martensite, retained austenite, carbide) were also observed. Examples of the results of the metallographic structure analysis are shown in Tables 9-11.

Table 9
AF and MAC phases in the WMD after MAG welding using Wire A regarding various microjet parameters

Wire (Table 1)	Gas mixture	Microjet gas pressure [MPa]	AF [%]	MAC phases [%]
A	-	-	41	3
A	Ar	0.5	52	3
A	Ar + 15% CO_2	0.5	54	3
A	Ar + 30% CO_2	0.5	52	3

A	Ar	0.6	53	2
A	Ar + 15% CO_2	0.6	58	3
A	Ar + 30% CO_2	0.6	55	2

The WMD gained after welding with microjet cooling did not guarantee a high content of ferrite AF, due to the unfavourable chemical composition of Wire A (0.08% C; 0.6% Si; 1.3% Mn; 0.01% Ni). Si as a ferrite stabilizer occurs with too much amount, while nickel, as an austenite stabilizer, occurs only in a trace amount. Too high a content of Si and Mn in WMDs creates larger non-metallic inclusions, which are not beneficial to AF nucleation.

Table 10

AF and MAC phases in the WMD after MAG welding using Wire A regarding various microjet parameters

Wire (Table 1)	Gas mixture	Microjet gas pressure [MPa]	AF [%]	MAC phases [%]
B	-	-	45	3
B	Ar	0.5	57	3
B	Ar + 15% CO_2	0.5	61	2
B	Ar + 30% CO_2	0.5	53	3
B	Ar	0.6	63	2
B	Ar + 15% CO_2	0.6	68	2
B	Ar + 30% CO_2	0.6	62	2

The WMD gained after welding with microjet cooling was able to guarantee a higher content of ferrite AF than in the previous case, due to a more favourable chemical composition of Wire B (0.08% C; 0.3% Si; 1.1% Mn; 0.1% Ni). Si as a ferrite stabilizer occurs at a lower level, while nickel as an austenite stabilizer occurs at a higher level. A lower content of Si and Mn in WMDs creates smaller non-metallic inclusions, which are very conducive to the nucleation of AF.

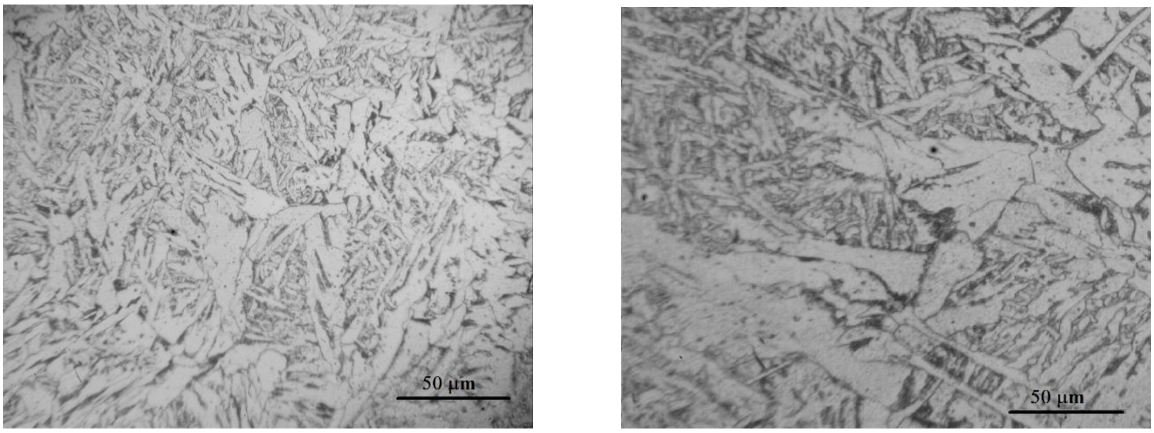
Table 11

AF and MAC phases in the WMD after MAG welding using Wire A regarding various microjet parameters

Wire (Table 1)	Gas mixture	Microjet gas pressure [MPa]	AF [%]	MAC phases [%]
C	-	-	45	3
C	Ar	0.5	59	2
C	Ar + 15% CO_2	0.5	64	2
C	Ar + 30% CO_2	0.5	59	2
C	Ar	0.6	66	2

C	Ar + 15% CO_2	0.6	69	2
C	Ar + 30% CO_2	0.6	61	2

The presence of nickel in the weld metal blocks the conversion of austenite into a coarse ferrite, which leads to the granulation of the ferrite grain. On analysing Tables 9-11, it is possible to deduce that MAG welding with microjet cooling could be treated as a strong option in all tested cases, due to the elevation of the ferrite content. It is also shown that microjet gas pressure after MAG welding, involving all tested gas mixtures, should always be at the level of 0.6 MPa. AF with a percentage above 60% was only achievable after microjet cooling in the case of Deposits B and C (Figure 2).



A WMD after microjet cooling (65% AF) A WMD without microjet cooling (45% AF)

Fig. 2. AF in various deposits (45-65%)

In the last part of the research, WMD impact strengths were tested at -20, 0 and 20°C and compared with the values reported in the literature for the MMA process (Figure 1). Additionally, it was decided to check the average size of non-metallic inclusions affecting the nucleation of ferrite AF. Toughness was only tested in the case of microjet-cooled deposits with a pressure of 0.6 MPa, because this parameter led to a higher content of ferrite AF (Tables 12-14).

Table 12

Impact toughness for MAG welding with varied microjet gases using Wire A

Microjet gas	Temperature [°C]	Impact toughness [KV, J]	Rounded amount of non-metallic inclusions sized 0.4-0.6 μm, %
Without cooling	- 20	below 47	15
Ar	- 20	61	25
Ar + 15% CO_2	- 20	63	35
Ar + 30% CO_2	- 20	51	30
Without cooling	0	54	15

Ar	0	75	25
Ar + 15% CO_2	0	81	35
Ar + 30% CO_2	0	69	30
Without cooling	+20	175	15
Ar	+20	177	25
Ar + 15% CO_2	+20	181	35
Ar + 30% CO_2	+20	166	30

Microjet cooling clearly allows for a second impact toughness class (i.e., a minimum value of 47 J at -20°C). The highest content of smaller non-metallic inclusions corresponds to the percentage of ferrite AF in a WMD. In addition to the positive cooling effect of microjet cooling on the impact toughness of a WMD, the oxygen concentration in the WMD plays an important role. The oxygen amount can be steered and precisely controlled by the microjet process parameters.

Table 13

Impact toughness for MAG welding with varied microjet gases using Wire B

Microjet gas	Temperature [°C]	Impact toughness [KV, J]	Rounded amount of non-metallic inclusions sized 0.4-0.6 µm, %
Without cooling	- 20	below 47	15
Ar	- 20	67	25
Ar + 15% CO_2	- 20	71	40
Ar + 30% CO_2	- 20	58	35
Without cooling	0	59	15
Ar	0	77	25
Ar + 15% CO_2	0	83	40
Ar + 30% CO_2	0	77	35
Without cooling	+20	176	15
Ar	+20	179	25
Ar + 15% CO_2	+20	185	40
Ar + 30% CO_2	+20	168	35

Microjet cooling makes it even easier to obtain a second impact toughness class (i.e., a minimum value of 47 J at -20°C) in this case. An even higher content of small inclusions was observed compared to the previous case (Wire A). A higher content of small non-metallic inclusions corresponds directly to the respectively higher percentage of ferrite AF within a WMD. Furthermore, in this case, the positive cooling effect of microjet cooling on the impact toughness of a WMD with oxygen concentration in the WMD was observed. This part of the investigation also confirmed that the oxygen amount can be steered and precisely controlled by the microjet process parameters.

Table 14
Impact toughness for MAG welding with varied microjet gases using Wire A

Microjet gas	Temperature [°C]	Impact toughness [KV, J]	Rounded amount of non-metallic inclusions sized 0.4-0.6 μm, %
Without cooling	- 20	52	25
Ar	- 20	71	40
Ar + 15% CO_2	- 20	86	45
Ar + 30% CO_2	- 20	73	40
Without cooling	0	62	25
Ar	0	74	40
Ar + 15% CO_2	0	92	45
Ar + 30% CO_2	0	75	40
Without cooling	+20	171	25
Ar	+20	172	40
Ar + 15% CO_2	+20	175	45
Ar + 30% CO_2	+20	169	40

Microjet cooling makes it even easier to obtain a second impact toughness class (i.e., a minimum value of 47 J at -20°C) in this case. An even higher content of small inclusions was observed, compared to the previous case (Wires A-B). The highest content of small non-metallic inclusions (compared with A and B) corresponds directly to the respective percentage of ferrite AF in the WMD. Furthermore, in this case, the positive cooling effect of microjet cooling on the impact toughness of a WMD with oxygen concentration in the WMD was observed. This part of the investigation also confirmed that the oxygen amount can be steered and precisely controlled by the microjet process parameters. A significant role for nickel in terms of the plastic properties of the joint was noted. The WMD had a second class of impact resistance, even without microjet cooling, while the best results were obtained with the use of Wire C and microjet cooling in comparison with the A and B deposits.

It is possible to deduce that impact toughness in the case of a negative temperature for the WMD is apparently affected by the type of microjet gas mixture in the cooling injector. A gas mixture of Ar + 15% CO_2 could be considered as optimal.

3. CONCLUSIONS

The connection between processes such as MAG welding and microjet cooling was tested with various filler materials. It was noticed that the chemical composition of the wire and the chemical composition of the gas mixture used for microjet cooling have an influence on

WMD structure and impact toughness. The preliminary results validate the theoretical assumptions and indicate that it will be possible to apply this technology in the automotive industry.

On the basis of the investigation, we may deduce that:

- microjet cooling could be treated as an important element in the MAG welding process
- microjet cooling after welding could provide an amount of AF that is the most beneficial phase in low-alloy steel WMDs
- a high amount of AF could guarantee, in relative terms, good impact toughness properties
- by using microjet cooling after welding, it may be possible to steer the metallographic structure (percentage of AF and MAC phases)
- only argon or helium should be used for microjet cooling after laser welding
- a gas mixture of Ar + 15% CO_2 could be considered as optimal

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