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WELDING OF S355J+N LOW ALLOY STEEL ELEMENTS IN RAILWAY CARRIAGES STRUCTURES

Summary. Various types of structures and materials play an important role in the creation modern means of transport, including various grades of steel with different mechanical properties. For the rolling stock, proper operation and meeting the operational conditions is very important. Welded structures play an important role in the construction of various means of transport. Correct welding of carriages is important both in production and when carrying out various types of repairs. Each repair a carriage depends on its advancement and condition and the time of its operation. Each inspection for a refurbished carriage is defined either by the service life or the big distance traveled by the carriage. Important factor that may lead to damage is the effect of the load transported in the carriage. Therefore, the causes of the wear of the rolling stock are investigated and measures are taken to prevent any

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damage. The appropriate technical condition of the carriage also ensures safety on railroads for users and owners of the rolling stock. In the case of welded structures in carriages, it is influenced by poorly materials choice, incorrectly selected production processes and wrong selection of parameters. The goal of this paper is the mechanical properties analyse of weld low alloy steel structure of carriages after MAG welding using the parameters of the process. Thick-walled steel structures are used to build carriages, which is often a serious welding problem. The main role of welding conditions is connected with filer materials, welding technology, state of stress and temperature. In this paper, the properties of low alloy steel S3555J+N structures after MAG welding are presented. Furthermore, metallographic structure, tensile strength, bending test and impact toughness welded joints were analysed regarding welding parameters. The amount of acicular ferrite in WMD oxygen after welding was tested. Gas mixtures of argon and carbon dioxide with various percentage was used for shielding gas.

Keywords: transport, welding, carriages

1. INTRODUCTION

This article deals with broadly understood welding problems in transport. It was decided to focus on matters that concern all modes of transport, and in this particular case, connections used in carriages and rail transport means in general. There is an increasing need for high impact toughness sheet steels for railway applications. Thus, a large part of current sheet steel research is focused on the development of high strength steels combining high tensile, good elongation, good impact toughness and innovative welding technologies [1-4]. The choice of alloying elements is very important due to their influence on the microstructure, tensile strength and impact toughness [5, 6]. The largest contribution of the steel composition is related 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 low steel WMD on Charpy V impact properties has been carefully analysed for the last 15 years [7, 8]. In S355J+N (EN10025-2:2004) steel and the wire SG3 (EN ISO 14341-A: G 46 5 M G4Si1) intended for this steel, there are mainly such elements such as C, Mn, Si, Cu, Al, P, S. Mn is treated as the carbide former that is simultaneously austenite stabilisers. Cu is a non-carbide former that is simultaneously austenite stabilisers. Si, P, Al are non-carbide formers that are ferrite stabiliser. An important role in the tensile properties of WMD is also played by oxygen. According to the current opinion, there is an optimum percentage of oxygen that gives optimal metallographic structure and the highest impact properties [9, 10]. The effect of oxygen on the good properties is recognised the best in the MMA welding process (Figure 1).

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Analysing Figure1, it is easy to deduce that the less oxygen is in WMD, the higher the impact toughness. It can be observed that the second class of impact toughness of weld metal deposit (47 J at -20°C) corresponds with a content not greater than 350 ppm oxygen in WMD. In other welding processes, these values (optimal oxygen amount in WMD) may be slightly different [11, 12].

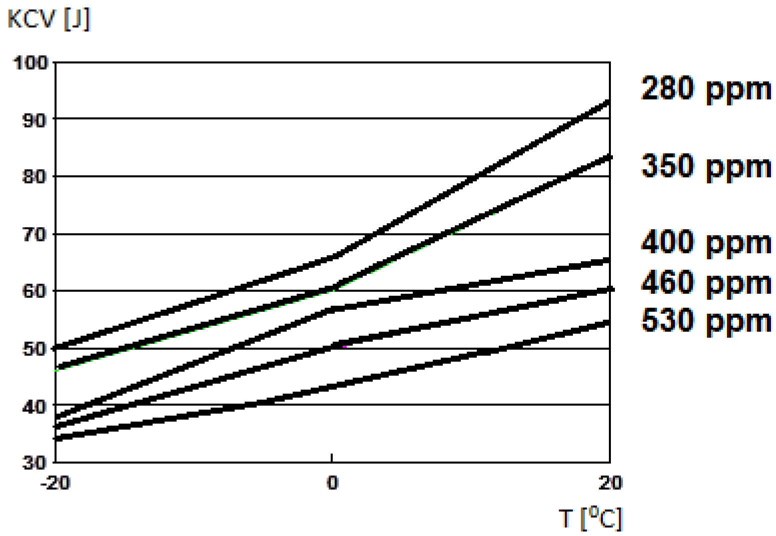

Fig. 1. The influence of oxygen on impact toughness properties of the WMD [2]

2. MATERIALS AND METHODS

Steel S355J+N is increasingly used in civil engineering and transport due to its good strength and high elongation. The tensile strength of this steel is high, and the relative elongation is very acceptable (Table 1). Therefore, it is recommended to limit the linear energy during the welding process to the level of 5 kJ/cm [2].

Table 1 presents the mechanical properties of S355J+N steel used for welded elements of carriages.

Tab. 1

Mechanical properties of S355J+N steel [8]

Steel	The yield point YS, MPa	Tensile strength UTS, MPa	Relative elongation A5, %
S355J+N	600	400	15

Thick-walled structures used to build carriages are considered difficult to weld due to appearing cracks in the weld (less often than in the heat affected zone) [1]. Hence, it is extremely important to correctly select the chemical composition of the wire and the appropriate welding parameters. Table 2 presents the chemical composition of S355J+N steel.

Tab. 2

Chemical composition of S355J+N [8]

Steel grade	C, %	Si, %	Mn, %	P, %	S, %	Al, %	Cu, %	O, ppm
S355J+N	0.19	0.55	1.7	0.035	0.035	0.01	0.6	95

It is easy to notice a very high content of phosphorus and sulfur. According to the definition of steel quality, it should not be more than 0.03% P + S in total. Excessive content of P and S creates welding difficulties. The following electrode wires were selected: SG3 (EN ISO 14341-A: G 46 5 M G4Si1). The chemical composition of the welding wire is presented in Table 3.

Tab. 3

Electrode wires used in the research - chemical composition [12]

wire	C %	Si %	Mn %	P %	S %
SG3	0.08	0.85	1.7	0.021	0.021

The chemical composition of steel and wire differs slightly. The diameter of the electrode wire was 1.2 mm. In both cases, three different welding speeds were verified: 300, 350 and 400 mm/min. According to the literature recommendations, the welding speed was changed three times to assess which linear energy is the most appropriate [8, 9]. The source of a direct current was connected to (+) on the electrode, the thick-walled weld was triple-stitched.

In addition, a joint of the tested sheets was made with a thickness of 12 mm, to analyse the strength and bending resistance. Similarly, again, in this case, the diameter of the electrode wire was 1.2 mm. Arc voltage 19 V and welding current 130 A were applied to the first layer, arc voltage 25 V and welding current 200 A were chosen for the second and third layer of the weld. Thus, the weld was triple-stitched. In addition, in this part of the study, two various argon shielding mixtures: Ar + 18% CO_2 and Ar +10% CO_2 (according to PN-EN 14175 norm) were used.

3. METHODS AND SCOPE OF RESEARCH

The research included non-destructive testing (NDT):

- visual testing (VT) of prepared welded joints was done with the use of an eye armed with a magnifying glass at the magnification of 3× – test was done according to the PN-EN ISO 17638 norm, assessment criteria according to the EN ISO 5817;
- magnetic particle testing (MT) – tests were carried out according to the PN-EN ISO 17638 norm, with assessment performed according to the EN ISO 5817, using a magnetic flaw detector of REM-230 type;
- radiographic tests – tests were carried out according to the PN-EN ISO 15614-1 norm. The type of radiation source was SMART 200.

Amongst the destructive tests, the following assessments of the researched pin to platform arm weld were performed:

- examination of the macrostructure of specimens digested with the use of Adler's reagent and a light microscope (LM);
- hardness measurement (HPO 250 hardness tester, HV10 test method).

In addition, for a mixed testing MAG joint made of two 12 mm thick sheets, the following tests were carried out:

- tensile strength test using a machine (ZWICK 100N5A strength testing machine);
- bending test (ZWICK 100N5A strength testing machine).

4. RESULTS AND DISCUSSION

A butt-type welded joint (BW) from S355J+N steel was made. MAG (135) welding method was applied in the down position (PA) according to the EN 15614-1 norm. The material preparation for triple-stitched welding is presented in Figure 2.

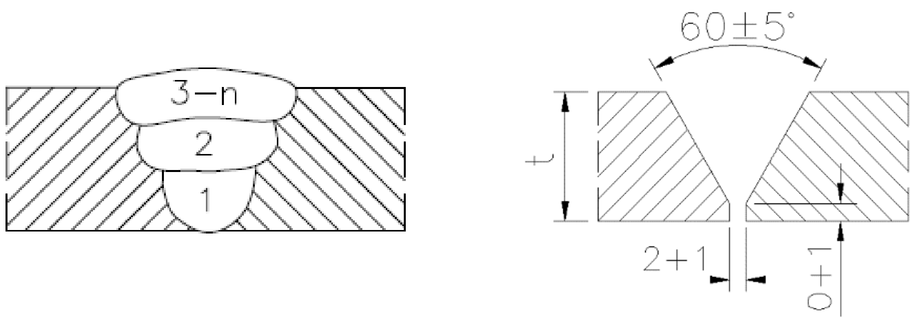

Fig. 2. Welding method and groove shape

To assess the weldability of the mobile platform components (pin and platform arm), two argon mixtures: 82% Ar-18% CO_2 and 90% Ar-10% CO_2 were selected to act as shielding gases, and wire SPG3 was applied. After the welding, the following non-destructive tests (NDT) were carried out: visual (VT), magnetic particle (MT) and radiographic. The results of the created mobile platform joint are presented in Table 4.

The table data shows that the type of a shielding mixture as well as the type of an electrode wire, and especially, the type of the linear energy affects the quality of the produced joint. For all twelve tested cases, no cracks in the MAG weld appeared in only two cases when:

- 90% Ar-10% CO_2 was used as the shielding gas mixture,
- the welding speed was at the level of 300 or 350 mm/min,
- interpass temperature was below 250°C.

These mentioned welds received the quality level B according to the PN-EN ISO 5817 norm. The image quality was W18 according to the EN ISO 19232-1 norm. Non-destructive testing showed that the less oxidising argon mixture (90% Ar-10% CO_2) is more appropriate as its use allows to avoid cracks in welds.

4.1. Results of destructive testing

For hardness testing, only joints made with the welding speed of 300 mm/min were considered. Joint hardness distribution was also carried out. The results are presented in Table 5.

Analysing the data from Table 5, it can be noted that the hardness value in the whole joints was always below 220 HV. Slightly lower hardness values occurred in joints with uncontrolled interpass temperature, which can be explained by the possibility of ferrite grain growth.

Tab. 4

Assessment of non-destructive testing of the movable platform joint

Shielding gas	Interpass temperature	Welding speed 300 mm/min	Welding speed 350 mm/min	Welding speed 400 mm/min
90% Ar-10% CO_2	below 250°C	No cracks	No cracks	Cracks in the weld
82% Ar-18% CO_2	below 250°C	Cracks in the weld	Cracks in the weld	Cracks in the weld
90% Ar-10% CO_2	over 250°C	Cracks in the weld	Cracks in the weld	Cracks in the weld and HAZ
82% Ar-18% CO_2	over 250°C	Cracks in the weld	Cracks in the weld	Cracks in the weld and HAZ

Tab. 5

Hardness distribution in the joints

Shielding gas	Interpass temperature	Base material	HAZ	Weld	HAZ	Base material
90% Ar-10% CO_2	below 250°C	167	214	205	213	165
82% Ar-18% CO_2	below 250°C	155	207	202	212	161
90% Ar-10% CO_2	over 250°C	168	216	207	215	166
82% Ar-18% CO_2	over 250°C	159	209	201	211	164

4.2. Strength tests

To obtain additional information regarding the correctness of the joint, it was decided to perform tensile strength tests. Once the joints welded with various parameters were completed, tests of immediate tensile strength were performed. Joint strength tests were carried out on the ZWICK 100N5A strength testing machine. Dimension of cross section of the sample was 12 mm × 25 mm. The results of the mechanical tests of the welds (an average of three measurements) are presented in Table 6. Only joints with a controlled interpass temperature below 250°C were taken for testing (because only these have no cracks).

The analysis of the array data shows that the welds were made correctly because the nominal value of this joint should be in the range of 470 MPA to 630 MPa.

Next, the bending test of the created joints was performed. For the test, a sample with a thickness of a = 12 mm, width of b = 25 mm, mandrel of d = 40 mm were used, the required bending angle was at the level of 180°. Five bending measurements were carried out both on the face side and on the root side of the weld. The tests results are summarised in Table 7.

Tab. 6

Mechanical properties of the joints

Shielding gas	Interpass temperature	R_m, MPa	A_5, %
90% Ar-10% CO_2	below 250°C	551	14.3
82% Ar-18% CO_2	below 250°C	557	13.9

Tab. 7

Joint bending test results

Shielding gas	Interpass temperature	Side deformation	Size [mm]	Comments
90% Ar-10% CO_2	below 250°C	Root of the weld	12 x 25	No cracks, no incompatibilities
90% Ar-10% CO_2	below 250°C	Face of the weld	12 x 25	No cracks, no incompatibilities
82% Ar-18% CO_2	below 250°C	Root of the weld	12 x 25	No cracks, no incompatibilities
82% Ar-18% CO_2	below 250°C	Face of the weld	12 x 25	No cracks, no incompatibilities

The analysis of Table 7 shows that the joints were made correctly. No cracks or other incompatibilities were found in the tested samples.

4.3. Metallographic examination

Next, the microstructure analysis was performed. Amount of acicular ferrite was counted in all tested cases (Table 8).

Tab. 8

Acicular ferrite and MAC phases in WMD after MAG welding using wire A regarding various micro-jet parameters

Shielding gas	Interpass temperature	Acicular ferrite [%]
90% Ar-10% CO_2	below 250°C	45
82% Ar-18% CO_2	below 250°C	42
90% Ar-10% CO_2	below 250°C	37
82% Ar-18% CO_2	below 250°C	35

It is easy to observe that acicular ferrite with a percentage above 40% was obtainable only after MAG welding with controlled interpass temperature below 250°C. Typical structure of the weld is presented in Figure 3.

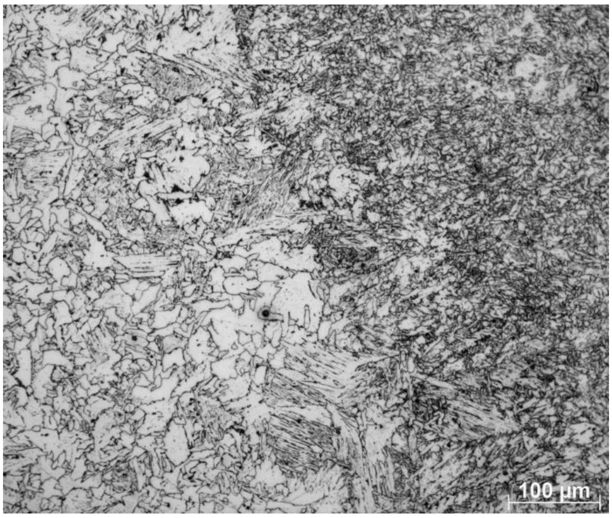

Fig. 3. Acicular ferrite (45%) in MAG weld
(shielding gas mixture 90% Ar-10% CO_2, controlled interpass temperature below 250°C)

In the last part of the research, WMD impact toughness was tested at -20 and -40°C. Only joints with a controlled interpass temperature below 250°C were taken for testing (because only these have no cracks) – Tables 9.

Tab. 9

Impact toughness for MAG welding

Shielding gas	Interpass temperature	Impact toughness [J] at -20°C	Impact toughness [J] at -40°C
90% Ar-10% CO_2	below 250°C	82	51
82% Ar-18% CO_2	below 250°C	76	44

Analysing the table data, it can be observed that the impact toughness of the junction is more favourable when the shielding gas 90% Ar-10% CO_2 is used. Only in this case, the fourth class of impact toughness is fulfilled with the breaking energy above 45 J at -40°C. This is due to the less oxidising nature of this sheath mixture as compared to the 82% Ar-18% CO_2 mixture.

3. CONCLUSIONS

Joints were made of S355J + N steel, used in the construction of carriage components. Welding a thicker structure of this steel is not easy due to the (elevated) content of phosphorus and sulfur, which is twice as high as the accepted requirements for the quality of low alloy steel.

Developing the welding method, it was decided to focus on the correct selection of the gas mixture and the thermodynamic conditions of the joint. Two argon mixtures with different carbon dioxide additions (90% Ar-10% CO_2 and 82% Ar-18% CO_2) were tested. It was decided that preheating before welding was not needed, but it was important to control the interpass temperature not to exceed 250°C. NDT tests showed that the joint has no welding defects and incompatibilities only when the interpass temperature is below 250°C. Thereafter, destructive tests were performed to check the correctness and quality of the joint. Joint hardness and tensile strength tests and bending tests were carried out. In all tested cases, it was confirmed that the joint is correctly done according to the nominal requirements for this type of design. The final stage of the research was to check the impact toughness of the joint, which showed that both mixtures used for welding are correct and allow to obtain a nominal value corresponding with the second impact class. To obtain the fourth impact strength class, a gas mixture should be used as a shielding gas, less oxidising the weld 90% Ar-10% CO_2.

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