

# SCIENTIFIC AND DIDACTIC EQUIPMENT

## Thermodynamic conditions during welding of railway carriage elements made of S355J+N STEEL

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**Keywords:** civil engineering, transport, means of transport, PBO4, welding

### ABSTRACT:

The article aims to analyse the mechanical properties of carriage structures made of MAG-welded, low-alloy S 355J+N steel.

Carriages are often made from thick-walled structures, which may cause problems during welding. The aforementioned issues stem from the chemical composition of the steel and electrode, the internal stress, as well as the thermodynamic conditions (which consist of the pre-heating temperature and interpass temperature). This article presents the properties of S 355J+N steel structures after MAG welding. In addition, non-destructive testing has been performed, and the metallographic structure and tensile strength of welded joints have been analysed. Different mixtures of argon with carbon dioxide or oxygen were used as the shielding gas, and the bevelling method used for sheets before welding was established. Welding speed was changed without pre-heating. The interpass temperature was controlled, so that it did not exceed 250°C.

## Warunki termodynamiczne podczas spawania elementów wagonów ze stali S355J+N

**Słowa kluczowe:** inżynieria lądowa, transport, środki transportu, PBO4, spawanie

### STRESZCZENIE:

Celem pracy jest analiza właściwości mechanicznych konstrukcji wagonów ze stali niskostopowej S355J+N, spawanej metodą MAG.

Do budowy wagonów używa się często grubościennych konstrukcji, co może stanowić problem spawalniczy. Trudności te związane są ze składem chemicznym stali i drutów elektrodowych, stanem naprężenia, warunkami termodynamicznymi (na które składają się temperatura podgrzewania wstępnego i temperatura międzyściegowa). W niniejszym artykule przedstawiono właściwości konstrukcji ze stali niskostopowej S355J+N po spawaniu metodą MAG różnymi parametrami procesu. Wykonano badania nieniszczące oraz przeanalizowano strukturę metalograficzną i wytrzymałość na rozciąganie złączy spawanych. Jako gazu osłonowego użyto różnych osłonowych mieszanin gazowych argonu z tlenem i dwutlenkiem węgla, ustalono też sposób ukosowania blach przed spawaniem. Zmieniano prędkość spawania nie stosując podgrzewania wstępnego. Temperatura międzyściegowa została poddana kontroli, tak aby nie przekraczała 250°C.

## 1. INTRODUCTION

The article presents the results of tests performed to select parameters for MAG welding used in constructing railway carriage elements made of S355J+N steel.

There is constantly growing demand for steel joints guaranteeing high impact strength in the creation of Smart City structures (research area PB04). Continuous improvements in the steel joints used in carriage construction are similarly important. A significant part of ongoing research concerns the development of steel joints demonstrating high resilience and high impact strength using new supplementary materials and innovative welding technologies [1-4]. The choice of alloying elements in the steel and in the weld is of great importance due to their influence on the joint's structure, temporary tensile strength and impact strength. The influence of the chemical composition of unalloyed steels on the aforementioned properties has been analysed with great diligence over the last 15 years [8-10]. In the case of S355J + N steel (EN10025-2: 2004) and an SG3 electrode (EN ISO 14341-A: G 46 5 M G4Si1) intended for this steel mainly such elements as: C, Mn, Si, Cu, Al, P and S are included. The addition of Mn increases strength and is neutral within the scope of its plastic properties (austenite-forming element). The addition of Cu changes the chemical properties and also improves the corrosion resistance of unalloyed steels. The addition of Si increases the strength of the steel and joints. Meanwhile, S and P are considered undesirable, as they deteriorate the plastic properties of steel.

## 2. MATERIALS AND METHODS

As stated in the introduction, S355J + N steel is increasingly often used in the creation of smart cities, as well as in civil engineering and transport thanks to its relatively high strength and good plastic properties. Its tensile strength is 600 MPa and the relative elongation considered satisfactory by designers. This material group has the advantage in that it is possible to obtain comparable mechanical properties after welding. Table 1 presents the mechanical properties of S355J + N steel intended for welded parts of railway carriages.

**Table 1** Mechanical properties of S355J + N steel [6]

Steel	Rm, MPa	Re, MPa	A5, %
S355J+N	600	435	16

Thick-walled structures used in the construction of carriages are considered difficult to weld due to cracks appearing in the weld (less frequently than in the heat affected zone) [1]. Therefore, correct selection of the electrode's chemical composition and determination of appropriate welding parameters are of utmost importance. Table 2 shows the chemical composition of S355J + N steel.

**Table 2** Chemical composition of the tested S355J+N steel [6]

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 the high phosphorus and sulphur content, which causes difficulties in welding. Therefore, the following electrodes were selected: SG3 (EN ISO 14341-A: G 46 5 M G4Si1). The chemical composition of the welding electrode is shown in Table 3.

**Table 3** The chemical composition of the SPG3 electrode[10]

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

The chemical compositions of the steel and electrode are similar in this case. The electrode diameter was 1.2 mm, the arc voltage 20 V, and the welding current 115 A. In both cases, three different welding speeds were tested: 300 mm/min, 350 mm/min and 400 mm/min. As per the recommendations of literature on the subject, it has been decided not to use preheating, while the interpass temperature was controlled and never exceeded 250°C. The welding speed was changed several times in order to assess the most appropriate heat input [6, 7]. The DC source was always connected to the (+) on the electrode and a three-pass weld was obtained. Two different argon shielding mixtures were also used: Ar+18% CO<sub>2</sub> and Ar+2% O<sub>2</sub> (according to the PN-EN 14175 standard). The tests included non-destructive testing (NDT), which consisted of:

- Visual tests (VT) of the prepared welded joints were performed with a magnifying glass with 3x

magnification – the test was conducted in accordance with PN-EN ISO 17835, with evaluation criteria according to EN ISO 5817;

- Magnetic particle testing (MT) – the tests were performed in accordance with PN-EN ISO 17638, with the assessment conducted in line with the EN ISO 5817 standard, with a REM-230 type magnetic flaw detector;
- Radiographic tests – the tests were performed in accordance with PN EN ISO 15614-1, with a SMART 200 radiation source.

In addition, the following destructive tests were performed:

- Machine tensile strength testing (with a ZWICK 100N5A testing machine);
- Examination of the sample macrostructure etched with Adler’s reagent and a light microscope (LM).

### 3. RESULTS AND DISCUSSION

A butt welded (BW) joint was made of S355J + N steel. MAG (135) welding was used in the lower position (PA) in accordance with EN 15614-1. Preparation of the material for triple pass welding is shown in Figure 1.

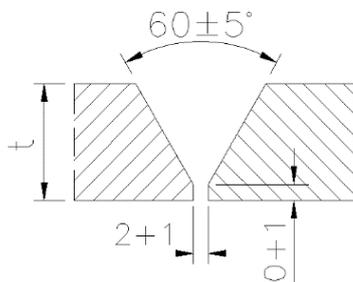


Figure 1 Manner of bevelling a three-pass joint

The following non-destructive tests (NDT) were performed after welding: visual (VT), magnetic particle (MT) and radiographic. They served as the basis for assessing the quality of joints (Tab. 4).

Table 4 Joint quality evaluation

Shielding gas	Gap between sheets, mm	Welding speed 300 mm/min	Welding speed 350 mm/min	Welding speed 400 mm/min
Ar-2% O <sub>2</sub>	2	Welding defects and non-conformities	Welding defects and non-conformities	Welding defects and non-conformities
Ar-18% CO <sub>2</sub>	2	<b>No cracks</b>	<b>No cracks</b>	Welding defects and non-conformities
Ar-2% O <sub>2</sub>	3	Welding defects and non-conformities	Welding defects and non-conformities	Welding defects and non-conformities
Ar-18% CO <sub>2</sub>	3	Welding defects and non-conformities	Welding defects and non-conformities	Welding defects and non-conformities

Data in the tables shows that the most appropriate shielding gas is Ar-18% CO<sub>2</sub>, which is less oxidising than the Ar-2% O<sub>2</sub> mixture. Correct bevelling plays a major role in obtaining a joint without defects. In case of “Y” bevelling (Fig. 1) the distance between the sheets should be 2 mm. According to non-destructive testing the welding speed should be 300 mm/min. or 350 mm/min. In order to obtain additional information regarding joint correctness, it has been decided to perform tensile strength tests. Once joints were made (with parameters showing positive results from the previous tests), tensile strength tests were performed. The joints were tested using a ZWICK 100N5A testing machine. The sample’s cross-section was 12 mm x 25 mm. The results of mechanical tests of welds (average of three measurements) are presented in Table 5.

Table 5 Mechanical properties of a joint made using two different welding speeds

Shielding gas	Welding speed, mm/min	R <sub>e</sub> , MPa	R <sub>m</sub> , MPa	A <sub>5</sub> , %
Ar-18% CO <sub>2</sub>	300	411	541	13.1
Ar-18% CO <sub>2</sub>	350	403	538	13.9

Table data shows that the welding speed does not have a significant effect on the joint’s mechanical properties (the distance between the sheets was 2 mm). Welding at a speed of 350 mm/min can therefore be deemed somewhat more advantageous. Next, the metallographic structure of the welds was assessed for the presence of the most favourable phase, namely AF (acicular ferrite).

**Table 6** Acicular ferrite content in tested joints

Shielding gas	Welding speed mm/min	Acicular ferrite [%]
Ar-2% O <sub>2</sub>	300	36
Ar-18% CO <sub>2</sub>	300	44
Ar-2% O <sub>2</sub>	350	37
Ar-18% CO <sub>2</sub>	350	45

Analysis of the data presented in Table 6 again shows that MAG welding in Ar-18% CO<sub>2</sub> shielding is more advantageous than welding with Ar-2% O<sub>2</sub> shielding. Excessively oxidising gas shielding does not facilitate the formation of high acicular ferrite content, which translates into worse plastic properties of the joint and the possibility of welding defects. Structural tests have confirmed that the most advantageous welding speed is 350 mm/min.

#### 4. SUMMARY

Joints of S355J + N steel were made using different welding parameters and various shielding mixtures, with variable welding speed and different bevelling methods.

Non-destructive testing showed that the Ar-2% O<sub>2</sub> shielding mixture is unsuitable for welding this steel; no welding defects or non-conformities were observed when the less oxidising Ar-18% CO<sub>2</sub> shielding mixture was used. Other factors, including proper bevelling and welding speed, also play an important role.

Destructive tests consisting of ongoing tensile strength testing and a structure test for acicular ferrite content, showed that a welding speed of 350 mm/min is more favourable.

#### BIBLIOGRAPHY

- [1] Hadryś D., Mechanical properties of plug welds after micro-jet cooling, [in:] Arch. Metall. Mater. No. 61(2016), pp. 1771-1775.
- [2] Tegoź, Impact load of welds after micro-jet cooling, [in:] Archives of Metallurgy and Materials, no. 60 (4), 2015, pp. 2525-2528.
- [3] Stanik Z., Mechatronic Systems, Mechanics and Materials, [in:] Solid State Phenomena, vol. 210/2014, pp. 58-64.
- [4] Evans G. M., Microstructure and properties of ferritic steel welds containing Al and Ti, [in:] Oerlikon-Schweissmitt, vol.130/1994, pp. 21-39.
- [5] Fornalczyk A., Willner J., Cebulski J., Pasek D., Saternus M., Czech P., Structure and surface state of different catalytic converters applied in cars. The 5th international Lower Silesia-Saxony conference "Advanced Metal Forming processes in automotive industry (AutoMetForm 2016)", Wroclaw (Poland), 28-29 June 2016, pp. 327-333.
- [6] Fornalczyk A., Saternus M., Willner J., Fafiński M., Kania H., Czech P., The results of platinum recovery from metal substrate catalytic converters by using magneto-hydro-dynamic pump. 25th Anniversary International Conference on Metallurgy and Materials "METAL 2016", Brno (Czech Republic), 25<sup>th</sup> - 27<sup>th</sup> May 2016, pp. 1382-1387. ISBN: 978-80-87294-67-3.
- [7] Burdzik R., Konieczny Ł., Stanik Z., Folęga P., Smalcerz A., Lisiecki A., Analysis of impact of chosen parameters on the wear of camshaft, [in:] Archives of Metallurgy and Materials, vol. 59 (3), 2014, pp. 957-963.
- [8] Kasuya T., Hashiba Y., Ohkita S., Fuji M., Hydrogen distribution in multipass submerged arc weld metals, [in:] Science and Technology of Welding&Joining, vol. 6 (4), 2001, pp. 261-266. DOI: 10.1179/136217101101538767.
- [9] Lukaszowicz K., Dobrzański L. et al, Characterization and properties of PVD coatings applied to extrusion dies, [in:] Vacuum, vol. 86/2012, pp. 2082-2088.
- [10] Evans G. M., The effect of micro-alloying elements on the microstructure and properties of ferritic all-weld metal deposits, IIW Doc II-A-855-92, 1992, pp. 1-20.

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