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COMPARATIVE STUDY CONCERNING THE MECHANICAL PROPERTIES OF WELDED S355J2+N STEEL USING MAG DC+ AND PULSED MAG

BY

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Abstract. Currently, welded assemblies produced through fusion processes rank among the most widely used assembly methods in the industry. The welding process selection is based on several criteria, particularly those related to the mechanical resistance characteristics of the welded materials. This paper analyses the mechanical properties of a specific material used in creating welded assemblies via MAG DC+ welding technology and Pulsed MAG welding. The study involves applying mechanical tests for tension and bending to specimens of S355J2+N steel. The experimental results indicate that, due to effective heat transfer, initial cracks do not occur in the welded area but rather in regions that are not influenced by the weld joint. Consequently, other considerations related to the welding performed were established.

Keywords: fusion welding processes, welding technology, tensile and bending strength, metal active gas, Pulsed MAG.

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1. Introduction

The welding process represents the assembly process obtained by melting two metallic or non-metallic material components, using an additional material or not, as is the case with pressure welding processes. A welded assembly can be done using various techniques and methods, among the most used being the electric arc welding process, laser welding, or ultrasonic welding. The welded assemblies can be found in various industrial branches, including naval and aeronautical constructions, as well as in the manufacturing processes used to produce industrial equipment and in the automotive industry, particularly in the production of vehicle bodies.

Regarding electric arc welding, the process of welding joints involves the assembly obtained through a fusion process applied between the basic materials and additional ones. The current used in such a welding process, whether from an alternating current source or a DC (Direct Current) one, determines the generation of heat in the melting area and through this, the creation of a new crystallisation pattern of the combined materials within the welding area. The joint between these two metallic materials is formed with the assistance of heat generated by the Joule effect, which occurs in the molten metal area in the presence of an inert or active assisting gas. The assisting gases serve to prevent the contact of the molten metal with atmospheric air until the metal solidifies and a crystalline network forms.

In the case of active gas (CO_2) welding processes, the MAG process (Metal Active Gas or GMAW-Gas Metal Active Welding) occurs by melting the fusible electrode within the protective atmosphere created by the gas used. The mentioned process offers several significant advantages, including obtaining a higher quality of welded assembly, high productivity, process flexibility, and the advantage that the gases eliminated during the process are less harmful than those eliminated in other welding processes.

For the accomplishment of the welding process, three types of welding options are available:

a. Short arc welding, which is supposed to use short circuits of the electric arc that occur with a 20 times/s frequency, based on small values of the voltage and the intensity of the electric current used;

b. Fine spray welding, where the electric arc is present at some high values of the voltage and the electric current, the additional material being scattered in fine drops on the basic material;

c. Pulsed electric arc welding, characterised by periodic variations in voltage and welding current, ensures that the additional material is sprayed onto the base metal.

The welding positions intended for use in the Pulsed MAG welding process have various applications similar to those in globular welding or spraying and the use of welding wire or additional material is certainly more efficient (Zhu *et al.*, 2008). By utilising a slow cooling of the welded cord provided by the process through the spray arc, the Pulsed MAG welding process can be applied to welding areas for which it is commonly used. In this case, the necessary heat supply is delivered in a smaller quantity, which means that the burning of thin metals has a significantly less influential effect. Thus, the Pulsed MAG process is one of the most well-suited welding processes for a wide variety of applications and types of metals, as well as for aluminium alloys (Brumm and Bürkner, 2015).

Compared to the Pulsed MAG process, the DC+ version is different from it by providing a high-intensity current with slow-increasing characteristics. This process is suitable for typical welding operations, characterised by a stable electric arc, which ensures more pronounced penetration without the production of splashes. Additionally, this process operates on one of the two polarities, either positive or negative, thereby generating a magnetic field and a constant current. Some authors, such as Zadoveev (Zadoveev *et al.*, 2020), note that in modern production, it is essential to investigate the impact of pulsed arc conditions on the results obtained with specific parameter values, particularly with the Heat-Affected Zone (HAZ) aspect and mechanical properties.

According to the technical literature, the pulsed current, also referred to as a pulsated or pulsating current, represents a specific characteristic of electric current shapes that fluctuate or vary over time. The evolution feature of such a current presents a repetitive propagation of a signal sequence, translated as a variation of the electric current according to its frequency and amplitude.

The pulsed current can be regarded as a Direct Current with a variable evolution characteristic generated when the electrical circuit is interrupted during the temporal evolution of a frequency. Thus, it is obtained in the form of an intermittent wave, which highlights the characteristic of a power impulse.

The Pulsed MAG process is performed by forming a melted metal drop at the end of the electrode at each pulse. Then, the right amount of power is added exactly to push that drop over the electric arc and the melted metallic bath. The transfer of these drops occurs through the electric arc, with one drop released with each pulse.

Regarding the difference between the two variants of welding processes mentioned above, which will be briefly highlighted in the following content, the Pulsed MAG procedure represents an advanced welding way of applying a welding process that takes the best elements from all other types of thermal transfer, produced by the generating source and minimising or eliminating their disadvantages. In addition to the short-circuit welding process type, the Pulsed MAG process does not create splashes due to a change in the velocity behaviour, which is quite different under different wire feed speeds (Wêglowski *et al.*, 2008). Therefore, considering the two welding procedures mentioned, the importance of this study lies in highlighting the pulsated electric arc welding type due to the potential variation in welding current over time.

The technical literature presents a limited number of studies conducted on the Pulsed MAG procedure. In the study conducted by Carter author (Carter, 2012, p.18), a series of elements such as advantages of the process are highlighted, among which are listed the versatility of the process in the case of different materials, reduction of splashes, and low level of pollution released during the process and others. In another study conducted by the same author, the considerable advantages of MAG welding are highlighted compared to DC welding, the significant difference being the superior quality of the welded cord.

2. Preparing the experimental setup

The experimental study is supposed to be performed in two stages. First of them needs to be obtained by cutting a series of 12 samples obtained from a laminated sheet steel (6000x1500x6 mm^3), type S355J2+N (according to EN 10025-1: 2019, normalised, hot laminated granted by EN 10029:2011), necessary for both welded joints, as well as for both resistance tests: tensile and bending tests of the basic material.

Some aspects of the preparation and cutting phase of these specimens are highlighted in Figs. 1-3. The cutting phase of the specimens was achieved through the laser beam cutting process, using Bodor A6 equipment, to minimise the risk that the influenced area would affect the final results.

The direction of cutting was chosen as being along the rolling direction.

To highlight the mechanical resistance characteristics that the welded assemblies offer to the two welding processes, 12 samples were considered as follows:

– 2 specimens from the basic material for cross-sectioned tensile strength;

– 2 specimens from the basic material for bending tensile strength;

– 2 specimens from the welded assembly by MAG DC+ process for transverse traction tensile strength;

– 2 specimens from the welded assembly by MAG DC+ process for bending tensile strength;

– 2 specimens from the welded assembly by Pulsed MAG process for transverse traction tensile strength;

– 2 specimens from the welded assembly by the Pulsed MAG process for bending tensile strength.

The dimensions of the non-welded samples were established (according to SR EN ISO 6892-1: 2020/SR EN ISO 7438: 2020) at 200 x 70 x 6 mm^3 each. After the cutting process was performed to obtain the samples, a milling process was necessary to prepare them.

Fig. 1 – Steel plate used for obtaining samples.

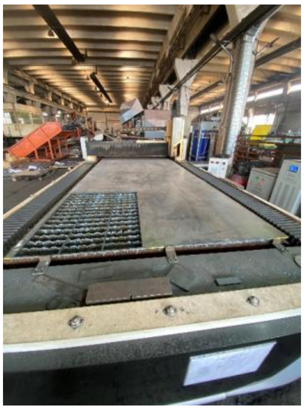

Fig. 2 – Cutting setup of the steel plate.

Fig. 3 – Aspects related to sample preparation.

To achieve the samples, processing of the lateral edges with a V-shaped purpose was performed, using an angle $\alpha = 60°$, a joint opening of $r = 2.5$ mm, and a joint thickness wall $c = 1.5 \pm 0.2$ mm.

The welding machine used was an EWM equipment, type Picomig 180 Puls (EWM Germany), with technical capabilities to provide a welding current between 5 and 180 A, operating at 60% of 120 A and 100% of 100 A. The sample preparations for welding were intended to use a milling process and a polishing process until a metallic gloss was achieved.

Table 1 lists all the values used to perform the welded assemblies required for the study.

The welding stage was initiated according to the work procedure specification (WPS) prepared by the welding engineer. The capabilities of the available current source limited the welding parameters. Otherwise, we have established that the welded joint should be made together, head-to-head (BW), from both slopes, with the removal and resumption of the root in 3 layers, where 1 layer = 1 passing trace.

The parameters used at each passing trace are included in Table 1. The additional material used is type G3S1 (SG2), ϕ 0.8. The gas mixture consisted of 82% argon (Ar) and 18% carbon dioxide (CO_2). The welding position was selected in accordance with SR EN ISO 6947:2020.

In Table 1, the feed used for the MAG DC+ process and the Pulsed MAG process is noted, along with F1 and F2.

To minimize the risk of sample movement during the welding process, guidance plates were utilised.

Table 1

Work parameters used for performing the welding process

Followed parameter	MAG DC+			PULSED MAG		
	I_s [A]	U_a [V]	F_1 [m/min]	I_s [A]	U [V]	F_2 [m/min]
Layer 1	132	20.7	8.8	119	26.4	9.9
Layer 2	132	20.7	8.8	119	26.4	9.9
Layer 3	101	18.1	6.1	71	22.1	5.7

After each welding layer was deposited, a visual control was applied, followed by one with penetrating liquids (according to CEN ISO/TR 16060:2015). This aspect was performed to determine if the welding was susceptible to manufacturing defects over time. No defects were found during the intermediate examinations, and none were detected after the final control was applied (see Fig. 4).

Fig. 4 – Penetration liquid was applied to the welded joint part.

From the welded samples, specimens were taken (Fig. 5) and subjected to tensile tests (Fig. 6) and bending tests (Fig. 7) in the laboratory. The purpose of these tests was to observe the material's behaviour under the stress conditions.

Fig. 6 – Numbering of samples.

Fig. 7 – Aspects of tensile tests.

Fig. 8 – Aspects of bending tests.

3. Analysis of the obtained results

As shown in Table 1, the welding parameters of the MAG Pulse process have reduced the welding current intensity by 10%. Still, the voltage has increased by 12.7%, which means that we can achieve good results with a lower energy cost than in the MAG DC+ case.

At the same time, we can observe a 12.5% increase in wire feed speed, allowing us to achieve a higher welding speed. Thus, within the same calculated time, we can submit a sufficient amount of additional material to cover a greater length of the welding workpiece.

Table 2
The results of the tensile test

Curr. No.	Characteristics of samples and process parameters used	Sample type					
		BM1	BM2	TT DC+	BT DC+	TT-P	BT-P
		Unwelded BM		DC+ Welded		Pulse Welding	
0	1	2	3	4	5	6	7
1	L [mm]	145	145	145	145	145	145
2	L_0 [mm]	25	25	25	25	25	25
3	t [mm]	5.8	5.8	5.8	5.8	5.8	5.8
4	α [°]	125°	124°	120°	124°	100°	108°
5	V[mm/min]	2	5	20	20	20	20

Table 2 notes the use of BM-base material, TT DC+ transversal tensile test, and BT DC+ bending tensile test for Direct Current, as well as a similar approach for Pulsed Welding; *α* represents the bending angle.

Also, the visual aspects of the two welding cords were followed for the welded cord obtained through the Pulsed MAG technology, and a nearly concave, flattened, and wide shape of the cord was achieved. This shape is compared to the one through the usual MAG DC+ technology, which has a more convex and narrower appearance.

Table 3
The results of the bending test

Curr. No.	Characteristics of samples and process parameters used	Sample type					
		UBM	DC+ Welded	PW	UBM	DC+ Welded	PW
		BM1		BM2		T1 DC+	
0	1	2	3	4	5	6	7
1	L_0 [mm]	60	60	60	61.1	60.0	59.0
2	L_F [mm]	72.0	71.0	70.36	73.8	70.0	73.00
3	T [mm]	5.8	5.8	5.8	5.8	5.8	5.9
4	A_5 [%]	20%	18.33%	17.26%	20.78%	16.66%	23.72%
5	Z [%]	22.58%	20.20%	38.09%	36.49%	34.61%	30.60%
6	L_0 [mm]	11.4	11.78	11.6	11.22	11.90	11.18
7	L_F [mm]	9.3	9.80	8.4	8.22	8.84	8.56

Table 3 includes values for UBM (the unwelded base material), PW (the pulse-welded joint), L_0 (the initial length of the sample), and L_F (the final length). A_5 represents the value for elongation, and Z is the thickness tensile test. Following the laboratory tests, it was observed that the specimens from the welded samples have achieved satisfactory results. In the case of tensile tests, as presented in Table 2, the length of the specimens increased by 16% compared to their initial length. Also, it was observed that the break between welded components occurred outside the heat-affected zone (HAZ) in the base material.

For the bending tests, with numerical values presented in Table 3, the results obtained exceeded our expectations because all samples resisted the bending process, even when the bending angle α was at least 100°, without any visible cracks.

4. Discussions

Following the experimental study, it was found that:

• An increase in mechanical resistance was observed when the MAG-type welding was used;

• The bending test applied to the considered samples was performed to obtain a break/crack in the area located quite far from the area the welded cord;

• The influence of the temperature in the thermally influenced area has not modified the mechanical resistance characteristics of the samples;

• Regarding the resistance to the bending process of the samples, it can be stated that no micro-cracks were observed in the specimens;

• The welding energy developed by both MAG welding variants are close, with: 0.656 kJ/mm at the MAG DC + and 0.688 kJ/mm at the MAG Pulse variant;

• The welding speed obtained at the Pulsed MAG version is 10% higher than that obtained at the MAG DC + variant;

• The Pulsed MAG alternative offers a deposit rate for the deposited metal (DM) 12% higher than the MAG DC + version;

• The productivity obtained at the welding process generated by the Pulsed MAG alternative is greater than that of conventional method, 5% higher than at the MAG DC + version.

5. Conclusions

This study highlights the methodology for performing mechanical tests, including tensile and bending tests, on two specimens made from a basic material, namely, steel type S355J2+N. Throughout the two welding processes, it was found that the MAG procedure with pulsating current enables the production of an electric arc without generating excess splashes. At the first examination, the specimens welded using the Pulsed MAG procedure have a higher quality of the welded cord.

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STUDIU COMPARATIV PRIVIND CARACTERISTICILE UTILIZĂRII PROCEDEULUI DE SUDARE MAG DC+ ŞI MAG PULSAT, LA SUDAREA OŢELULUI S355J2+N

(Rezumat)

În momentul de față, asamblările sudate realizate prin topire sunt printre cele mai des utilizate procedee de asamblare. Alegerea procedeului de îmbinare prin sudare se realizează în funcție de mai multe criterii, printre acestea fiind și cele legate de caracteristicile de rezistență mecanică. În lucrarea de față, se prezintă o analiză a caracteristicilor mecanice ale unor asamblări sudate realizate atât prin intermediul tehnologiei de sudare MAG DC+, cât și folosind tehnologia de sudare Pulsed MAG. Realizarea studiului a presupus aplicarea unor încercări mecanice la tracțiune și la îndoire în cazul unor epruvete realizate din oțel de tip S355J2+N. Rezultatele experimentale au evidențiat faptul că cedarea ansamblului realizat prin sudare nu se produce în zona de îmbinare sudată, ci în zone care nu sunt influențate de îmbinarea sudată realizată.