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PROPERTIES OF JOINTS WELDED USING THE MAG METHOD S355J2+N STEEL AFTER PEENING PROCESS

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Abstract: The aim of the research was to determine the impact of peening of each weld on the properties of a butt joint made of S355J2+N steel welded using a ceramic washer. The welding process was carried out using the MAG method on a robotic station. The analysis was based on a comparison of three butt joints: after welded, with peening of each bead and with post weld heat treatment – stress relief annealing. High frequency peening (90Hz) of each bead made was intended to reduce stress in the weld joint by introducing compressive stress into it. A Weld Line 10 pneumatic hammer was used. Tests such as visual, penetration, radiographic and destructive tests (macroscopic, transverse tensile test, transverse bending test, impact strength test, hardness) are conducted on the test samples prepared in the MAG process. The test results are compared to the acceptance values from the ISO standard. Additionally, stress measurements were made using the Barkhausen effect based on the research procedure of the technology supplier. The research performed showed that use of high – frequency peening after each bead did not affect the negative results of all the required tests during the qualification of the welding technology of S355J2+N steel compared to the test plates (after welded and after post weld heat treatment – stress relief annealing).

Key words S355J2+N steel, MAG welding, qualification of welding technology, peeling of a weld.

1. INTRODUCTION

Welding technologies are the main method of producing metal constructions in the word. Welding processes creates a lot of technological problems that welding engineers have to deal with every day. However, welded structures usually exhibit a rather low fatigue strength in comparison to that of the parent and filler materials used. Some of the most important of technological problems are deformations and stresses resulting from the welding process. These are caused by closely related and characteristic for welding processes: phase transformations, uneven and rapid heating and cooling. These also include changes in properties such as Young's modulus E, yield strength Re or thermal expansion coefficient during heating and cooling. The most commonly used method of reducing post-welding stresses and deformations is heat treatment, such as stress relief annealing. This treatment uses an electric or gas furnace. One of the alternatives to classic post-weld heat treatment is peening of a weld. This method involves inter-pass peening or machining the face of butt joints or fillet joints to introduce compressive stresses though plastic deformation. The advantage of this method is the ability to perform local or global effective post-welding treatment [1-5]. Peening can be carried out using several systems, including conventional methods such as peening with an electric or pneumatic device. Among the relatively new methods of stress reduction by peening are: „Ultrasonic Peening Treatment" (UPT), „High Frequency Impact Treatment" (HiFIT), „Ultrasonic Peening" (UP), „Pneumatic Impact Treatment" (PIT) or „Ultrasonic Needle Peening" (UNP). Each of these methods was developed mainly to increase the effectiveness of the impact effect, machining precision and work comfort by reducing the impact on the person conducting the process [6-11]. European standards don't contain information whether the use of the HFMI method (High Frequency Mechanical Impact) is an important variable for the welding process. Therefore, research should be carried out on main issues when qualifying metal arc welding technologies, such as meeting the requirements of the PN EN ISO 15614-1 standard and the impact of peening on the results of the required tests.

2. MATERIALS AND METHODS

2.1 Materials

The aim of the work was to determine the impact of peening of each weld on the properties of a butt joint welded using a ceramic washer on a robotic station using the 135 method (MAG – Metal Active Gas) and to determine the impact of peening on the stress level. This analysis was based on the comparison of three butt joints made of S355J2+N sheet metal: after welded, with peening of each bead and with post weld heat treatment – stress relief annealing. The additional material used for MAG welding process was IMT-2 electrode wire form Multimet with a diameter of 1.2 mm. The chemical composition of the tested material and additional material are presented in Tables 1 and 2.

Table 1. Chemical composition of S355J2+N steel

Chemical composition %			
C	Mn	Si	P
0.12	1.45	0.17	0.015
S	Cr	Mo	Ni
0.006	0.04	0.005	0.03
V	Cu	Al	Ti
0.005	0.05	0.034	0.005
Nb	As		
0.042	0.005		

Table 2. Chemical composition of additional material (ITM-2 wire, diameter 1.2mm)

Chemical composition %			
C	Mn	Si	P
0.069	1.441	0.875	0.007
S	Cr	Ni	V
0.017	0.066	0.063	0.003
Cu	Al	Mo	Ti+Zr
0.074	0.002	0.014	0.0095

2.2. Welding process

Three test plates were made of S355J2+N steel with dimensions of 600x150x10 mm. For each of the test plates, there were two sheets with a welding groove beveled at 1/2V. The test joints were made on CLOOS robotic stations. These plates were mounted on the station table with a ceramic washer placed in the axis of the welded joints. A view of the prepared joint for welding and the method of preparing the joint for welding are shown in the figures 1 and 2.

Fig. 1. A view of test plate with a ceramic washer mounted on the robot's welding table

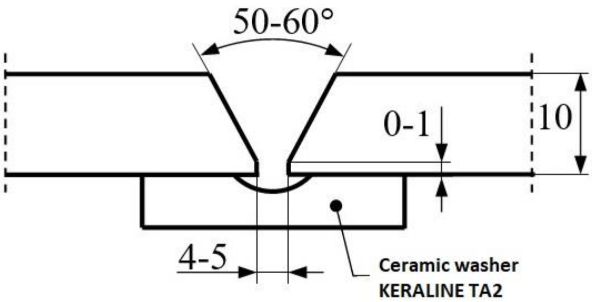


Fig 2. A view of preparing the joint for welding

Fig. 3. A view of the welding process on the robotic station

A ceramic washer was used to ensure correct melting and formation of the weld root on the robotic station. The welding process was carried out on a robotic station which ensure comparable welding parameters of the test plates. The parameters of the welding process are presented in Table 3. Each plate was welded with three beads. The achieved results of the average linear energy prove that welding on a robotic station allowed for achieving similar welding conditions (comparable linear energy of each bead). A view of welding process is shown in the figure 3.

Table 3. Welding parameters of test plates

Weld design.	No. of the bead	Average current [A]	Average arc voltage [V]	Linear energy [kJ/mm]
S355J2+N after welded	1	193	24.0	0.93
	2	219	26.6	0.83
	3	255	26.5	1.48
S355J2+N peening of each bead	1	192	24.1	0.93
	2	220	26.7	0.83
	3	257	26.6	1.49
S355J2+N post weld heat treatment	1	193	24.1	0.94
	2	221	26.8	0.84
	3	254	26.5	1.45

2.3. Peening of a weld

High-frequency peening (90Hz) of each bead made was intended to reduce stress in the weld joint by introducing comprehensive stresses into it. A Weld Line 10 pneumatic hammer was used. Correct peening was achieved when 100% of the surface of each bead with the face was processed. Peening process was carried out manually, figure 4 and 5.

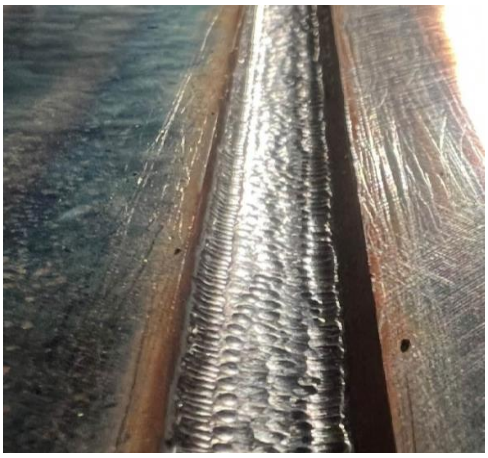


Fig. 4. The weld after peening, a radius of a pin – 4mm

Fig. 5. Peening of a weld of a test plate process

2.4. Heat treatment of a welded joint - stress relief annealing

The third test plate after welding was subjected to heat treatment, which is commonly used to reduce stresses and deformations resulting from welding processes. The stress relief annealing process in electric furnace was divided into three stages: controlled heating, heating and controlled cooling.

2.5. Testing of a welded joint

In accordance with the requirements of the specification and qualification of welding procedures for metallic materials technology (ISO 15614 – part 1) the obtained test plates were subjected to non-destructive tests:

- Visual tests according to PN EN ISO 17637
- Penetrant tests according to PN EN 3452-1
- Radiography tests according to PN EN ISO 17636-1

After non-destructive tests, the welded joint was subjected to destructive tests in the following scope:

- transverse tensile strength tests according to EN ISO 6892-1 on a ZWICK/ROELL Z 330RED testing machine
- transverse bending test of the butt joint with stretching from the weld face side and bending test of the butt joint with stretching from the weld root side according to the PN-EN ISO 5173 standard. Bending tests were carried out using a ZWICK/ROELL Z 330RED machine with an additional module for bending tests
- impact tests in accordance with PN EN ISO 9016
- metallographic macroscopic examinations were performed according to PN EN ISO 17639
- hardness measurement was carried out using a Vickers 401MVD device by Wilson Wolpert according to PN EN ISO 9015-1

The tests were performed in the destructive testing laboratory of the FAMET SA Group in Kędzierzyn Koźle in Poland. This laboratory is recognized by the Office of Technical Inspection for performing destructive tests.

3. RESULTS AND DISCUSSION

Visual tests and penetrant tests of the welded test plates did not show any welding defects coming to the surface. Also, radiography tests and macroscopic examinations did not show any welding non conformities in the area of the weld and HAZ.

The acceptance criteria for destructive testing are presented in Table 4. The results obtained during the tests are presented in Tables 5-10.

The conducted transverse tensile strength test showed that all joints are characterized by high transverse tensile strength. Transverse tensile strength Rm results were achieved in the range of acceptance criteria specified in the standards, Table 5,7,9.

The bending test made it possible to achieve a bending angle of 180°, both during bending from the face and root side of the joint, which proves the high plastic properties of the joint obtained, Table 5,7,9.

The results of hardness measurements show the increase in hardness in the heat affected zone and in the weld in relation to the parent material, whose hardness was approx. 170 HV10. Taking into account hardness measurements of the after welded test plate the hardness was 189 HV10 in the weld area and 176 HV10 in the HAZ, Table 6. In regard to the post weld heat treatment – stress relief annealing test plate the hardness was 193 HV10 in the weld area and 180 HV10 in the HAZ, Table 8. In regard to the test plate after peening of a weld, it was 174 HV10 in weld area and 209 HV10 in the HAZ. There is a noticeable increase the hardness in the weld and HAZ – areas subjected to peening, Table 10.

Considering only the surface layer and results of its hardness measurement, the increase in hardness in the weld area and in the HAZ of the peening test plate compared to the after welded test plate was about 40 HV10 for the weld, which is a 21% increase and for the HAZ about 60 HV10, which is 30% increase.

Comparing the surface layer and hardness measurements results, the increase in hardness in the weld area and in the HAZ of the peening test plate compared to the stress relief annealing test plate was about 40 HV10 for the weld, which is a 21% increase and for the HAZ about 50 HV10, which is 29% increase.

Table 4. Acceptance criteria for destructive tests performed on test plates

Type of examination	Acceptance criteria
transverse tensile strength	the Rm value should not be less than the appropriate minimum value for the base material – Rm minimum 470 MPa
transverse bending	during testing, no defects of more than 3 mm in any direction should occur in the test plates
impact test	the breaking force should be in accordance with the appropriate standard of the base material – KV2 minimum 27J at -20^0C

hardness measurements	for unheat-treated samples – HV10 max 380 for heat treated samples – HV10 max 320
macroscopic examination	No imperfections described in table 4 of PN EN ISO 15614-1 standard for example: crack, lack of fusion, incomplete root penetration – are not permitted at B quality level

Table 5. Test results for after welded test plate

Type of examination	Weld designation	Result
Transverse tensile strength	TT-1	525 MPa
	TT-2	539 MPa
Transverse bending test, face bend test	TFBB1	positive
	TFBB2	positive
Transverse bending test, root bend test	TRBB1	positive
	TRBB2	positive
Impact test	VWT 0/2	147 J
	VWT 0/2	145 J
	VWT 0/2	149 J
	VWT 0/2	142 J
	VWT 0/2	109 J
	VWT 0/2	108 J

Table 6. Hardness measurements and a view of the macrostructure of the after welded test plate

Hardness measurement HV10									
162	164	175	195	177	182	190	194	183	163
172	168	172	172	172	184	185	186	181	178

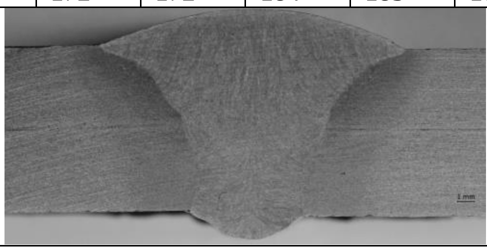


Table 7. Test results for a peening of each bead of test plate

Type of examination	Weld designation	Result
Transverse tensile strength	TT-1	542 MPa
	TT-2	544 MPa
Transverse bending test, face bend test	TFBB1	positive
	TFBB2	positive
Transverse bending test, root bend test	TRBB1	positive
	TRBB2	positive
Impact test	VWT 0/2	107 J
	VWT 0/2	115 J
	VWT 0/2	109 J
	VWT 0/2	124 J
	VWT 0/2	118 J
	VWT 0/2	114 J

Table 8. Hardness measurements and a view of the macrostructure of the peening of each bead test plate

Hardness measurement HV10									
175	188	215	233	233	227	232	229	289	172
172	164	178	181	182	194	190	185	183	163

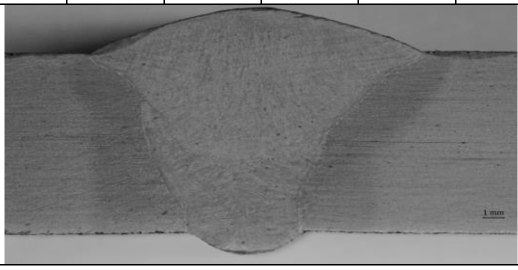
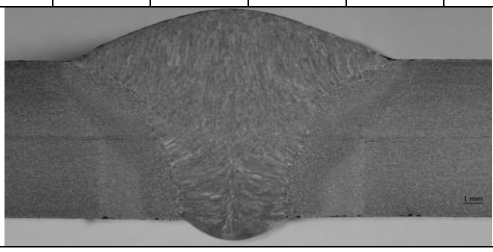


Table 9. Test results for a post weld heat treatment test plate

Type of examination	Weld designation	Result
Transverse tensile strength	TT-1	529 MPa
	TT-2	528 MPa
Transverse bending test, face bend test	TFBB1	positive
	TFBB2	positive
Transverse bending test, root bend test	TRBB1	positive
	TRBB2	positive
Impact test	VWT 0/2	146 J
	VWT 0/2	140 J
	VWT 0/2	141 J
	VWT 0/2	113 J
	VWT 0/2	141 J
	VWT 0/2	114 J

Table 10. Hardness measurements and a view of the macrostructure of a post weld heat treatment test plate

Hardness measurement HV10									
176	172	174	177	196	188	187	211	180	170
177	167	161	176	183	182	202	171	179	169



4. CONCLUSIONS

The research was based on a comparison of three butt joints: after welded, with peening of each bead and with post weld heat treatment – stress relief annealing. It was shown that the use of high-frequency peening after each bead didn't affect the negative results of all the required test for qualifying the welding technology of S355J2+N sheet metal. Peening after each bead test plate compared also to the test plates after state welding and after post weld heat treatment – stress relief annealing.
Based on the research results, the following conclusions can be drawn:

- transverse tensile strength for all three test plates showed tensile strength results Rm within the acceptance criteria specified in the ISO standards – above 470 MPa;

• the bending test made it possible to achieve a bending angle of 180°, both during bending from the face and root side of the joint, which proves the high plastic properties of the joint obtained;
• the impact test result of the test plates for samples taken from the test plate with peening of each bead was on average approximately 34J less than for the other two plates. The reason may be an increase in hardness confirmed during the test;
• the hardness values in the individual zones did not exceed the permissible value of 380 HV10 for unheat-treated samples and 320 HV10 for heat treated samples – HV10 max 320;
• both the increase in hardness and the decrease in impact strength in peening area are caused by local intense plastic deformation;
• macroscopic examination didn't show any defect in the cross section for all pest plates;
• the results of non-destructive and destructive testing for all test plates meet the acceptance criteria specified in the standards. They achieved quality level B according to ISO 5817 standard.

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Conflicts of Interest: There is no conflict of interest.

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