PROPERTIES AND MICROSTRUCTURE OF HYBRIDE PLASMA+MAG WELDED JOINTS OF THERMOMECHANICALLY TREATED S700MC STEEL

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Abstract

The purpose of this paper is to describe the microstructure of welded joints produced by the Plasma+MAG method of S700 MC steel (high strength Re = 700 MPa). Welded joints of thermomechanical steel have been made with different values of heat input. The results of metallographic research of welded joints, microstructure, hardness distribution and impact toughness are presented. The weldability of S700MC steel in condition of hybrid Plasma + MAG is generally described.

Keywords: Plasma + MAG; hybrid welding; high strength steel

1. WELDING PROCESS CHARACTERISTICS

Hybrid welding is a combination of two independent welding methods in simultaneous work in the same welding pool. The described method combines the MAG (Metal Active Gas) method and the plasma method to increase the welding performance. The purpose of the plasma application is to achieve deep penetration (opened evaporation canal - key hole) in welded material. The creation of a evaporation channel is possible when the plasma arc's density is above 10^{10} W / m^2 [1]. The role of the MAG method is to fill the opened channel with the metal of the weld and create the suitable shape of joint's face. The hybrid process has the selected advantages of both welding heat sources. Deep penetration hybrid welds can be made, comparable with the penetration depths achieved by plasma key-hole in the same time having a tolerance to joints fit-up and weld cap profile more comparable with MAG welds. In general, the hybrid welding system is characterized by an extremely high welding efficiency, measured by the mass of fused metal. Schematic diagram of the hybrid plasmotron is presented in **Figure 1**. The construction of the hybrid system and its technological properties are described in the publication [2].

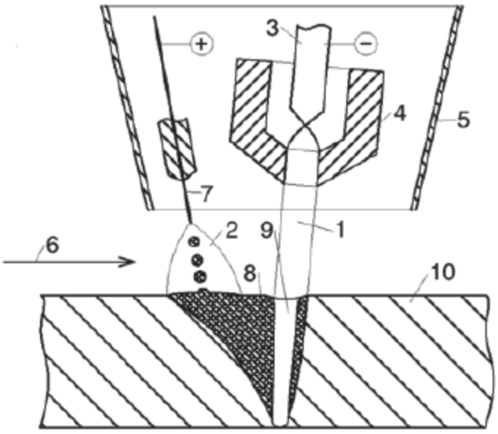

Figure 1 Schematic diagram of the hybrid plasmatron: 1 - plasma arc, 2 - GMA arc, 3 - plasmatron cathode, 4 - plasma nozzle, 5 - common shielding gas nozzle, 6 - welding direction, 7 - GMA wire elec- trode, 8 - liquid metal, 9 - plasma keyhole, 10 - substrate material

2. WELDING PROCESS

The Weldability of this steel grade is relatively good. The weakest place of welded joints of this steel is a high - temperature coarse grain heat affected zone (HAZ) in which due to the nucleation effect of the dissolved phases, strengthening the matrix and their subsequent uncontrolled separation precipitation in the form of finely disperse and rapid decrease impact toughness is observed. Performed hybrid welding tests have shown that in order to ensure high quality of welded joints, it is necessary to limit the welding linear heat input. During the welding process of S700MC steel, it is not recommended to use pre heating before the welding process and heat treatment post welding, and the number of welding repairs should be kept to a minimum, because it leads to a reduction of strength and plastic properties in the HAZ area, as a result of aging processes, dissolution of strengthening phases in the matrix and their subsequent uncontrolled precipitation during cooling [3-8]. The research test aimed to describe the properties of butt hybrid welded (Plasma + MAG) joints made of 10 mm thickness steel S700MC a water cooled copper strip and solid filler wire G69 6 M21 Mn4Ni1 having a diameter of 1.2 mm. The chemical composition and the properties of the steel are presented in **Table 1**, whereas the steel microstructure is presented **Figure 2**.

Table 1 The chemical composition performed using OES and the mechanical properties of S700MC steel

Chemical Composition, wt. %											
C	Si	Mn	P	S	Al tot.	Nb	V	Ti	B	Mo	C equivalent
0.059	0.253	1.912	0.009	0.006	0.027	0.057	0.021	0.087	0.087	0.106	0.33

Mechanical Properties				
Tensile Strength Rm, MPa	Yield Point Re, MPa	Elongation A5, %	Hardness HV	Impact strength, J / cm^2 (−20 °C)
830	767	19	280	135

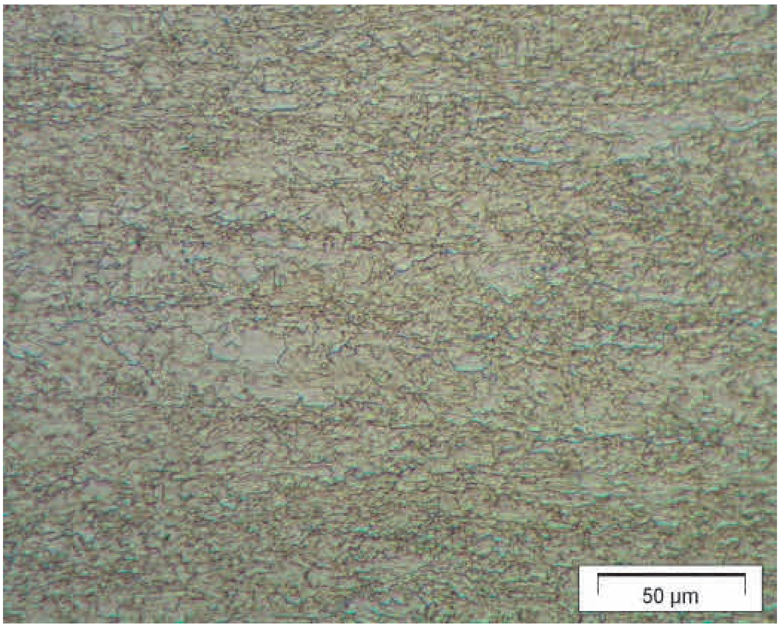

Figure 2 Microstructure of bainitic-ferritic steel S700MC with visible effects of plastic deformation

The welded joints were prepared at Warsaw University of Technology in Warsaw using a robotic station. Tests were performed using a PLT Hybrid Super MIG System. The hybrid welding plasmotron was fixed on KUKA robot's wrist. Parameters of welding processes are presented in **Table 2**. The plasma gas used in test was Ar -100 % and the shielding gas used in the test was mixture (18 % CO_2 + 82 % Ar), whereas the gas flow rate amounted to 22 dm^3 / min. The welding process was carried out using one pass. The parameters used during making the butt joints and other welding conditions (adjusted on the basis of preliminary test [10]) are presented in **Table 2**.

Table 2 The Parameters of the hybrid welding of 10 mm thickness steel S700MC

Welded joint No	Voltage of Plasma Arc U, V	Current of Plasma Arc I, V	Voltage of MAG Arc U, V	Current of MAG Arc I, V	Travel speed V, m/min.	Heat input, kJ / mm
C2	23.4	335.4	31.8	360.6	0.75	1.11
C4	23.9	332.4	33.6	390.7	0.95	0.96

3. TESTS OF WELDED JOINTS

Welded joints were prepared for testing by cleaning the surface in accordance with the procedure described in the literature [11,12]. Welded joints were visual test and the magnetic particle test did not reveal shape and surface welding imperfections. The welded joints satisfied the requirements related to quality level B according to ISO 12932. The microscopic metallographic tests did not reveal the presence of welding imperfections in the weld and Heat Affected Zone (**Figure 3**). The weld root was related to the shape and dimensions of the copper strip used during welding.

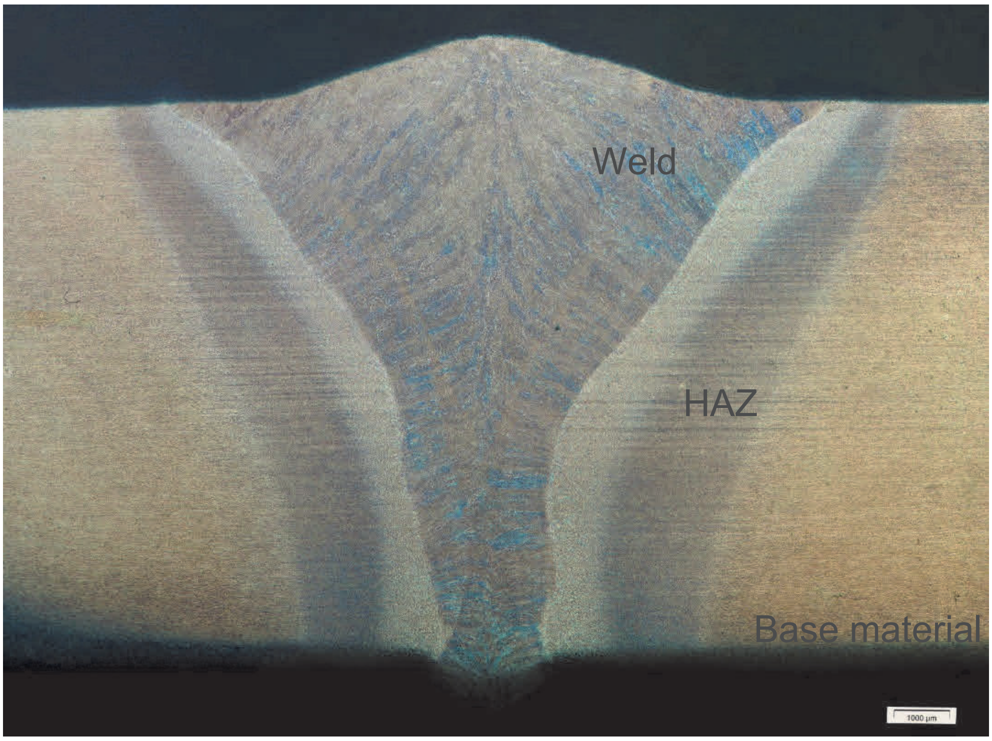

Figure 3 Microstructure of the hybrid welded joints (Plasma + MAG) made in steel S700MC

The microscopic metallographic tests revealed a bainitic-ferritic microstructure in the weld area. The HAZ was characterised by variably sized grains, which could be described a significant heat input during the innovative welding process (**Figure 4**). Microscopic test revealed the probability of nitride precipitates presence in the HAZ and in the base material. Hybrid Plasma + MAG welding is characterized by relatively short cooling time form temperature 800 to 500 °C, what leads to the formation of martensite in the HAZ. However, as it is low-carbon martensite, it has no strong negative influence on platic properties of the welded joints. In specific region of the Heat Affected Zone with an increase of distance to the fusion line, ferrite content seems to be increasing in lieu of bainite [14-17].

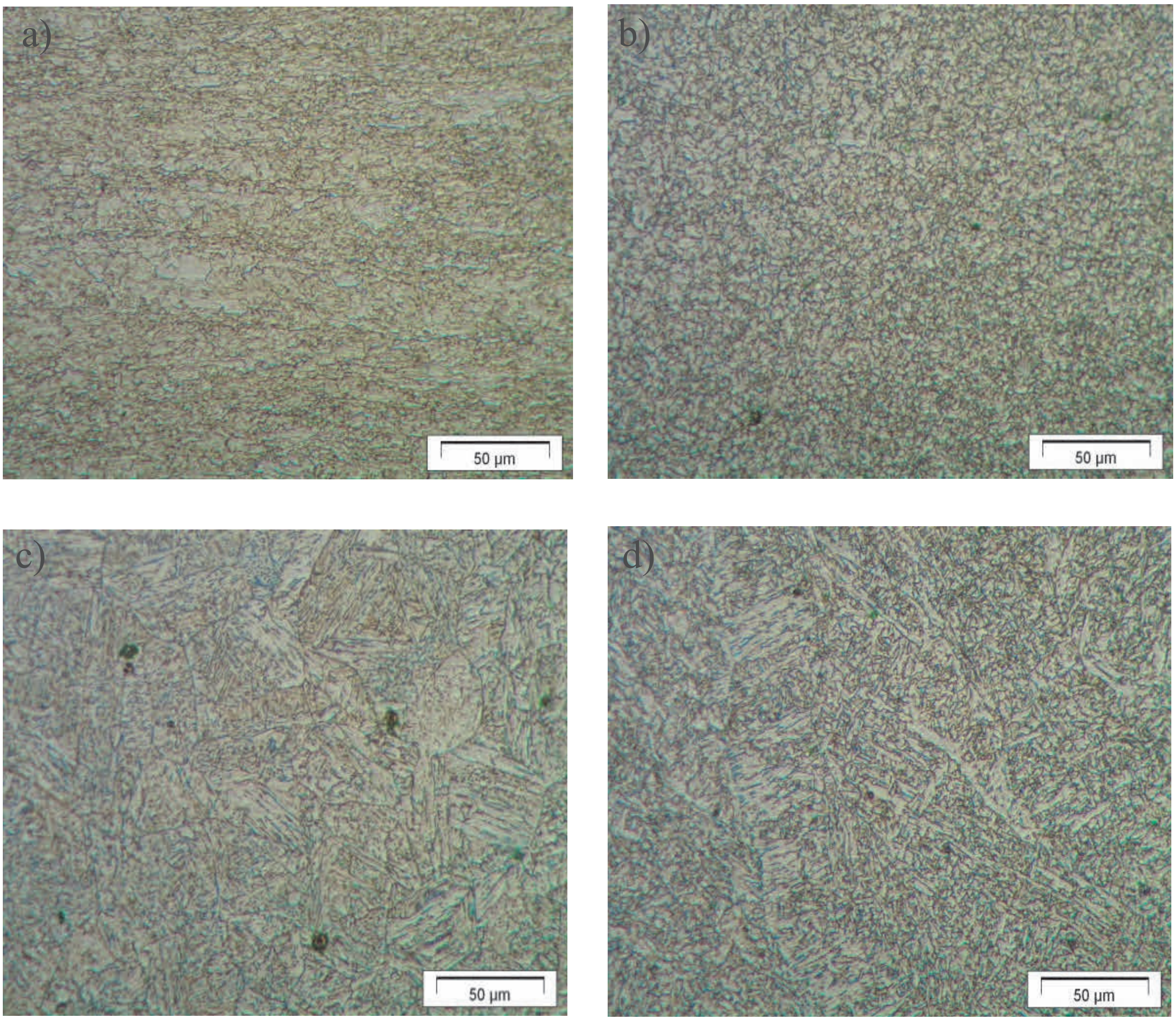

Figure 4 Microstructure of the hybrid welded joint (Plasma + MAG) - (a) microstructure of the base material, (b) microstructure of the HAZ from the base material side, (c) microstructure of the HAZ close to the fusion line, (d) microstructure of the weld

The analysis of the destructive test results of the hybrid Plasma + MAG butt welded joints revealed that the obtained joints satisfied the requirements of the EN-ISO 15614-14 standard. The hybrid welding process resulted in a slight decrease in tensile strength 780 MPa in relation to the hardness of the base material. The rupture took place in the HAZ in area of slight grain growth. The above-named decrease in tensile strength was connected with the loss of properties obtained by steel S700MC through the thermo-mechanical control process. This is mainly related to the increase in the proportion of ferrite in the structure and the grain growth in this area. The bend test resulted in a bend angle of 180°, both during bending on the face and root side, which demonstrated the high plastic properties of the joint. The impact strength test performed at a temperature of −30 °C revealed satisfactory toughness values in the weld, fusion line, and the HAZ. In the weld area, the toughness amounted to 206 J / cm^2. In the HAZ, the toughness amounted to approximately 170 J / cm^2, (samples for impact tests were cut across the welded joint).

The hardness measurements concerning the hybrid welded joints made in steel S700MC revealed that the lowest hardness was characteristic of the heat-affected zone and amounted to approximately 210 HV0,1, whereas the highest hardness was that of the base material and amounted, on average, to 285 HV0,1. The difference between the hardness of the base material and that of the HAZ amounted to approximately 15 %. The hardness value in the upper part of the weld was similar to that of the base material (280 HV0.1) and was higher than the value measured in the lower part of the weld (by approximately 8 %). The foregoing could be attributed to the fact that the upper part of the weld contained more alloying elements, increasing the hardenability (nickel, chromium) supplied along with the filler metal (**Figures 5** and **6**).

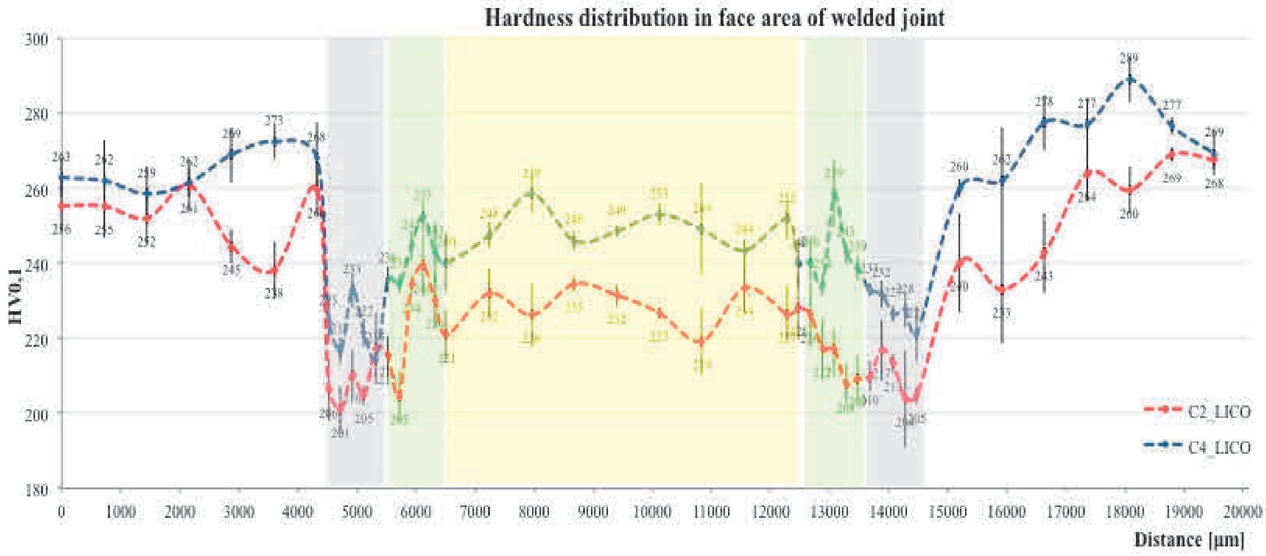

Figure 5 Hardness of the hybrid weld joint (Plasma - MAG) made of S700MC steel (position of measuring lines 2 mm from the top surface of the sheet), C2 a C4 welding parameters

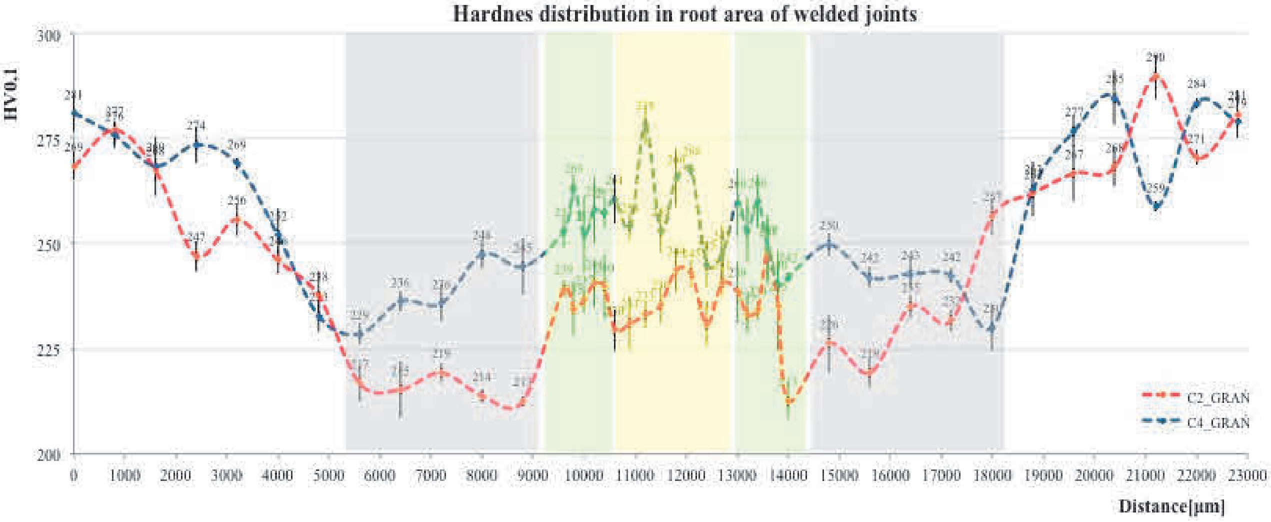

Figure 6 Hardness of the hybrid weld joint (Plasma - MAG) made of S700MC steel (position of measuring lines 2 mm from the bottom surface of the sheet), C2 a C4 welding parameters

4. CONCLUSIONS

The tests of the hybrid welding Plasma + MAG of 10 mm thickness steel S700MC involving the use of a filler metal having the form of solid filler wire revealed the possibility of making welded joints satisfying the criteria formulated in the ISO 15614-14 standard. The tested joints were characterised by a lack of welding imperfections as regards the shape, geometry, and discontinuity. The tensile strength of the welded joints was similar to that of the base material properties, whereas the plastic properties of the joints were satisfactory. The fusion line revealed a decrease in hardness, yet within a relatively narrow range and without compromising the operational properties of the welded joints. The microscopic tests of the welded joints revealed that the weld contained the typical bainitic-ferritic microstructure of dendritic nature. The heat affected zone contained areas of variously sized grains, which was triggered by the thermal cycle effect.

REFERENCES

[1] WLOSINSKI, W., CHMIELEWSKI, T. Plasma-hardfaced chromium protective coatings-effect of ceramic reinforcement on their wettability by glass. In *3rd International Conference on Surface Engineering,* Chengdu: 2002, pp. 135-140.

[2] PILAT, Z., SZULC, J. Concept of the Model Robotized Cell for Plasma-GMAW Hybrid Welding. *Applied Mechanics and Materials*, 2014, vol. 613, 43-52.

[3] GÓRKA, J., STANO, S. Microstructure and Properties of Hybrid Laser Arc Welded Joints (Laser Beam-MAG) in Thermo-Mechanical Control Processed S700MC Steel. *Metals*, 2018, vol. 8, no. 2, pp. 132-137.

[4] GÓRKA, J.,, Weldability of Thermomechanically Treated Steels Having a High Yield Point. *Archives of Metallurgy and Materials*, 2015, vol. 60, no. 1, 469-475.

[5] GÓRKA, J,, Study of structural changes in S700MC steel thermomechanically treated under the influence of simulated welding thermal cycles. *Indian Journal of Engineering and Materials Sciences*, 2015, vol. 22, 497-502.

[6] GÓRKA, J., Welding Thermal Cycle-Triggered Pre. *Archives of Metallurgy and Materials*, 2017, vol. 62, no. 1, 321-326.

[7] GÓRKA, J., JANICKI, D., FIDALI, M., JAMROZIK, W. Thermographic Assessment of the HAZ Properties and Structure of Thermomechanically Treated Steel. *International Journal of Thermophysics*, 2017, vol. 38, no. 12, pp. 182,189.

[8] GÓRKA, J., Thermographic Assessment of the HAZ Properties and Structure of Thermomechanically Treated Steel, Microstructure and properties of the high-temperature (HAZ) of thermo-mechanically treated S700MC high-yield-strength steel. *Materiali in Tehnologije*, 2016, vol. 50, no. 4, pp. 617-621.

[9] CZUPRYŃSKI, A., GÓRKA, J., ADAMIAK, M., TOMICZEK, B. Testing of flame sprayed Al2O3 matrix coatings containing TiO2. *Arch. of Metallurgy and Materials*, 2016, vol. 61, no. 3, pp. 1363-1370.

[10] SKOWROŃSKA, B., SZULC, J., CHMIELEWSKI, T., GOLAŃSKI, D. Wybrane właściwości złączy spawanych stali S700 MC wykonanych metodą hybrydową plazma+ MAG, Przegląd Spawalnictwa-Welding. *Technology Review,* 2017, vol. 89, no. 10, pp. 104-111.

[11] SAŁACIŃSKI, T., CHMIELEWSKI, T., WINIARSKI, M., CACKO, R., ŚWIERCZ, R. Roughness of Metal Surface After Finishing Using Ceramic Brush Tools. *Advances in Materials Science*, 2018, vol. 18, no. 1, pp. 20-27.

[12] DOLZHENKOA, A., YANUSHKEVICHA, Z., NIKULINB ,S.A. BELYAKOVA A., KAIBYSHEVA R., Impact toughness of an S700MC-type steel: Tempforming vs ausforming. *Materials Science & Engineering A*, 2018, vol. 723, pp. 259- 268.

[13] SPACHINGER, S. J., ERNST, W., ENZINGER, N. Influence of Ti on the toughness of the FGHAZ and the CGHAZ of high-strength microalloyed S700MC steels. *Weld World*, 2017, vol. 61, pp. 1117-1131.

[14] OPIELA, M. Elaboration of thermomechanical treatment conditions of Ti-V and Ti-Nb-V microalloyed forging steels. *Arch. Metall. Mater.*, 2014, vol. 59, pp. 1181-1188.

[15] FYDRYCH, D., ŁABANOWSKI, J., ROGALSKI, G. Weldability of high strength steels in wet welding conditions. *Polish Maritime Research*, 2013, vol. 20, no. 2, pp. 67-73.

[16] FYDRYCH, D., ŁABANOWSKI, J., ROGALSKI, G., HARAS, J., TOMKÓW, J., ŚWIERCZYŃSKA, A, JAKÓBCZAK, P., KOSTRO, Ł. Weldability of S500MC steel in underwater conditions. *Advances in Materials Science,* 2014, vol. 14, no. 2, pp. 37-45.

[17] FYDRYCH, D., ŁABANOWSKI, J., TOMKÓW, J., ROGALSKI, G. Cold Cracking Of Underwater Wet Welded S355G10+N High Strength Steel. *Advances in Materials Science*, 2015, vol. 15, no. 3, 48-56, 2015.