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Multiple MAG Repair Welding of Steel S1100QL with the Removal of Defective Fragments of Welds Using Mechanical Treatment

Abstract: The research discussed in the article involved the performance of tests assessing the effect of a one-time and four-time repair welding thermal cycle on mechanical properties of 18 mm thick butt joints made of toughened steel S1100QL. The tests also involved the determination of mechanical properties of a production joint and joints subjected to mechanical treatment-based repair, involving the use of the MAG method (138) and metallic flux-cored wire STEIN-MEGAFIL 1100 M. It was ascertained that the mechanical properties of the joints subjected to mechanical treatment-based repair were similar to those of the joints subjected to repair welding involving the removal of a defective part using arc-air gouging.

Keywords: repair welding, Steel S1100QL, mechanical properties of joints

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Introduction

Discrepant information contained in various scientific reference publications related to the repair welding of high-strength steels have inspired tests concerning the effect of a multiple thermal cycle on the structure and properties of the heat affected zone in joints made of 18 mm thick steel S1100QL having a yield point of 1100 MPa as well as on the properties of the aforesaid joints.

The test-accompanying assumptions included repair welding performed using grooves modelling the removal of an imperfection (crack) across the entire cross-section of the V type weld except for the root layer having an approximate thickness of 4 mm. The subsequent weld (referred to as a repair weld) made in the root aimed to provide the repeated effect of a welding thermal cycle on the heat affected zone (HAZ) of steel S1100QL. The above-named approach should provide the possibility of identifying the effect of n-fold repairs (repair welding) in the structure and properties of the HAZ.

The test results concerning the effect of a multiple repair welding thermal cycle and the removal of a defective weld fragment (performed using arc-air gouging) on the properties of joints subjected to one and four repairs are presented in publication [1]. The tests confirmed the possibility of performing the four-fold repair welding of joints made in steel S1100QL involving the grooving of the defective weld fragment.

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Analogous tests involved the removal of a weld fragment defined as defective using mechanical treatment (milling). As opposed to arc-air gouging, mechanical treatment does not entail the thermal effect on the HAZ of the weld groove but enables the precise removal of the weld metal up to the fusion line.

Schedule of tests

The tests involved the making of the following variants of butt joints:

a) production joint (used in the comparison with joints subjected to repairs),
b) production joint, the removal of the weld + the first repair,
c) production joint, the removal of the weld + the first repair, the removal of the weld + the second repair, the removal of the weld + the third repair and the removal of the weld + the fourth repair.

The tests concerning the effect of a multiple repair welding thermal cycle on properties of joints (in relation to each welding variant) involved transverse tensile tests, bend tests, impact strength tests as well as macro and microscopic metallographic tests. The chemical compositions of the test steels are presented in the Table 1. The tests along with their results are presented in the remainder of the study.

Welded joints

The making of joints in test plates (18 mm x 150 mm x 400 mm) was performed in the same manner as that described in publication [1]. The process was performed semi-automatically (138) using a Stein-Megafil 1100 M metallic flux-cored wire (classification EN ISO 18276-A - T 89 4 Mn2Ni1CrMo M M 1 H5) [3] having a diameter of 1.2 mm. The shielding gas used in the process was mixture ISO 14175 - M21 - ArC-18.

The technological tests were performed applying the conditions required for the welding of butt joints in steel S1100QL, satisfying the requirements specified by the manufacturer of the plates, i.e. the SSAB company [4]:

- heat input ≤ 10 kJ/cm,
- preheating temperature of 125°C,
- interpass temperature of 150°C,

as well as following technological recommendations formulated by the manufacturer of the electrode wire, i.e. the Drahtzug Stein company [5, 6].

The production joint was prepared for welding in the manner presented in Figure 1a. The penetration run and the filling runs were made in the flat position (Fig. 1b), using the parameters presented in Table 2.

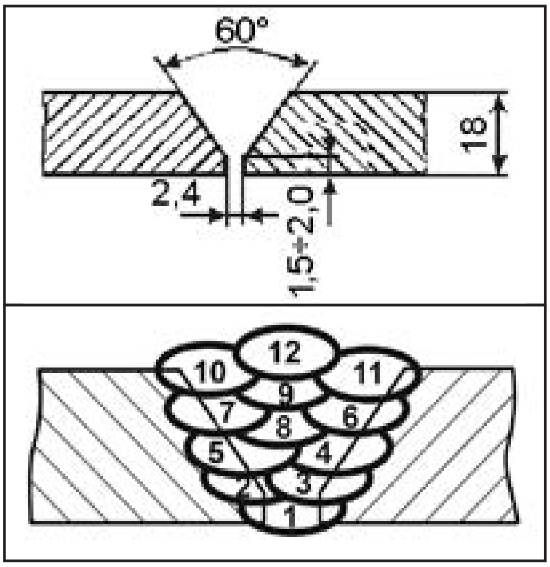

Fig. 1. Shape of the weld groove (a) and the welding sequence applied in relation to (b) production joint

Table 1. Chemical composition of steel S1100QL

Chemical element content, % by weight									
C	Si	Mn	P	S	Cr	Cu	Ni	Mo	B
0.192	0.220	0.855	0.014	0.0034	0.606	0.012	1.858	0.636	0.0017
Chemical element content, % by weight according to the manufacturer [2]									
C	Si	Mn	P	S	Cr	Cu	Ni	Mo	B
max 0.21	max 0.50	max 1.40	max 0.020	max 0.005	max 0.80	max 0.30	max 3.00	max 0.70	max 0.005

Table 2. Welding parameters used when making the production joint using the STEIN-MEGAFIL 1100 M electrode wire

Run	Current, A	Arc voltage, V	Filler metal wire feeding rate, m/min	Welding rate, cm/min	Heat input, kJ/cm
1	155	17.1	3.8	14.4	8.84
2	210÷225	24.9÷25.0	6.0	43.6	5.76÷6.19
3÷12	210÷225	24.9÷25.0	6.0	28.3÷35.3	7.11÷9.54

Electrode extension: 16÷18 mm
Shielding gas flow rate: 15 l/min
Additional remarks: programme no. 81 Lincoln Power WAVE 455 STT

The visual, penetrant and radiographic tests of the test joint finished positively. Because of this, the subsequent test joint was provided with a (milled) grove modelling the removal of welding imperfections when repairing the joint (Fig. 2, 3a). The making of the repair joint was performed using parameters presented in Table 2 in relation to filling runs nos. 3÷12, making joints subjected to one (Fig. 3b) and four repairs.

Similar to the production joint, the joints after one and those after four repairs were subjected to visual, penetrant and radiographic tests. The above-named tests revealed that the joints represented quality level B according to standard PN-EN ISO 5817:2014-05. The non-destructive tests were followed by tests of the mechanical properties as well as by metallographic tests of the production joint and the joints subjected to one and four repairs. The results of the tests concerned with mechanical properties (apart from bend test results) are presented below.

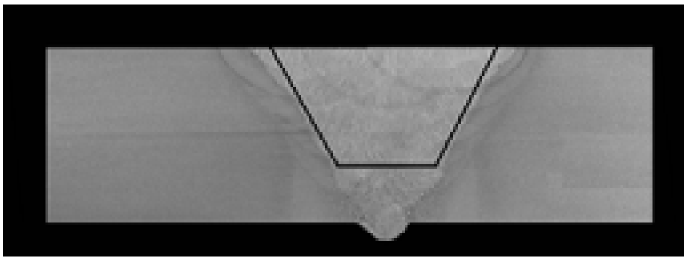

Fig. 2. Macrostructure of the test joints with the marked shape of the groove before the first repair welding process and subsequent processes (groove width at the top: 28 mm, at the bottom: 12 mm, groove depth: 13 mm)

Test results concerning mechanical properties

Tests results concerning the mechanical properties of the production joint and the repaired as well as, for comparison, data according to publications [1, 7] are presented in Tables 3 and 4.

The tensile tests of production joint no. 0 as well as joints nos. 1 and 4, repaired using mechanical treatment, revealed that the tensile strength of the above-named joints was restricted within the range of 795 MPa to 1039 MPa (Table 3) and, with one exception, i.e. the strength of the joint after the fourth repair performed using mechanical treatment (amounting to 795 MPa), corresponded to the tensile

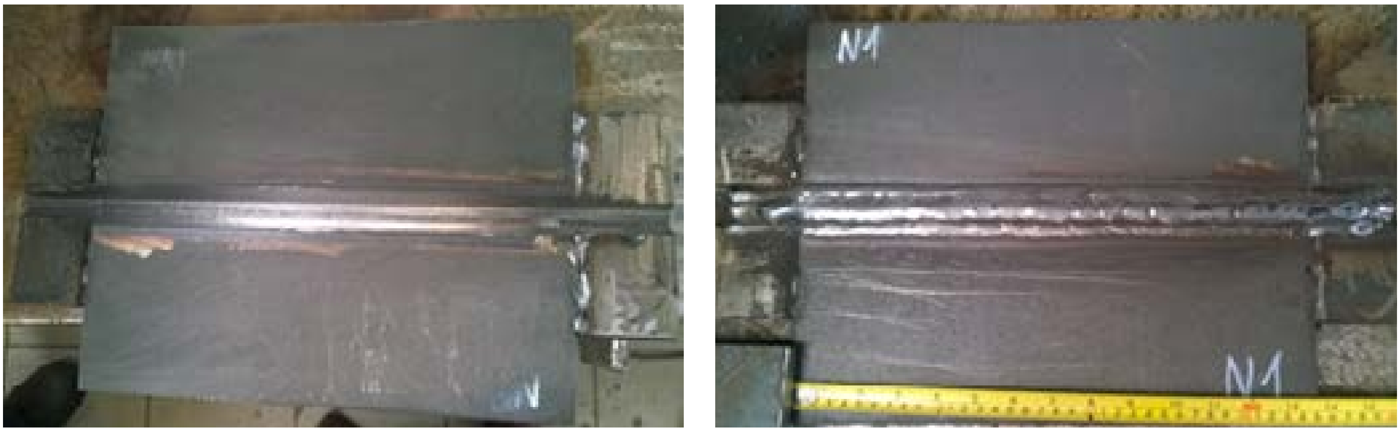

Fig. 3. Test plate: a) with the milled grove according to Fig. 2; b) face of the test joint subjected to one repair (joint no. 1)

strength of the weld deposit of wire STEIN-MEGAFIL 1100M (980÷1180 MPa) [3] and was lower than the tensile strength of the base material (all of the test specimens ruptured in the weld). The above-presented results were similar to those concerning the tensile strength of joints nos. 3 [1] and 5 [7], repaired using arc-air gouging.

The impact tests results revealed that in all of the cases (Table 4) the requirement concerning the value of impact energy in relation to the base material (according to PN-EN ISO 15614-1:2017-08, item 7.4.4), in the case under discussion being ≥ 27 J at a temperature of -40°C [2], was satisfied.

Table 3. Static tensile test results related to the production joint and repair joints

Joint / joint number	Rm, MPa	Area of rupture
Production joint / no. 0	1039	weld
	1035	weld
Joint after one repair / no. 1	1014	weld
	995	weld
Joint after one repair * / no. 5 [7]	1005	weld
	1015	weld
Joint after four repairs / no. 4	1026	weld
	795	weld
Joint after four repairs * / no. 3 [1]	973	HAZ
	980	weld

Note: * - repair involving the removal of the defective fragment of the weld performed using arc-air gouging

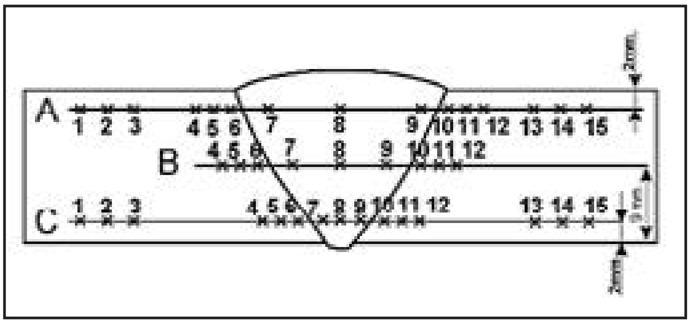

Fig. 4. Arrangement of hardness measurement points (schematic diagram)

The hardness results revealed that the hardness of the base material was restricted within the range of 406 HV to 469 HV. The hardness of the welds was restricted within the range of 268 HV to 386 HV. The hardness of the HAZ of the production joints was restricted within the range of 329 HV to 465 HV, the hardness of joint no. 1 (subjected to one repair involving the making of a groove performed using mechanical treatment) was restricted within the range of 345 HV to 456 HV and the hardness of joint no. 4 (subjected to four repairs involving mechanical treatment) was restricted within the

Table 4. Impact strength test results related to the production joint and repair joints at a test temperature of -40°C

Joint / joint number	Notch location/direction – specimen designation	Impact energy KV, J			Mean value KV, J
		1	2	3	
Production joint / no. 0	HAZ/0/KV/VHT	140	108	122	123.3
	Weld/0/KV/VWT	60	60	58	59.3
Joint after one repair / no. 1	HAZ/1/KV/VHT	93	100	90	94.3
	Weld/1/KV/VWT	70	68	68	68.7
Joint after one repair * / no. 5 [7]	HAZ/5/KV/VHT	198	230	195	207.7
	Weld/5/KV/VWT	93	93	90	92.0
Joint after four repairs /no. 4	HAZ/4/KV/VHT	190	160	198	182.7
	Weld/4/KV/VWT	90	85	93	89.3
Joint after four repairs * / no. 3 [1]	HAZ/3/KV/VHT	202	160	70	144.0
	Weld/3/KV/VWT	84	82	86	84.0

Note: * - repair involving the removal of the defective fragment of the weld performed using arc-air gouging
VHT – specimen with the V-notch in the HAZ
VWT - specimen with the V-notch in the weld

range of 361 HV to 449 HV. In terms of repairs involving the removal of a defective part of the weld performed using arc-air gouging, the hardness of the HAZ of joint no. 5 subjected to one repair was restricted within the range of 344 HV to 461 HV, whereas the hardness of the HAZ of joint no. 3 subjected to four repairs was restricted within the range of 332 HV to 416 HV. As can be seen, both the hardness of the base material and that of the HAZ exceeded the permissible values of 450 HV10 (according to PN-EN ISO 15614-1:2017-08, Table 3) in relation to steels of group 3 according to ISO/TR 15608. It should be emphasized that when qualifying welding technologies, steels having Re > 890 MPa should meet specific values determined on the basis of results of the remaining tests or requirements formulated by customers or values referred to in the documentation concerning a related welded structure. The above-named results confirm the statement contained in publication [1], whereby, when qualifying a technology used for the welding of steels, the maximum allowed hardness of a joint not exceeding the maximum hardness of a base material could be suggested as the acceptance criterion.

The use of high-strength steels in welded structures of critical importance requires the qualification of the production and repair welding of the above-named structures in accordance with the requirements of PN-EN ISO 15614-1:2017-08, Table 2, in relation to level 2. The procedure governing the qualification of a technology of multiple repair welding should take into consideration requirements concerning the repair welding of a specific welded structure (if such welding is governed

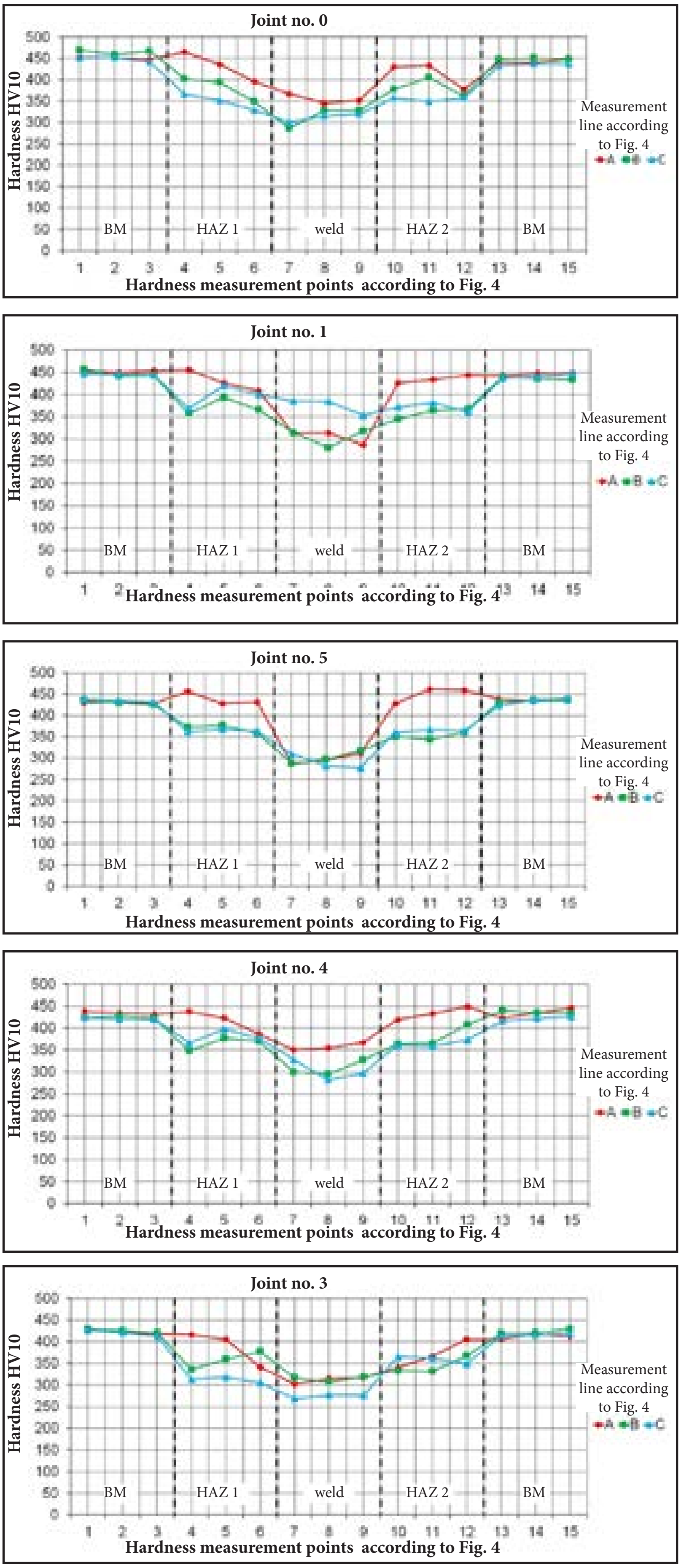

Fig. 5. Hardness test results in relation to the production joint and repair joints: a) production joint (no. 0), b) joint after one repair (no. 1), c) joint after one repair (no. 5) [7], d) joint after four repairs (no. 4), and e) joint after four repairs (no. 3) [1], BM – base material, HAZ – heat affected zone

by inspection regulations or standards) or appropriate requirements specified in related design documentation. In relation to a number of structures, inspection bodies impose additional requirements, e.g. *repairs of welded joints are not allowed unless agreed with … inspection body or repairs of … load-bearing structures by welding or through the removal or the replacement of elements requires that repair documentation be agreed with … inspection body*. As a result of the foregoing, companies should apply repair welding technologies substantiated by appropriate test results and satisfying related requirements.

Concluding remarks

The research involving the tests concerned with the production welding and repair welding of steel S1100QL justified the formulation of the following conclusions:

1. The technology involving the MAG welding of butt joints made of 18 mm thick steel S1100QL, used for the welding of the production joint and the joints repaired using mechanical treatment, enabled the obtainment of joints representing quality level B. The aforesaid conclusion was confirmed by non-destructive test results.
2. The tensile strength of the test joints was restricted within the range of 795 MPa to 1039 MPa.
3. Requirements related to the toughness of the weld and that of the HAZ were satisfied both in terms of the production joint and both repair joints. In the HAZ area, the average value of impact energy at a temperature of -40oC amounted to 123.3 J in relation to the production joint (no. 0), 94.3 J in relation to the joint subjected to one repair (no. 1) and 182.7 J in relation to the joint subjected to four repairs (no. 4). The average value of impact energy of the weld area at a temperature of -40oC amounted to 59.3 J in relation to joint no. 0, 68.7 J in relation to joint no.1 and 89.3 J in relation to joint no. 4.
4. The hardness in the HAZ of the production joint reached 465 HV (base material hardness was restricted within the range of 406 HV to 469 HV).
5. The above-presented mechanical properties of the joints repaired using mechanical treatment were similar to those of the joints where the defective part of the weld was removed using arc-air gouging.

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References

[1] Łomozik M., Turyk E.: Mechanical Properties of Welded Joints in Steel S1100QL after Multiple Repair Welding (Własności mechaniczne złączy spawanych stali S1100QL po wielokrotnym spawaniu naprawczym). Biuletyn Instytutu Spawalnictwa, 2018 r., no. 3, doi: 10.17729/ebis.2018.3/1.

[2] Data sheet 2017 Strenx 1100. Prospekt firmy SSAB. https://venturiacciai.it/wp-content/uploads/2017/03/STRENX-1100-Data-Sheet.pdf, accessed on 14.06.2018

[3] Drahtzug Stein wire & welding. Seamless flux-cored wire STEIN-MEGAFIL 1100 M. http://www.anapol.ee/images/fsrv/dokumendid/Datasheets/DRAHTZUG/Megafil_1100M.pdf, accessed on 22.08.2017

[4] Welding Hardox and Weldox. SSAB.

http://www.damatech.com/en/files/default/damatech/pdf-EN/11%20Hardox%20plate%20welding%20-%20ENG.pdf. accessed on 10.06.2018
[5] Welding parameters: STEIN-MEGAFIL 1100M. DRAHTZUG STEIN.
[6] MEGAFIL Welding parameters – guidance values: metal-cored wires. ITW Welding Europe Corporation.
[7] Łomozik M., Turyk E.: Badania wpływu spawania naprawczego stali ulepszonych cieplnie o granicy plastyczności powyżej 900 MPa na własności mechaniczne i mikrostrukturę złączy. Sprawozdanie z pracy badawczej no. Hb-109. Instytut Spawalnictwa, Gliwice, 2017