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Effect of Repair Welding On the Properties of Welded Joints of Steel S700MC

Jacek Górka ,Welding Department – Silesian University of Technology, Poland

Abstract*—The article is describing the influence of linear energy of and repairable welding on the joints properties of S700MC steel, with 10 mm thickness treated using thermo mechanical method. In the case of steel treated using the thermo mechanical method, which has high level of plastic tolerance (deformation), during the welding process it is very important to control the level of heat introduced into the area of the joints (weld). The linear energy during the welding process should be limited to 10 kJ/cm. Furthermore, the additional heat introduced to the welded area after the welding process can rapidly deteriorate the properties of the created joints, particularly effected can be yield of the joints and HAZ. Too much heat delivered to the area of the welded joints will cause recrystallization and growth of the grain in the HAZ area resulting in the loss of properties gained during the thermo mechanical treatment, and in the joints there will be uncontrollable processes of MX type phase separation causing deterioration of properties of the welded joints.

Index Terms—**Heating Effected Zone, Repair Welding, Thermo mechanical Steel.**

I. INTRODUCTION

During the last decades the producers of steel focused their efforts on the production of construction materials with higher and higher strength and yield, with characteristic improved weld ability and containing cheaper alloying additives. There has been a trend for the use of high performance steels in the construction, with the aim to lower the weight and production costs. In order to achieve such aims the appearance of thermo mechanical process of steel rolling (TMCP) was found particularly useful, which is based on a controllable rolling process with the accelerated cooling. The usefulness of materials for the production of welding constructions depends on different factors, which until now were not greatly considered in the assessment their welding abilities. An important problem in steels is the influence of alloy micro additives (niobium and vanadium) on the weld ability and properties of the welded joints. The role of the micro additives in these steels comes down to the creation of appropriate dispersion of carbides, nitrides and cabinetries of niobium and vanadium, during the controlled rolling process, which increase the strength properties through micro phase reinforcement and limited size of the grains [1-8].

II. RESEARCH

In this work, joints based on the S700 MC (Table 1, Fig. 1) steel with thickness of 10 mm were investigated, and welded using MAG method (Table 2). The drying and heating up temperature was 80 ^{o}C and the interlayer temperature was 60 ^{o}C. The chemical composition was carried out on the steel, on the G Mn4Ni1, 5CrMo weld and the joint material (Table 3-5).

Table 1. The chemical composition according to the regulation PN EN 10149-2 and mechanical properties of the S700 MC steel subjected to thermomechanical treatment used for cold moulding

Chemical composition [%]											
C max.	Si max.	Mn max.	P max.	S max.	$Al_{calk.}$ min.	Nb max*.	V max.	Ti max.	B max.	Mo max.	C_e** max.
0,12	0,60	2,10	0,008	0,015	0,015	0,09	0,20	0,22	0,005	0,50	0,61
Mechanical properties											
Tensile strength Rm, MPa			Yield limit Re, MPa			Elongation A_5, %			Impact strength, J/cm^2 (-20°C)		
822			768			19			135		

* - total amount of Nb, V and Ti should be max. 0,22%
** C_e – carbon equivalent (1)

$$C_e = C + \frac{Mn}{6} + \frac{Cr + No + V}{5} + \frac{Ni + Cu}{15}, [\%] \qquad (1)$$

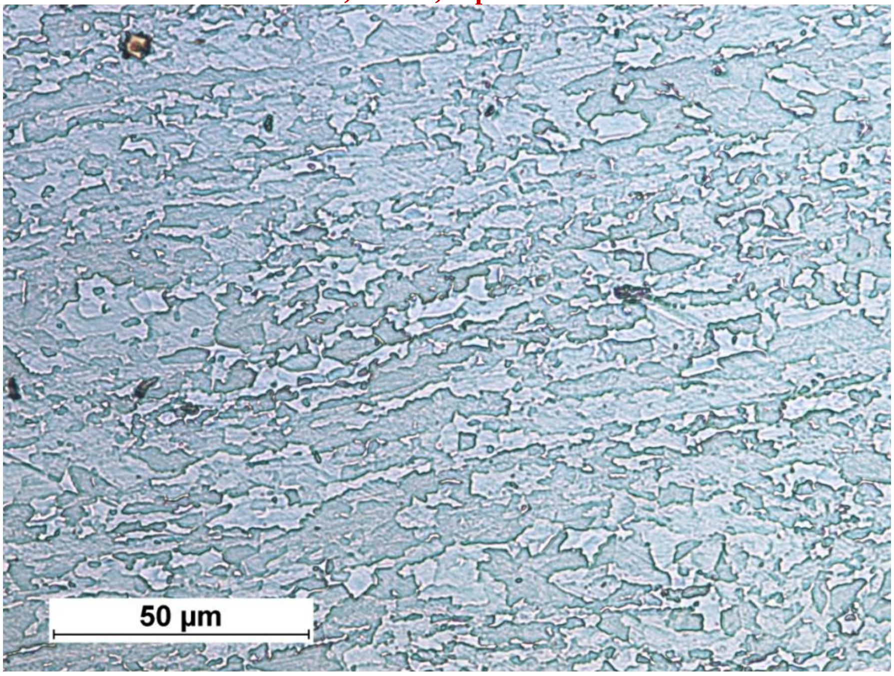


Fig. 1. Bainite-ferrite microstructure of the S700 MC steel subjected to thermo mechanical treatment

Table 2. Description of the different joints prepared using the MAG method with the G Mn4Ni1, 5CrMo weld

Designation	The amount of linear energy introduced 8 kJ/cm
MAG	The joints without repaired
MAG + I	The joints repaired once (electro air grooving plus repair welding using MAG method)
MAG + II	The joints repaired twice (electro air grooving plus repair welding using MAG method)
MAG + III	The joints repaired three time (electro air grooving plus repair welding using MAG method)

Table 3. The real chemical composition of the original S700 MC steel material

Chemical composition, %										
C	Mn	Si	S	P	Al	Nb	Ti	V	N*	C_e
0,056	1,68	0,16	0,005	0,01	0,027	0,044	0,12	0,006	72	0,33

* - N: the amount given in ppm, the nitrogen was measured using the high temperature extraction method

Table 4. Chemical composition was obtained using remelting method and mechanical properties of the melt in the form of a solid Mn4Ni1, 5CrMo wire using EN 12534 protocol

Chemical composition, %								
C	Si	Mn	P	S	Cr	Mo	Ni	C_e
0,09	0,52	1,68	0,005	0,012	0,21	0,50	1,50	0,61

Mechanical properties			
Tensile strength Rm, MPa	Yield limit Re, MPa	Elongation A_5, %	Impact strength, J/cm^2 (-60°C)
780	720	16	47

Table 5. Chemical composition of the joints material

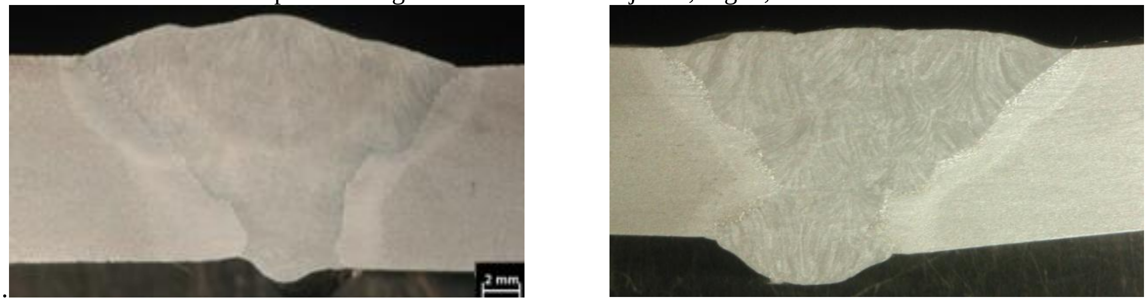
Chemical composition, %									
C	Mn	Si	S	P	Cr	Ni	Mo	N*	C_e
0,090	1,46	0,46	0,012	0,009	0,18	1,26	0,42	78	0,53

* - N: the amount given in ppm, the nitrogen was measured using the high temperature extraction method

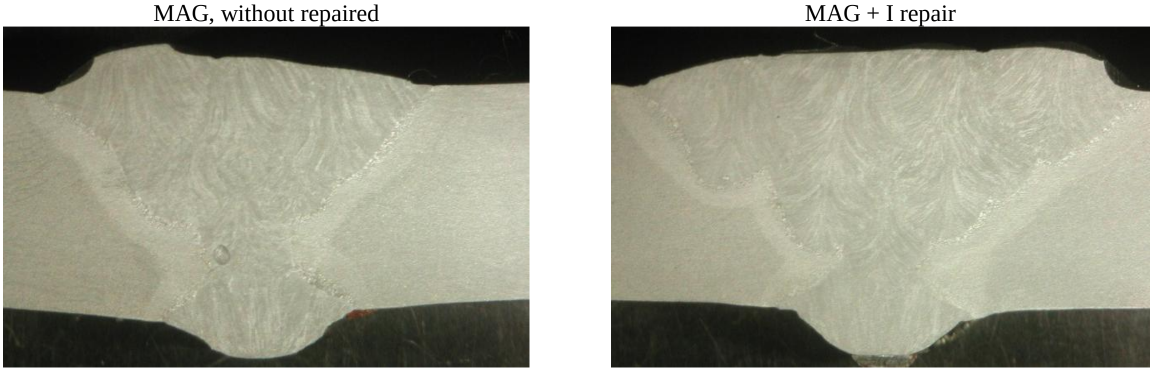
The chemical and structural analysis of the welded joint

The prepared joints were subjected to metallographic microscopy analysis, Fig. 2, using stereo microscope Olympus SZX 9 as well as standard optical microscopy using LEICA MEF4A, in the area of the joints and in HAZ,

Fig. 3. Chemical analysis in the S700 MC steel (Table 3) and in the joints (Table 5), x-ray diffraction (Table 6, Fig. 4) and phase determination by x-ray diffraction was carried out in order to describe the effect of the welding process on the chemical and phase changes in the areas of the joints, Fig. 5, 6.

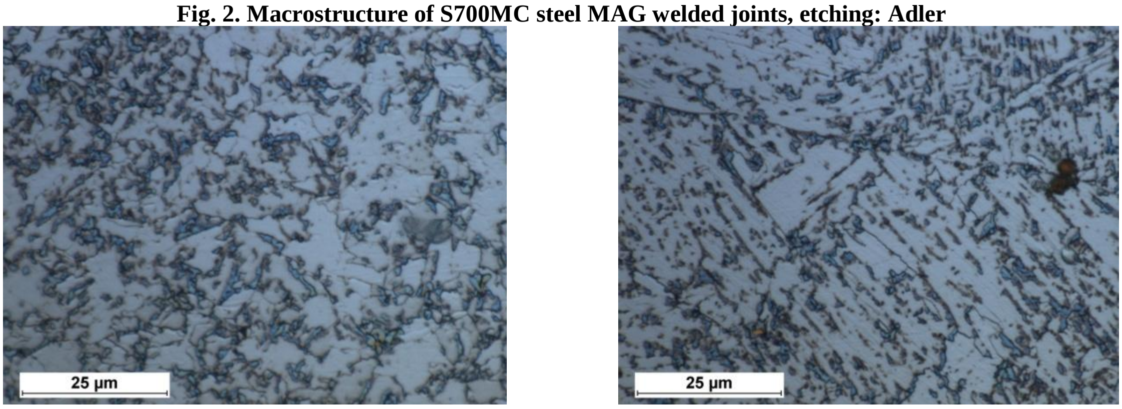


MAG, without repaired MAG + I repair

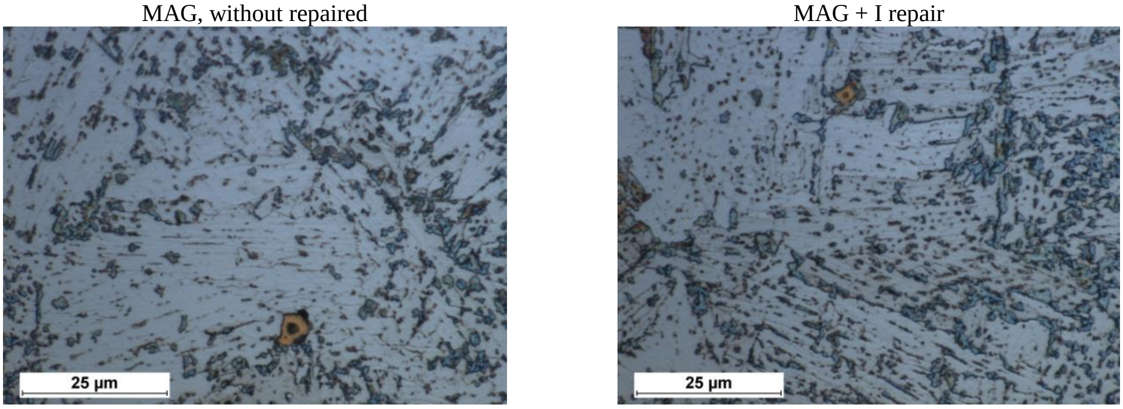


MAG + II repairs MAG + III repairs

Fig. 2. Macrostructure of S700MC steel MAG welded joints, etching: Adler

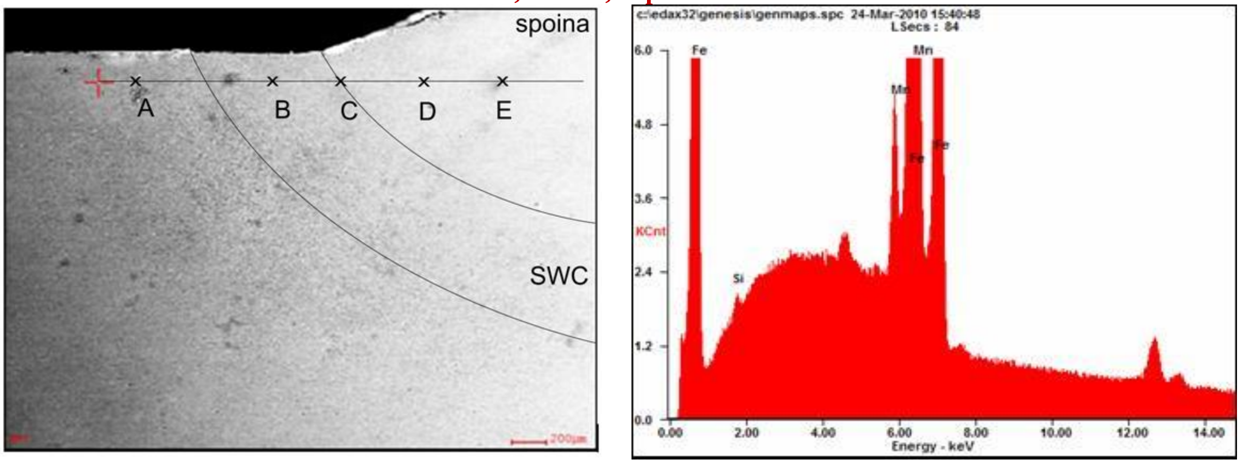


MAG, without repaired MAG + I repair



MAG + II repairs MAG + III repairs

Fig. 3. The microstructure of the HAZ joints welded using the MAG method on S700MC steel; the surface preparation was done using the nital treatment



The area of the X-ray analysis

Area A

Fig. 4. EDS spectra obtained in different areas of the welded joints using S700MC steel

Table 6. Detailed XRD analysis of the of the welded joints using S700MC steel

Element	Area A		Area B		Area C		Area D		Area E	
	Wt%	At%	Wt%	At%	Wt%	At%	Wt%	At%	Wt%	At%
MoK	-	-	-	-	0,31	0,53	0,33	0,56	0,31	0,53
CrK	-	-	-	-	0,14	0,17	0,13	0,16	0,12	0,16
NiK	-	-	-	-	0,82	0,77	0,77	0,73	0,71	0,67

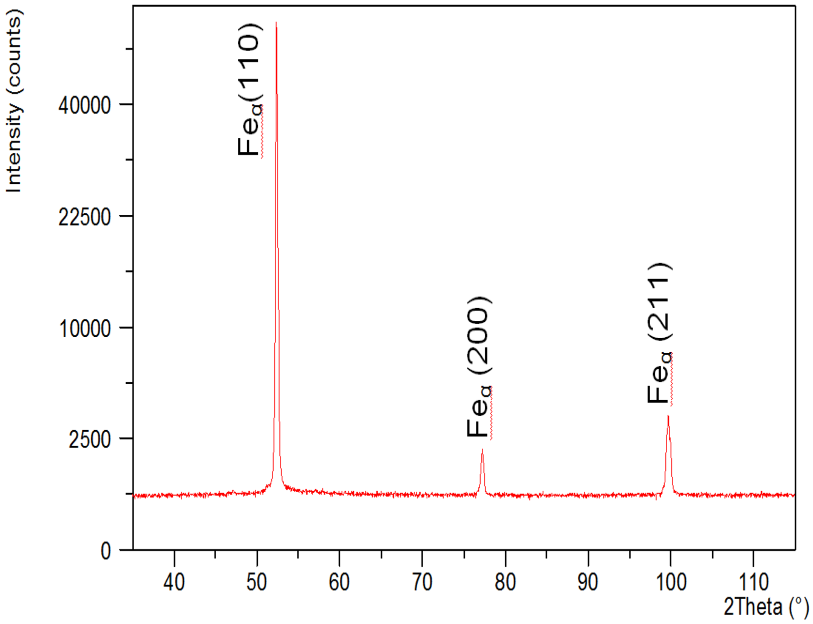


Fig. 5. X-ray analysis for base metal of S700MC steel

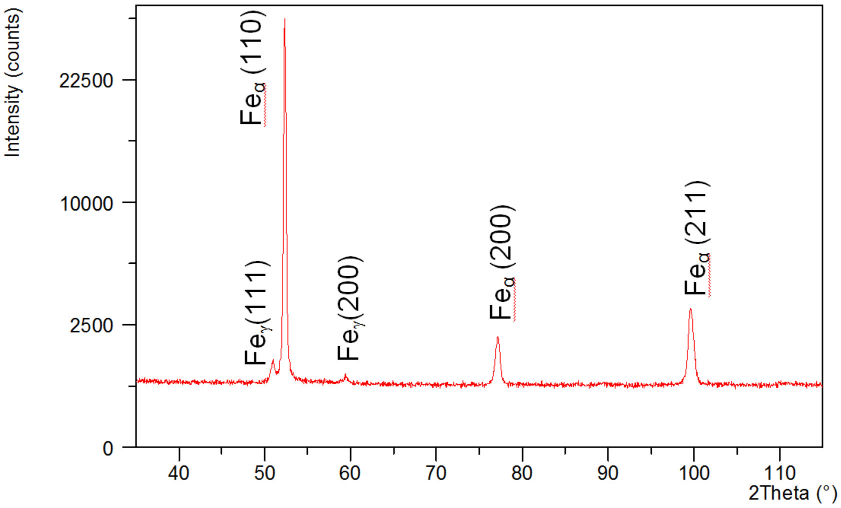


Fig. 6. X-ray analysis for weld area of S700MC steel

Mechanical performance analysis

The mechanical assessment of the welded joints was carried out based on elongation, bending, as well as form face and root side of weld in the temperature -30 °C. The results are summarized in Table 7.

Table 7. The results of the mechanical performance analysis of welded joints based on S700MC steel

Welding method	Tensile strength		Bending, bend angle °		Impact strength, - 30 °C, KV, J/cm^2	
	R_m, MPa	Rupture place	Face	Root	Weld	HAZ
MAG	830	Base material	180	180	93	65
MAG + I	817	Melting line	180	180	87	33
MAG + II	790	Melting line	180	180	65	28
MAG + III	765	Melting line	180	180	48	25

Hardness tests

In order to describe the effect of welding process on the change of hardness in the area of the joints, Vickers testing method was used, with 30kG force according to schematic in Fig. 7. The summary of hardness testing results is presented in Table 8.

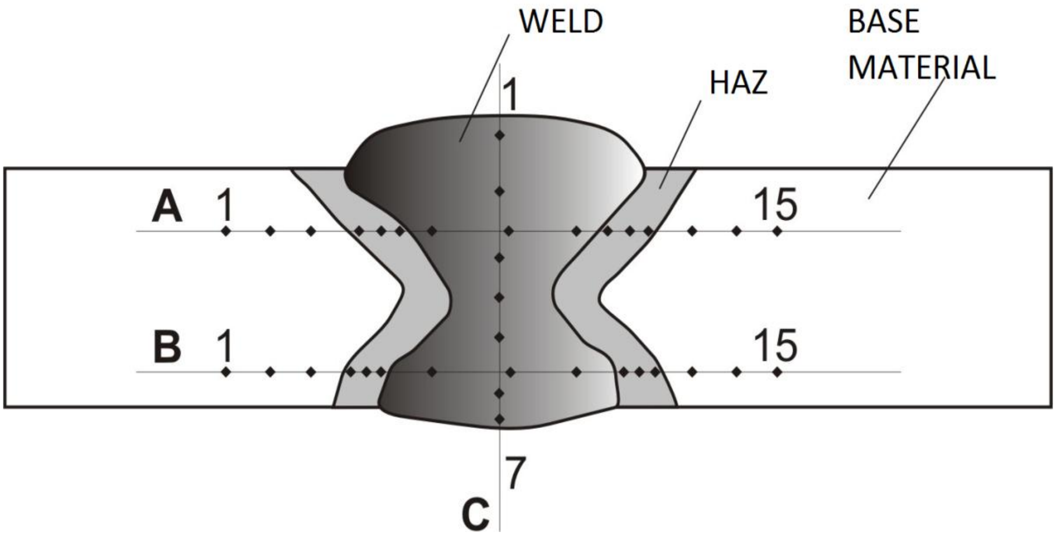


Fig. 7. The diagram showing the locations of different hardness testing carried out on welded joints from S700 MC Steel

Table 8. Results of the hardness testing HV30 in the areas of the welded joints in S700MC steel

Measure line	Measurement points, Fig. 7														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	MAG, without repair														
A	282	279	282	271	262	273	294	299	280	257	274	265	285	282	278
B	279	284	282	263	278	269	283	287	279	263	259	270	279	283	280
C*	284	286	284	270	268	269	258								
	MAG + I repair														
A	277	279	285	235	246	238	277	290	288	225	229	230	275	272	265
B	274	274	272	215	213	220	271	264	258	201	216	238	264	269	271
C*	220	217	224	271	279	276	245	209	224						
	MAG + II repairs														
A	265	277	279	227	226	233	279	270	276	232	227	223	280	274	274
B	264	271	270	232	210	219	241	244	263	241	228	230	267	270	272
C*	226	230	220	231	257	253	271	281	226						
	MAG + III repairs														
A	278	282	286	240	240	232	272	283	295	258	247	246	289	288	279
B	280	285	285	219	215	226	280	272	278	217	204	214	285	280	284
C*	256	275	274	287	275	280	235	221	240						

* - hardness HV1

III. THE ANALYSIS OF THE RESULTS

According to the generally accepted rules, in order to ensure the appropriate quality of welded joints, the joint material should be matched with the chemical composition close to the welded material. However in the case of steel, which has undergone the thermo mechanical process, especially with high yield point (700 MPa), such approach in incorrect. In order to obtain joints with the properties similar to the properties of such materials (R_m, KV) it is required to use joint materials with higher presence of alloying components compared to the native material, which is related to the increase of the carbon equivalent and can be the cause of deterioration in welding properties during the absence of controlled heat input into the welded joint. In the analyzed case the native material has carbon equivalent at the level of 0.33%, whereas the additional material for welding 0.61%. As a result of the welding process described using the method and parameters defined in this work, the native material was mixed with the weld and lowering of the carbon equivalent to the level of 0.53%. Such amount of carbon equivalent is exceeding the recommended level of 0.44% . The experimental work has shown that the welded joints has non uniform structure. The joint has ferritic-bainite structure. In HAZ, a recrystallization effect was observed and small growth of grains caused by the welding process thermal cycling. The X-ray phase analysis has shown in the native material the presence of Feα phase (Fig. 5), however in the area of the joints, besides the Feα phase there was also Feγ phase (Fig. 6), most probably the residual austenite, which unfavorably influences the functional properties of the welding constructions performing in the mechanical and thermal environments. The chemical analysis confirmed the difference in the composition of the native material and the joints. The composition of the joints is the product sum of the chemical composition of the weld and melted native material. In the area of the joints the presence of Ni, Mo and Cr, was detected, the elements which offer suitable mechanical stability as well as plasticity of the joint (Table 6). These results were further confirmed using XRD by scanning from the native material into the joint area (Fig. 4). The nitrogen analysis carried out using temperature extraction method showed that in the native material as well as in the joints contains about 70-80 ppm and it doesn't exceed allowed levels for this type of materials, Table 3 and 5. As a result formation of tempered structures takes place in the joints with hardness not exceeding the values of 300 HV30 (Table 8, Fig. 8). Although the hardness values are not high this results in deterioration of plastic deformation of the joint and HAZ welded joint in comparison to the native material. In the area of HAZ welded joint with the heating treatment after the process and repaired there was a clear decrease in the hardness in comparison to the native material (280 HV) and hardness of the joint caused by the grain growth processes and partial recrystallization. These observations were confirmed using statistical elongation test, which demonstrated that the repaired joints as well as heat treated joints after the welding process, there was clear deterioration in the elongation performance. In these joints the breakage of the samples took place in HAZ or the melting line (Table 7). The testing of impact strength has shown that the amount of heat introduced to the joints area has clear effect on the properties of the joints and HAZ. During the welding using the energy level of 8 kJ/cm, the joints and HAZ has characteristic values of high impact strength, at the level of 90 and 50 J/cm^2. In the case of repair welding, with the increasing number of repairs, equivalent to the increased amount of introduced heat to the joint, there is a decrease in the impact strength values in HAZ below the acceptable level of 27 J/cm^2 (Table 7, Fig. 9). The loss impact strength of the joints and HAZ can be caused by excretions of the MX phases in the ferrite and bainite grains; however confirmation of this mechanism requires further experimental work.

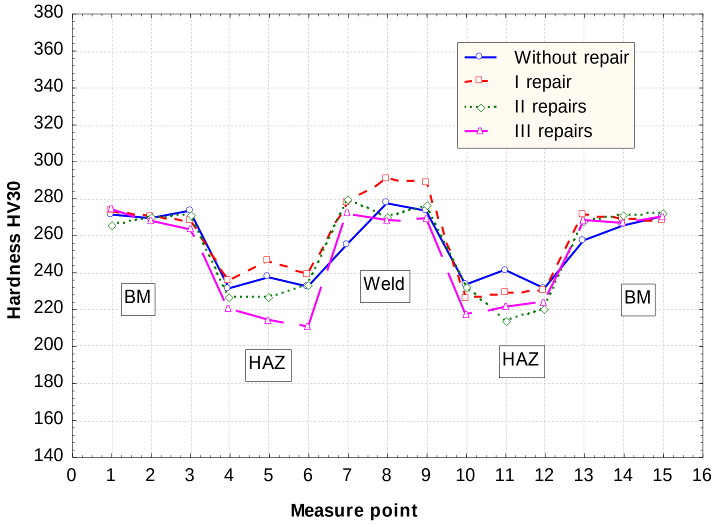


Fig. 8. The hardness distributions in the area of the welded joints made from S700MC steel

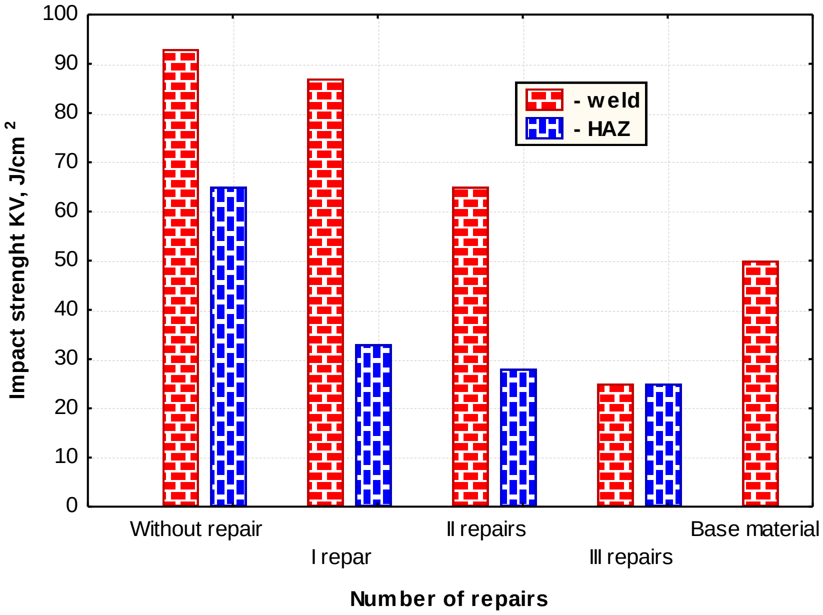


Fig. 9. Impact strength of the welded joints made from S700MC steel

IV. CONCLUSION

The weld ability research have shown, that the biggest problems during welding of steel, which has undergone the thermo mechanical process are causing joints properties, and in smaller degree the properties of HAZ. The possible influencing cause on the joints properties of steel treated using the thermo mechanical process can have uncontrollable processes of MX type intermetallic phase's separation (fine grain segregation of carbides/carbonitrides. Nb(C, N), V(C,N) and others), which significantly lower the plastic properties of the welded joints and their crack resistance. It is also worth mentioning the negative influence of nitrogen, which is responsible for the ageing processes. The native material contains sufficient amount of active titan and aluminum, in comparison to the amount of nitrogen, which form stable and low solubility phases in austenite of the type: TiN and AlN. In the joints the amount of titan will depend on the welding parameters and in the case of high level of nitrogen in the steel could be not sufficient to limit the ageing processes, what is causing deterioration the functional properties of the joints. In summary, during the welding of the steel subjected to thermo mechanical treatment with high limits of plasticity, the amount of injected heat into the joints area is crucial. The linear energy of the welding process should be limited to 8 kJ/cm. Furthermore the additional heat delivered to the joints after the welding process (repair welding) can cause rapid deterioration of the joints properties, especially impact strength of the material. Too much heat delivered to the welded joints area will cause recrystallization and growth of the crystal domain in the HAZ area what will result in the loss of the properties gained during the thermo mechanical treatment, and in the joints it can lead to uncontrollable separation processes deteriorating the properties of the welded joints.

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AUTHOR BIOGRAPHY

Doctor of technical sciences in the field of materials engineering, specializing in welding. He has the title of International Welding Engineer (IWE). He has authored or co-authored more than 100 scientific publications in the field of welding. The main areas of research interest include the use of electrical plasma arc welding processes, physics and metallurgy of welding processes, weld ability of high-strength fine-grained. He is the author of monographs: "Properties and structure of steel welded joints thermo mechanically treated high yield".