Possibility of replacing low-carbon structural steel with high-strength steels, for producing welded structures in industry of heavy machines

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Modern trends of research and development of new products are focused on saving materials through mass reduction of various parts, so the high-strength steels (HSS) are used more often than conventional low-carbon structural steels. It is well known that high strength of HSS is providing a possibility for parts to be produced with smaller dimensions and cross-sections. This often results in decreasing in weight of parts and whole structures. In this paper possibility for replacing commonly used, low-carbon, structural steels which have good weldability, with HSS, in industry of heavy machines is analysed. Main goal of this replacement is weight reduction as well as to keep adequate load capacity and reliability of parts and structures. Properties of three structural steels were analysed: Č0562 (S355J0), ČRO460 (P460NL1) and STRENX 700 (S690QL). Furthermore, both advantages and disadvantages of HSS application, complexity of choosing the correct welding method, correct filler materials and favourable welding technology are indicated. After the trial welding on samples, experimental investigation of important mechanical and microstructural properties such as strength, plasticity, impact toughness, hardness and microstructure evaluation were conducted. Based on the obtained experimental results the specific conclusions were given.

Keywords: Welding, Structural steel, High Strength Steel, Mechanical Properties, Microstructure

1. INTRODUCTION

As the trends in modern industry are focused on material saving, lowering energy (fuel) consumption, emissions of CO_2 and etc. to achieve this, several separate or one single solution could be applied. That single solution is downgauging through application of high-strength steel (HSS), instead of commonly used low-carbon structural steel. HSS have great strength values and allow parts and structures cross-sections to be smaller, which results in lower weight of part or structure. Thus, achieved lower weight of parts and structures reduces fuel and energy consumption and in some cases due to application of stronger material structures can withstand greater loads.

When changing materials due to complex production procedure of HSS, great attention needs to be paid especially when selecting most appropriate welding technology. Consequently, to achieve full benefits of HSS application, this problem needs specific approach, as to one complex technical and technological problem.

In this paper possibility for replacing low carbon structural steel with high-strength steels Č0562/S355JR, ČRO460/S460N and S690QL, their advantages and disadvantages were analysed, as well as favourable welding technologies for the mentioned steels were selected.

2. BASE MATERIALS

2.1. Chemical composition and mechanical properties of steel Č0562/S355JR

Steel Č0562/S355JR belongs to the group of C-Mn structural steels. Because yield stress values are greater than 360 MPa, it belongs to HSS. Due to low carbon content it has good weldability and formability and it is often used in production of welded structures. Chemical composition and mechanical properties of this steel are shown in table 1 and table 2 [1].

2.2. Chemical composition and mechanical properties of steel ČRO460/S460N

Steel ČRO460/S460N belongs to group of fine-grain HSS. Its main purpose is production responsible structures. In table 3 and table 4 chemical composition and mechanical properties are displayed [1].

2.3. Chemical composition and mechanical properties of steel STRENX 700/S690QL

Production of S690QL steel is achieved with strict chemical content and complex production procedures. Consequently its strength is greater than strength of many usually applied steels. Two separate grades of this steel could be identified, one for welded structures production and the other intended for manufacturing pressurised vessels. In the table 5 and table 6 chemical composition and mechanical properties are shown [2, 3].

Table 1 [1]: Chemical composition of steel Č0562/S355JR

Steel	Chemical composition, %										
Č0562/S355JR	C	Mn	Si	P_{max}	S_{max}	Cr_{max}	Ni	Al	Cu_{max}	Ti_{max}	Nb_{max}
	0.11	1.2	0.118	0.016	0.008	0.02	0.02	0.052	0.02	0.013	0.04

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Table 2 [1]: Mechanical properties of steel Č0562/S355JR

Steel	R_m, MPa	R_{eh}, MPa	A_5,%	$KCV_{0°C}$, J
Č0562/S355JR	512	439	25	168

Table 3 [1]: Chemical composition of steel Č0562/S355JR

Steel	Chemical composition, %								
ČRO460/S460N	C	Mn	Si	P_{max}	S_{max}	Cr_{max}	Ni	Mo_{max}	Al
	0.20	1.52	0.41	0.008	0.001	0.13	0.47	0.02	0.02
	Cu_{max}	Sn_{max}	V	Ti_{max}	Nb_{max}	As_{max}	Sb_{max}	Co_{max}	Pb_{max}
	0.18	0.014	0.111	0.0029	0.002	0.009	0.001	0.001	0.001

Table 4 [1]: Mechanical properties of steel ČRO460/S460N

Steel	R_m, MPa	R_{eH}, MPa	A_5,%	Z, %	$KCV_{-40°C}$, J	$KCV_{-30°C}$, J	HV
ČRO460/S460N	725	473	19.2	38.0	32-35	42-45	207-210

Table 5[2,3]: Chemical composition of steel STRENGTH 700/S690QL

Steel	Chemical composition, %													
S690QL	C	Mn	Si	P	S	Cr	Mo	Ni	V	Al	B	Cu	Ti	N	Nb
	0.2	1.5	0.6	0.02	0.01	0.7	0.7	2.0	0.09	0.015	0.005	0.3	0.04	0.01	0.04

Table 6 [2,3]: Mechanical properties of steel STRENGTH 700/S690QL

Steel	R_m, MPa	R_{eH}, MPa	A_5,%	Tvrdoća HBW	$KCV_{-40°C}$, J
S690QL	770-940	700	14	260-310	30

3. WELDABILITY ASSESSMENT OF HIGH STRENGTH STEELS

Selection of the favourable welding technology requires a special approach as well as gathering as much information about the base materials (BM) as possible. Having great amounts of data allows greater perspective to be seen, such as material behaviour in various conditions. Except chemical composition and mechanical properties, in this particular case ability of BM to form welded joints (weldability) needs to be known. Weldability of steels can be estimated in many different ways, but in this paper analytic/computational methods have been applied. Following criterions were used: CE, CET, CEV, P_{hp} (Czech authors) and P_C (Japanese authors) [4].

Weldability assessment by CE (Carbon Equivalent) criterion is conducted using special equations according to type of steel which weldability needs to be assessed. For weldability assessment of steel Č0562/S355JR equation 1 is applied. If the calculated value of CE exceeds 0.45, analysed steel is prone to cold cracking and it can be welded only by applying additional steps and measures [5].

$$CE=C+\frac{Mn}{6}+\frac{Cr+Mo+V}{5}+\frac{Ni+Cu}{15} \quad (1)$$

For weldability assessment of steel ČRO460/S460N equation 2 is applied. For this steel critical value of CE is 0.35. If the calculated value is exceeded, additional steps and measures need to be taken during welding procedues [4].

$$CE=C+\frac{Mn}{10}+\frac{V}{3}+3\cdot N \quad (2)$$

For weldability assessment of steel STRENX 700/S690QL by CE, usually applied equations for CE calculation couldn’t be applied, instead CEV (equation 3) and CET (equation 4) equations were used [2].

$$CEV=C+\frac{Mn}{6}+\frac{Cr+Mo+V}{5}+\frac{Ni+Cu}{15},\% \quad (3)$$

$$CET=C+\frac{Mn+Mo}{10}+\frac{Cr+Cu}{20}+\frac{Ni}{40},\% \quad (4)$$

For determining cold crack proneness, equations of Czech and Japanese authors were used. This equations beside chemical composition take into consideration the influence of thickness of welded parts as well as amount of diffused hydrogen, that could be brought in welded joints from filler materials (FM). Equations of Czech authors have the following form [5]:

$$P_{hp}=P_{CM}+\frac{K}{40000}+0.015\cdot log\frac{H}{2.77}, \quad za \quad K\leq 1300 \text{ and} \quad (5)$$

$$P_{hp}=P_{CM}+\frac{K}{40000}+0.075\cdot log\frac{H}{2.77}, \quad za \quad K>1300\,, \quad (6)$$

where:

$$P_{CM}=C+\frac{Si}{30}+\frac{Mn+Cu+Cr}{20}+\frac{Ni}{60}+\frac{Mo+V}{15}+5\cdot B, \quad (7)$$

s – parts thickness *mm*,
H – ammount of diffused hydorgen, *ml*/100 *g* welded joint,
K = 69·s – Stiffness, *N*/*mm*

Japanese authors formula for assessing cold crack pronenes have the following form:

$$P_C=P_{cM}+\frac{s}{600}+\frac{H}{60}, \quad (9)$$

$$P_W=P_{cM}+\frac{K}{40\cdot 10^4}+\frac{H}{60}, \quad (10)$$

where:

$$P_{CM}=C+\frac{Si}{30}+\frac{Mn+Cu+Cr}{20}+\frac{Ni}{60}+\frac{Mo}{15}+\frac{V}{10}+5\cdot B,\ \%, \quad (11)$$

s – parts thickness *mm*,
H – ammount of diffused hydorgen, *ml*/100 *g* welded joint,
K = 69·s – Stiffness, *N*/*mm*

3.1. Weldability assessment results

As results of replacing numbers in previous formulas, weldability was graded (Table 7).

Analysing displayed results it can be concluded that two out of three analysed steels need additional steps and measures to be taken during their welding procedure, due to their proneness to cold cracks.

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Table 7 [1, 2]: Computational wledability assessment grades for analysed steels

Criterion	Designation	Calculated value for steel			Condition for welding without preheating	Preheating required		
		Č0562	ĆRO460	S690QL		Č0562	ČRO0460	S690QL
CE	CE	0.315	-	-	CE< 0.35	No	-	-
		-	0.392	-	CE< 0.45	-	Yes	-
CET	CET	-	-	0.32	-	-	-	-
CEV	CEV	-	-	0.48	-	-	-	-
Czech authors	P_{hp}	0.202	0.357	0.484	P_{hp} <0.24	No	Yes	Yes
Japanese authors	P_C	0.251	0.405	0.529	P_C<0.30	No	Yes	Yes

Based on weldability assessment results it can be concluded that for welding steels ČRO460/S460N and STRENX 700/S690QL preheating of welded parts is needed.

Preheating as well as other additional steps and measures taken during welding procedures represent additional costs, therefore an in depth economic viability analysis needs to be conducted to determine if those additional steps and measures are economically justified when compared to achieved properties [1].

For welding steel ČRO460/S460N preheating temperature was calculated using equation 12. Based on results preheating temperature of 265°C was adopted [1]:

$$T_p = 1600 \cdot P_{hp} - 308, \ °C. \quad (12)$$

Preheating temperature for steel STRENX 700/S690QL is adopted from recommended temperature interval 150-200°C so that no alteration of mechanical properties could occur due to high preheating temperature [2].

If welding for this two steels is done without preheating, there is great probability of cold crack formation. Their appearance isn't allowed in any structure type, specially in the responsible ones [4].

4. SELECTION OF MOST APPROPRIATE WELDING TECHNOLOGY

For reviewed HSS steels favourable welding technology needs to be selected. As the first step in the procedure, FM and methods were selected. As mentioned before, because steels ČRO460/S460N and STRENX700/S690QL are prone to cold cracking, preheating needs to be done. Based on selected FM welding parameters were selected and welding tests on steel plates were performed.

4.1. Selection of most favourable welding technology for Č0562/S355JR

For steel Č0562/S355JR GMAW procedure was selected. As a FM, VAC 60 (EN ISO 636-A:W 42 5 W3Si1) electrode wire with diameter 1.2 mm was selected, due to similar mechanical properties with base material. Chemical composition and mechanical properties of VAC 60 are given in tables 8 and 9. When welding Č0562/S355JR preheating is not required, because this steel is not prone to cold cracking. Trial welding was performed on 10 mm thick plates using parameters given in table 10. [1].

Table 8 [1,5]: Chemical composition of electrode wire VAC 60

FM		Chemical composition, %		
Commercial	EN ISO	C	Si	Mn
VAC 60	W 42 5 W3Si1	0.1	0.9	1.5

Table 9 [1,5]: Mechanical properties of electrode wire VAC 60

FM		R_m, MPa	R_{eH}, MPa	A_5, %	KV, J
Commercial	EN ISO				
VAC 60	W 42 5 W3Si1	510-590	410-490	22-30	80-125

Table 10 [1]: Welding parameters for electrode wire VAC 60

Base material thickness, mm	FM	Preheating temperature, °C	Electrode wire diameter, mm	Current, A	Voltage, V	Welding speed, cm/s	Drive energy, J/cm	Shielding gas	Shielding gas flow, l/min
10	VAC60 (MMAW)	0	1.2	170-200	25.9-26.3	0.281-0.456	8207-15911	CO_2	18-20

4.2. Selection of most favourable welding technology for ČRO460/S460N

Welding trials for ČRO460/S460N were performed using metal manual arc welding (MMAW) with prior preheating to 265°C of the parts to avoid formation of cold cracks. As FM electrode GALEB 70 (EN ISO 2560-A: E 50 2 Mn1Ni B 42 H5) was used, and thickness of base material was 20 mm. In the tables 11 and 12 chemical composition, mechanical properties, as well as welding parameters are shown [1].

Table 11 [1,5]: Chemical composition of filler material GALEB 70

FM		Chemical composition, %				
Commercial	EN ISO	C	Si	Mn	Ni	Mo
GALEB 70	E 50 2 Mn1Ni B 42 H5	0.1	0.9	1.5	0.7	0.2

Table 12 [1,5]: Mechanical properties of GALEB 70

FM		R_m, MPa	R_{eH}, MPa	A_5, %	KV, J
Commercial	EN ISO				
GALEB 70	E 50 2 Mn1Ni B 42 H5	640-710	520-600	22-26	125-155

Table 13 [1]: Welding parameters for GALEB 70

Base material thickness, mm	FM	Prehaeating temperature, °C	Electrode core diameter, mm	Current, A	Voltage, V	Welding speed, cm/s	Drive energy, J/cm
20	GALEB 70 (MMAW)	265	2.5-3.25	90-130	23-25	0.146-0.38	6958-17808

4.3. Selection of most favourable welding technology for S690QL

Due to proneness of steel STRENX 700/S690QL to form cold cracks, when welding this steel, parts need to be preheated, heated during the welding procedure and tempered (150-200°C) after welding procedure is finished. This additional heat treatment steps are performed to reduce probability of cold cracks to form [2-4].

Except additional heat treatment, when welding STRENX 700/S690QL grade of steel, special filler materials need to be applied. For root welding procedure of thicker parts made from this steel, special austenitic filler material needs to be used. Main reason for that is the ability of this FM type to reduce amount of residual stress caused by heat inputted welding procedure and to improve plasticity and impact toughness of the welded joint [6]. In this particular case, for root welding, MMAW procedure was performed using filler material INOX B 18/8/6 (EN ISO 3581-A: E 18 8 Mn B 22). The rest of welded joint was filled using GMAW procedure and filler material MIG 75 (EN 12 534: Mn3Ni1CrMo). This FM application is intended for welding fine-grain HSS [6]. Test welding was done using mentioned FM on 15 mm thick steel plates. Chemical composition, mechanical properties and welding parameters of test welding are displayed in table 14, table 15 and table 16.

Table 14 [2,6]: Chemical composition of INOX B 18/8/6 and MIG 75

FM		Chemical composition, %					
Commercial	EN ISO	C	Si	Mn	Cr	Ni	Mo
INOX B 18/8/6	E 18 8 Mn B 22	0.12	0.8	7	19	9	-
MIG 75	Mn3Ni1CrMo	0.6	0.6	1.7	0.25	1.5	0.5

Table 15 [2,6]: Mechanical properties of INOX B 18/8/6 and MIG 75

FM		R_m, MPa	R_{eH}, MPa	A_5, %	KV, J
Commercial	EN ISO				
INOX B 18/8/6	E 18 8 Mn B 22	590-690	>350	>40	>80 (+20°C)
MIG 75	Mn3Ni1CrMo	770-940	>690	>17	>47 (-40°C)

Table 16 [2]:Welding parameters for INOX B 18/8/6 and MIG 75

Base material thickness, mm	FM	Diameter, mm	Preheating temperature, °C	Current, A	Voltage, V	Welding speed cm/s	Drive energy, J/cm	Shielding gas	Shielding gas flow, l/min
15	INOX B 18/8/6 (MMAW)	3.25	140-150	120	24.5	0.2	12000	-	-
	MIG 75 (GMAW)	1.2		240-250	25	0.35	14885	82% Ar+ 18% CO_2	14

5. WELDING OF EXPERIMENTAL SAMPLES AND TESTS

Test welding of steel plates was performed according to previously described technologies. Welding of steel Č0562/S355JR was concluded withouth any additional heat treatment step (preheating, tempering) [1].

Due to cold crack pronneness steel plates from ČRO460/S460N according to weldabillity assessment need to be preheated to 265°C [1].

Additional heat treatment steps need to be applied when welding S690QL, as well. In this case except preheating (140-150°C), an interpass temperature of 200°C was defined [2]. After test welding, steel plates were inserted in furnace to slowly cool down [5].

From test welded steel plates, samples for following tests were prepared: tensile testing, measuring of impact toughness, hardness measurements and metallographic tests of specific areas of the welded joints.

For tensile test, prismatic samples with parallel sides were prepared from Č0562/S355JR and ČRO460/S460N and for steel STRENX 700/S690QL cylindrical samples were prepared.

For impact toughness measurements samples with V-cut were prepared, according to standard EN 10045-1**.** Two types of samples were prepared, one from base material, and the other from the welded joints, with the cut positioned in the middle of the welded bead.

5.1. Experimental tests of Č0562/S355JR

Total of 6 samples were prepared for tensile tests, three out of base material and three out of welded samples. Dimensions of the samples is displayed on Figure 1, and prepared samples on Figure 2. On Figure 3 tensile test results are displayed. According to SRPS C.T3. 051 strength of welded joints was reduced by 7.4% [2].

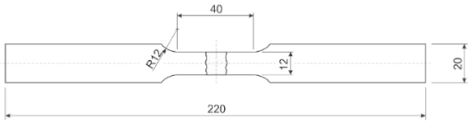


Figure 1[1]: Display of tensile test sample dimensions

a) b)

Figure 2 [1] Prepared samples for tensile test BM a) and welded joint b)

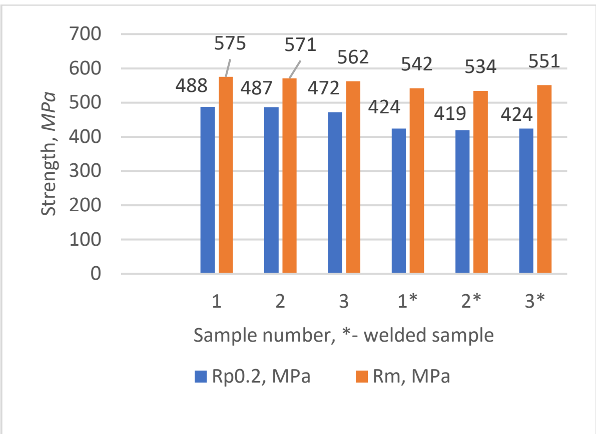


Figure 3 [1]: Results obtained by tensile test

Analysis of tensile test results shows that strength of welded joints is slightly lower than strength of BM, thus conclusion can be made that implemented welding technology according to tensile test result is favourable.

Impact toughness test was performed on six V-cut joint samples, three made out of base material and three out of welded. Samples made from welded steel plates were machined so that V-cut is positioned in the middle of the welded joint. Dimensions of prepared samples are displayed on Figure 4, real samples are shown on Figure 5 and results of impact toughness are shown in table 17 [1].

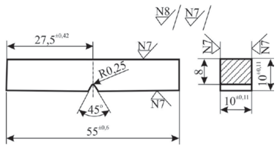
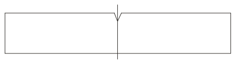
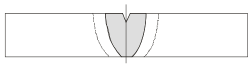


Figure 4 [2]: Appearance of toughness sample dimensions

a) b)

Figure 5 [1]: Display of prepared samples BM a) welded steel plate b) [1]

Table 17 [1]: Impact toughness test results [1]

Cut	BM			Middle of welded bead		
Sketch						
No.	1	2	3	1	2	3
KV_2, J/cm^2	202	197	216	134	172	191

According to obtained results, welded samples have lower toughness values, but results imply that no formation of brittle structures occured, so the followed welding procedure is favourable.

Hardness measurement was performed as well, in two directions. Both directions were paralel to top and bottom surfaces. First direction was located slightly bellow the top, and the second was located slightly above the bottom sruface (across the root weld). Measured values (Figure 6) are far lower than 350HV so it can be concluded that no brittlement had occured due to heat input during the welding procedure.

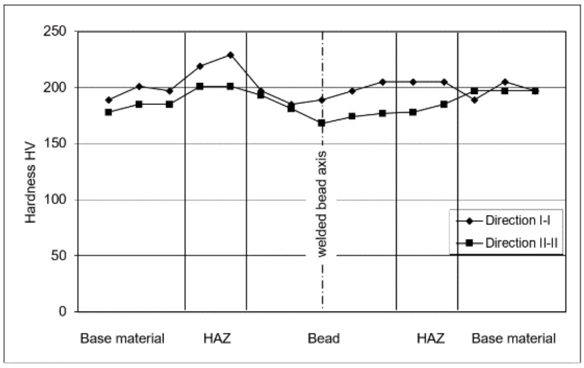


Figure 6 [1]: Hardness measurments in welded joint

On appropriate selection of welding technology, and non-existence of brittle phases/structures imply the metallographic examination of welded samples (Figure 7). Observed microstructures in BM and HAZ show fine-grain ferrite-pearlitic, and in welded bead zone Widmanstätten's microstructures is achived.

a) b) c)

Figure 7 [1]: Observed microstructures in BM a) HAZ b) welded bead c) of steel Č0562/S355JR at zoom 200x

5.2. Experimental tests of ČRO460/S460N

In this case six samples were prepared as well, three from BM and three from welded steel plates. Geometry of prepared samples is shown on Figure 8, and prepared samples on Figure 9. Results obtained during the tensile test are displayed on Figure 10.

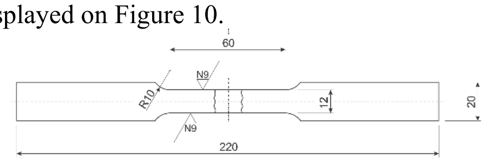


Figure 8 [1]: Display of tensile test dimensions

a) b)

Figure 9 [1]: Display of prepared samples

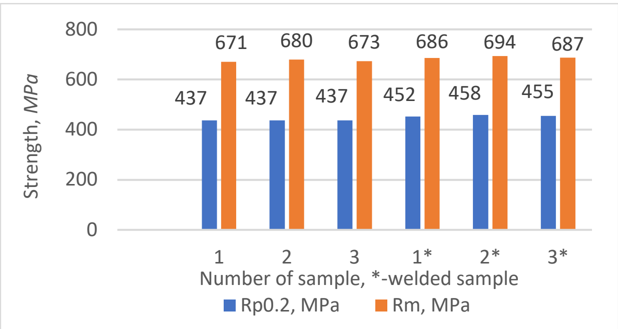
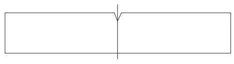
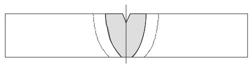


Figure 10 [1]: Results obtained by tensile test

Obtained results show that welding technology is appropriately selected due to strength values of welded samples is higher than strength of BM.

As in previous case six samples for impact toughness measurements were prepared. Results in table 18 show that welded samples have greater toughness than samples from BM implying that selected technology is suitable for welding.

Table 18 [1]: Impact toughnes test results [1]

Cut	BM			Middle of welded bead		
Sketch						
No.	1	2	3	1	2	3
KV_2, *J/cm^2*	129	94	120	228	195	246

Hardness measurements values (Figure 11) are higher compared to the values of the previous steel but, still are bellow 350HV which means that heat inputted during the welding procedure didn't cause martensitic transformation.

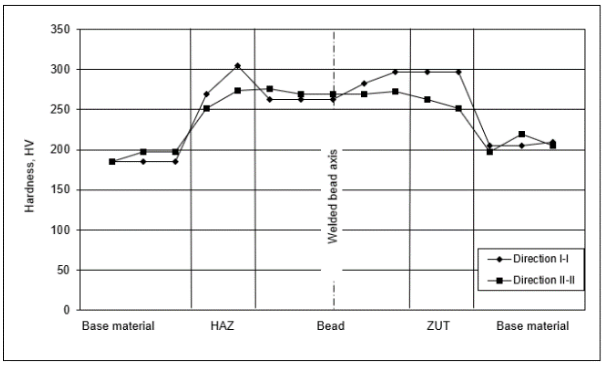


Figure 11 [1]: Hardness measurements in specific areas of welded joint

Metallographic tests were conducted to observe achieved microstructures in important areas of welded joint. In BM and HAZ ferrite-pearlitic microstructure is achieved, and in welded bead Widmanstätten's microstructure was found (Figure 12).

a) b) c)

Figure 12 [1]: Observed microstructures in BM a) HAZ b) welded bead c) of steel ČRO460/S460N at zoom 200x

5.3. Experimental tests of STRENX 700/S690QL

For the tensile test of S690QL total of six cylindrical samples were prepared. Three out of base material, three out of welded samples. Dimensions of used samples are shown on Figure 13 and obtained results are displayed on Figure 14.

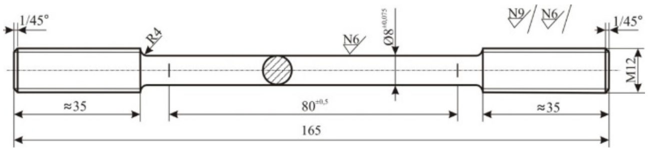


Figure 13 [2]: Display of sample dimensions

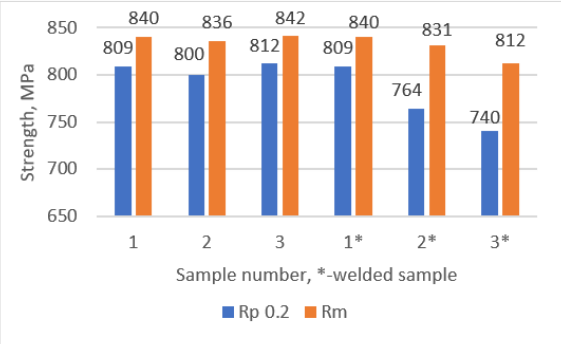
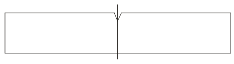
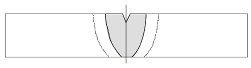


Figure 14 [2]: Results obtained by tensile test

Observing the results of tensile test, it can be notices that R_m values are almost equal, but R_{eH} values of welded samples are lower that values of BM. Even tough there is a slight difference in R_{eH} values it can be concluded that applied technology is favourable.

As in previous cases six samples were prepared, and results of impact toughness measurements, displayed in table 19, are showing great difference between BM and welded samples. This implies on possibility of brittle phases formation.

Table 19 [2]: Impact toughnes test results

Cut	BM			Middle of welded bead		
Sketch						
No.	1	2	3	1	2	3
KV_2, *J/cm²*	294	278	293	56	65	59

Hardness measurements results (Figure 15), in certain spots showed values above 350HV which is a sure sign that embrittlement has resulted from inputted heat during test welding. Finally performed metallographic observations in the specific areas of welded joint, show occurrence of tempered martensite and small amount of bainite in BM (Figure 16a). In the HAZ (Figure 16b) fine needle-like martensite with small amount of residual austenite could be observed and in the welded bead (Figure 16c) a tempered martensitic structure with small amount of bainite and pearlite can be observed.

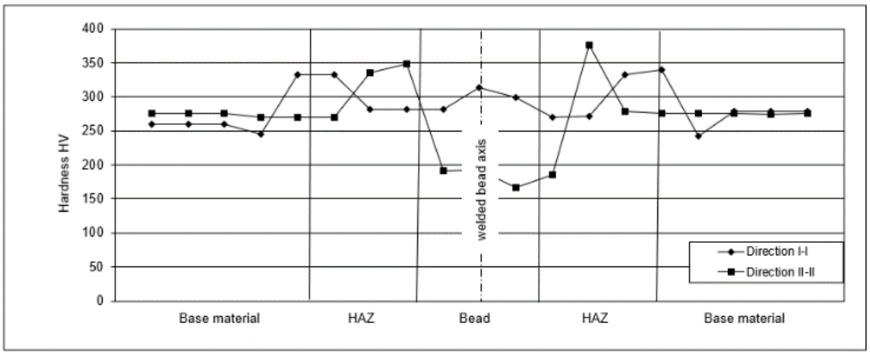
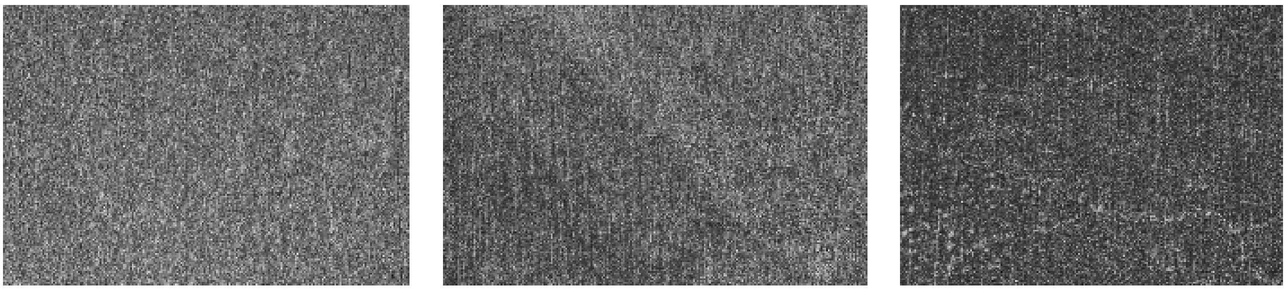


Figure 15 [2]: Hardness measurements in specific areas of welded joint



a) b) c)

Figure 16 [2]: Observed microstructures in BM a) HAZ b) welded bead c) of steel S690QL at zoom 200x

6. EFFECT OF REPLACING LOW CARBON STRUCTURAL STEEL WITH HSS

In most equations for determination parts dimensions (cross-sections), materials yield stress value is the most influential criterion. A relation between yield stress value and cross-sections dimensions of parts can be established. For the same load values, higher values of yield stress will result in smaller cross-sections and vice versa, lower yield stress requires cross-sections of parts to be greater so that same load could be withstood. Considering that all steels have same or slightly different density values, for the same length, but different size cross-section, parts will have different weight.

On a theoretical example, weight reduction potential through implementation of HSS instead of regular low-carbon structural S235JR steel will be demonstrated.

In mechanical engineering, steel S235JR is often used for producing wide variety of parts and structures.

Main reason for that is its good weldability, due to low carbon content, and adequate strength values R_m= 360-500 MPa, $R_{p0.2}$=235 MPa. This steel also has significantly lower price in comparison to other structural steels.

Complex structure of railway carriage chassis is made out of steel S235JR which yield strength is 235MPa and it has a certain weight. Implementation of steel with higher strength will result in smaller thickness of parts thus, the chassis will have less weight. As for demonstration purposes of weight saving potential evaluation, yield stress ratios of HSS and used S235JR steel could be observed. This ratio directly shows how many times the structure could be lighter if the HSS were implemented in production of chassis parts. In the table 20

Table 20: Yield stress ratios between HSS and S235JR

Steel	$R_{p0.2}$	$R_{p0.2}^{HSS}/R_{p0.2}^{S235JR}$
S235JR	235	1
S355JR	439	1.86
S460N	473	2.01
S690QL	700	2.97

Observing data from the previous table it could be concluded that implementation of HSS allows substantial weight save to be achieved. For the given theoretical example, using steel Č0562/S355JR instead of S235JR structures can be 1.86 times or 46.23% lighter, using ČRO460/S460N structures can be 2.01 times or 50.25% lighter, and using steel STRENX 700/S690QL structures can be lighter up to 2.97 times or 66.33% in comparison to to S235JR steel. Clearly, the steel STRENX 700/S690QL allows the greatest weight reduction to be made out of all analyzed steels. This is due to its yield stress values being higher than values of other steels.

It needs to be emphasized that given results are theoretical. Some parts even though they have greater strength, need to be made at certain dimensions and cross-sections so that adequate stiffness of structure could be maintained, but in general weight saving potential with application of HSS is demonstrated. Lower weight of structures allows energy/fuel consumption to be lower and energy efficiency to increase as well as payload mass.

7. CONCLUSION

The global trend in automotive and transportation industry tends to reduce structure weight so that lower energy/fuel consumption, lower CO_2 emissions and higher payload weight could be achieved. One of many other ways to achieve this goal is to replace low-carbon structural steels with HSS. These steels have great strength which is achieved by complex production process (heat treatment, rolling, cooling etc.), so when choosing appropriate welding technology great attention needs to be paid, due to possibility of achieved mechanical properties to be compromised by the heat released during welding.

In this paper application of three HSS is considered Č0562/S355JR, ČRO460/S460N and STRENX 700/S690QL.For two out of three steels, results of computational weldability assessment shows proneness of steels to form cold cracks. Additional steps and measures such as pre heating, tempering need to be taken to prevent cold crack formation. Because those additional steps are categorised as additional manufacturing costs an in depth economic analysis needs to be conducted, whether those costs are justified compared to potential benefits of HSS implementation. Additional costs and complex welding technology combined with heat treatment steps are definitely the greatest disadvantage of HSS application.

For the analysed HSS, FM, welding parameters as well as additional heat treatment steps for cold crack prone steels, were proposed. Following the proposed welding technology test welding on steel plates was performed and samples for tensile test, impact toughness, hardness measurements and metallography were prepared. Results of conducted tests imply that appropriate welding technology is selected, and that can be transferred on real-life structure parts.

In the end weight saving potential of HSS was evaluated through one theoretical example. Obtained results show theoretical potential for weight reduction. In real-life experience some parts need to be produced with certain dimensions and corss-sections so that adequate stiffness could be maintained.

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