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Optimization of application techniques for quenched and tempered steel-S550Q

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ABSTRACT

EN10025-6 S550Q is high strength steel classified under quenched and tempered (Q&T) manufacturing technique.S550Q is specially designed and used by us for welded steel structures for the purpose of heavy lifting and lowering. The entire processing techniques like cutting, edge preparation, welding, and bending are of major importance to the consistency of fabricated structure. This study comprises of an introduction to HSS-S550Q and addresses various important variables by practically. The following main factors are taken to consideration heat input during cutting, edge preparation, and welding, cooling cycle, Hydrogen induced cracking (HIC) Stress Relieving (SR) is mandatory after weld fabrication. The first was to establish a need for SR to achieve desirable weldment properties.SR has been reported to have Complementary benefits such as tempering of WM and HAZ regions and allowing the effusion/diffusion of hydrogen away from the weld region. Bend testing of cross-weld samples was used to qualify the ductility of the weldment before and after SR. In addition, impact, tensile and hardness properties, microstructures were quantified before and after SR.

Keywords— *S550Q-EN 1011-2, Thermal cutting, Welding-Stress reliving, ASME SEC-IX (2015)-EN ISO15614*

1. INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction to High Strength Steel (HSS)

High strength steel has been used in many manufacturing sectors. It has been classified into three manufacturing classification

- Quenched and tempered – Q&T
- Thermomechanical controlled process-TMCP
- Direct quenching-DQ

1.2 Properties of Alloying Elements in the base material and its welding

Every single alloy or combination of alloys has a diverse effect on the metal. These elements constitute inclusions and precipitations in the material and prevent grain growth process.

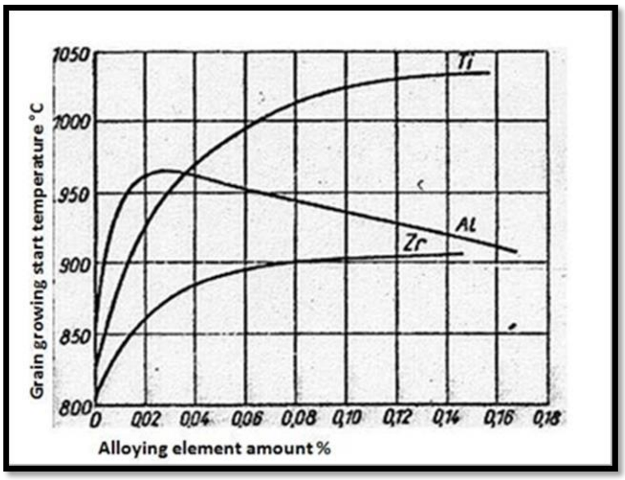


Fig.1: The effects of microalloying on various elements (Harry Nevalainen-1984)

Table 1: Properties of Alloying Elements in the base material and its welding

Alloying elements	Effects	Reference
Aluminum and Silicon	Deoxidizer-control austenite grain growth	(Metal Handbook 1990)
Niobium	HAZ toughness (Heat input)	(Tian 1998; Hatting & Pienaar-1998)
Vanadium	Rises the austenite recrystallization temperature in HSS	(Sampath-2005)
Titanium	Prevent grain growing process in the Heat affected zone during welding	(Liu & Liao-1998)
Zirconium	Improves ductility in transverse bending. Improves through thickness property of a material to prevent lamellar tearing	(Metal Handbook1990)
Boron, Copper	To increase hardenability	(Metal Handbook 1990)
Manganese, Nickel	Increases the strength of the material and also maintain its toughness property, if excess increase hardenability and reduce weldability	(Sampath-2005)

1.3 Microstructure of welding

The following factors are considered to control the weld microstructure

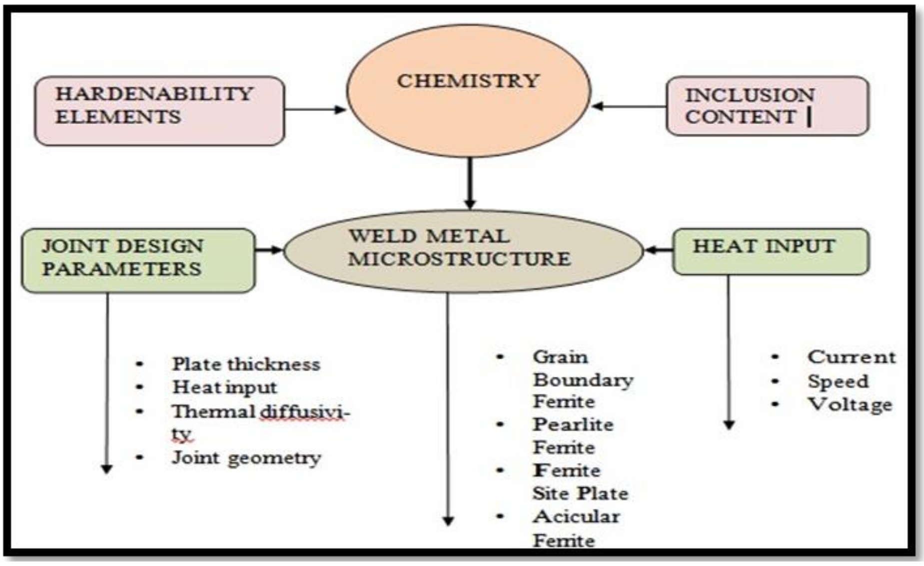


Fig. 2: Influences for determining the welding microstructure [1]

1.4 Filler Metal Selection

The following factors are considered for selection of filler materials and detailed study has been conducted

I. Yield strength, Tensile strength
II. Alloying elements and its contribution
III. Hydrogen-induced cracking
IV. Fracture toughness in HAZ
V. Cooling cycle requirement

1.5 Heat Input and Cooling Time

A study shows a cooling time $T_{8/5}$ =10 - 20 s increases toughness in the HAZ, when heat input during welding is considered in between 1.30 – 2.0 kJ/mm [5]

The calculation for $T_{8/5}$ (time) was:

$$T_{8/5}=(6700-5*T_0)*k*E*[(1/500-To)-(1/800-T_0)]*F_3$$

Reference: SFS-EN 1011-2

Where, the $T_{8/5}$-Cooling time between 800-500°C (s); T_0-Work temperature (°C),k-Thermal efficiency; E-welding energy; F_3-Coefficient depending on the type of joint in three-dimensional heat conduction

Heat input, E= (1*V*A*60)/(1000*T.S); Where, V - Voltage applied in the electrode (Volt), A – Current (Amps), T.S-travelling speed of electrode in mm/min

2. SCOPE OF THE RESEARCH

After an extensive literature analysis of different fabrication variables, the fabrication techniques have been formulated. To demonstrate the application techniques a practical has been performed considering the following variables,

- Welding Process- SMAW, SAW, GMAW
- Weld Joint configuration-Butt Joint- Single- "V" but welds joint and single-bevel butt welds

The heat input during welding was measured and well controlled by digital electronic controllers and equipment.

3. MATERIAL SELECTION

The S550Q is a high strength quenched and tempered steel which is selected according to the chemical and physical requirement of the project. As per EN 10025-6 table 5 and 6.

Table 2: Chemical and mechanical properties for S550Q

C	Mn	S	P	Si	Al	Cu	Cr
0.13	1.3	0.003	0.014	0.35	0.035	0.005	0.32
Ni	**Mo**	**Nb**	**Ti**	**V**	**B**	**N**	**Mo**
0.006	0.14	0.002	0.02	0.04	0.0020	0.004	0.14

	Impact @ -20 ℃	Yield Strength Ys (Mpa)	Tensile Strength Ys (Mpa)	Elongation (%)
Standard		≥530	568	17
Typical	160J	568	684	21

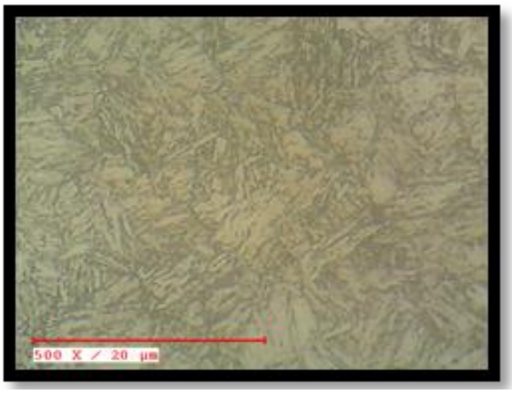
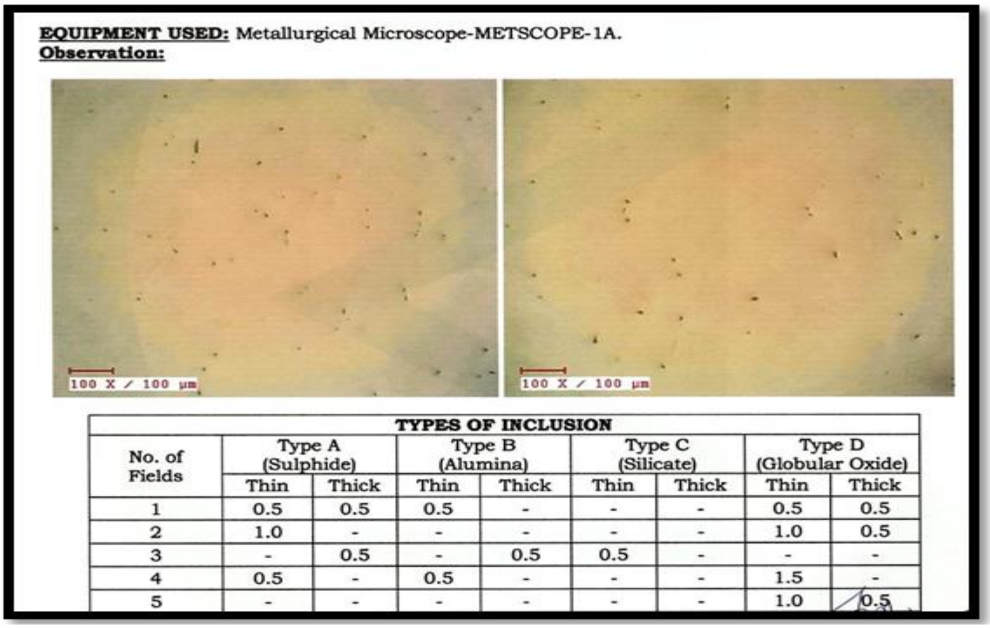


Fig. 3: Microstructure Analysis of base material-low carbon Martensitic structure



TYPES OF INCLUSION

No. of Fields	Type A (Sulphide)		Type B (Alumina)		Type C (Silicate)		Type D (Globular Oxide)	
	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
1	0.5	0.5	0.5	-	-	-	0.5	0.5
2	1.0	-	-	-	-	-	1.0	0.5
3	-	0.5	-	0.5	0.5	-	-	-
4	0.5	-	0.5	-	-	-	1.5	-
5	-	-	-	-	-	-	1.0	0.5

Fig. 4: Grain size and includes analysis of base material

Table 3: Through thickness-Z-test evaluation

	ID :01	ID :02	ID :03
Tensile strength in Mpa	800	820	815
Yield stress in Mpa	626	608	643
Elongation in gauge length ogf 5.65_{VA}	21%	22%	22%
Reduction in area	68%	67%	66%

4. FILLER MATERIAL PROPERTIES

The electrode selection is carried out as per standards from ASME BPVC SEC II C.

Table 4: Chemical composition and mechanical properties of SMAW filler material (E9018-G)

Typical analysis of all-weld metal (wt.-%)								
	C	Si	Mn	P	S	Mo	Ni	Cu
wt-%	0.06	0.30	1.25	≤ 0.01	≤ 0.01	0.40	0.95	≤ 0.08

Mechanical properties of all-weld metal					
Heat-treatment	Yield strength $R_{p0.2}$	Tensile strength R_m	Elongation A (L_0=5d_0)	Impact work ISO-V KV J	
	MPa	MPa	%	+20 °C	–40 °C
as welded	570	670	20	140	50
After SR	550	650	21	140	47

Table 5: Chemical and mechanical properties of SAW filler material F9P2EF3-F3

Typical analysis of the wire and of all-weld metal (wt.-%)							
	C	Si	Mn	Ni	Mo	P	S
Wire %	0.12	0.20	1.70	0.95	0.60	≤ 0.010	≤ 0.010
Weld metal	0.08	0.25	1.70	0.90	0.55	≤ 0.014	≤ 0.010

Mechanical properties of all-weld metal									
Heat-treat-ment	Tensile test				Impact work ISO-V CVN J (Average value from 3 test results)				
	Tensile test Temperature	Yield strength $R_{p0,2}$	Tensile strength R_m	Elongation A (L_0=5d_0)					
	°C	MPa	MPa	%	+20°C	0°C	-20°C	-40°C	-60°C
AW	+20°C (68°F)	≥ 560	≥680	≥ 22	≥140	≥120	≥100	≥70	≥47
SR	+20°C (68°F)	≥ 560	≥660	≥ 22	≥140			≥70	≥47

Table 6: Characteristics of SAW flux

Flux properties	
Grain size (EN ISO 14174)	3-20 (0.3 – 2.0 mm)
Polarity	DC+ ; AC
Re-drying conditions	350°C, min 2 hrs ; max 3 cycles
Moisture content (AWS A4.4M: 2001)	≤ 0.10% (as produced / re-dried)
Diffusible hydrogen (ISO 3690)	≤ 5 ml/ 100gm (as produced / re-dried)

Typical Composition of sub-arc welding flux (weight %)				
$SiO_2 + TiO_2$	CaO + MgO	Al_2O_3 + MnO	CaF_2	Basicity (Weight %)
15	32	20	28	2.5

Table 7: Chemical and mechanical properties of GMAW filler material- ER90S-G

Mechanical properties of all weld metal				
Tensile strength MPa	**Yield Strength MPa**		**Elongation (%)**	**Charpy V-Notch,J (ft.lbf) @-30°C**
Requirements - AWS ER90S-G	620 min	--	--	27 (20) min
(2)Typical results- As welded 100% CO2	644	547	24	51 (46)

Chemical composition, filler						
% C	**% Mn**	**% Si**	**% S**	**% P**	**% Cu (Total)**	
Typical results	0.07-0.12	1.60-2.10	0.50-0.80	0.025 max	0.025 max	0.10 max

5. JOINT GEOMETRIES AND PREPARATION

The below figure shows the edge preparation of the weld, groove configuration, and assembly considering welding distortion and other factors. Since it's a Q&T steel to maintain the hardness in weld groove preparation area during cutting we need to preheat before cutting. Hardness values are to be measured to ensure the same within the desirable limit.

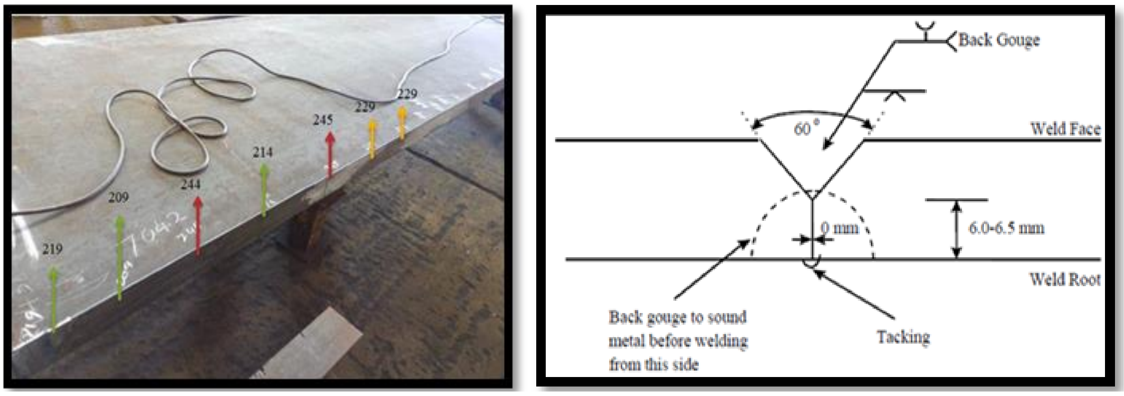


Fig. 5: Schematic representation of the joint preparation and hardness

Fig. 6: Test Setup for the welding process

Table 8: Key weld process variables

Process/ Run	Polarity	Current (Amps)	Wire Feed (mm/min)	Voltage (V)	Travel Speed (mm/min)	Heat Input (KJ/mm)	Stick out (mm)	Flux height (mm)	Feed angle (^{0})
SMAW-Root	DC+	85	N.A	24	79		N.A	N.A	N.A
SMAW-Fill Up	DC+	150	N.A	26	118		N.A	N.A	N.A
SAW-Root	DC+	540	540	28	620		25 to30	25 to30	90
SAW-Fill up	DC+	540	540	33	620		25 to30	25 to30	90

6. RESEARCH METHODS

For welding procedure qualification SFS-EN ISO 15164-1 and ASME SEC IX are taken as a reference standard. The following tests have been evaluated according to the described reference standard. CTOD tests have been performed to evaluate HAZ.

1. Standard procedure for Mechanical Testing is referred from ASTM A-370 document.
2. The destructive test is referred from ASTM E8.
3. The Notch impact test is referred from ASTM E23.
4. The Vickers hardness test is referred from ASTM E92.
5. The macro etch test is referred from ASTM E381.
6. The Ultrasonic test examination is referred from ASTM E164.
7. The Dye penetrant test examination is referred from ASTM E 165M.
8. The Radiographic test examination is referred from ASTM E 1032.
9. The Magnetic particle test examination is referred from ASTM E 1444.
10. CTOD examination is referred from BS7448-2
11. Hydrogen Induced cracking referred from NACE TM-0284

6.1 Non-Destructive Examination of welded joints

The following NDE examinations are carried out as per reference standards and found satisfactory. Surface NDE 1.Visual Examination 2. The Magnetic particle test examination 3.Dye penetrant test examination and Subsurface NDE 1. Ultrasonic examination 2. Radiographic examination

6.2 Mechanical examinations of welded joints

6.2.1 Tensile tests: The weld samples were subjected to the tensile test. Tests were conducted at NABL accredited laboratory. For each type, we have taken two samples and the average result is listed below

6.2.2 Bend Test: Bend tests are carried out as per reference standard before and after SR found satisfactory

6.2.3 Impact tests: Results of the toughness tests @-20^{0}c are found satisfactory in all the stages.

Table 9: Results of the tensile test

Sample identification	Welding Process	Stress Relieving	Yield strength (Mpa)	Tensile strength (Mpa)	Elongation in GL of 5.65vA
1-BaseMetal-40mm thickness	N.A	Without	583	710	33%
2-Base Metal-90mm thickness	N.A	Without	571	697	31%
3-Base Metal-40mm thickness	N.A	With	571	697	31%
4-Base Metal-90mm thickness	N.A	With	570	678	30%
5-Weld Metal-40mm thickness	SMAW	With	581	699	N.A
6-Weld Metal-40mm thickness	SMAW	Without	610	700	N.A
7-Weld Metal-40mm thickness	SAW	With	572	695	N.A
8-Weld Metal-40mm thickness	SAW	Without	598	704	N.A
9-Weld Metal-40mm thickness	GMAW	With	567	687	N.A
10-Weld Metal-40mm thickness	GMAW	Without	587	697	N.A

Table 10: Results of toughness tests

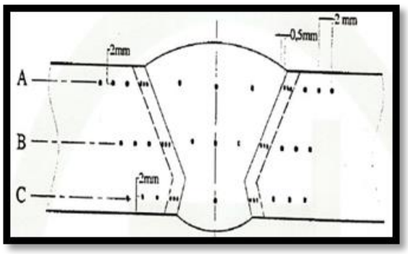
Sample identification	Stress Relieving	Weld-1.5mm from the top surface	HAZ-1.5mm from the top surface	Weld-1/4T to 1/2T from the top surface	HAZ--1/4T to 1/2T from the top surface	Weld-Centre of the test plate	HAZ-Centre of the test plate	Weld-1/4T to 1/2T from the bottom surface	HAZ--1/4T to 1/2T from the bottom surface
1-Base Metal-40mm thickness	Without	220,232,248							
2-Base Metal-90mm thickness	Without	240,222,238							
SMAW -40mm thickness	With	102,92,76	220,234,222	92,94,88	200,198,204	104,108,90	200,198,204	90,112,114	242,216,214
SMAW-40mm thickness	Without	114, 100, 148	234,234,254	80,100, 92	192,224,208	80,110, 70	184,196,212	88,86, 70	192, 198, 220
SAW-40mm thickness	With	110, 130, 112	90,114, 102	160,190,162	238,202,210	160,156,162	238,240,222	156,162,144	188, 204, 204
SAW-40mm thickness	Without	122, 110,96	98,114, 106	150,186,176	76,88,78	110,112,108	96,98,74	98,96, 68	150, 156, 166

**All values are in joules*

6.3 Metallographic examinations of the welded joints

The macro graphics and micrographic examinations were performed on those samples.

Fig. 7: Typical microstructures of individual zones of but weld



	A	B	C
Base Metal	193,196,195,193,195,195	197,192,194,195,193,192	197,192,194,195,193,198
HAZ	208,213,211,207,212,213	207,205,209,205,210,207	210,203,206,210,203,202
Weld Metal	257,254,253	256,253,253	258,253,251

Fig. 8: Hardness analysis of the but weld sample (Unit in HV 10Kg)

6.4 CTOD Testing of Weld sample

CTOD testing of weld sample was performed with Reference specification: BS 7448-1991 Part 2 and found satisfactory

Geometry	Bend		
Crack Plane Orientation	Weld Centre		
Test Temperature	-10 °C		
Requirement	0.25mm Min		
	ID No.01	**ID No.02**	**ID No.03**
T*W*Notch Length mm	16.0*32.0*12.0	16.03*32.05*12.00	16.02*32.02*12.00
No of Cycles	236606.00	131971.00	93909.00
Final Crack Length mm	15.90	16.61	16.54
CTOD Value mm	0.76	0.58	0.75
Average CTOD mm	0.70		

6.5 Hydrogen Induced Cracking

Hydrogen-induced Cracking (HIC) of weld sample was performed with reference specification as per NACE TM-0284-2003, using solution 'A' found satisfactory

7. CONCLUSION

In this project, we carried out the detailed examination of Welded EN10025-2 S550Q. After the thorough examination of the most significant properties of both weld metal and base metal, the obtained results show its weldability, selection of the optimum combination of the filler materials, welding procedure specification, Etc.,

Since the literature in this area does not contain an plenty of papers, we consider that our work is an attempt to create the necessary welding procedure specification for EN10025-2 S550Q-Quenched and tempered steel for higher thickness welded structures.

8. ACKNOWLEDGMENT

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9. REFERENCES

[1] Basu, B. Raman, R. Microstructural Variations in a High-Strength Structural Steel Weld under Isoheat Input Conditions. Welding Journal, pp. 239- 248.2002.
[2] Porter, D. Development in hot-rolled high-strength steel. Nordic welding conference 06, New trends in welding technology, Tampere, Finland. 2006.
[3] Pisarski, H.G. Dolby, R.E. The significance of softened HAZs in high strength structural steels. Welding in the World, vol. 47, no 5/6, pp. 32-40. 2003.
[4] Umekuni, A. Masubuchi, K. Usefulness of under matched Welds for High-Strength Steels. Welding Journal, vol. 76, No 7, pp. 256-263. 1997.
[5] Wang, J. Li, Y. Liu, P. Effect of weld heat input on toughness and structure of HAZ of a new super-HSS, Material Science, Vol 26, No 3, pp 301-305. 2003.
[6] Magudeeswaran, G. Balasubramanian, V. Madhusudhan Reddy, G.Balasubramanian, T.S. Effect of Welding Processes and Consumables on Tensile and Impact Properties of High Strength Quenched and Tempered Steel Joints. Journal of Iron and Steel Research, International, 15, pp. 87-94. 2008.
[7] Shi, Y. Han, Z. Effect of weld thermal cycle on microstructure and fracture toughness of simulated heat-affected zone for an 800 MPa grade HSS. Journal of materials processing technology 207, pp. 30-39. 2008.

APPENDIX

Steel manufacturers recommendations:

1. High strength quenched and tempered fine-grained steel-aldur-Voestalpine
2. High strength quenched and tempered fine-grained steel-ThyssenKrupp steel-N-A-XTRA
3. Welding-Bisplate
4. High strength fine-grained structural steel –DILLIMAX-DILLINGER