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Abstract

This paper details the influence of the welding parameters of submerged arc welding in the hardness of welded joint of S235JR construction steel. The planned experiment work is conducted in the semiautomatic submerged arc welding machine and the contribution of each factor has been considering, such as: (intensity, voltage, trolley welding speed, diameter of the wire, wire speed, cooling speed of the welded joint, OK Flux 1071, chemical properties of material and wire). The results of the present investigation indicate that the welding voltage, current intensity and environment of cooling of the welded joint are the most significant factors that controls the hardness of bead. Optimal results were obtained by using the tension of 37 V, intensity of 350 A at a trolley speed of 6.0 mm/s and wire diameter 2.4 mm.

Keywords: S235 Steel, Submerged Arc Welding, Welding Parameters, Weld bead, Hardness.

1 Introduction

Mechanical properties and reliability of weld joint were subject of different authors [1, 2, 3, 4]. The energy is devoted also on effect of microdefects under cyclic load of weld joint [5] and in optimization of weldbead geometrical parameters during Submerged Arc Welding (SAW) [6] where is revealed that SAW largely depend upon the weld bead geometrical parameters such as weld width, depth of penetration and reinforcement height. Prediction of SAW process parameters is a very complex process. Many investigators have tried to correlate the process parameters with the weld bead which geometrical shape characteristics result into high strength and high quality welds [6]. In recent years, research and development efforts have focused on refining SAW techniques to meet the evolving demands of industries such as shipbuilding, construction, and heavy manufacturing. This review explores the advancements in SAW technology, including innovations in flux formulations, automation, and adaptive control systems, aiming to enhance weld quality, productivity, and overall process efficiency.

Furthermore, the article delves into the current applications of SAW, ranging from the fabrication of structural components to the manufacturing of pressure vessels and pipelines. Through a critical analysis of existing literature and case studies, this review aims to provide insights into the performance, challenges, and potential solutions associated with submerged arc welding.

As we navigate the intricacies of SAW, this article not only serves as a comprehensive resource for welding professionals, researchers, and academicians but also sets the stage for envisioning the future prospects of this indispensable welding technology. In an era of rapid technological evolution, understanding and advancing SAW capabilities hold the key to unlocking new frontiers in welding excellence and industrial progress.

This paper presents the details of an experimental work on S235JR steel (10mm thickness) using SAW process to yield desired quality of bead, in terms of beads geometry and hardness, as influenced by voltage (V), current(A), welding speed and diameter of wire which are varied at four different levels. Our aim of this investigation is that through measurements we have done to alleviate and propose different manufacturers which use S235JR steel as base material, proper selection of welding parameters depending on the level of strength that they want to reach or level of strength that they are required.

2 Materials and methods

Submerged arc welding (SAW) was used as welding process to prepare our testing specimens. SAW is normally operated in the automatic or mechanized mode, however, semi-automatic (hand-held) SAW guns with pressurized or gravity flux feed delivery are available. The process is normally limited to the flat or horizontal-fillet welding positions (although horizontal groove position welds have been done with a special arrangement to support the flux). Deposition rates approaching 45 kg/h (100 lb/h) have been reported this compares to ~5 kg/h (10 lb/h) (max) for shielded metal arc welding. Although currents ranging from 300 to 2000 A are commonly utilized, currents of up to 5000 A have also been used (multiple arcs). Single or multiple (2 to 5) electrode wire variations of the process exist. SAW strip-cladding utilizes a flat strip electrode (e.g. 60 mm wide x 0.5 mm thick). DC or AC power can be used, and combinations of DC and AC are common on multiple electrode systems. Constant voltage welding power supplies are most commonly used; however, constant current systems in combination with a voltage sensing wire-feeder are available [7]. SAW filler material usually is a standard wire as well as other special forms. This wire normally has a thickness of 1.6 mm to 6 mm (1/16 in. to 1/4 in.). In certain circumstances, twisted wire can be used to give the arc an oscillating movement. This helps fuse the toe of the weld to the base metal. The electrode composition depends upon the material being welded. Alloying elements may be added in the electrodes. Electrodes are available to weld mild steels, high carbon steels, low and special alloy steels, stainless steel and some of the nonferrous of copper and nickel. Electrodes are generally copper coated to prevent rusting and to increase their electrical conductivity. Electrodes are available in straight lengths and coils. Their diameters may be 1.6, 2.0, 2.4, 3, 4.0, 4.8, and 6.4 mm. The approximate value of currents to weld with 1.6, 3.2 and 6.4 mm diameter electrodes are 150–350, 250–800 and 650–1350 Amps respectively [8]. On figure below is shown submerged arc welding machine.

Fig 1. *a) submerged arc welding machine*
b) wire and OK Flux 1071 [7].

2.1 Base material, welding parameters, wire and dimensions of PLATE 5

Dimensions of plate P1, P2, P3, P4, P5 are described on table 1, while welding parameters are given on table 2.

Table 1. Dimensions of plate

Plate	*Thickness [mm]*	*Width [mm]*	*Length [mm]*
P1	10	80	320
P2	10	80	320
P3	10	80	320
P4	10	80	320
P5	10	80	320

Table 2. Welding parameters for each welding seam

Seam nr.	I [A]	U [V]	dw [mm]	t [s]	vw [mm/s]	vt [mm/s]
T5.1	400	42	2.4	50	6.0	6.0
T5.2	270	28	2.4	66.6	4.0	4.5
T5.3	310	32	2.4	60	5.3	5.0
T5.4	350	37	2.4	50	5.5	6.0

I- intesity, **U-** tension, **d_w** – diameter of wire, **t-** time of weld for a seam, ***v_w****- speed of wire flow,* ***v_t****-speed of troley* .

On the table 3 and table 4 are given chemical properties of S235JR steel and chemical properties of wire SW-702Si [8] which we have used during welding of plates .

Table 3. Chemical properties of S235JR steel

Steel	C max. %			Mn max. %	Si max. %	P max. %	S max. %	N max. %	Cu max. %	Other max. %	CEV max. %		
	Nominal thickness mm										Nominal thickness mm		
	≤16	>16 ≤40	>40								≤30	>30 ≤40	>40 ≤125
S235JR	0,17	0,17	0,20	1,40	-	0.040	0,040	0,012	0,55	-	0,35	0,35	0,38

Table 4. Chemical properties of wire(wire SW-702Si)

C	Si	Mn
0.08	0.20	1.00

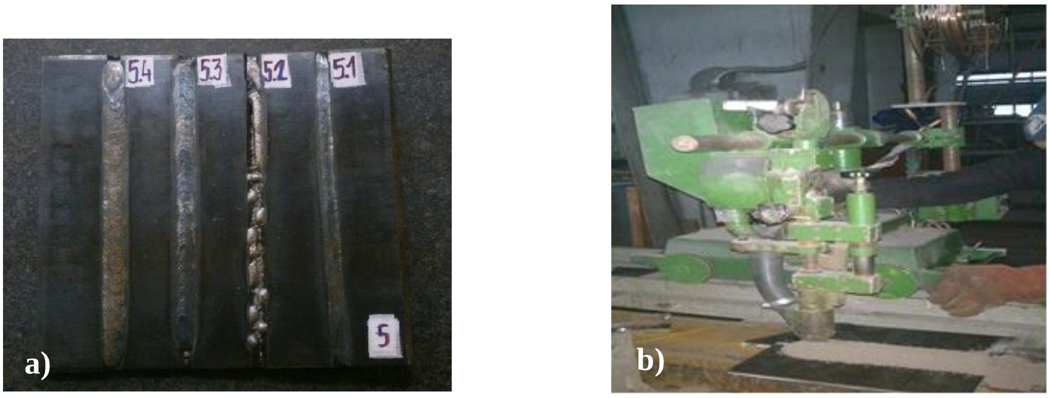

Fig 2. a) plate number 5 and it's welding seam with reference number 5.1, 5.2, 5.3 and 5.4

b) moments during welding of plate 5.

2.2 Measure device HARTIP 3000 Portable Metal Hardness Tester

The HARTIP 3000 device emerges as a groundbreaking solution in the realm of portable metal hardness testing, embodying a fusion of cutting-edge technology and user-friendly design. Crafted to meet the demanding needs of industries where accuracy and mobility are paramount, this device redefines the landscape of metal hardness assessment. Compact and portable, the HARTIP 3000 brings laboratory-grade precision directly to the field, allowing for on-the-spot hardness testing of diverse metallic surfaces [9]. Designed for ease of use, its intuitive interface ensures that both seasoned professionals and novices alike can obtain accurate and reliable hardness measurements effortlessly. Equipped with advanced features, including a high-resolution LCD display and a range of selectable impact devices, the HARTIP 3000 caters to a broad spectrum of applications across industries such as manufacturing, construction, and quality control. This portable metal hardness tester promises not only efficiency in operation but also versatility in accommodating various testing scenarios and material types.

In this era of heightened quality standards and stringent specifications, the HARTIP 3000 stands as a beacon of innovation, offering a robust solution for precise, on-the-go metal hardness assessment. As we delve into the features and capabilities of this cutting-edge device, a new standard for portable hardness testing unfolds, promising to elevate the efficiency and accuracy of hardness measurements across diverse industrial landscapes.

The HARTIP 3000 Portable Metal Hardness Tester which is shown on figure 3.

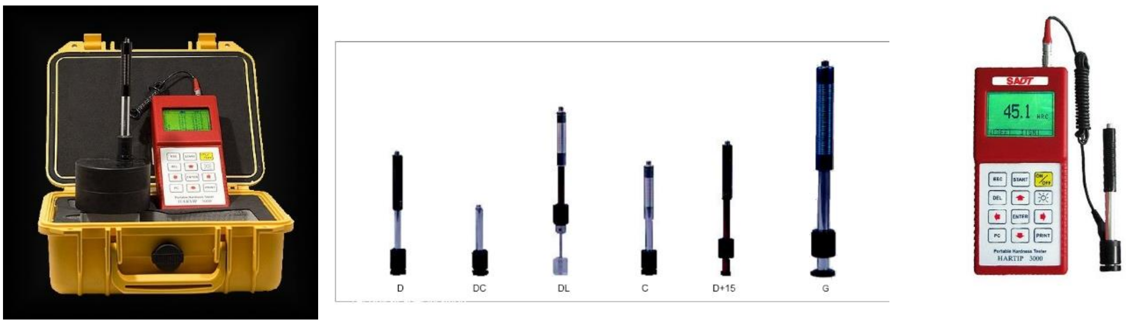

Fig 3. Measurement device HARTIP 3000 Portable Metal Hardness Tester

3 Results and discussion

3.1 Measument of value of hardness welding seam nr. 5.1 of plate 5

Weld parameters (I= 400 A, U= 42V , d_w = 2.4 mm, ν_w = 6.0 mm/s , ν_t = 6.0 mm/s) earn (overheight h= 0.417mm**,** width b= 12.128mm).

Table 5. Value of hardness data (LDL- Leeb hardness value used with impact device DL, HV- Vicker hardness value, HB- Brinell hardness value, HRB- Rockwell B hardness value, HRC- Rockwell C hardness value, HSD – Shore hardness value)

Nr.	LDL	HV	HB	HRB
1.	593	104	103	58.9
2.	623	130	128	72.8
3.	607	115	114	66.0
4.	624	131	129	73.2
5.	642	148	146	79.6
6.	600	109	109	62.6
7.	630	136	135	75.5
8.	604	113	112	64.5
9.	610	118	117	67.3
$V_{averege}$	615	122	121	69.5
10.	651	157	155	82.4
11.	576	91	91	48.6
12.	598	108	107	61.5
13.	603	112	111	64.0
14.	588	100	99	56.1
15.	623	130	128	72.8
16.	630	136	135	75.5
17.	630	136	135	75.5
18.	612	120	119	68.2
$V_{average}$	612	120	119	68.2
19.	626	133	131	74.0
20.	627	133	132	74.4
21.	629	135	134	75.1

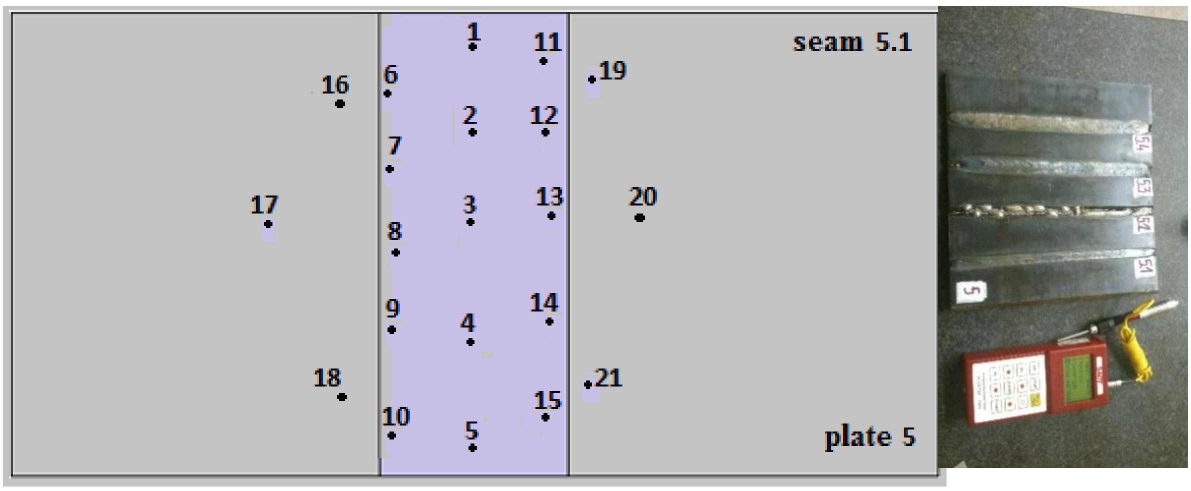

Fig 4. Data point of measurments of the welding seam 5.1 at plate 5.

3.2 Measument of value of hardness welding seam nr. 5.3 of plate 5

Weld parameters (I = 310 A, U = 32 V , d_w = 2.4 mm, v_w = 5.3 mm/s , v_t = 5.0 mm/s) earn (overheight h=0.55 mm, width b=20.05mm)

Table 6. Value of hardness data (LDL- Leeb hardness value used with impact device DL, HV- Vicker hardness value, HB- Brinell hardness value, HRB- Rockwell B hardness value, HRC- Rockwell C hardness value, HSD – Shore hardness value)

Nr.	LDL	HV	HB	HRB
1.	659	166	163	84.8
2.	648	154	152	81.5
3.	628	134	133	74.7
4.	648	154	152	81.5
5.	674	128	179	88.7
6.	606	114	114	65.5
7.	609	117	116	66.9
8.	631	137	136	75.8
9.	618	125	124	70.8
$V_{average}$	636	142	141	77.6
10.	620	127	126	71.6
11.	610	118	117	67.3
12.	626	133	131	74.0
13.	646	152	150	80.9
14.	615	122	121	69.5
15.	631	137	136	75.8
16.	627	133	132	74.4
17.	632	138	137	76.2
18.	638	144	142	78.3
$V_{average}$	627	133	132	74.4
19.	623	130	128	72.8
20.	635	141	140	77.3
21.	641	147	145	79.3

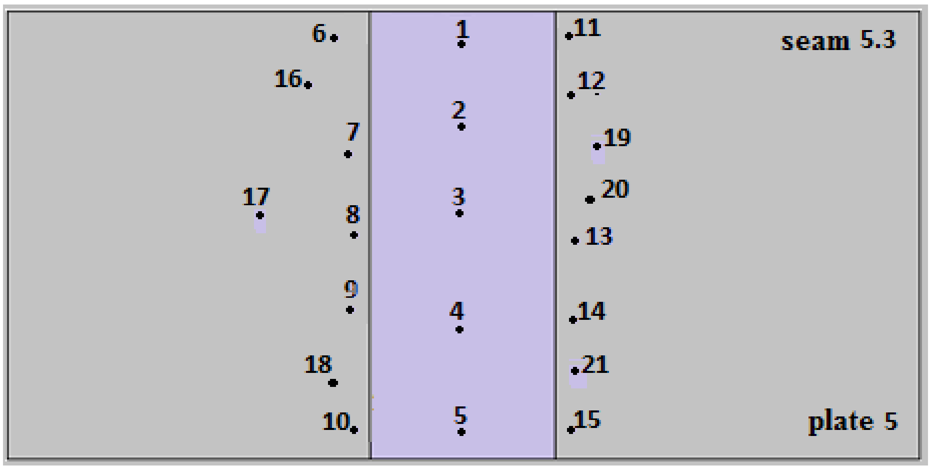

Fig 5. Data point of measurments of the welding seam 5.3 at plate 5.

3.3 Measument of value of hardness welding seam nr. 5.4 of plate 5

Weld parameters (I = 350 A, U = 37 V , d_w = 2.4 mm, v_w = 5.5 mm/s , v_t = 6.0 mm/s) earn (overheight h=0.822mm, width b=21.132mm)

Table 7. Value of hardness data (LDL- Leeb hardness value used with impact device DL, HV- Vicker hardness value, HB- Brinell hardness value, HRB- Rockwell B hardness value, HRC- Rockwell C hardness value, HSD – Shore hardness value)

Nr.	LDL	HV	HB	HRB
1.	634	140	139	76.9
2.	627	133	132	74.4
3.	603	112	111	64.0
4.	607	115	114	66.0
5.	656	162	160	83.9
6.	617	124	123	70.4
7.	589	110	100	56.7
8.	621	128	127	72.0
9.	579	93	93	50.6
$V_{average}$	615	121	121	69.5
10.	610	118	117	67.3
11.	604	113	112	64.5
12.	609	117	116	66.9
13.	614	121	120	69.1
14.	619	126	125	71.2
15.	610	118	117	67.3
16.	605	114	113	65.0
17.	607	115	114	66.0
18.	613	121	120	68.7
$V_{average}$	610	118	117	67.3
19.	610	118	117	67.3
20.	605	114	113	65.0
21.	618	125	124	70.8

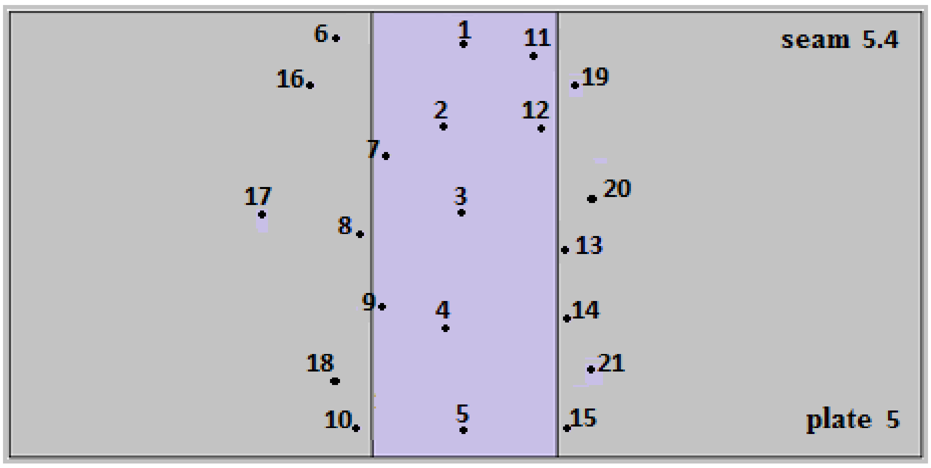

Fig 6. Data point of measurments of the welding seam 5.4 at plate 5.

3.4 Measument of value of hardness welding seam nr. 5.2 of plate 5

Weld parameters (I = 270A, U = 28V , d_w = 2.4 mm, ν_w = 4.0 mm/s , ν_t = 4.5 mm/s)

Table 8. Value of hardness data (LDL- Leeb hardness value used with impact device DL, HV- Vicker hardness value, HB- Brinell hardness value, HRB- Rockwell B hardness value, HRC- Rockwell C hardness value, HSD – Shore hardness value)

Nr.	LDL	HV	HB	HRB	HRC	HSD
1.	674	182	179	88.7	-	-
2.	638	144	142	78.3	-	-
3.	704	217	213	95.6	-	31.4
4.	628	134	133	74.7	-	-
5.	728	248	243	-	22.5	35.9
6.	681	190	187	90.5	-	-
7.	604	113	112	64.5	-	-
8.	648	154	152	81.5	-	-
9.	622	129	128	72.4	-	-
$V_{average}$	659	166	163	84.8	-	-
10.	616	123	122	70.0	-	-
11.	633	139	138	76.6	-	-
12.	630	136	135	75.5	-	-

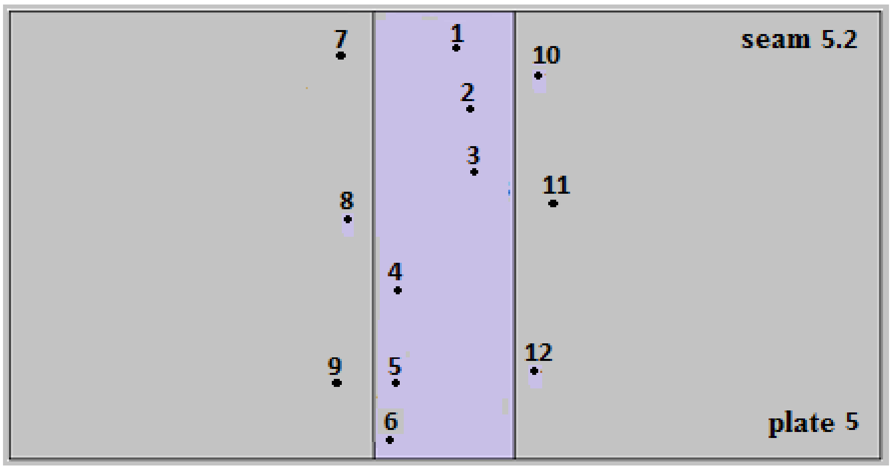

Fig 7. Data point of measurments of the welding seam 5.2 at plate 5

The data of the hardness collected by using divice HARTIP 3000 Portable Metal Hardness Tester (divice which is disigned to measure hardness of metals) were done in accordance with standard EN 1043-1:1996 for hardness testing of metallic materials *[10]* and to disign the graphs and diagrams Excel was used.

Comparison of hardness value according to Vickers (HV), Brinell (HB) and Rockwell B (HRB) were presented on the next subchapter were for three different hardness number were prepared separated diagrams in order to have better visualization and clear comparison.

3.5 Comperison of hardness value of the welding seam 5.1, 5.2, 5.3 and 5.4 at plate 5

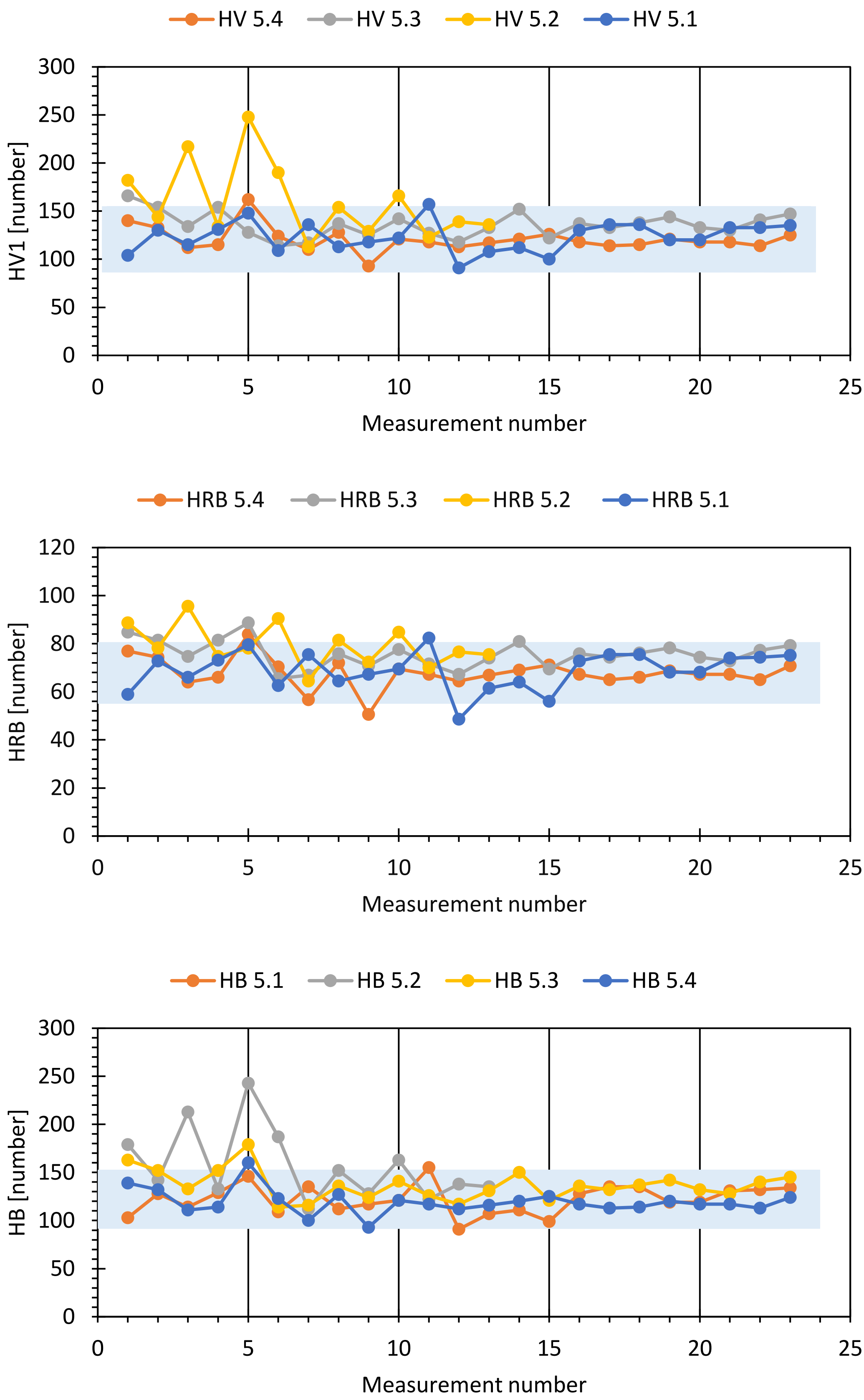

Fig 8. Comparison of hardness value according to Vickers (HV), Brinell (HB) and Rockwell B (HRB) of the welding seam 5.1, 5.2, 5.3 and 5.4 at plate 5

4 Conclusion

Based on the value of the hardness the following conclusion could be drawn from the above investigation :

- optimal welding parameters applied on the S235JR steel are on the 5.4 seam welding with these values (intensity I=350 A, tension U=37 V, speed of the wire v_w =5.5 mm/s, diameter of the wire d_w =2.4 mm, speed of the troley v_t=6.0 mm/s),
- parameters of the welding applied at welding bead 5.4 give uniform distribution of the value of hardness between the point of measurements.
- Welding bead is characterized also by a smooth surface and stable arc.
- Welding beads 5.1, 5.2 and 5.3 are characterized with a great difference in some of point of measurements, surface of the welding bead is not smooth and is characterized by hills and valleys, and sometimes the arc is unstable.

Therefore we suggest to all manufactures which use the S235JR steel to apply the same parameters of welding which we applied at welding seam 5.4 in order to achieve an uniform hardness.

5 References

[1] Smaili F.,Sylaj A., Berisha B., Gjelaj A., Beqiri D., "Static Analysis of Welded Bead of Street Lighting Construction," *UBT Knowledge Center,* p. 14, 2022.

[2] Smaili, F., Vuherer, T., Ibishi, H., & Gjelaj, A., "Heat affected zone microstructure of weld joint preparation in artificial manner," *UBT International Conference,* p. 144, 2019.

[3] B. Bytyçi, Saldim I dhe II, Prishtine: Universiteti i Prishtinës –Fakulteti i Inxhinierisë Mekanike Prishtinë, 2002.

[4] Smoljan, B., Iljkić, D. , "Predictions of mechanical properties of quenched and tempered steel," *Strojniški vestnik - Journal of Mechanical Engineering,* vol. 56, no. 2, pp. 115-120, 2010.

[5] Smaili F., Influence of microdefect on fatigue properties in weld fine grain heat affected zone on nickel molybdenum alloy steel : doctoral dissertation, Maribor: University of Maribor, 2023.

[6] Sharma M., Kahn M.I., Optimization of weldbead geometrical parameters for bead on plate submerged arc welds deposited on IS-2062 steel using Taguchi method, Lucknow: Integral University, 2012.

[7] ESAB, "ESAB OK Flux 10.71," [Online]. Available: https://esab.com/us/nam_en/products-solutions/product/filler-metals/low-alloy/subarc-saw/ok-flux-10-71/. [Accessed 2023 11 26].

[8] Magmaweld, "Magmaweld," [Online]. Available: https://www.magmaweld.com/sw-702si-uo. [Accessed 2023 11 26].

[9] HARTIP 3000 Portable Metal Hardness Tester, [Online]. Available: https://www.bulutmak.net/hartip-3000.html.

[10] EN 1043-1:1996, *Destructive tests on welds in metallic materials. Hardness testing. Hardness test on arc welded joints,* Brussels: European Committee for Standardization, 1996.

[11] EN 12534:1999. , *Welding consumables - Wire electrodes, wires, rods and deposits for gas shielded metal arc welding of high strength steels – Classification,* Brussels: European Committee for Standardization, 1999.