Research Article

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Feasibility study of welding dissimilar Advanced and Ultra High Strength Steels

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Abstract: This study concerns the weldability of dissimilar Ultra high-strength steel (UHSS) and advanced high-strength steel (AHSS), which is used in the modern machine industry. The materials offered superior strength as well as relatively low weight, which reduces microstructure contamination during a live cycle. The choice of the welding process base of the base material (BM) and welding parameters is essential to improve the weld joint quality. S700MC/S960QC was welded using a gas metal arc welding (GMAW) process and overmatched filler wire, which was performed using three heat input (7, 10, and 15 kJ/cm). The weld samples were characterized by a Vickers-hardness test, scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS). The test reveals a decrease of softening areas in the HAZ and the formation of the stable formation of Bainite-Ferrite for S700MC and Bainite-martensite for S960QC when the heat input of 10 kJ/cm is used. It is recommended to use the GMAW process and Laser welding (Laser beam-MIG), with an optimal welding parameter, which will be achieved a high quality of manufacturing products.

Keywords: UHSS, AHSS, welding processes, welding parameters, dissimilar weld joint, welding quality

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1 Introduction

Nowadays, many industrial enterprises are starting to make greater use of high strength materials in the manufacturing of their products. A significant factor in driving the utilization of high strength materials is environmental concerns. The higher strength of such materials enables products of lower weight, for example, lighter automotive vehicle bodies and maritime vessel hulls. According to the energy conservation law, the lower body weight decreases the required kinetic energy transformed from the chemical energy of the burning of the fossil fuels used in the operation of such machines, therefore decreasing emissions of carbon dioxide [1–3]. Ultra-high strength steel is one of the groups of high strength materials suitable for machine manufacturing industries. Such steels are used in many different sectors like light cranes manufacturing, construction machines manufacturing, the automotive and vehicle industry, trucks, and vehicles, locomotive bodies, pipelines, ships, and other maritime vessels, aircraft, lightweight constructions, offshore constructions and highly loaded welded structures [4]. The global industry nowadays needs steel with low weight high-strength, which will increase their strength and their metallurgical properties. UHSS/AHSS was developed to be able to solve that problem and increase the quality of manufacturing products [5, 6].

In the literature, several different definitions have been presented for UHSS from the perspective of material strength:

1. The yield strength of the material is over 560 MPa;
2. The tensile strength of the material is over 700 MPa;
3. The yield strength of the material is 900 MPa and above;
4. The tensile strength of UHSS is up to 1700 MPa, especially for the martensitic steels [7–10].

Different definitions of UHSS exist, firstly, because of the novelty and rapid development of UHSS and, secondly, because of various researchers using different standards in different countries or industries. The term UHSS refers to the group of steel materials that have ultra-high-

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strength, but the point at which material strength becomes ‘ultra-high’ is still under discussion in both industry and the research community. One standard definition defines steels with 210 to 550 MPa yield strength as “high strength steel” and other stronger types of steels as advanced high strength steel (AHSS). The term UHSS is then used for AHSS with tensile strengths exceeding 780 MPa. The AHSS is situated between HSS and UHSS, which differed with them by their allow element composition and the production process.

The ultra-high-strength of UHSS is generated by the carefully defined chemical composition and the manufacturing methods used. The ultra-high-strength of the steels is achieved by employing precisely controlled amounts of common alloying elements like C, Mn, Si, Ni, Cr, and Mo and micro-alloying elements like Nb, Ti, V, B together with underlying metallurgical strengthening mechanisms. Such strengthening mechanisms are precipitation hardening, grain refinement, solid solution hardening, dislocation hardening, and transformation hardening. Usually, transformation hardening is the principal strengthening mechanism employed in manufacturing UHSS/AHSS in steel plant processes.

One area of interest is the so-called “third-generation steels” to link the gap of strength-elongation balance (both global and local) between conventional and UHS/AHS steels and austenitic-based steels. Other research concentrates on increasing processing methods for already-developed UHSS/AHSS materials. Many researchers see occasions for emerging new approaches to generate and form these brand-new steels, such as introduction heating procedures and advanced cooling techniques [6, 11–13]. In the research, some results were carried out in the prevention of carbide precipitation by investigated the optimal quenching temperature in the exceptional steel products such as sheet steel [14, 15]. On the product manufacturing side, stamping and cooling operations are being examined, as well as joining strategies and models for formability. The mechanical properties of base materials are also needed to well know, because of their implications in the formability and corrosion resistance.

The main problems encountered in the welding of UHSS/AHSS materials are softening and cracking. Figure 1 below shows the position of the UHSS and AHSS according to the ratio tensile strength and elongation. For the AHSS grade, the researchers evaluated the increase of the tensile strength, which reduced his elongation %. Idem for the UHSS that has an issue with the increase of the strength. The issues that those are faced now are to improve the mechanical properties of their weld joints, improve the weldability.

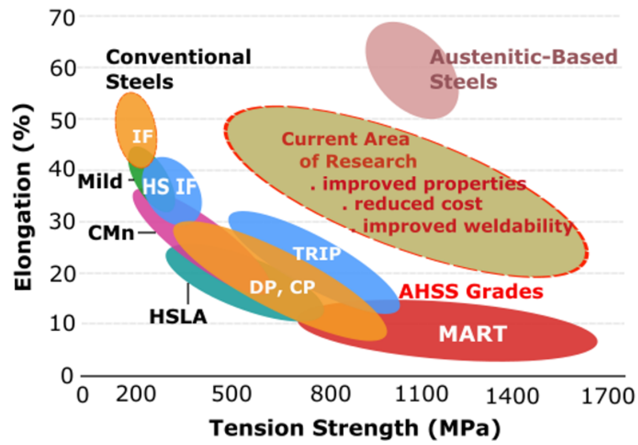

Figure 1: Strength distribution of different types of steels and the zone of the third generation of steels, an object of the current area of research [4, 7, 16].

The studies were conducted on the effect of welding parameters on the mechanical properties and microstructure formation of AHSS/UHSS steels. Their results were showing the implication of the welding parameters such as heat input, filler wire composition [16–18]. The research was also based on the effect of alloy element compositions, which has an effect on the strength of the weld joint [19–22]. The welding process, such as GMAW, Laser beam, Submerged arc welding, or Tungsten inert gas, has a standard parameter that influences the weld quality. The heat source data [12]. The weldability of UHSS/AHSS will depend on the welding parameter, which has an impact on their properties.

This paper aims to improve the weldability of dissimilar UHSS/AHSS. The study was evaluated the different UHSS/AHSS bases of the metallurgical production process and the chemical composition. The experimental method base of a Vickers-hardness test, the microstructure identification (SEM micrograph), and alloy element analysis (EDS X-ray mapping) on the HAZ were performed. The recommendation on the optimal welding process was set up to improve the strength and the microstructure formation on the weld joint.

2 Method and materials used to weld Category of UHSS/AHSS, Methods, and materials

The welding of UHSS and AHSS can be done base on many parameters such as the heat input parameters, the base material chemical characteristics and mechanical properties, filler wire characteristics for some welding process. By analyzing the differences between UHSS and AHSS will be set up according to their manufacturing, mechanical properties, and chemical composition. The improvement of the weld quality of UHSS/AHSS welded also depend on the mechanical properties and microstructure behavior were investigated. Knowing the mechanical properties of the base materials, the control of the welding process will lead to optimizing the strength of the weld joint by the reduction softening on the HAZ.

The classification of different UHSS/AHSS steels can be based on the Thermo metallurgical production process. The Transformation Induced Plasticity steel (TRIP), which is the formation of ferrite (F), Martensite (M), Bainite (B), and some retained of austenite (RA) at the end of the transformation. Figure 1a below shows the microstructure of TRIP- steel, which, when his temperature increases, the cooling process can be the result of more Ferrite causing at the end of the transformation, the formation of more carbide [20, 23]. The twinning induced plasticity steel (TWIP) is a steel that has a large amount of manganese (Mn) content. This alloy element has the particularity to increase the strength at the high temperature, causing a crack propagation in the HAZ of the weld joint. In TWIP-steel, the microstructure is based on his high amount of martensite and ferrite. The development of this amount causes some soft ferrite matrix (Figure 1b). It is also observed a hard bloc of martensite on the austenite grain. Figure 1c shows the microstructure of Dual phases (DP) steel. The composition of DP-steel is the base of ferrite and martensite formation.

The formation of hard martensite increases the strength of the material. The excellent ductility of the material is giving by the formation of the ferrite matrix. This type of UHSS can be hot or cold -formed and have a high hardening behavior, which should be carefully controlled to produce Ferritic-martensitic structure from the austenite grain.

Figure 1d below illustrates the microstructure of CP-steel. In the microstructure, the formation of granular bainite ferrite (GBF), and Martensite in the austenite grain are observed. His complexity is caused by the extreme refinement grain that created the retarded a precipitation of micro-alloy elements like Titanium (Ti) and Niobium (Nb). It has a high energy absorption, high residual stress, and excellent thermal expansion. Martensitic steel (MS) is is illustrated in Figure 1e. The formation of tempered martensite gives the ultra-strength to the material. The composition of more tempered martensite is found in the austenite grain, which gave an ultra-strength in the material. Depending on the thermal process, it can be found some trace of ferrite and bainite in the microstructure. UHSS and AHSS can exist as Ferrite-Bainite steel (FB), which can be described as fine ferrite matric and fine second phase bainite. The bainite-ferrite (FB) steel is the composition of Bainite- ferrite formation in his microstructure.

Base on the description of the production of UHSS and AHSS, the welding dissimilar AHSS of S700MC with UHSS of S960QC was done. The welding was carried out using an overmatched filler wire in order to evaluate the influence of heat input in the softening area of the HAZ. The experiments were performed using the GMAW process, which followed by the microstructure formation at the starting Bainite and Martensite formation using SEM and EDS-X ray spectroscopy mapping. The mechanical tests were performed using Vickers-hardness tests and tensile tests. Table 1 below presents the chemical and mechanical properties of the materials used in this analysis. The welded specimens were welded with dimensions of 300 × 200 × 8 mm^2 using V-groove butt joint, 60° of angle, and 2 mm of a gap. The samples were welded using the overmatched filler wire with 1 mm of diameter. Table 2 below shows the welding parameters, which presents the shielding gas that was used in this analysis with a flow rate of 16 L/min. The welding process was conducted using a two-pass welds.

3 Results and discussions

3.1 Welding dissimilar UHSS/AHSS

In manufacturing, welding is the most important process, which allows having to finish products. Joining UHSS/AHSS using the GMAW process has one of the welding processes that can improve the strength in the HAZ area of the weld joint. Figure 2 below shows the macro picture showing the welded samples using GMAW with overmatched filler wire, which must increase the strength of the weld metal. Using the heat input of 7 kJ/cm, the geometry of the weld metal is small compared to those samples. Because of the low heat input, the temperature maximum in the melting zone is 1140°C. When it is applied, the respective heat input of 10 kJ/cm and 15 kJ/cm, and the maxi temperature reaches respectively 1400 and 1700°C. The mechanical properties and microstructures of the welded joints being strongly affected by the characteristics of the welding processes employed. The input behavior using a different form of welding process on the structure of the weld joint of UHSS/AHSS is a critical task. From the available investigations, the result of the temperature max has modified welding outcomes for specific UHSS/AHSS materials.

Table 1: AHSS/UHSS chemical composition and mechanical properties using overmatched filler wire.

	Chemical composition, wt %.															
Materials	**C**	**Si**	**Mn**	**Al**	**B**	**Nb**	**Ti**	**V**	**Cu**	**Cr**	**Ni**	**Mo**	**N**	**P**	**S**	**CE**
S700MC	0.056	0.16	1.18	0.027	0.002	0.044	0.12	0.006	0.02	0.062	0.066	0.0150	0.005	0.01	0.005	0.38
S960QC	0.09	0.21	1.05	0.03	0.002	0.003	0.032	0.008	0.025	0.82	0.04	0.04	-	0.01	0.004	0.49
Filler material	0.08	0.60	1.40		-	-	0.05	-	≤ 0.30	0.30	2.50	0.45				0,45

	Mechanical properties			
Materials	**Yield strength, MPa**	**Tensile strength, MPa**	**Elongation A_5, %**	**Hardness HV5**
S700MC	768	822	12	280
S960QC	960	1000	18	320
Filler material	780	830	≥ 17	270

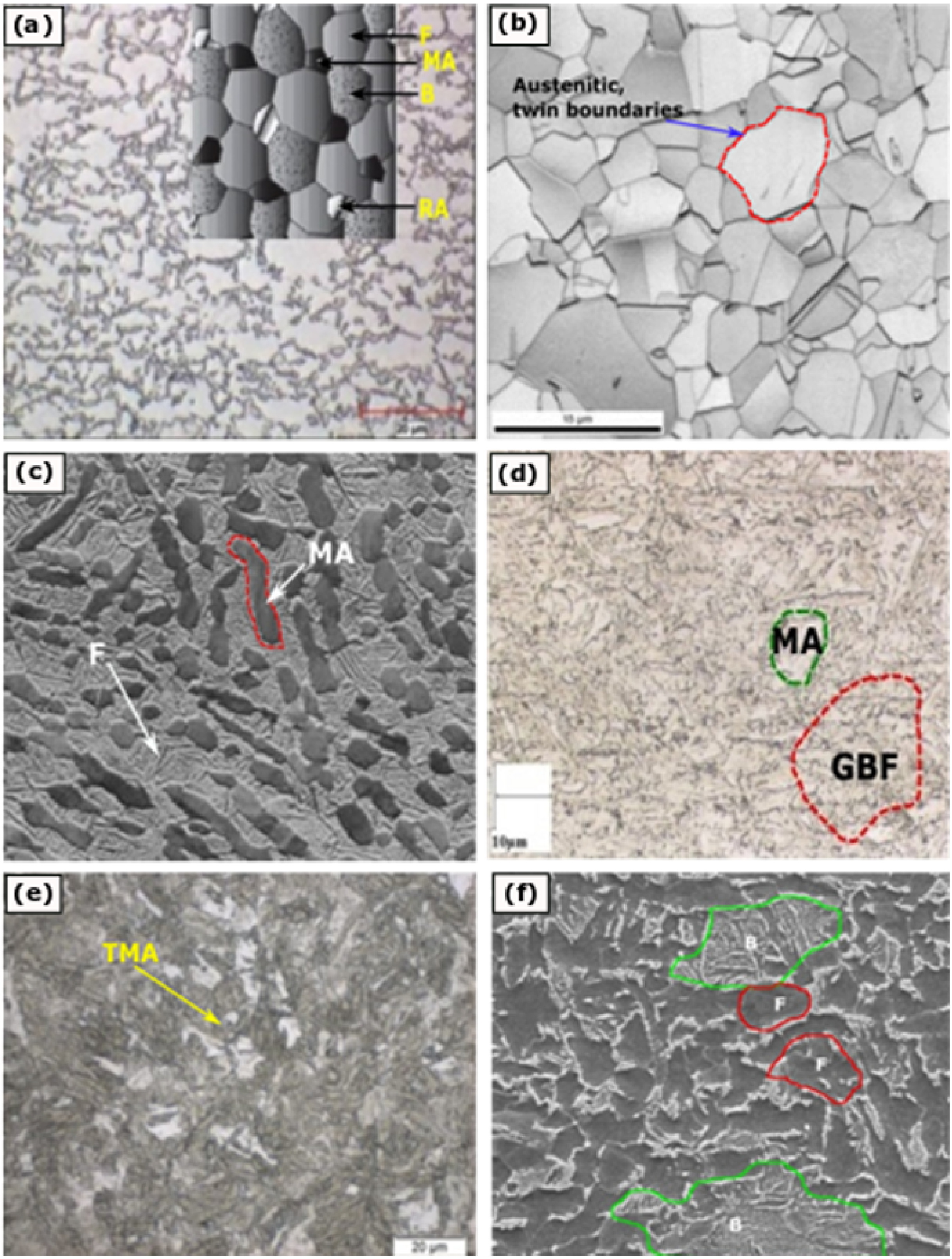

Figure 2: Microstructure UHSS and AHSS; (a) microstructure of TRIP 690 steel, (b) microstructure of TWIP steel, (c) microstructure of DP steel, (d) microstructure of CP 800/1000 steel, (e) microstructure of MS 950/1200 steel, and (f) The microstructure of FB 450/600 steel [16, 21].

Table 2: AHSS/UHSS Welding conditions

	P1				P2			
Welded samples	[A]	[V]	s [cm/min]	Q [kJ/cm]	[A]	[V]	s [cm/min]	Q [kJ/cm]
S1	215	25.3	60.2	7	208	26.7	60.2	7
S2	215	25.3	60.2	7	206	26.7	40	10
S3	211	25.3	60.2	7	211	26.7	30	15

The two significant factors that affect product quality in welded dissimilar UHSS/AHSS materials are softening and a tendency to crack propagations in the heat-affected zone (HAZ). The source of those issues is the heat input and the filler wire composition [24, 25]. Softening of the welded joint has undesirable effects such as:

- A decrease in strength compared to the base material, especially tensile strength;
- The hardness of the HAZ falling below that of the base material;
- A reduction in the fatigue strength of the material [26–28].

The experimental analysis made in this study showed the Vickers-hardness behavior of dissimilar joints of S700MC-S960QC- steels. Figure 2 below shows the results of tree samples using the different heat input parameters defined above. From Figure 2a, using the heat input of 7 kJ/cm, the most softening areas were in the FGHAZ of S960QC and S700MC. The weld metal area was the area that had a high average value of hardness (420 HV5). The lowest average hardness of the S960QC was 255 HV5, which was 19% lowest than the BM. In the S700MC side, the hardness average was evaluated at 210 HV5, which was 16% lowest than the BM. Using the heat input of 10 kJ/cm, Figure 2b below shows the hardness behavior in the weld joint, which was observed the decrease of its values in the CGHAZ of both sides of the HAZ and increased in the WM area. The lowest average value was observed in the SGHAZ of S700MC, which was 220 HV5 lowest than the BM. For the S960QC side, it was observed a relative change of the hardness values, which was increased a bit than the previous sample. The average value measured was 280 HV5, which was the reduction of 15% lowest than the BM. Figure 2c shows the hardness profile using the heat input of 15 kJ/cm. The results show the impact of the welding process in the HAZ and WM, which produced a softening area across the weld joint. The average hardness in the WM was 380 HV5, a bit highest than his initial value. The lowest average hardness was obtained in the FGHAZ of both sides of the material, which was evaluated at 259 HV5 for S960QC and 220 HV5 for S700MC.

From this analysis, it is observed that the softening area at the edge of the HAZ area using the different heat input values. This experiment illustrates why the avoidance of material softening has become a significant area of study in welding research on dissimilar UHSS/AHSS. One of the reasons having to soften in the HAZ when weld UHSS/AHSS is the welding process, which links between the heat input parameters, the filler wire compositions (GMAW) [23, 29]. It can be added to the production process of the BM and the geometry of the weld joint. From the welding process, it is important to analyze the cooling process of the welded joint, which has an impact on the hardening behavior and the strength of the weld joint. The cooling process, which can be slow or rapid, can affect the strength of the weld joint. From the experimental analysis, when using the heat input of 7 kJ/cm, the cooling time results were 11.2 s. Using the heat input of 10 kJ/cm, the cooling time was 27.84 s and using the heat input of 15 kJ/cm, and the cooling time was 45.48 s. Having different cooling times, it is evident that the strength and the microstructure precipitation affect the welding process compare to the BM.

Figure 3 below shows the microstructure formation in the different areas of the HAZ of a dissimilar weld joint of S700MC/S960QC-steels. The images were performed using the SEM images with a resolution of 20 µm. The images were taken in the FGHAZ, CGHAZ of both parts of materials, and in the WM. The sample showing in this microstructure analysis was welded using the heat input of 10 kJ/cm, which had relatively good results when analyzed a hardness previously. The formation of martensite (M) and bainite (B) was observed in the FGHAZ of S700MC-steel (Figure 3a). From this microstructure formations, it was added some retained austenite (RA) formations due to incomplete transformations. In the S960QC side, the formation of tempered martensite (TMA) and bainite (B) were observed in his FGHAZ (Figure 3b). In the CGHAZ, the temperature can reach 900°C, and it was created some microstructure precipitation and micro strengthening ar-

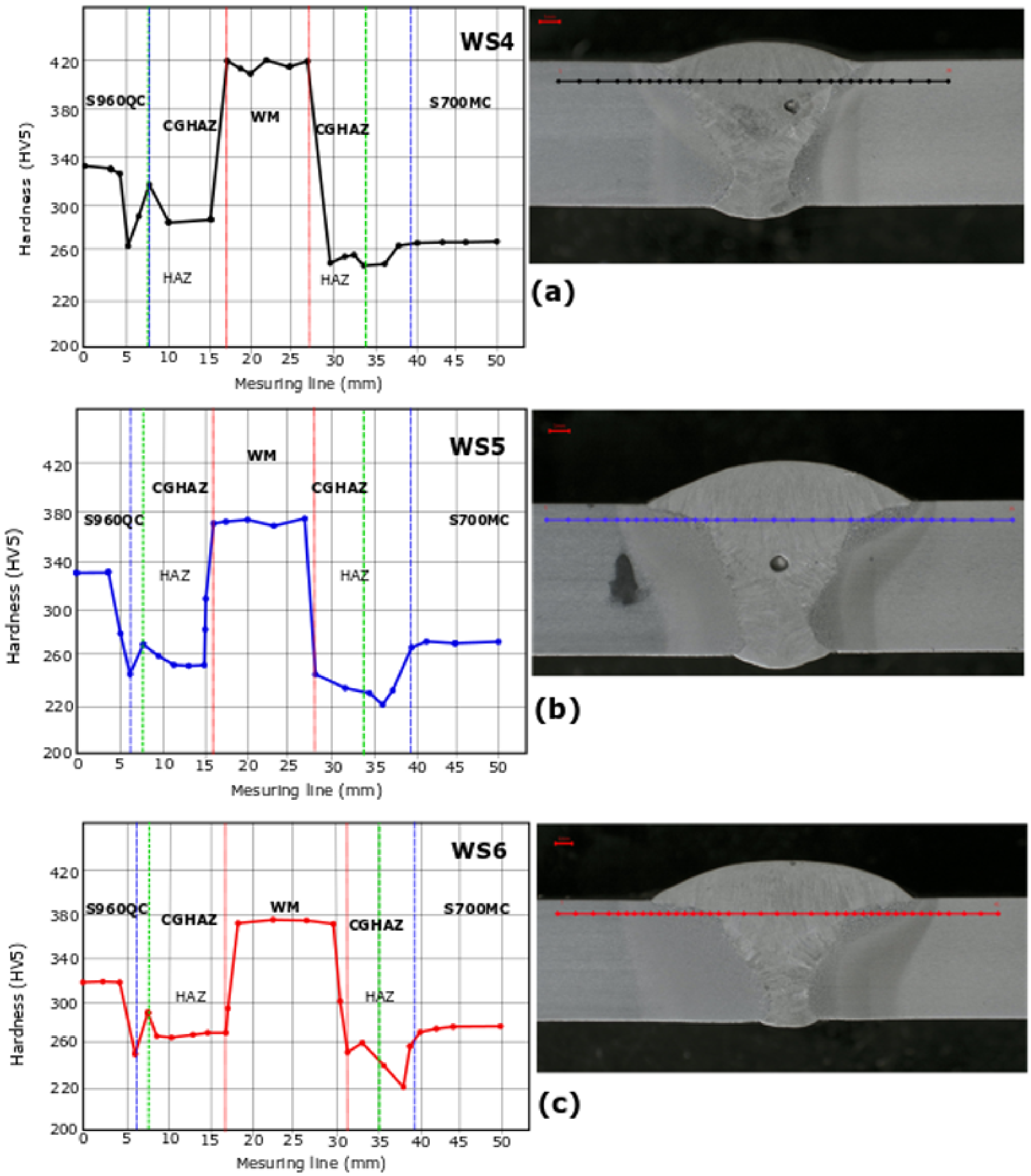

Figure 3: Vickers- hardness profile using overmatched filler wire in the weld joint: (a) hardness profile of weld sample using 7 kJ/cm of heat input, (b) hardness profile of weld sample using 10 kJ/cm of heat input, (c) hardness profile of weld sample using 15 kJ/cm of heat input.

eas. The micro strengthening formations in the microstructure was caused a formation of some Cementite across the grain boundaries of both materials. The Formation of B and RA were observed on the microstructure of S700MC steel (Figure 3c). From this microstructure was added some fine ferrite (F) formation due to the austenite temperature propagation in the austenite grain. Figure 3d below shows the formation of B and some trace of F in the CGHAZ microstructure of S960QC-steel. The formation of F results by the most affected area by the thermal shook produced during the welding process. The microstructure was composed mostly of the filler wire chemical composition, in the melting zone. The microstructure formation was composed of an Acicular ferrite (AF), and Widmanstätten ferrite (WF) (Figure 3e).

Applying welding operations to dissimilar UHSS/AHSS steels requires careful compliance with the welding procedure. The welding procedure is the procedure that includes the selection of welding parameters according to the mechanical characteristics. The chemical composition of a base material (carbon capacity in weight %, Mn, Ti, Ni, Al, B) has to be knowing when welding a sample. In this experiment, it was essential to evaluate the alloy element content in the HAZ of both materials, which participated in improving the strength of the weld joint. By applying the EDS X-ray spectrum mapping, the microstructure of the CGHAZ of both materials was analyzed. The results observed the proportion of weight % of micro-elements such as carbon (C), chromium (Cr), Manganese (Mn), Nickel (Ni), Molybdenum (Mo), Niobium (Nb), Silicon (Si), Vanadium (V). Figure 4a shows the EDS mapping, which observed the composition of 3.6C, 0.7Si, 0.5Cr, 1.7Mn, 1.6Ni, and Mo in the microstructure formation of the WM during the transformation. The increase of the carbon content, Mn, and Ni than their BM weight % content can be the reason that the increase of the hardness was observed above. The respective weights of Mn, Mo, Si, and Cr obtained were 1, 0.2, 0.2, and 1.2 for S700MC (Figure 4b) and 2, 0, 0.4, and 0 for S960QC (Figure 4c). The absence of Ni was observed, which has an impact on the strengthening of the weld joint.

3.2 Welding parameters on UHSS/AHSS for different processes

Welding dissimilar UHSS/AHSS is a big challenge that requires several methods to consider, which will lead to improving the microstructure and mechanical properties of the weld joint. It is essential to note that their microstructures change as a result of welding operations (welding parameters), which has an impact directly on the crack formation in the weld joint. To improve the quality of the weld joint when weld dissimilar UHSS/AHSS, the heat input values, welding geometry, filler wire composition, and the cooling rate are the most critical parameters to be controlled during the welding process. The cooling rate is reliant on many considerations: heat input value, cooling time itself, preheat temperature, a filler wire composition, process efficiency, material properties, and material geometric characteristics. Appropriate and effective control of multiple parameters and variables of the welding processes is required to control the heat input.

Power density is one crucial parameter closely linked to the heat input during the welding processes. In arc welding, the power density at the cross-section of the weldment normal to the welding direction for an arc moving at speed v is given by [14]:

$$q\,(x,\ t) = \frac{3IEf_1}{\pi\bar{r}^2} exp\left\{-3\left(\frac{x}{\bar{r}}\right)^2\right\} exp\left\{-3\left(\frac{vt_{\frac{8}{5}}}{\bar{r}}\right)^2\right\}$$

Where:

x – distance from the center of the heat source on the weldment surface in the cross-section;

$t_{8/5}$ – cooling time during the welding process;

I – welding current, (A);

E – welding arc voltage (V);

f_1 – arc efficiency (%);

$\bar{r}$ – a characteristic radial dimensional distribution parameter that defines the region in which 95% of the heat-flux is deposited [21, 24].

From the equation, the current and voltage are proportional to the power density, and the traveling speed is inversely proportional to the power density. The two values $\boldsymbol{x}$ and $\boldsymbol{t}$ also meet the real situation, which is that the power density will decrease over time and with distance from the heat source to the weldment material. This equation can be applied to weld dissimilar UHSS/AHSS as well as conventional steel materials.

UHSS/AHSS steels require special attention when applying any welding procedure. The application of conventional or hybrid-electric arc welding can be used as in the case of mild steels, which combines MIG, MAG, TIG, or plasma. They are reputed to have good weldability better than for mild steel. The recurrent problem that recalls when welding this type of dissimilar steel is the application of the heat input parameters (current, voltage, heat input). The filler wire also needs to be analyzed when welding UHSS/AHSS for some welding process. The current polarity (AC and DC) will have to consider the ratios of lower or upper thickness to 2:1, which are considered very sensitive to welding operations. It is imperative to analyze the relationship that will have to exist in welding parameters and welding operations [20, 25, 27, 29]. The welding process using pulsion current recommends a specific filler wire resistance of 482 MPa. The use of this type of filler wire will optimize the current effect on the structure of the weld joint by effecting his strength and fatigue behavior. The electric resistance weld (ERW) can be used to weld dissimilar UHSS/AHSS. The only issue that has the ERW weld process his lowest input current compared to other welding processes. Depending on the chemical composition of the base materials, this current intensity can be even low-

Table 3: Comparison of different welding processes used with UHSS.

	SAW	MIG/MAG	Laser	ERW	TIG
Process	easy	easy	Need accurate inspection, operation, and preparation	Need proper preparation	Need to be controlled
Heat Input	low	high	low	low	high
Cooling Rate	controlled	controlled	controlled	/	controlled
HAZ	Small HAZ, and low softening	Wide-ranging HAZ, and high softening	Slight HAZ, and little softening	/	Wide HAZ, and High softening
Joint Preparation	/	Good strength and mechanical properties	Excellent strength and mechanical properties, bending properties may vary	/	Excellent strength and mechanical properties

Table 4: Different welding processes using different UHSS/AHSS materials.

	SAW	MIG/MAG	Laser	ERW	TIG
TRIP	/	Weldability is good	Yttrium-aluminum-garnet laser for TRIP780 is good	+ electrode force, time, weld size, tip diameter, tightly controlled	/
TWIP	/	Weldability is good	/	+ electrode force, time, weld size, tip diameter	/
MS	/	Weldability is good	/	+ electrode force, time, weld size, tip diameter	/
DP	/	Good weldability for MIG/MAG, HAZ softening	Excellent weldability, low heat input	+ electrode force, time, weld size, tip diameter	/
CP	/	Weldability is good	/	+ electrode force, time, weld size, tip diameter	/
FB	Weldability is good	Weldability is good	Weldability is good	+ electrode force, time, weld size, tip diameter, Weldability is good	Weldability is good
QT	Weldability is good	Weldability is good	Weldability is good	+ electrode force, time, weld size, tip diameter	Weldability is good
TMCP	Weldability is good	Weldability is good	Weldability is good	+ electrode force, time, weld size, tip diameter	Weldability is good

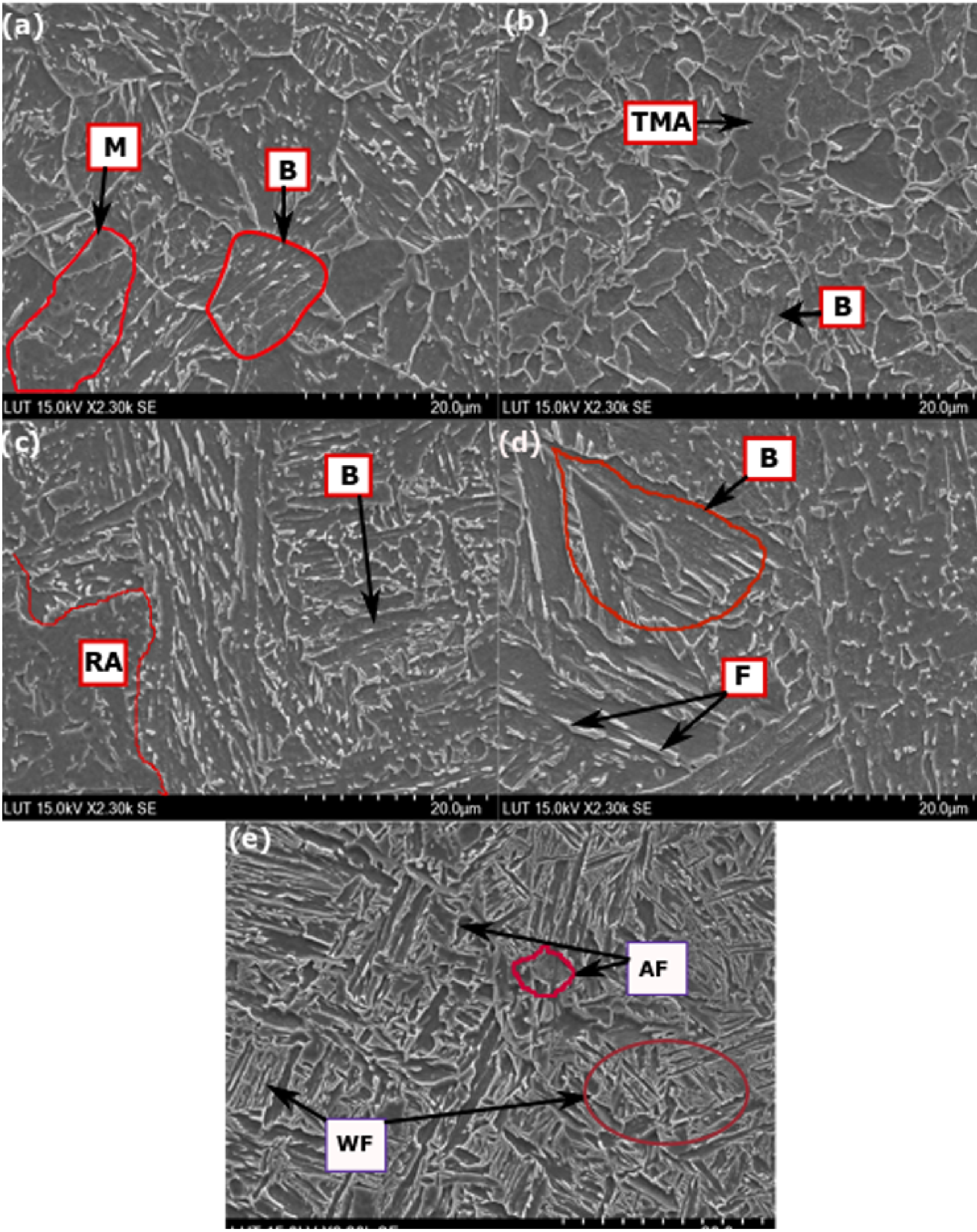

Figure 4: SEM micrograph, showing the microstructure of dissimilar S700MC/S960QC weld joint using overmatched filler wire: (a) FGHAZ of S700MC, (b) FGHAZ of S960QC, (c) CGHAZ of S700MC, (d) CGHAZ of S960QC, and WM.

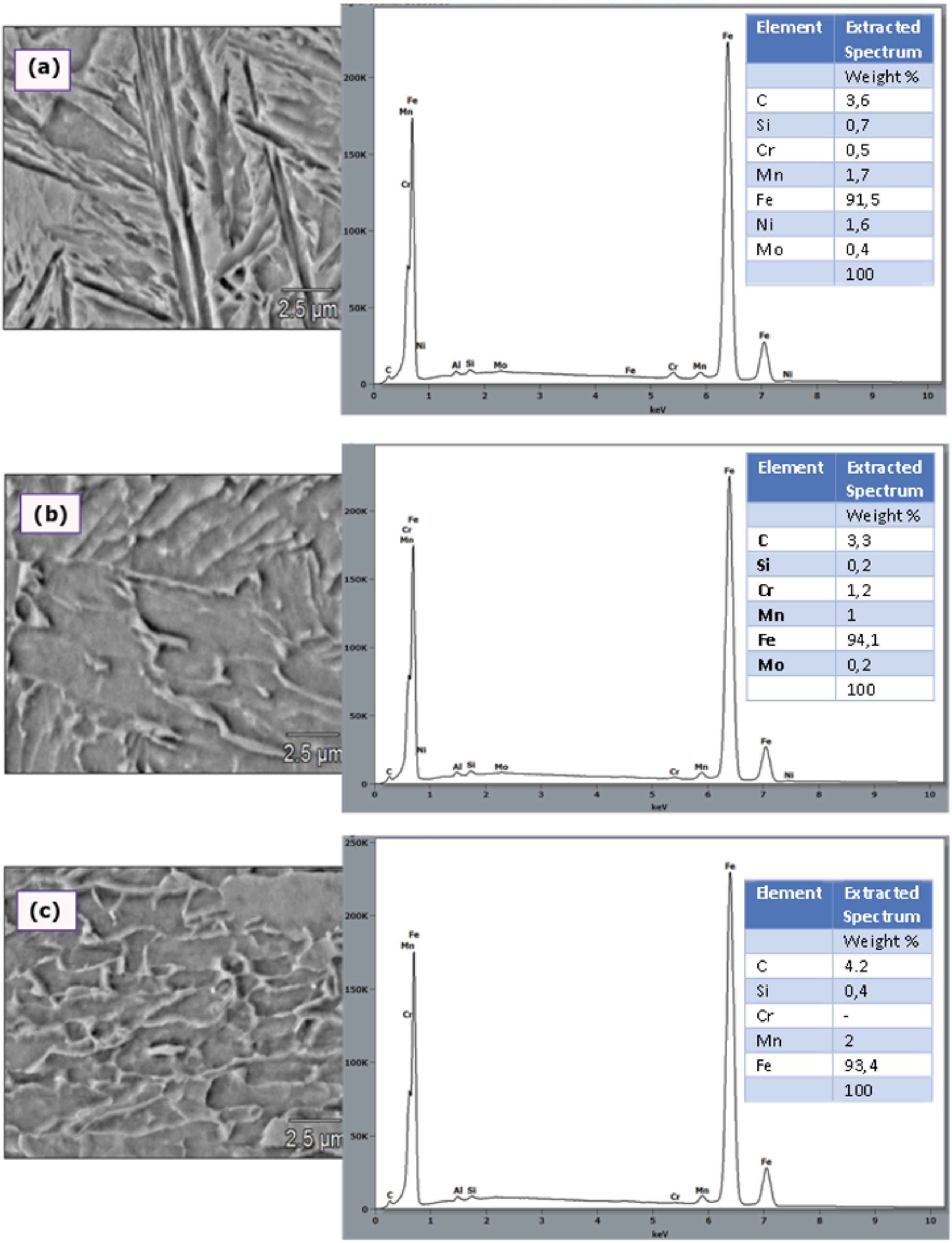

Figure 5: EDS X-ray mapping showing the alloy element composition: (a) WM mapping using overmatched filler wire, (b) CGHAZ of S700MC, (c) CGHAZ of S960QC.

ered. The following instructions shall be applied for welding of steels of type QT, TRIP, CP, FB, TWIP, and MS [19, 29]:

- Adjust the welding time according to the mechanical parameters and the chemical composition of the BM;
- Adjust weld size;
- The mechanical characteristics (yield strength, tensile yield strength) shall be in accord with the electrode forces;
- Adjust the electrode type with the largest possible diameter, as appropriate;
- Adjust the geometric characteristics of the weld joint with the welding time

Currently, there is a lack of systematic theoretical research and practical experimental work on welding methods for dissimilar UHSS/AHSS. The benefits from the use of such steels, a better understanding of their behavior is required. Moreover, the advantages of and complications involved with the welding dissimilar UHSS/AHSS are becoming more evident, listed in Table 1. Table 1 below shows a comparative analysis of the influence of the welding process on the weldability of dissimilar UHSS/AHSS. The results show a good behavior of dissimilar UHSS/AHSS when applied Laser welding process. It can be better to associate, for example, MIG welding with Laser welding, which will optimize the microstructure precipitation and the strength of the weld joint. Welding UHSS/AHSS using the Laser process will consider all those parameters that were cited above to produce an excellent strength minimizing softening in the HAZ. To preconize a welding process function of the type of material, Table 2 below presents the type of materials that can be welded using a different welding process. It is recommended to apply the MIG/MAG welding process to weld a material such as TRIP, TWIP, MS, DP, CP, FB, QT, and TMCP steel, which have a good result. From Table 2, it can be seen, based on current knowledge, that the most suitable welding process for UHSS/UHSS is resistance welding. However, data for some welding processes is lacking, indicated with the mark '/' in the table. Robotic MIG welding of QT (S960QC) and TMCP (S700MC) materials were tested in the Welding Laboratory of Lappeenranta-Lahti University of Technology, and as was seen above, the evaluations from Hardness and microstructure (SEM, EDS). The analysis has shown excellent results when the excellent choice has operated in the welding parameters and filler wire composition.

4 Conclusions

In this study, the weldability of dissimilar UHSS/AHSS was analyzed, and experimental methods were performed using three heat input parameters and overmatched filler wire. The Hardness tests, SEM scanning test, and EDS X-ray spectrum mapping were carried out in order to observe the hardness behavior and the microstructure precipitations in the HAZ of the weld joints. The paper presents some recommendations that need to be considering, which found that;

- The increase of the heat input (15 kJ/cm) when welded dissimilar UHSS/AHSS results in the formation of more carbide in the austenite grain. The softening area will increase in the HSZ;
- The quantitative relationship was established between the heat input, the hardness, and the microstructure precipitation in the HAZ. Two significant problems have been recognized as regards welding processes the UHSS/AHSS materials: cold cracking and material softening near the HAZ. Precise and accurate control of heat input during the welding process is required;
- Welding dissimilar UHSS/AHSS using overmatched filler wire produces an increase of hardness in the WM area. His increase can optimize the strength of the weld joint when the ideal heat input is applied;
- The use of GMAW process with 10 kJ/cm as heat input value produces an equilibrium microstructure formation in the HAZ. This heat input develops a formation of Bainite-ferrite in the S700MC side and Bainite-Martensite in the S960QC side. This microstructure formation favorites to optimize the strength of the weld joint and avoid cracks propagation;
- Based on the equation of power density, welding parameters like arc voltage, welding current, and traveling speed affect the heat input of the welding joint. The power density equation illustrates that to ensure appropriate heat input, the welding parameters should be designed and tested before utilization of welding processes for UHSS/AHSS materials;
- As regards the different types of UHSS/AHSS materials used in production, it is noted that ferrite-bainite (FB) steel material has the best weldability. In industry, MIG/MAG and laser welding are the most common methods used, and UHSS/AHSS materials have shown good weldability with such processes;

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