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Research Paper / Makale

The Effects of Flux Type on Mechanical and Microstructural Properties of S235 Structural Steel by Submerged Arc Welding

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Abstract: S235 fine grained steel alloys are demanded especially in structural components of buildings, factories and mechanical parts of machines where yield strength values close to minimum 235 mega-pascals (MPa) are in concern. These steels are classified in low alloyed steel groups and in consequence of the cheapness of these alloys their consumption is increasing as well. In this work; 15 mm of S235 structural steel plates are submerged arc welded by 2 types of welding fluxes. The first welding flux is selected as SA AB 1 68 AC H5 as basic character with the basicity index of 1.4 while the second flux is SA AR 1 77 AC rutile as low basic character with the basicity index of 0.7 according to TS EN ISO 14174 by both using the same welding wire S2 of 4mm in diameter according to TS EN ISO 14171-A standard. The effects of flux composition on microstructural and mechanical properties of welded S235 steel alloy are examined. Micro-vickers hardness surveys of base metal and heat affected zones with weld metals, transverse tensile tests and micro-structural investigations are applied for comparison of these two types of welding fluxes. The samples joined by basic and rutile flux are both qualified in micro-vickers hardness surveys and transverse tensile tests. Rutile flux transformed the ferritic-pearlitic microstructure into needle like view while basic flux maintained it more globular. Whether globular microstructure is desired in case of toughness considerations in industrial applications, basic flux should be preferred.

Keywords: Fine grained steel alloys, S235 steel alloy, Submerged arc welding, Welding fluxes.

S235 Yapı Çeliğinin Tozaltı Kaynağında Toz Türünün Mekanik ve Mikroyapısal Özelliklere Etkileri

Öz: S235 ince taneli yapı çelikleri; bilhassa akma mukavemeti değerlerinin en az 235 mega-paskal (MPa) istendiği yapılar, fabrikalar ve makine parçalarında tercih edilmektedir. Bu çelikler düşük alaşımlı çelik gruplarında sınıflandırıldıklarından ve bu alaşımların fiyatlarının ucuz oluşu tüketimlerinin artmasını da beraberinde getirmiştir. Bu çalışmada; 15 mm kalınlığındaki S235 yapı çeliği plakaları 2 farklı kaynak tozu kullanılarak tozaltı kaynak yöntemiyle kaynak edilmiştir. Tozaltı kaynak tozları; TS EN ISO 14174 standardına göre sırasıyla; bazik karakterde SA AB 1 68 AC H5 baziklik indeksi 1.4 ve ikinci toz, rutil-bazik karakterde SA AR 1 77 AC baziklik indeksi 0.7 ve kaynak teli TS EN ISO 14171-A standardına göre 4mm çapında S2 seçilmiştir. Kaynak tozu bileşiminin kaynak edilmiş S235 çelik alaşımının mikro-yapısal ve mekanik özellikleri üzerindeki etkileri incelenmiştir. Bu iki tür kaynak tozunun karşılaştırılması amacıyla; ana malzeme ve kaynaklı bağlantının ısının tesiri altındaki bölgeleri ve kaynak metalinin mikro-vikers sertlik taramaları, enine çekme deneyleri, mikroyapısal incelemeler uygulanmıştır. Bazik ve rutil toz ile birleştirilen numunelerin her ikisi de mikro-vikers sertlik taramalarında ve enine çekme deneylerinde başarılı olmuşlardır. Rutil toz, ferritik-perlitik mikroyapıyı iğnemsi görünüme dönüştürmüş, bazik toz ise daha küresel hale getirmiştir. Endüstriyel uygulamalardaki tokluk gereksinimleri durumunda bazik tozun tercih edilebileceği görülmektedir.

Anahtar kelimeler: İnce taneli yapı çelikleri, S235 çelik alaşımı, tozaltı kaynağı, kaynak tozları.

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1. Introduction

Fine grained steel alloys are mainly used in structural parts and also at buildings in various industries. The consumption of these alloys is increasing day by day in consequence of the low alloying elements and hence low costs in products. They have good weldability properties.

They are classified according to their minimum yield strength values. They have been also grouped by minimum tensile strength values prior to their yield strength classifications in early times. S235 wrought fine grained steel is alloyed to ensure minimum 235 MPa of yield strength values [1,2].

These alloys are joined with numerous kinds of fusion welding methods as mostly pronounced electrode arc and MIG/MAG (Metal Inert/Active Gas) welding processes also with screwing and fastening by rivets. Submerged arc welding process is preferred for joining especially thick parts of these alloys and where high speed of welding is very important [1].

Many studies are prepared about submerged arc welding processes and welding fluxes. These investigations mainly covers the subjects about current effects, optimizing the welding parameters, analysis of welding aspects, dilution in weld zones, chemical and thermo-physical properties of weld metals and heat affected zones (HAZ), prediction of weld regions behavior properties, the effects of inclusions and alloying elements on weld zones [3-14]. But this study especially focuses on the effects of flux types on micro-structural and mechanical developments of S235 steel alloys joined by submerged arc welding.

Hence, the transverse tensile strength tests, micro-hardness surveys and micro-structural inspections of welded samples are thoroughly investigated.

2. Experimental Methods

2.1. Materials

S235 steel alloy plate couples of 15 mm in thicknesses and 70x200 mm in dimensions are prepared for joining with submerged arc welding. The elemental spectral analysis results of S235 steel by AMETEK Spectromax Argon Optical Emission Spectrometer are given in Table 1. The samples chemical composition is consistent with the specification [2].

Table 1. Spectral Analysis of S235 steel.

Analyse No.	C	Si	Mn	P	S	Fe	Others
1	0.125	0.0067	0.639	0.0126	0.0076	99.1	0.1091
2	0.127	0.0068	0.642	0.0138	0.0087	99.1	0.1017

2.2. Joining Operation and Tests

Submerged arc welding is applied with totally 7 individual passes. After the first (root) pass has completed, the temperature change for each sub-pass is controlled as all of the next 6 passes are completed by waiting until the temperature of the previous pass decreases not below to 100°C. The temperature control is made by temperature chalk pencil that is capable of measuring approximately 100°C in color contrast.

The welded samples are shown in Figure 1.

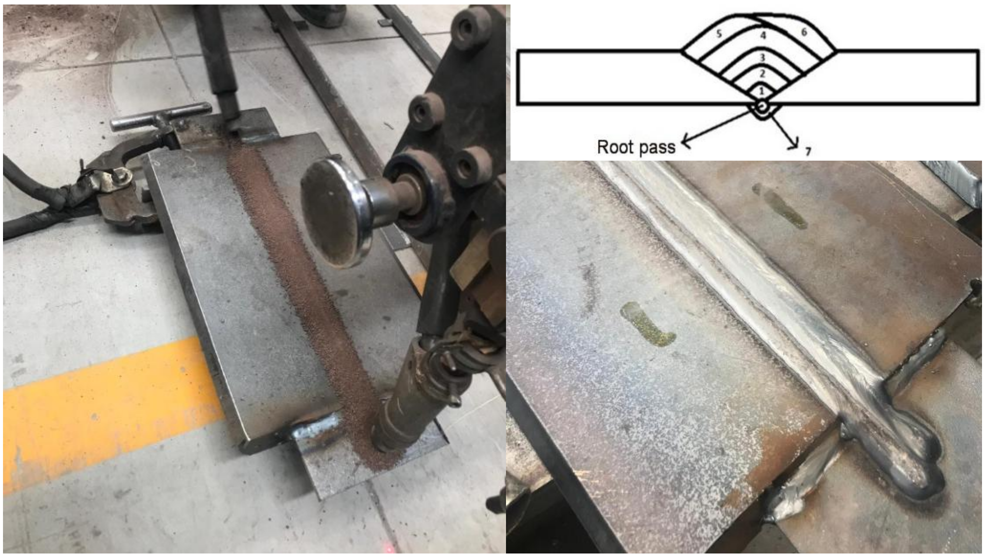


Figure 1. Welded samples

Samples both sides of surfaces are all grinded before the last root pass (indicated by 7 in Figure 1) from their back sides.

After welding operation samples are cut for micro-vickers hardness testing [15], micro-structural inspections [16] and transverse tensile tests [17].

Submerged arc welding parameters are listed in Table 2.

Table 2. Welding parameters.

***Parameters are applied at the same conditions for both welding fluxes**	**Passes**						
	1st (root)pass	**2nd pass**	**3rd pass**	**4rd pass**	**5th pass**	**6th (final) pass**	**7th (Backside root pass)**
Current AC (Amperes)	350	400	470	470	600	520	450
Welding speed (mm/s)	50	50	45	45	40	45	50
Welding wire	TS EN ISO 14171-A; S2 (Ø4mm) [18]						
Flux types	**Flux 1.** TS EN ISO 14174; SA AB 1 68 AC H5 (Basic-Basicity:1.4). **Flux 2.** SA AR 1 77 AC (Rutile-Low basic, Basicity:0.7) [19]						

The chemical compositions of welding wire from the manufacturers' analysis are given in Table 3.

Table 3.

	C	**Si**	**Mn**
Welding wire (S2)	0.12	0.10	1.0

Micro-structural investigations of welded samples were carried out by Leica Brand optical metallurgical microscope after etching samples with 3% nital solution. Base metal, weld metals and heat affected zones are all investigated.

The micro-vickers hardness test is applied onto three distinct places on welded samples for each welding fluxes including weld metals and heat affected zones separately according to the EN ISO 9015-2 standard [15] by 0.3 kg loading for 15 seconds at 22°C constant laboratory temperature.

Transverse tensile tests of 3 samples are applied per each welding condition according to AWS B4.0 [17] standard as given in Figure 2.

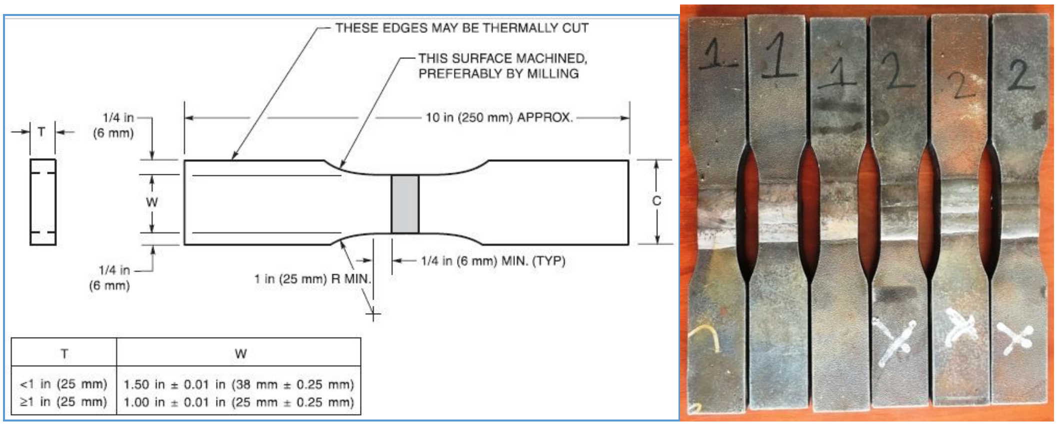


Figure 2. Transverse tensile test samples according to AWS B4.0 standard.

3. Results and Discussion

3.1. Micro-structural investigations

Micro-structural examinations are applied on weld metals and both two opposite sides of heat affected zones.

Micrographs of Base Metal

Microstructure of S235 fine grained steel alloy (unwelded) is given in Figure 3. The structure basically consists of ferrite and pearlite. Darker phases are pearlite and lighter are ferrite in Figure 3.


Figure 3. S235 base metal microstructure, nital 3%, (50X)

The alloying elements are intentionally kept in low amounts in S235 fine grained steel alloy in order not to be hardened by thermal processes mainly like welding as a result of hardening effects of fast cooling problems of welded parts. Hence, there should be no other harder phases like martensite or bainite to be found in normal fusion welding conditions of these alloys below 15 mm in thicknesses.

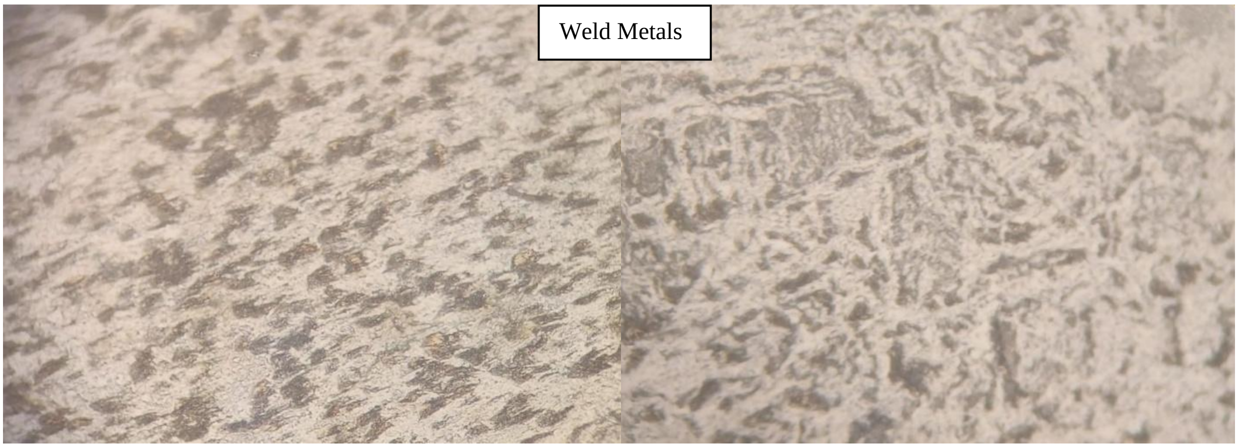
But for such materials more than 15 mm in thicknesses in extremely fast cooling thermal welding conditions such as laser or electron beam welding processes it is possible to meet martensite or bainite in minor amounts within HAZ regions of these alloys weldments [20,21].

Neverthless, there are no other types of phases noted in unwelded base metal microstructure of this study.

Micrographs of welded samples

The micrographs of samples joined by basic and rutile fluxes are investigated.

The weld metals microstructures of the sample welded with basic and rutile fluxes are given in Figure 4.



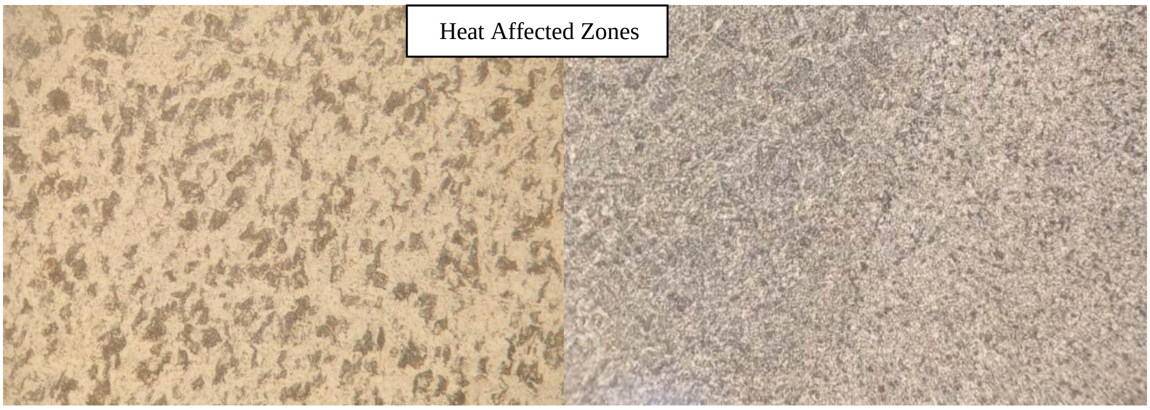
(a) **(b)**

Figure 4. Weld metal microstructures of samples joined by **(a)** basic **(b)** rutile welding fluxes. (100X)

Basic flux maintained the ferritic-pearlitic microstructure more globular while rutile flux transformed it into needle like view. Pearlitic-ferritic structure is observed in both weld metals of samples. Darker phases are pearlite and the lighter phases are ferrite in both microstructures.

Microstructures of heat effected zones on welded samples

Microstructures of heat affected zones are given in Figure 5.



(a) **(b)**

Figure 5. HAZ microstructures of samples joined by **(a)** basic **(b)** rutile welding fluxes. (100X)

Samples joined by basic flux exhibited more globular microstructure (see Figure 5-a) while samples joined by rutile flux displayed needle like microstructure (see Figure 5-b) in heat affected zones. Pearlitic-ferritic structure is observed in both heat affected zones of welded samples.

Darker phases are pearlite and the lighter phases are ferrite in both samples microstructures.

3.2. Micro-hardness surveys

Micro-hardness test results on base metal, weld metal centerline and heat affected zones are given in Table 4.

Table 4. Micro-hardness test results ($HV_{0.3}$)

Flux Type	Base Metal	HAZ_1 (left side)			Average Values	Weld Metal			Average Values	HAZ_2 (right side)			Average values
Basic	119	139	139	141	140	140	141	173	151	141	141	142	141
Rutile		127	127	133	129	142	143	167	151	136	145	145	142

According to micro-vickers hardness test results, all of the regions in weldments have qualified. Fine grained low carbon alloyed S235 steels have to exhibit micro-hardness values below 350HV according to IIW specifications [20, 22, 23].

The hardness results of weld metals of both samples are a few greater than heat affected zones. That's most probably because of welding wire carbon content supported the total carbon amounts in weld metal regions. Hence, the hardenability of weld metal region is preserved as compared to heat affected zones under cooling conditions of welding operations.

3.3. Transverse Tensile tests

All of the tensile test samples are split apart from their close HAZ regions.

Transverse tensile test results are given in Table 5.

Table 5. Transverse tensile test results

Flux Type	Tensile Strength (MPa)			Mean Values
Samples welded by basic flux	425	430	445	433
Samples welded by rutile flux	430	430	430	430

According to transverse tensile tests all of the samples are qualified. These steels base metals typically exhibit approximately 360MPa to 510MPa of tensile strength values between 3 and 100 mm thicknesses [2]. Besides, there are no major tensile strength differences recorded between the samples that welded by basic and rutile fluxes.

4. Conclusions

The samples joined by basic and rutile flux are both qualified in micro vickers hardness surveys and transverse tensile tests.

Rutile flux transformed the ferritic-pearlitic microstructure into needle like appearance while basic flux provided it more globular.

All the samples have exhibited ferritic-pearlitic microstructure besides no other phases observed because of the low amounts of carbon and alloying elements in S235 steel. The second reason is; welded samples were controlled during welding cooling conditions.

Basic or rutile welding fluxes both can be selected in submerged arc welding of S235 fine grained structural steel alloys.

Nevertheless, whether the globular microstructure is desired in case of toughness considerations in applications, basic flux characterized submerged arc welding should be a well choice in joining of S235 fine grained steel alloys.

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References

[1]. ASM Metals Handbook, Volume 6, ASM Handbook Committee, Welding, Brazing and Soldering, ASM International, 1993, p.1059.
[2]. TS EN 10025-2, Part 2, Hot-rolled Products of structural steels, 2019, TSE.
[3]. Cho D., Kiran D. V., Na S.J., Analysis of molten pool behavior by flux-wall guided metal transfer in low-current submerged arc welding process, International Journal of Heat and Mass Transfer, doi: 10.1016/j.ijheatmasstransfer.2017.02.060, 110, 2017, 104-112.
[4]. Ahmad M. A., Sheikh A. K., Nazir K., Design of experiment based statistical approaches to optimize submerged arc welding process parameters, ISA Transactions, doi:10.1016/j.isatra.2019.04.003, 94, 2019, 307–315.
[5]. Sailender M. et.al, Prediction and comparison of the dilution and heat affected zone in submerged arc welding of low carbon alloy steel joints, Measurement, doi:10.1016/j.measurement.2019, 107084.150.
[6]. Sharma L., Chhibber R., Investigating the physicochemical and thermo-physical properties of submerged arc welding fluxes designed using TiO2-SiO2-MgO and SiO2-MgO-Al2O3 flux systems for line-pipe steels, Ceramics International, doi:10.1016/j.ceramint.2018.10.032, 45, 2019, 1569–1587.
[7]. Kanjilal P., Pal T.K., Majumdarc S.K., Combined effect of flux and welding parameters on chemical composition and mechanical properties of submerged arc weld metal, Journal of Materials Processing Technology, doi:10.1016/j.jmatprotec.2005.06.083, 171, 2006, 223–231.
[8]. Pua J, Yua S., Lib Y., Role of inclusions in flux aided backing submerged arc welding, Journal of Materials Processing Technology, dx.doi.org/10.1016/j.jmatprotec.2016.09.016, 240, 2017, 145–153.
[9]. Li K., Wu Z., Zhu Y., Liu C., Journal of Materials Processing Technology, doi:10.1016/j.jmatprotec.2017.02.004, 244, 2017, 314–319.

[10]. Osorioa A.G., Souzab D., Passosb T., Dalpiazb L., Airesa T., Effect of niobium addition on the flux of submerged arc welding of low carbon steels, Journal of Materials Processing Technology, 2019, doi:10.1016/j.jmatprotec.2018.10.020, 266, 46–51.
[11]. Winczeka J., Parkitny R., Modelling of heat affected zone in submerged arc welding butt joint with thorough penetration, Procedia Engineering, doi: 10.1016/j.proeng.2017.02.195, 177, 2017, 241–246.
[12]. Sirisatiena T., Mahabunphachaib S., Sojiphana K., Effect of submerged arc welding process with one-side one-pass welding technique on distortion behavior of shipbuilding steel plate, ASTM A131 grade A, Materials Today, 5, 2018, 9543–9551.
[13]. Kara R, Çolak F, Yıldırım G, Hiçyılmaz V. Investigation of natural gas pipes with different welding processes. El-Cezeri Journal of Science and Engineering, 2017, 4 (1), 0-0, doi: 10.31202/ecjse.289643.
[14]. Aksöz S, Ada H, Fındık T, Çetinkaya C, Bostan B, Candan İ., The Investigation of Effect of Welding Process on The Microstructure and Mechanical Properties of API 5L X65 Steel Welded with Electric Arc Welding Method, El-Cezeri Journal of Science and Engineering, 2017, 4 (1), 0-0 . doi: 10.31202/ecjse.289639.
[15]. EN ISO 9015-2, Destructive tests on welds in metallic materials, Hardness testing, Part 2, 2016, Micro-hardness testing of welded joints. International Standards Organization.
[16]. ASM Metals Handbook Volume 9, Metallography and Microstructures, 2004, ASM International, 1387-1485.
[17]. AWS B4.0: 2016, Standard test methods for mechanical testing of welds. American Welding Society. USA.
[18]. TS EN ISO 14171, 2016, Welding consumables, Solid wire electrodes, tubular cored electrodes, and electrode/flux combinations for submerged arc welding of non alloy and fine grain steels. International Standards Organization.
[19]. TS EN ISO 14174, 2012, Welding consumables, fluxes for submerged arc welding and electro-slag welding. International Standards Organization.
[20]. EWF, IIW, Welding Engineering Course Notes 2005, GSI SLV München, European Welding Federation, International Institute of Welding, Germany.
[21]. Kou S. Welding Metallurgy, 2nd Edition, 2003, New York, John Wiley and Sons, 232-238.
[22]. Reeve L., "Metallurgy of ferrous welding", Note on Cambridge Welding Conference, Transactions of the Institute of Welding, 1939, Vol. II., 7-18.
[23]. Dearden, J., and O'Neill, H., "A guide to the selection and welding of low alloy strucutural steels", Transactions of the Institute of Welding, 1940, Vol III, 203-214.