The Comparison of Microstructure and Mechanical Properties of Flux-Cored Wires (FCW)

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Abstract

In this study, low carbon structural steels was welded using commercially available and newly developed flux cored arc welding (FCAW) consumables. The goal is to find relationships between microstructures and mechanical properties. Through the experiments, St 52, 3 steel was used as base metal. Also, 1.2 mm diameter of different flux cored wires (FCWs) with rutile, basic and metal cored types are used. The shielding gas 80% Ar + 20% CO_2 mix and 100% CO_2 were chosen during the butt-welding for different type FCWs. The resulting weld joints were examined with respect to microstructure, tensile and Charpy-V impact toughness properties. The aim of this study is to examine microstructure-property relationships of the commercially available and newly developed prototype FCWs and determining the underlying factors for the superior mechanical properties for the prototype and give an impetus for their further development. The partial results of the ongoing investigations on the cooperative characterizations between six different FCWs are presented in this manuscript.

Keywords: *Flux-Cored Arc Welding (FCAW), rutile, basic and metal flux cored wires, mechanical properties, microstructure*

1. Introduction

The use of FCWs for gas-shielded, arc welding has significantly increased over the past 30 years with their successful applications in welding of steel structures, shipbuilding, offshore constructions, and petro-chemical and power generation industries [1].

Flux cored wire welding (FCAW) has been compared to other welding processes and reported to have benefits like easy handling, higher productivity (lower cost) and a significant lower risk for defects like porosity and lack of fusion [2].

Demands of higher levels of weld performance in service of the welded structures have challenged both fabricators and welding consumables manufacturers to develop innovative design and product solutions to generate and maintain the high level of productivity and benefits of innovative welding consumables [3].

Recently, some reviews state that FCWs covers more than 30% of the total amount of arc welding materials [3]. Therefore, significant effort has been made to develop FCW technologies to achieve better mechanical properties for welding of various types of steels used at sub-zero temperatures to higher service temperatures.

This short paper presents the partial results of the on-going investigations on the FCWs using method of comparative investigations on the commercially available FCWs and newly developed prototype FCWs. The basic micro-mechanical characterization results are reported in this manuscript. It should be noted that G rutile wire and B basic FCWs are prototypes of GEDİK Welding. The other wires also have been obtained from different manufacturing companies.

2. Background

In this section, some basic information on the FCW types and technologies are provided. FCAW is a semi-automatic or automatic process which requires a continuously-fed consumable tubular electrode containing a flux and other alloying elements which enable some special welding features of the weld metal. Figure 1 shows the FCAW process [4].

There are several advantages of the FCWs compared to stick electrode and solid wires [5]. Namely,

- Higher deposition rates than SMAW with good quality weld metal deposit
- Compared to GMAW All position capability with less operator skill required
- Deeper penetration than SMAW with spatter-reduced welding behavior
- Time saving process with semi-automatic or automatic and continuously feed from a spool
- Minimum electrode wastage
- Metallurgical benefits that can be gained from a flux

FCW types are generally grouped as rutile, basic, metal, stainless and hard facing. There are two basic process variants; self shielded FCAW (without shielding gas) and gas shielded FCAW (with shielding gas). The difference between them stem from different fluxing agents in the consumables, which addresses different needs of different customer segments.

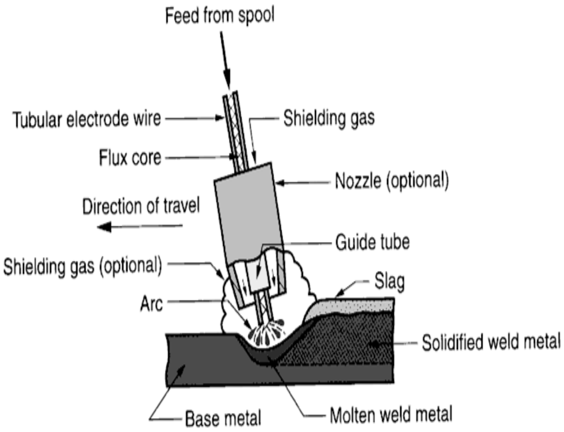

Figure 1. The FCAW process

As it is known, the primary function of the shielding gas is to protect the molten metal from atmospheric N_2 and O_2 as the weld pool is being formed. The gas also promotes a stable arc and uniform metal transfer. It also affects the spatter rate and penetration pattern [6]. The most common shielding gases: are $C0_2$ and Argon-CO_2 mixtures for FCWs. Traditionally, CO_2 is used as a shielding gas due to its cheapness, but its use has been limited because of the problem of spatter, poor all-position performance [7].

On the other hand, argon alone is also unsuitable for welding steel as it cannot sustain the desired arc stability and desired weld bead characteristics [8].

The flux, which is contained within the core of the tubular electrode, melts during welding and shields the weld pool from the atmosphere.

Flux contains substantial amounts of deoxidizing, denitrifying ingredients, arc stabilizers and alloying elements. These are common core ingredients for FCWs. It is known that nitrogen and oxygen can cause porosity or brittleness while oxygen significantly affects the volume fraction and morphology of the inclusions so deoxidizers such as Mn and Si and denitrifiers such as Al are added to purify the weld metal. Furthermore, slag formers such as oxides of Ca, K, Si or Na are added to protect the molten weld pool from the atmosphere.

Alloying elements Mo, Cr, C, Ni, Mn and V, are generally used, in a balanced manner to increase strength, ductility, hardness and toughness. Beside this, arc stabilizers such as Ka and Na, help to produce a smooth arc and reduce spatter [4]. The design of the chemical composition of the FCWs is also needs to comprise all those above listed generally known structures of the conventional welding consumables while taking into account of the special feature of the FCW and molten metal-transfer mechanism which differs from solid wires.

3. Experimental Procedure

The flux cored welding method were used for production of butt-welded plates of St 52,3 steel using six different types of FCWs using ceramic backing tape and mixed gas of 80% +20% CO_2 for basic and metal cored wire and 100% CO_2 for rutile FCWs.

The wires used in the study are 1.2 mm diameter and conform to the AWS A5.20 specifications. Rutile wires have E71-T1 type, Basic and Metal wires have also E71-T5 type. Table 1 shows the list and types of the consumables wires.

Table 1. Characteristics of flux-cored consumables

Characteristic of consumables		
Welding Deposit	Wire Type	Diameter (mm)
G Wire	Rutile	1,2
K Wire	Rutile	1,2
S Wire	Rutile	1,2
E Wire	Rutile	1,2
B Wire	Basic	1,2
M Wire	Metal	1,2

Test pieces were cut from welded plates of 300 mm (width) ×500 mm (length) ×15mm (thickness). This base material with a 60º V-shaped groove was used and multipass (5 passes) welding procedure was carried out in flat position with the interpass temperature of about 150ºC.

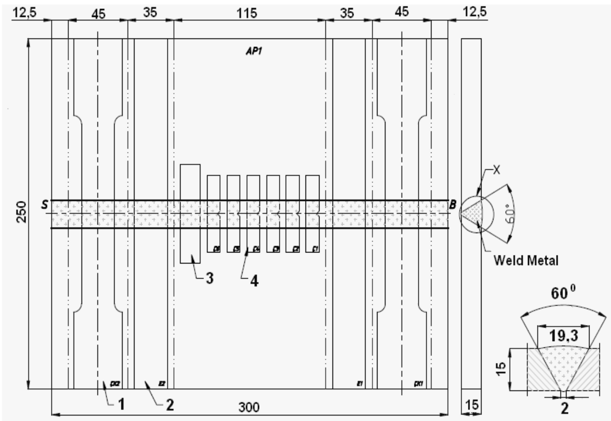

Figure 2a. The plan of cutting for mechanical tests; tensile samples (1), bending samples (2), macro and micrography samples (3) and Charpy V-Notch samples (4).

The chemical analyses of weld metals, which were welded with different type FCWs, are given in Table 2. During the welding, semi-automatic welding machine was used.

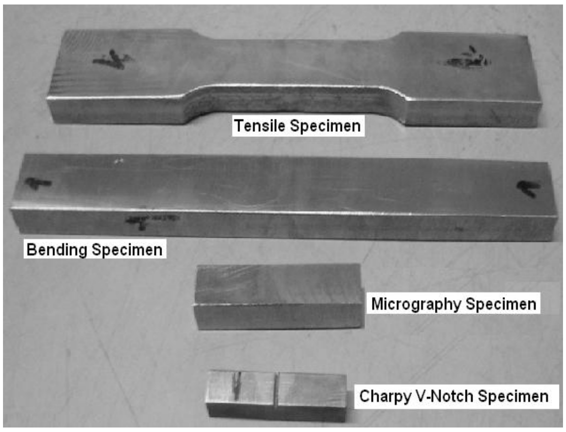

Figure 2b. Test specimens

Table 2. Chemical compositions of the weld metals and base metal

Elements	Wt. (%)						
		Rutile				Metal	Basic
	Base Metal	G Wire	K Wire	S Wire	E Wire	M Wire	B Wire
C	0.162	0.039	0.034	0.031	0.05	0.048	0.071
Si	0.293	0.428	0.73	0.39	0.51	0.589	0.55
Mn	1.37	1.29	1.28	1.09	1.22	1.35	1.464
S	0.0045	0.003	0.0074	0.003	0.02	0.024	0.010
Cr	0.041	0.024	0.024	0.021	0.03	0.021	0.030
Mo	0.013	-	0.0038	-	0.04	-	0.013
Cu	0.049	0.035	0.0271	0.068	0.02	0.061	0.060
V	0.0768	0.015	0.0216	0.014	0.02	-	0.006
Ni	0.04	0.009	0.057	0.192	0.46	0.007	0.040
Fe	97.922	98.163	97.863	98.18	97.63	99.25	98.25

Figure 3. Experimental setup by using semi-automatic welding procedure

During the welding, the voltage was held at 30 V. A constant wire-feeding rate of 8,5 m/min was maintained for all the welds .The welding current was in the range of 240-250 A. 170-190 A, 23 V and 5,5 m/min wire speed were used for the root passes. Top weld of the basic FCW is shown in Figure 4.

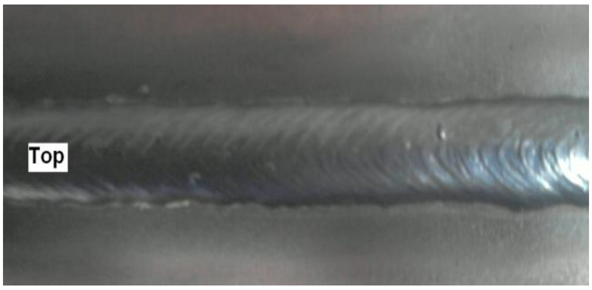

Figure 4. The top side of one of the FCWs

4. Results and Discussion

The mechanical and microstructural properties (tensile, impact toughness, bending, microhardness and micrography studies) of FCWs were tested on butt-weld metal. Test temperature has been chosen to be 20º C. The tensile strength, bending, micro hardness and impact toughness results from the butt-weld test can be seen in Table 3.

Table 3. Mechanical properties of the weld metals

FCW Types		Tensile Strength (MPa)	Bend Test	Impact Energy (J) 20°C	Impact Energy (J) - 20°C	Micro hardness (Hv)
Rutile	**G wire**	581	Ok	**80** 110 122	**32** 34 80	255
	K wire	550	Ok	**46** 61 77	**14** 18 21	258
	S Wire	550	Ok	**85** 108 132	**32** 40 46	287
	E Wire	551	Ok	**94** 104 108	**22** 30 36	306
Basic	**B wire**	603	Ok	**158** 159 166	**88** 106 110	268
Metal	**M wire**	513	Ok	**126** 132 144	**63** 71 80	272

The microstructures of the welding materials were examined by Optical Microscope after polishing and etching with Nital 10%. Figure 5 shows the macrostructure of G wire with 500 magnifications (50X). Figure 6 a, b, c, d, e, f show the microstructure of rutile, basic and metal FCWs.

Figure 5. The cross-section of the weld joints i.e. G wire

As shown in the microstructures K wire has exhibited coarser grains compared to other FCWs. E wire has also fine-grains.

Beside this, it is seen some inclusions in K wire. It must be pointed out that, O_2 and N_2 levels have not yet been carried out.

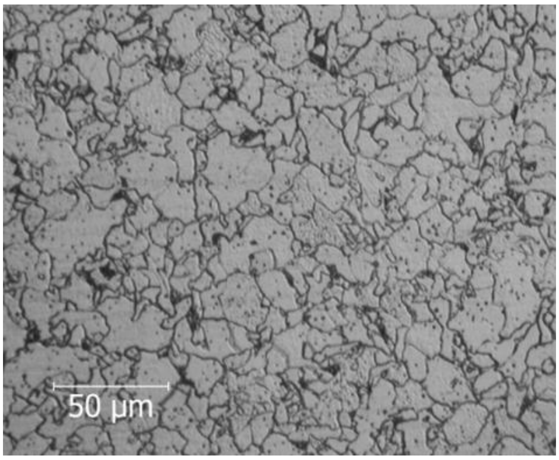

Figure 6a. **The microstructure of G (Rutile) FCW**

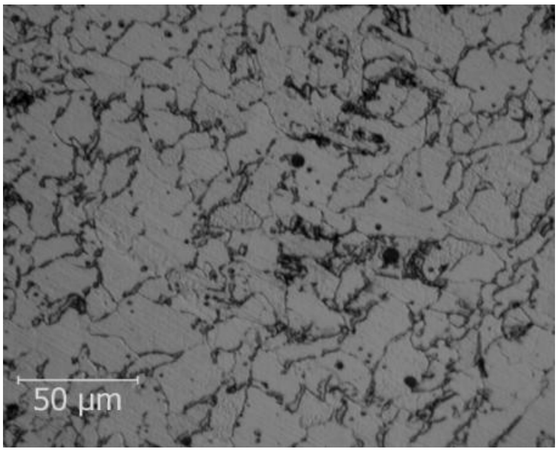

Figure 6b. **The microstructure of K (Rutile) FCW**

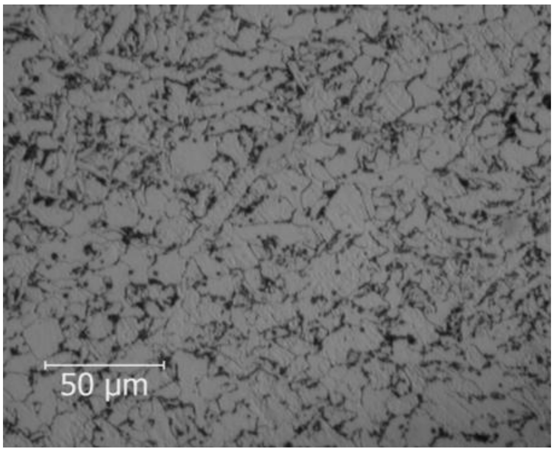

Figure 6c. The microstructure of S (Rutile) FCW

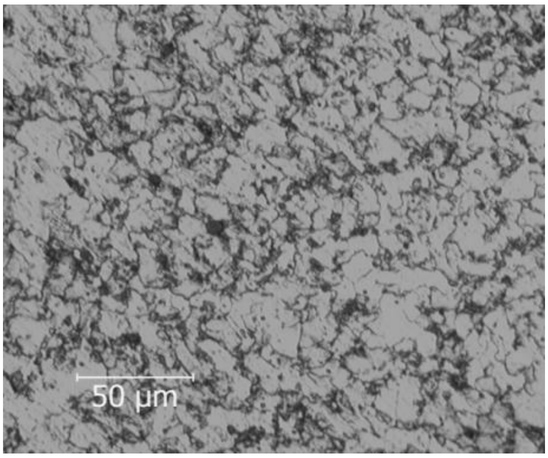

Figure 6d. The microstructure of E (Rutile) FCW

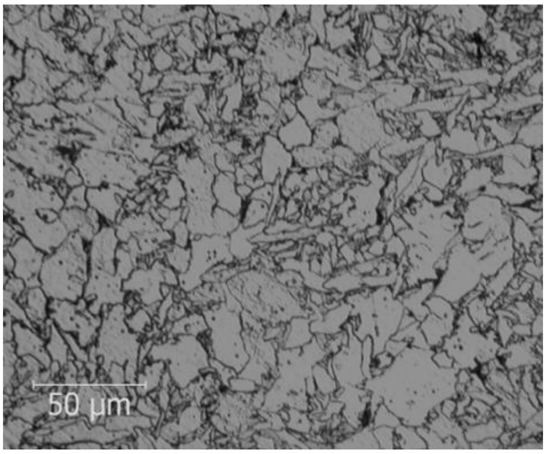

Figure 6e. The microstructure of B (Basic) FCW

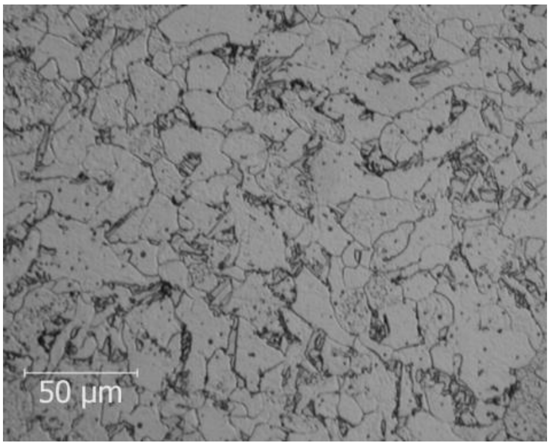

Figure 6f. The microstructure of M (Metal) FCW

Among the rutile FCWs, G wire has the highest strength with 581 MPa. The other K, S and E rutile wires have tensile strength of 550 MPa, 550 MPa and 551 MPa, respectively. Beside this, B wire which is basic FCW has the highest tensile strength of 603 MPa. As shown in the Table 3, M wire has the lowest strength value with 513 MPa. Figure 7 shows the tensile specimen ruptured from base metal of S wire and Figure 8 shows tensile strength values of the wires.

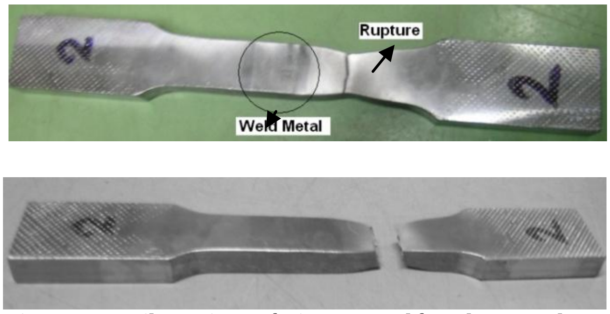

Figure 7. Tensile specimen of wire ruptured from base metal as a sample

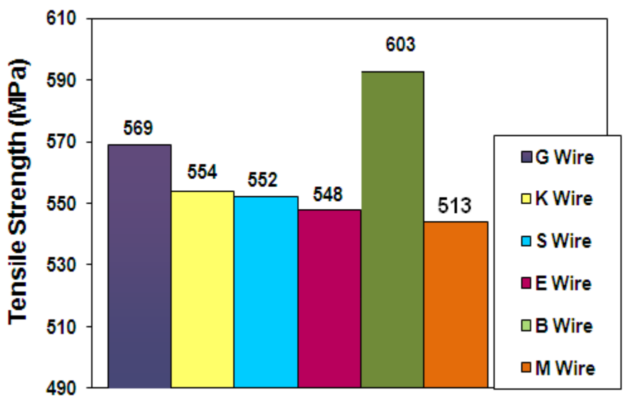

Figure 8. Tensile strength values of FCWs

Bending results were given as bendability. It has not observed any problems during the bending tests of the wires. Figure 9a shows the bending specimen and bending test machine. Figure 9b shows facial and root bend images of one of the wires.

Figure 9a. Bending specimen image and bending test

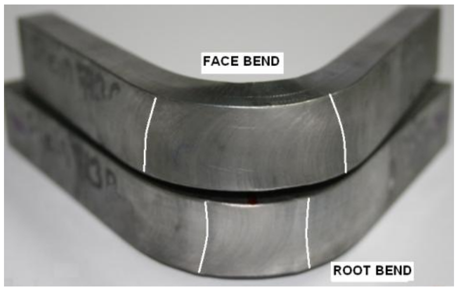

Figure 9b. Root and facial images of one of the wires

The impact toughness of the weld metals was evaluated by Charpy impact testing. Impact test results are seen in Table 1 and Figure 10 also shows the values of Charpy V-Notches parallel to the weld axis (Figure 2a) tested at -20ºC and 20 ºC for G, K, S, E, B and M FCWs.

The charpy impact values at 20ºC and -20ºC indicate that maximum toughness was obtained for B wire, with 158 joule at 20ºC and 88 joule at -20ºC. It is attributed to the low hardness showed in Table 3. E wire has also very low impact energy compared to other wires. It is known that when the hardness value increase, the impact toughness decreases. Thus, it is concluded that E wire, which has high hardness strength, shows brittle character so impact toughness decreases. E wire's fine grain size also supports its high hardness. M wire also has the second highest value with 63 joule at -20ºC.

As shown in the Table 3, K wire with 14 joule and G wire with 32 joule at -20 ºC have the lowest toughness value. It appears that the toughness values obtained one lower than the values which could be generally generated for low carbon structural steels.

In this study, st 52, 3 grade steel was used and this has caused some degree of dilution into the weld metal and has adversely affected the properties of the weld metal toughness values. However, the values obtained for the comparison reason can still be used for comparing the weldments.

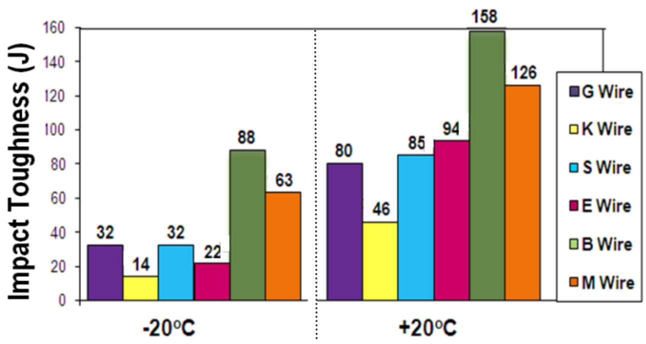

Figure 10. Charpy impact values of FCWs

Different FCWs' hardnesses were performed on the samples with a Vickers indenter with a load 300 g. force. Figure 11 shows the hardness values of FCWs. As shown in figure, E wire has the highest hardness with 306 Hv among the all FCWs.

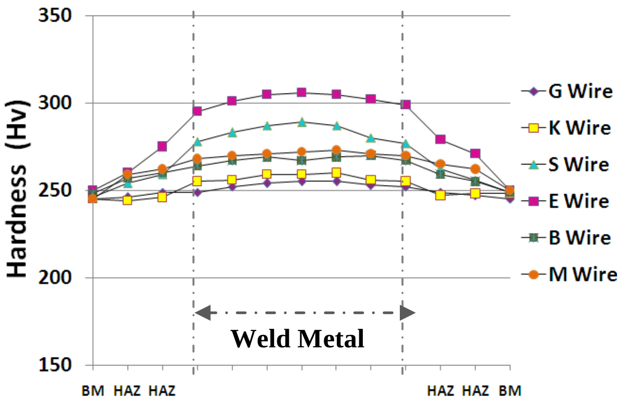

Figure 11. Hardness values of FCWs

It is evident from the data presented in Table 2, Nickel content are obtained for weld metal is high in E wire since higher nickel content supports the highest hardness values. Nickel content of E wire is about % 0.46, G, K, S, B and M wire's nickel contents are 0.009, 0.057, 0.192, 0.04 and 0.007 respectively. As reported by Kang et al. [9] for a low-Mn composition, Ni addition increases hardness without sacrificing impact toughness much whereas for a high Mn composition (1.6 % Mn), Ni deteriorates the impact toughness seriously. Furthermore, E wire has fine grain size. This property makes the wire harder. The lowest hardness value is G wire with 255 Hv and K wire's hardness value is also low compared to others. Coarse grain and inclusions in weld metal keep the G and K wire's hardness low. B and M wire's hardnesses were found approximately 270 Hv.

5. Conclusions

In this study, FCWs in rutile, basic and metal-cored types were used to produce butt-joints and the welds were investigated in terms of microstructural features and mechanical properties to find out the microstructure-property relationships. Commercially available FCWs (from different manufacturing companies and countries) were used and their results are compared with prototype wires which are currently in development.
Microstructural features were examined using optical micrograpical examinations while Charpy-V toughness was obtained both at RT and -20ºC temperatures. Tensile tests were conducted at RT.
Following conclusions could be made for the results obtained:

- For all FCWs, no major weldability problem was observed and all weld joints were produced without any weld defects.
- Tensile strength values of all weld metals were above 510 MPa while Charpy-V toughness values at RT were above 80 Joule except FC-wire K (46 Joule). This rutile K wire has also produced lowest impact toughness value (14 Joule) at -20ºC. The E wire has produced 22 Joule Charpy impact energy at -20ºC while it has exhibited highest hardness values of 306.
- The reason of low impact toughness values needs to be clarified. Hence, oxygen levels are currently examined and also new welds are being made for new sets of tests.
- The microstructure of the K wire has exhibited coarse grains while E wire assumed to have higher content and coarser non-metallic inclusions to cause lower impact toughness properties. The measurements of the oxygen levels and SEM investigations of the morphology of inclusions and fracture surfaces of the welds are in progress.

References

[1] Pitrun M., Nolan D., Dunne D., "Diffusiable Hydrogen Content in Rutile Flux-cored Arc Welds as a Function of the Welding Parameters", Welding In the World, Vol 48, n ½, 2004.

[2] Posh G., Baumgartner S., Fiedler M., "GMA-Welding of creep resistant steels with flux cored wires (FCAW): perspectives and limitations", IIW International Conference on Advances in Welding and Allied Technologies, 2009.

[3] Marie A., Zhang J. , "Self-Shielded Flux Cored Welding for Steel Constructions- Productivity and Performance", IFWT 2006.

[4] "Welding, Brazing and Soldering" ASM Handbook, Vol 6, 1993.

[5] Kannan T., Murugan N.," Effect of flux cored arc welding process parameters on duplex stainless steel clad quality", Journals of Materials Processing Technology, 2006.

[6] Liao M. T. and Chen W. J., "A Comparison of Gas Metal Arc Welding with Flux-Cored Wires and Solid Wires Using Shielding Gas", The International Journal of Advanced Manufacturing Technology, 1999.

[7] Varga T, Konkoly T, Straube H. "Investigation on microstructure, toughness, and defect tolerence of gas metal arc weld metal"., IIW Document, X-1205-90.

[8] Mukhopadhyay S., Pal T.K., "Effect of shielding gas mixture on gas metal arc welding of HSLA steel using solid and flux-core wires", The International Journal of Advanced Manufacturing Technology,29: 262-268, 2006.

[9] Coronado J.J., Ceron C.,"Fracture mechanisms of CTOD samples of submerged and flux cored arc welding", Theoretical and Applied Fracture Mechanics,2010.