Recycling of Slag to Act as Rutile in E71T-1 Type FCW

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Abstract: Rutile is non-renewable resources which are getting exhausted fast due to continuous mining for minerals required for manufacturing of fluxes. The successful development of recycling technology that allows the use of slag to partly replace the natural rutile will surely overcome the above-mentioned problems and will also prove to be very economical. Slag was processed by necessary steps and is referred to as recycled slag. Recycled slag added into E71T-1 type flux-cored wire to replace half of the total natural rutile was used in these investigations. The properties of weld metal deposited with recycled slag were investigated. The mechanical properties were satisfactory and satisfied AWS (American Welding Society) requirements. The chemical composition of weld metal was within the acceptance range of AWS specifications. Comparison of arc stability is also satisfactory. The slag can be recycled and used many times as long as its composition and particle size meet the required standard.

Keywords: Recycled slag, E71T-1 type FCW

1 Introduction

Since the development of the gas shielded flux-cored wire process, attempts have been made by technologists and researchers to increase its productivity and to decrease the welding cost. Productivity of a welding process is analogous to the efficiency of a machine. Just as it is desired to increase the efficiency of a machine, it is also aimed to raise the productivity of a welding process within available resources. Productivity may be defined as the ratio of output and input. Output means the amount of metal deposited or number of items produced and inputs are the various resources used such as electrical energy, equipment and machinery, consumable materials and labor cost, etc.

Flux used in flux-cored wire welding is converted into slag during welding which is presently a waste. About 80000 tons of E71T-1 type flux cored wire was consumed in china alone in year of 2010 which may risen to 200000-300000 tons in the following ten years. And about 70-90kg natural rutile in per ton E71T-1 type flux-cored wire. Such a large quantity of natural rutile, after welding, becomes slag waste and has to be disposed-of. Land-fill space is required to dump the slag waste. Disposal cost will increase apart from environment pollution.

Non-renewable resources such as natural rutile may get exhausted due to continuous mining. Thus slag generated during E71T-1 type flux-cored wire arc welding is a waste and imposes a number of problems. It is not possible to stop the generation of slag because it is a by-product of the weld process but slag can be reused as a flux in the same E71T-1 type flux-cored wire welding process and can partly replace natural rutile.

2 Processing of slag

Following steps were followed for processing of slag:

1. Collection of slag.
2. Crushing and sieving of slag.
3. Pre-screening of slag.
4. Electromagnetic screening of slag.
5. Fine grinding of slag.
6 Particle size and composition analysis of slag.

2.1 Collection and Crushing

Slag was collected from their dump yard for processing. It is available free of cost. Collected slag was crushed with a crusher to convert it into granular form crushed mass was then sieved to the pass through 10-mesh size.

2.2 Pre-screening and electromagnetic screening

This process is aimed to remove splash metal mixed in the slag.

2.3 Fine grinding and analysis

This process is aimed to convert slag into appropriate particle size powder, and detect whether the ingredients is acceptable.

3 Physical and chemical properties of the multiple recycled slag powder

3.1 Chemical composition

We collect four types which are no recycled, recycled one time, two times and three times, we name them R1, R2, R3 and R4.The chemical composition of recycled slag are in the following table:

Table 1 Chemical composition of recycled slag powder

	TiO_2	MnO	Al_2O_3	SiO_2	MgO	Fe_2O_3
R	49.1401	13.5323	5.0634	8.1556	10.7165	5.3471
R	48.2230	14.1501	5.7714	9.1225	11.5322	6.6641
R	47.3936	14.0227	6.2130	10.0094	12.4325	7.9271
R	46.3558	14.6102	6.6784	10.8912	12.9991	8.2281

3.2 Linear expansion coefficient

Linear expansion coefficient is closely related to slag detachability, appropriate linear expansion coefficient will bring excellent slag detachability.

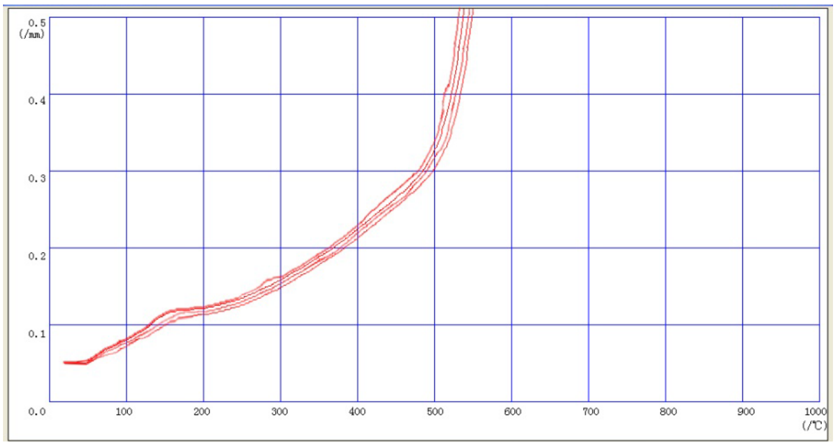

Figure 1 Linear expansion coefficient test results

4 Weld qualification tests

The chemical content of the deposited metal is in the following table:

Table 2 Chemical Composition of deposited metal (wt. %)

	C	Si	Mn	Ni	S	P	Mo	V	Ti
R1	0.045	041	1.41	0.01	0.007	0.012	0.001	0.01	0.054
R2	0.049	0.44	1.39	0.01	0.007	0.011	0.001	0.02	0.049
R3	0.052	0.46	1.48	0.01	0.007	0.012	0.001	0.03	0.053
R4	0.055	0.50	1.48	0.01	0.007	0.011	0.002	0.01	0.051

From Table 2, we can see the chemical composition of the deposited metal all satisfied AWS specification. Once acceptable chemical composition of weld metal was achieved with recycled slag, following tests were performed to ascertain its performance: Arc stability; Tensile and impact testing; Slag detachability and visual inspection; all-position weld ability and Feeding performance.

4.1 Arc stability

Using Hanover arc stability analyzer Analysis the stability of welding current and welding voltage, results as follows:

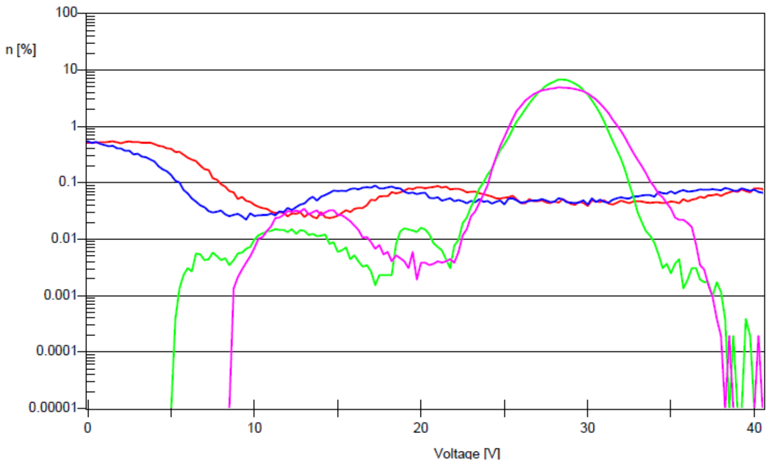

Fig 2. Test result of welding voltage stability

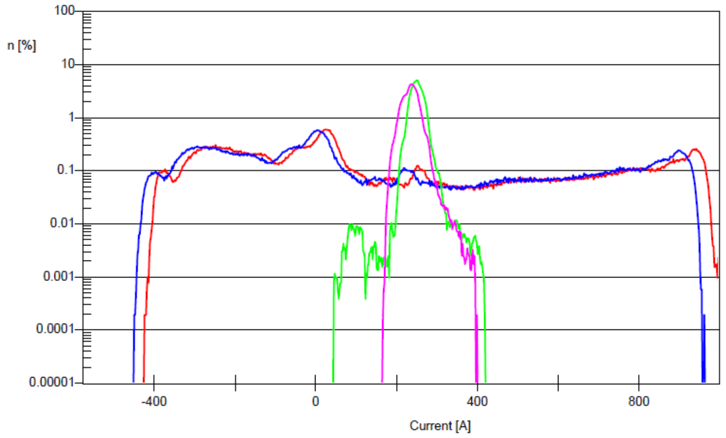

Fig 3. Test result of welding current stability

4.2 Mechanical properties test

Mechanical properties test results are in table 3.

Table 3 Mechanical properties of deposited metal (Mpa)

	Tensile	Yield	Elongation	Impact（-20℃）	[HD]
R1	560	480	26.5	117	4.50
R2	565	475	27	122	4.11
R3	535	482	27	108	3.91
R4	555	481	26.5	99	4.22

4.3 Slag detachability

According to AWS A5.20, slag detachability of R1, R2, R3 and R4 are showed in Table 4.

Table 4 Slag detachability test results

	R1	R2	R3	R4
First layer	62.31％	59.23％	55.14％	49.92
Number of hitting	5	5	5	5

Second layer	100％	100％	92％	81.30％
Number of hitting	1	1	1	1

4.4 Feeding performance

Feeding performance of R1, R2, R3 and R4 are showed in Figure 1 and Table 5.

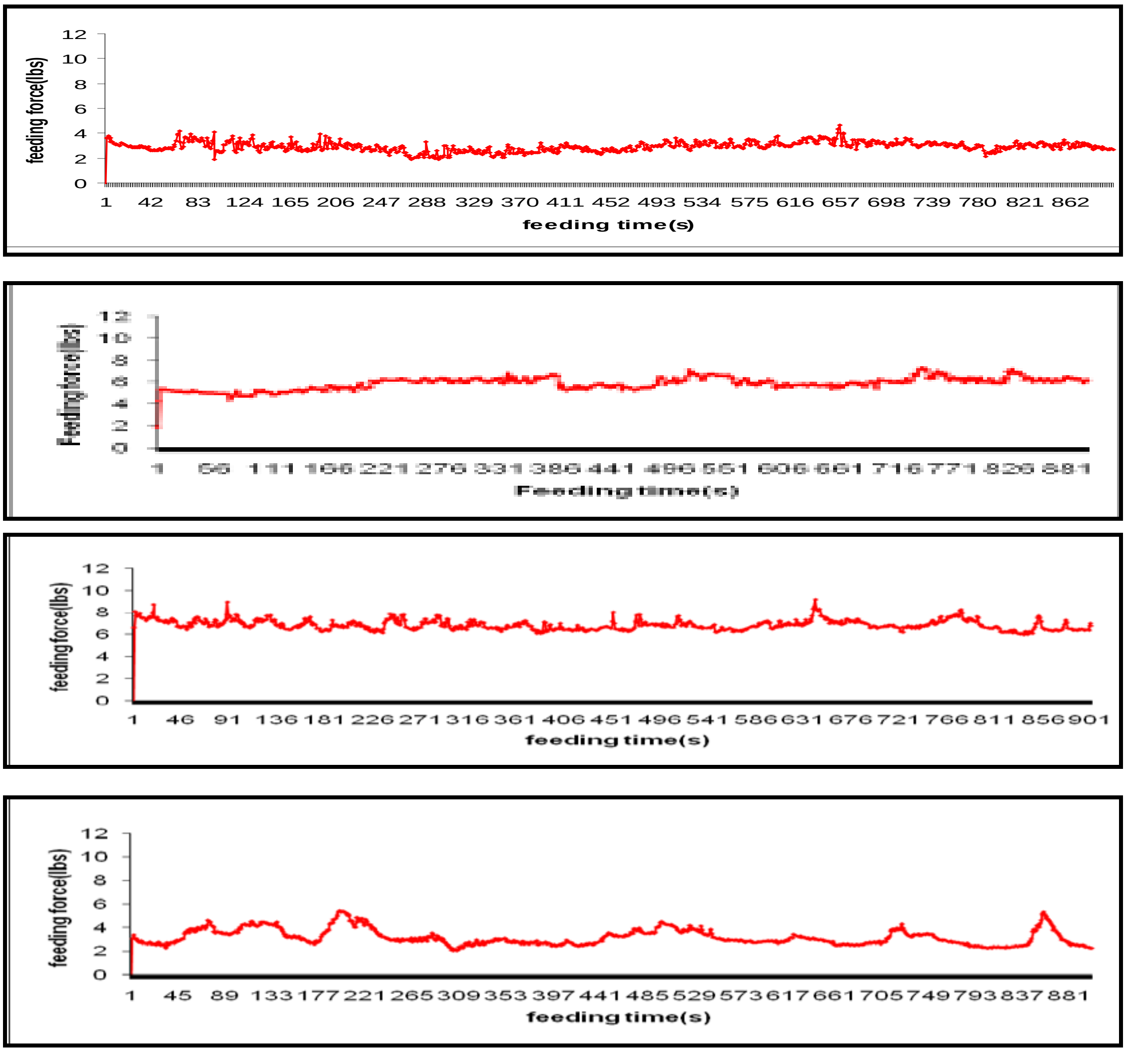

Fig 1 Results of feeding performance test

Table 5 Results of feeding performance test

	Wire Feed Speed (inch/min)	Voltage (Volt)	Average Feeding Force (lbs)	Feeding Force Instability (lbs)	Maximum Feeding Force (lbs)	Average Welding Current (Amps	Welding Current Instability (Amps)
R1	400	29	6.861169	0.442361	9.130311	224.655155	5.286211
R2	400	29	2.961269	0.422361	4.651762	240.365661	5.132232
R3	400	29	5.877048	0.528921	7.298007	207.52953	7.110241
R4	400	29	3.159878	0.670392	5.451662	239.450536	5.107538

5. Analysis of results

5.1 Chemical composition of recycled slag powder

From table 1 we can see that with the mumble of the cycles increased, the proportion of TiO_2 reducing and the proportion of other oxides increasing. As we know, with the decrease of TiO_2, the welding performance of the flux-cored wire may become poor, but we can adjust the formulation of the flux to compensate. With the proportion of other oxides increasing, deoxidation capacity of weld slag become poor, so it is necessary to restrict the recycling times of the slag. We believe that the oxygen content of the weld will not beyond our acceptance within three times recycle.

5.2 Linear expansion coefficient

Linear expansion coefficient test show that R1, R2, R3 and R4 all have satisfied linear expansion coefficient which is conducive to the improvement of slag detachability.

5.3 Chemistry of weld metal

Chemical composition of weld deposited metal along with AWS requirement is shown in Table 2.Chemical composition of R1shows lesser amount of carbon (0.045%), silicon (0.41%) and manganese (1.41%). As there were no deoxidizers available in the slag, which have already been exhausted, and due to presence of oxygen, the above elements might have been lost by oxidation. But R1, R2, R3 and R4 are all within the acceptable range of AWS specification.

5.4 Mechanical properties

The results of all weld tensile and impact tests of all the test assemblies as well as AWS requirements are shown in Table.3.Mechanical properties test results show shat with the mumble of the cycles increased, mechanical properties of deposited metal become poor, but also satisfied AWS standard, diffusible hydrogen content of the four types deposited metal are in low level.

5.5 Arc stability

Fig.2 show the arc voltage stability of R1, R2, R3 and R4, Fig 3 show arc current stability of R1, R2, R3 and R4.R1 and R2 have larger arc voltage density and arc current density compare to R3 and R4.This shows that R1 and R2 have more stable arc than R3 and R4.In general, R1, R2, R3 and R4 all have satisfied weld arc stability, and meet our requirements.

5.6 Slag detachability

From Table 4, we can see that R1, R2, R3 and R4 are all have satisfied slag detachability.

5.5 Feeding performance

As shown in Fig and Table 5, feeding force instability is an important evaluation criteria of feeding performance. In general, if feeding Force Instability is below 1, we believe that feeding performance is good.R1, R2, R3 and R4 are all have excellent feeding performance.

6 Conclusions

1. E71T-1 type flux-cored wire welding slag can be recycled after necessary modification.

2. Weld metal chemistry achieved with recycled slag was within the acceptable range of AWS specifications.

3. The mechanical properties of weld metal deposited with recycled slag were acceptable by AWS A-5.20.

4. Arc stability and slag detachability both were good with the recycled slag.

References:

[1] T.Kasuya, R.Shimura, Y.Totsuka.Annealing flux cored wires and the reduction of diffusible hydrogen[C]. Annual Assembly 2009 in Singapore, 2009, II-1708r1-09 (II-A-201r2-09).

[2] M.Matsushita, S.Liu. Hydrogen control in steel weld metal by means of fluoride addition in welding flux [J].Welding research supplement, 2000, 10:295-303.

[3] T.Hidaka, S.Yoshitomi. Influence of Oxides on Microstructure and Notch Toughness of Weld Metal with Flux-cored Wires for High Strength Steel[C]. Annual Assembly 2009 in Singapore, 2009, II-1710-09 (II-A-202r1-08)

[4] L.Dangs. A new flux-cored wire [P]. USA, United States Patent: 5540127.2001-09-22.

[5] K.Nikodym, A.Franklin. Weld wire with enhanced slag removal [P].USA, United States Patent: 20030178402.2003-11-14.

[6] Y.Kevin. Core flux composition for flux-cored wires [P]. USA, United States Patent: 4339286.1999.

[7] G.Yoshiya, L.Sakai. Flux-cored wire for gas-shield arc welding with low fume [P].USA, United States Patent: 4510374.1985-04-09.

[8] F.Stanley. New generation of cored wires creates less fume and spatter [J].Welding Journal, 1995, 74(12):45-49