Novel Production of Granular Flux for Welding Carbon Steel Plates

Dr. Basim A. Abdul Hayi
Research and Development Department /The State Company for Iron and Steel
Email: basim.11@yahoo.com

Abstract
This study was carried out to produce granular submerged arc welding flux type MS (MnO-SiO$_2$-CaO) for welding plate grad X 52 thickness 10.4 mm by using welding wires type S2 and S2Mo diameter 4 mm. The quality of the prepared flux was compared with the Chinese flux by mechanical and chemical analysis. Moreover, the prepared flux was used to weld carbon steel plate to evaluate its efficiency compared with the Chinese flux. The results show that there is a possibility to use prepared flux for welding carbon steel plates as the certification and approval that issued from Specialist Institute of industrial engineering in Iraq and from SGS in Dubai. There is an improvement in the welded zone structure which lead to refining the structure and produced fine perlite which lead to improve the mechanical properties of welded metal. The comparison between the tensile strength and yield strength value show increase an 107.59 % and 111.91 % respectively from Chinese flux. Moreover, there is an easily removal glassy slag behavior in the absent of TiO$_2$ which is normally used in the commercial flux.

1. Introduction
Submerged Arc Welding (SAW) is welding process that widely used for automatic welding processes which was introduced in 1930s. It is used to provide high qualities through controlling the variables of welding process such as current, voltage, welding speed and electrodes stick out. The process has different advantages such as high productivity, capability to weld and good welding for manufacturing pressure vessels, pipes, and heat exchangers, therefore it becomes a natural choice in fabrication industries although is a very complex physical and chemical reactions. Lincoln electric company (1953) had modified the flux composition by fusion anhydrous sodium or potassium silicate or both as a binder with flux material [1]. Moreover, Biggs Trevor Edward (1955) studied the effect of adding titanium oxide with percentage of 18 – 50 % and manganese oxide of 10 – 30 % with silicon dioxides of 20 – 40 % on the quality of flux. They found the quality of welding was improved [2]. On the other hand, Leonidas K et al. (1959), improved the compositions of granular flux by using basic oxides with the flux materials such as manganese, titanium, magnesium and aluminum [3]. Moreover, Crockett Dennis D. and Weaver Robert J (1982) had predicted the effect of aluminum oxide and silicon dioxide percentages in the alkalinity flux increase the penetration of welding [4]. Melfiteresa et al. (1988) used 10 – 30% Al$_2$O$_3$ from the total mix, whereas the other researchers have used 20 - 50 % to obtain low oxygen in the welding pool with low pollution and high depth weld [5]. On the other hand, Crockett Dennis D. et al. (1988) suggested that the reaction of agglomerated submerged arc welding flux by mixing the basic
and acidic oxides improved the weld properties by using the percent of calcium fluoride from 11 – 25 % and titanium oxide from 18 – 30 % from the total weight of the ingredients flux [6]. Kumanan S, and coworkers had predicted the optimal process parameters for SAW process by using mathematical model with Taguchi technique and regression analysis [7]. In addition, Dalgobind Mahto and Anjani Kumar, (2010) found that there was a possibility to recycle the waste slag [8]. On the other hand, Vinod Kumar et al (2010) developed agglomerated acidic flux with wasted flux dust to reduce the cost and pollution that happened due to transportation and handling [9]. Moreover, Dae-Won Cho et al. (2013) suggested a new way to describe the molten pool flows in single-electrode SAW process by using three-dimensional simulation of heat transfer in the molten slag as heat input [10]. Aditya Kumar, (2015) predicted the optimal condition for flux constituents for weld bead width in flux system of submerged arc welding by using Taguchi analysis[11].

In this research, sodium silicate and potassium silicate were used as a binder to produce granular welding flux material by changing the ratio of ingredients of basic and acidic oxides without using titanium oxide.

2. Experimental Work
1. Materials

Different materials have been used to prepare welding flux as shown in Tables 1- 4.

**Table 1**: Specification of acidic and basic oxides

| Oxide   | Classified | Melting point | Concentration % Min |
|---------|------------|---------------|---------------------|
| SiO₂    | Acidic     | 1713          | 98                  |
| CaO     | Basic      | 2590          | 95                  |
| Al₂O₃   | Neutral    | 2045          | 90                  |
| CaF₂    | Acidic     | 800           | 90                  |
| MgO     | Basic      | 2800          | 95                  |
| MnO₂    | Basic      | 1240          | 80                  |

**Table 2**: Specification of liquid binder

| Binder  | % Na₂O or % K₂O | % SiO₂ | % SiO₂ Na₂O or K₂O |
|---------|-----------------|-------|--------------------|
| Na₂SiO₄ | 12              | 30    | 3.5:1              |
| K₂SiO₄  | 15              | 35    | 4:1                |

**Table 3**: Chemical composition of plate grad 52 X.

| C%     | Si%     | S%      | P%      | Mn%     | Ni%     | Cr%     | Mo%     |
|--------|---------|---------|---------|---------|---------|---------|---------|
| 0.1948 | 0.298   | 0.0014  | 0.1085  | 1.569   | 0.0340  | 0.0243  | 0.05629 |
| Cu%    | V%      | W%      | Ti%     | Sn%     | Al%     | Pb%     | Zn%     |
| 0.0412 | 0.0035  | 0.0003  | 0.0022  | 0.0023  | 0.0342  | 0.0087  | 0.0016  |
| Fe%    |         |         |         |         |         |         |         |
| 97.7115|         |         |         |         |         |         |         |
Table 4: Chemical composition of Chinese flux type SJ 901 (GB/T 5293-99)

| Impotent flux | SiO$_2$+TiO$_2$ | CaO +MgO | Al$_2$O$_3$+MnO | CaF$_2$ |
|---------------|----------------|-----------|-----------------|--------|
| CS            | 15-35          | 20-30     | 20-30           | 5 - 15 |

2. Flux Preparation

In this work, different percentages of raw materials such as SiO$_2$, MgO, MnO$_2$, CaO, CaF$_2$ and Al$_2$O$_3$ are crushed and added to potassium and sodium silicate solution. They mixed for 10 minutes and passed through a 10 mesh screen to form small pallets. Then the pallets were dried in the air for 24 hours and baked in the muffle furnace with temperature in the range of 650-700 °C for 10-15 minutes. It is cooled and crushed to subsequently sieved and keep in air tight bags. The chemical compositions of prepare granular welding flux is shown in Table 5 and the welding conditions shown in Table 6.

Table 5: Chemical composition of flux type (MS) as (BI = 1).

| Prepare flux | SiO$_2$ + CaO MgO | Al$_2$O$_3$+MnO + CaF$_2$ |
|--------------|-------------------|---------------------------|
| MS           | 35 - 40           | 20 - 35                   |

Table 6: Submerged arc welding parameters.

| Parameter            | Units       | Symbol | Value      |
|----------------------|-------------|--------|------------|
| Open circuit voltage | Volts       | V      | 30 ± 2     |
| Current              | Ampere      | I      | 400 ± 30   |
| Travel speed         | mm/min      | S      | 120        |
| Pull the arm machinist | mm/min   | P      | 5          |
| Nozzle to plat distance | mm        | N      | 24         |

3. Results and Discussions

3.1 Chemical Analysis

The chemical compositions of welded zone for the plates that welded by using Chinese and prepared welding flux are shown in Table 7 and 8. They were examined by using 3460 MA spectrophotometer device. The welding process was done by applying two types of welding wire with diameter of 4mm according to AWS A5.17: EM 12 or DIN EN 756: S2 and AWS A5.23: EA1 or DIN EN 8557: S2Mo.

Intensive experimental work as shown in Table 7 and Table 8 has been made to change the oxides percentage of composition of prepare flux by selecting the class of basic or acidic oxides with welding plates. These parameters are kept constant throughout the experimentation and analysis for the composition that was made for welded zone metal and plates metals to obtained
the approximate composition of base metal as shown in Table 3. Successful estimations for percentage of the total mix materials specification are shown in Table 8.

### Table 7: Chemical composition of carbon steel welded plates by using Chinese flux

| C%  | Si%  | S%  | P%  | Mn%  | Ni%  | Cr%  | Mo%  |
|-----|------|-----|-----|------|------|------|------|
| 0.1200 | 0.3044 | 0.0116 | 0.0170 | 1.2620 | 0.0320 | 0.0215 | 0.2252 |
| Cu% | V%  | W%  | Ti%  | Sn%  | Al%  | Pb%  | Zn%  |
| 0.0396 | 0.0069 | 0.0008 | 0.0017 | 0.0019 | 0.0050 | 0.0089 | 0.0016 |
| Fe% | 97.936 |

### Table 8: Chemical composition of carbon steel welded plates by using prepare flux

| C%  | Si%  | S%  | P%  | Mn%  | Ni%  | Cr%  | Mo%  |
|-----|------|-----|-----|------|------|------|------|
| 0.9501 | 0.3124 | 0.0120 | 0.0155 | 1.2130 | 0.0120 | 0.0313 | 0.3253 |
| Cu% | V%  | W%  | Ti%  | Sn%  | Al%  | Pb%  | Zn%  |
| 0.0336 | 0.0056 | 0.0006 | 0.0027 | 0.0023 | 0.0060 | 0.0079 | 0.0015 |
| Fe% | 98.010 |

3.2. Mechanical Test

Welded zone metal has higher tensile strength and yield strength than the base metal plate due to the finer microstructure that forms during cooling of the heat-affect zone.

#### 3.2.1 Tensile strength

The tests were carried out according to the ASTM A370 standard and the results of tensile strength were obtained shown in Table 9 and behavior shown in Figures 1-3 and Figures of samples from 4-6 and bend in Figure 7. The results were compared with the results of Chinese flux.
Table 9: Mechanical properties of plates welded by using Chinese and prepare flux

| Sample NO. | Dimension mm | Area $\text{mm}^2$ | Load Kg | Yield Kg $/\text{mm}^2$ | Load Kg | Tensile stress Kg $/\text{mm}^2$ | Bend | Elongation % | Remarks |
|------------|--------------|---------------------|---------|-------------------------|---------|-------------------------------|------|--------------|---------|
| Plates grade X52 | 38×10.3 | 391.78 | 16100 | 41.09 | 22400 | 57.16 | OK | 20 |
| welded Chinese flux | 38×10.3 | 391.78 | 18300 | 46.7 | 22600 | 57.68 | OK | 18 |
| welded Chinese flux | 38×10.3 | 391.78 | 18200 | 46.45 | 23200 | 59.2 | OK | 17 |
| welded prepare flux | 38×10.3 | 391.78 | 18400 | 46.25 | 22500 | 57.43 | OK | 18 |
| welded Prepare flux | 38×10.3 | 391.78 | 18200 | 46.45 | 22500 | 57.43 | OK | 17 |

Figure 1. Behavior of tensile strength for plate grad X 52
Figure 2. (B) plate weld with Chinese flux

Figure 3. (C) plate weld with prepare flux

Figure 4. Tensile sample (A) Plates grade X52
3.2.2 Hardness

The tests were done according to the ASTM A370 standard and the results are shown in Table 10.
Table 10: Hardness for welded plates with Chinese and prepare flux

| Sample NO. | Metal                  | Heat affected zone | Weld  |
|------------|------------------------|--------------------|-------|
|            | Read 1 | Read 2 | Read 3 | Avg  | Read 1 | Read 2 | Read 3 | Avg  | Read 1 | Read 2 | Read 3 | Avg  |
| Plates welded with Chinese flux | 70.9   | 76.3   | 77.8   | 75   | 86.1   | 83.8   | 86.9   | 85.6 | 78.5   | 87.8   | 86.6   | 88.8 |
| Plates welded with prepared flux  | 75.5   | 82     | 80     | 79.5 | 79.5   | 80.8   | 79.3   | 79.5 | 80.4   | 83.1   | 81.7   | 81.7 |
| Plates welded with prepared flux  | 76     | 78.5   | 84     | 79.5 | 89.5   | 85.3   | 83.5   | 86.0 | 84.3   | 85.2   | 90.5   | 86.6 |

3.2.3 Impact test

The tests were carried out according to the ASTM A370 standard and the results were shown in Table 11 and Figure 8.

Table 11: Impact test samples

| Sample NO. | Metal                  | Weld  |
|------------|------------------------|-------|
|            | Reading (1) | Reading (2) | Average | Reading (1) | Reading (2) | Reading (3) | Reading (4) | Average |
| Plates grade X52 | 213.6   | 214.6   | 214.1  |         |         |     |         | |       |
| Plates welded Chinese flux | 133.2   | 154.8   | 123.4   | 119.5   | 132.7  |       |         | |       |
| Plates welded prepare flux  | 103.8   | 96.0    | 72.5    | 96.0    | 92.07  |       |         | |       |
Figure 8. Impact test for welded plates with (A) Chinese flux and (B) prepare flux

3.2.4 Radiographic Test

Intensive tests of X-ray radiographic was used to detect defects in the samples were carried out by using a copper target and a Ni filter producing Cu K\(\alpha\) radiation (\(\lambda = 0.15418\) nm) was employed with working voltage and current of 40 kV and 150 mA, respectively. The results show no defect when using prepare flux welding plates as shown in Figure 9.

Figure 9. X-ray pattern for stander total mix prepare flux

3.2.5 Microstructure:

The microstructure of welded plates that welded by using prepare flux and Chinese flux have been tested by using optical microstructure device for base metal, heat affected zone and welded zone (fusion zone) as shown in Figure 10 - 11. The results show that there are dendritic structures of solidification in welded zone and recrystallization fine grains in HAZ. However, in base metal the deformation of grain structure of lamellar ferrite and pearlite were appeared.
Figure 10: Microstructure welding zone sample that was welded using prepare flux.

Figure 11. Microstructure welding zone sample that was welded using Chinese flux
1. Evaluation of prepare flux as made

The evaluation of prepare flux in Instituted especially industrial engineering Baghdad/Iraq and SGS in Dubai.

The results were obtained by specialized industrial engineering institute in Baghdad to examine the prepared flux and certificated to be equivalent to international standard of flux which equal to AWS SF A5.17-80: F6A4 – EM12, F6A6 –EM12K, ASW SF A5.23-80: FA4 – EA1, DIN 32522: BFB 165 DC 7M, Grade X60 API – 5L, Ok FLUX 10.61, Autrod 12.24 and Bulk density: 0.67 gm/cm³. It is equal to Ok Flux 10.61.

Whereas, SGS was evaluated the prepared flux according to equivalent to be F64.EM12 and F76.EA1. The results shown in Tables 12 and 13; In addition, Figures as 12-15. Show samples prepared and tested. The results were compared with AWS SF 5.17 and AWS SF 5.23 standard results.

Figure 12. Preparation samples plates welded by submerged arc welding prepare flux with wires EM12 (L-61) and EA1 (L-70)
Figure 13. (A) Joint configuration and location of test specimen. Dalgobind Mahto and Anjani Kumar, (2010)

Figure 14. (B) Location of all weld metal tension and impact test specimen. Dalgobind Mahto and Anjani Kumar, (2010)

Figure 15. Samples before test
Table 12: Results of tension and impact test of prepare flux AWS SF 5.17, with wires EM12 (L-61)

| Heading                  | YS Mpa | UTS Mpa | % Elong. | Charpy Impact J (at 0°C) |
|--------------------------|--------|---------|----------|--------------------------|
| AWS 5.17 Requirement     | 330    | 415     | 22       | Ref. Standard AWS B 4.0-1998 Average ≥ 27 |
| Prepared Flux Analysis   | 332    | 423     | 35.5     | 114.20                   |

Table 13: Results of tension and impact test of prepare flux AWS SF 5.23, with wires EA1 (L-70)

| Heading                  | YS Mpa | UTS Mpa | % Elong. | Charpy Impact J (at 0°C) |
|--------------------------|--------|---------|----------|--------------------------|
| AWS 5.23 Requirement     | 400    | 480     | 22       | Ref. Standard AWS B 4.0-1998 Average ≥ 27 |
| Prepared Flux Analysis   | 414    | 495     | 36.5     | 126.75                   |

4. Conclusion
1. Flux product is a cheaper compared with the Chinese flux materials which is less than half of the Chinese flux cost.
2. The absence of using of titanium oxide during the preparation process comparing to the most conventional welding fluxes types use.
3. The glassy welding slag which is lead to quenching and tempering the weld zone by decrease the excessive heat that case undercutting effect as in the Chinese flux.
4. Increase the impact strengths value from (124 – 135) J with the increased the percentage 108.86 % from plate using grade X 52.
5. Increase the hardness value of welded zone by percentage of 106.36 % comparing with hardness of using Chinese welding flux.
6. Increase the tensile strength and yield strength value by 107.59 % and 111.91 % respectively.

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