Flux Classification

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Keywords: physicochemical properties ; calphad ; material design

1. Introduction

The atmosphere is primarily composed of N_2 and O_2. When the weld pool is exposed to the atmosphere, it tends to combine with O and N elements. The formation of oxides in the weld metal (WM) varies under different circumstances. The oxide layer on the metal surface may prevent the joining of the two workpieces together [1]. Additionally, an excess of O in the WM may incur unexpected problems, such as enhanced porosity, reduced toughness, and depreciated hardenability [2]. When N is absorbed by the molten metal, its presence exerts adverse impacts on the mechanical properties unless it combines with a strong nitride-forming element [3].

Submerged arc welding (SAW) is an automatic welding process particularly suitable for the joining of thick workpieces [4]. Instead of permitting the air to exist between the base metal (BM) and the electrode, the arc cavity and weld pool are submerged under a layer of granular flux [1]. **Figure 1** illustrates the diagrammatic sketch of SAW. The SAW process is unique due to the permission of high welding currents in the absence of a violent arc [5]. Therefore, high deposition rates and welding efficiencies are expected when SAW is applied [6]. Flux is defined by the American Welding Society (AWS) as a material used for preventing, dissolving, or facilitating the removal of oxides and other undesirable surface substances [7].

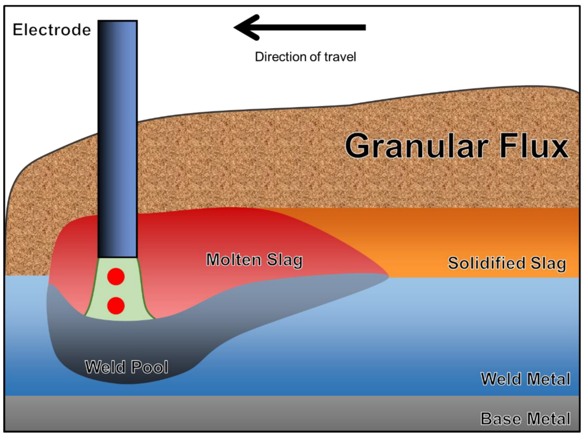

Figure 1. Diagrammatic sketch of the SAW process.

2. Flux Classification

Flux is a granular material that primarily consists of oxides and CaF_2 [4]. The manufacturing method plays an important role in shaping the flux features. In this section, the flux classification methods are documented to detail the manufacturing methods and to introduce an important definition widely applied in the field of flux design, namely, flux basicity.

2.1. Manufacturing Methods

2.1.1. Fused Flux

The fused flux is manufactured by melting the raw materials in a furnace at 1500 °C or higher. The melt is stirred for homogenization and then solidified by water or a metal plate. At last, the solidified fragments are screened to a proper size range [2].

2.1.2. Bonded Flux

Raw materials for producing the bonded flux are dry mixed and then combined with an addition of potassium silicate or sodium silicate at approximately 300 °C or higher. The resulting mixture is then dried at a relatively low temperature and screened [3].

2.1.3. Agglomerated Flux

The agglomerated flux is similar to the bonded flux except that it is bonded at a temperature higher than 760 °C. **Table 1** summarizes the advantages and disadvantages of fused flux, bonded flux, and agglomerated flux [8].

Table 1. Advantages and disadvantages of fused flux, bonded flux, and agglomerated flux [8].

Flux	Advantages	Disadvantages
Fused flux	**Excellent homogeneity. Nonhygroscopic Recyclable**	**Inability to add deoxidizers and ferroalloys**
Bonded flux	**Permit the extensive use of deoxidizers and ferroalloys**	**Tendency to pick up moisture Require better protection during storage**

2.2. Basicity Assessment of SAW Flux

The most widely accepted BI was proposed by Tuliani et al. [9], as shown in Equation (1) (wt pct). The oxygen-free compound is CaF_2. The basic oxides include CaO, CaF_2, MgO, Na_2O, K_2O, MnO, and FeO, while the acid oxides include SiO_2, Al_2O_3, Cr_2O_3, TiO_2, and ZrO_2. Fluxes can be classified into three categories: acidic (BI < 1.0), neutral (1 ≤ BI < 1.2), and basic (BI ≥ 1.2) [2]. Tuliania et al. [9] have regressed the tendency of O level as a function of BI, as shown by Equation (1). Eagar [10] then removed CaF_2 from Equation (1) since he assumed that CaF_2 should be considered as a neural component. Generally, the predicted O content decreases with increasing BI and then reaches a constant [2]. From the empirical relationship between BI and WM O content, the flux's O potential can be estimated, as shown in **Figure 2** [9][10][11].

$$\mathrm{BI} = \frac{\mathrm{CaO} + \mathrm{CaF_2} + \mathrm{MgO} + \mathrm{K_2O} + \mathrm{Na_2O} + \mathrm{Li_2O} + 1/2(\mathrm{MnO} + \mathrm{FeO})}{\mathrm{SiO_2} + 1/2(\mathrm{Al_2O_3} + \mathrm{TiO_2} + \mathrm{ZrO_2})} \quad (1)$$

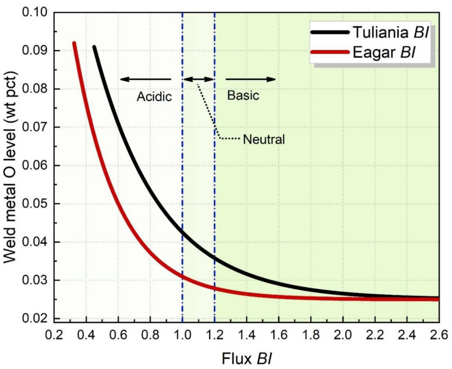

Figure 2. Predicted WM O level as a function of flux BI [9][10][11].

BI definition is a controversial subject. Much research has been performed in this area, but most of it has been empirical in nature [3]. Numbers of controversy centers around the BI definition subject to SAW and how different components in a flux contribute to the flux behavior [12]. Palm et al. [13] also pointed out that there is a lack of fundamental basis regarding the correlation between BI and flux O potential.

2.3. Workflow Methodology

Submerged arc welding is a metallurgical process with a temperature as high as 2000 °C, which puts forward techniques and scientific challenges for flux design. An understanding of the physicochemical properties of flux and slag, especially under high temperatures, is essential to optimize the flux formula.

The overall flow diagram with respect to workflow methodology is plotted in **Figure 3** for better readership. As shown in **Figure 3**, the development of the flux in submerged arc welding experiences three stages: the binary system, ternary system, and multicomponent system. Within this framework, the flux design stages have been documented and reviewed in detail. The design principles for fluxes are evaluated, and the limitations of each flux are elucidated. Furthermore, researchers explain and analyze the scientific significance of the designed fluxes upon the development of the welding metallurgy, especially in terms of the thermodynamic models developed to aid in the flux design. As last, the application of Calphad technology in welding metallurgy has been summarized.

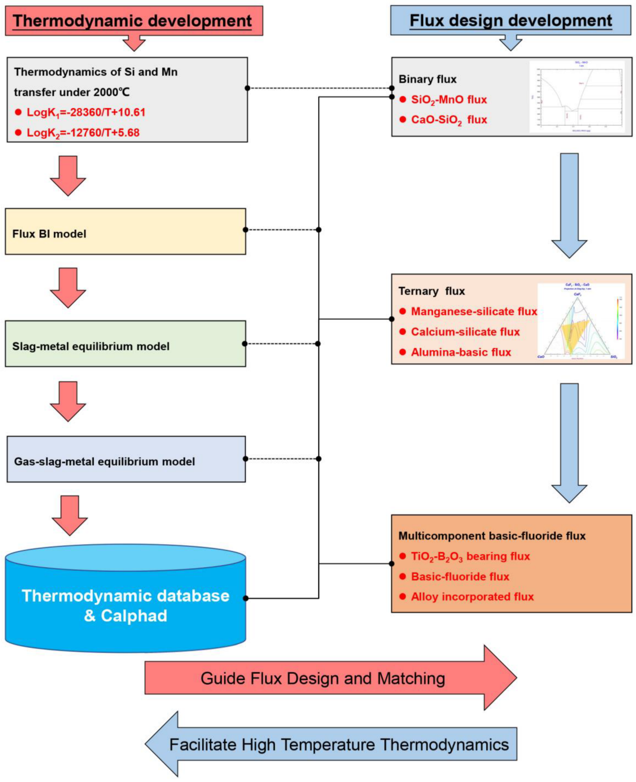

Figure 3. Flow diagram with respect to workflow methodology.

The review above has demonstrated that the thermodynamics is vital for the development of the flux design, while the ongoing flux design requirement further foster the research in thermodynamics subject to high temperature. From the perspective of technology, the measurement of thermodynamic data under the temperature of 2000℃ is impossible[4]. Therefore, to further improve the thermodynamic calculation accuracy, the development of the thermodynamic data under high temperature is anticipated.

Then, a significant feature of SAW concerns the chemical interaction between plasma and the alloy element. For intendance, it has been extensively established that the element loss of Mn is favored during SAW process, and the sole consideration of thermodynamic equilibrium is insufficient to explain such loss. Therefore, a deeper understand of the interconnection between plasma and welding consumables is required.

The development of new fluxes for submerged arc welding is ongoing. The present study provides a revealing insight into the flux design at various stages from the thermodynamic perspective: The flux design philosophy regarding binary, ternary, and multicomponent systems have been systematically reviewed. The contribution of each flux system to the development of welding thermodynamics and technology are documented. The Claphad technology is introduced to facilitate the flux design, flux selection, and the matching of welding consumables. Based on the critical outcome, the following conclusions can be drawn:

1. Binary fluxes were mainly applied in the early trails of SAW primarily focused on the flux capability to perform the submerging function with high currents and facilitate high deposition rates. Despite of several limitations, the binary fluxes promote the development of welding thermodynamics, especially in terms of the transfer of Si and Mn mechanisms at slag-metal interface.
2. Ternary fluxes were developed based on binary fluxes benefiting from deeper understandings of the thermodynamics. Within this stages, various types of fluxes, such as manganese-silicate fluxes, calcium-silicate fluxes, and alumina-basic fluxes have been developed to fulfill different SAW conditions. With the development of welding metallurgy and growing demand in the arctic regions for large welded structures, investigators began trying the development of multicomponent fluxes.

3. The Calphad technology and progressive thermodynamic databases facilitate the flux design process and strengthen the understanding of SAW process. By using Calphad technology, gas-slag-metal equilibrium model has been developed, which processes stronger universality than the traditional BI slag-metal equilibrium models.
4. Then Viscosity module, Phase Diagram module, and Equilib module is able to aid in the flux design so that some random experiments regarding flux design can be replace, thereby saving human and material resources.

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