

Experimental Investigations on Dissimilar Metal Welds Fabricated Using Nickel Based Welding Consumables

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Conclusions and Scope of Future Work

This chapter summarizes the outcomes of the present research work by presenting its significant achievements, conclusions, and some identified scope for future research work.

6.1 Conclusions based on the study of physicochemical and thermophysical properties for the developed electrode coatings using CaO-SiO₂-TiO₂-Na₃AlF₆ flux system

- Experimental investigations and regression analysis of the physicochemical and thermophysical properties shows that individual constituents, binary interaction SiO₂.Na₃AlF₆ and ternary interaction CaO.TiO₂.Na₃AlF₆ has a significant effect on density because of SiO₂ and Al₂O₃, known as network-former oxide. In addition, the complex tetrahedral structured silicate ions [SiO₄⁴⁻] also play a significant role in increasing the density of the coating.
- Individually SiO₂, Na₃AlF₆, binary interactions of SiO₂.CaO, CaO.TiO₂, CaO.Na₃AlF₆ and ternary interactions of CaO.TiO₂.Na₃AlF₆, CaO.SiO₂.Na₃AlF₆, shows increasing effect on enthalpy change.
- Binary interaction SiO₂.TiO₂, SiO₂.Na₃AlF₆, TiO₂.Na₃AlF₆ and ternary interactions SiO₂.TiO₂.Na₃AlF₆ increases the thermal stability of coating as these interactions show significant effects on weight loss. Also, weight loss is due to the moisture content present in the mixture. Calcite is an essential flux ingredient that reduces moisture content by providing gaseous protection in welding and reducing weld defects.
- The binary interaction of CaO.SiO₂, CaO.Na₃AlF₆, SiO₂.TiO₂, SiO₂.Na₃AlF₆ and ternary interaction of CaO.SiO₂.TiO₂ shows an increasing effect on conductivity, whereas other components show a negative impact on conductivity. Better conductivity can be achieved with a higher concentration of network-forming ions.
- Individually CaO, SiO₂, TiO₂, binary mixture of CaO.Na₃AlF₆ and ternary mixture of CaO.SiO₂.Na₃AlF₆, SiO₂.TiO₂.Na₃AlF₆, shows an increasing effect on thermal diffusivity.
- SiO₂.CaO, TiO₂.CaO, TiO₂.SiO₂, Na₃AlF₆.SiO₂ binary mixture shows significant and increasing effect on specific heat.
- The contact angle reported that the binary interaction of CaO.SiO₂, CaO.Na₃AlF₆, and SiO₂.Na₃AlF₆ has a significant and increasing effect. It is due to the basic oxide's capacity to supply free oxygen and depolymerization of silicate ions, influencing the contact angle.
- Individual coating constituent and the binary mixture of CaO.Na₃AlF₆ is significant and has an increasing effect on surface tension. Due to its high network forming capacity, free oxygen (O₂) is released when basic oxides like CaO and CaF₂ dissociate. SiO₂ decreases free oxygen ions, increasing interfacial tension.
- The binary interaction of CaO.TiO₂, CaO.SiO₂, and CaO.Na₃AlF₆ along with ternary interaction of SiO₂.TiO₂.Na₃AlF₆ has an increasing effect on adhesion energy. Adhesion energy is the amount of energy needed to remove the contacting material from the substrate. The molten slag flow is enhanced as the contact angle lowers, while adhesion energy improves as the contact angle reduces.
- The binary interaction of TiO₂.Na₃AlF₆, CaO.TiO₂ and ternary interaction of CaO.SiO₂.Na₃AlF₆, CaO.SiO₂.TiO₂ has an increasing effect on spread area. Adding basic oxides reduces melt viscosity, resulting in a low contact angle and broad spread area. The

contact angle is inversely proportional to spreadability. Hence lower contact angle had the largest spreading area.

6.2 Conclusions based on the study of physicochemical and thermophysical properties for the developed electrode coatings using CaO-SiO₂-CaF₂-SrO flux system

- Experimental investigations and regression analysis of the physicochemical and thermophysical properties shows that primary and ternary components containing SiO₂ and SrO (CaO.SiO₂.SrO, CaF₂.SiO₂.SrO) have a significant and increasing impact on the density parameter. The mixture components containing SiO₂ and SrO enhanced the slag detachability and other related parameters.
- The thermal stability of coatings is related to weight loss at elevated temperatures. The individual constituents of the coating show an increasing effect significantly. CaO.CaF₂.SiO₂, CaO.CaF₂.SrO, and CaF₂.SiO₂.SrO of ternary interactions increases the thermal stability of coatings as the interaction between this component mixtures affects weight loss significantly. In addition, the mixture's high moisture content contributes to the weight reduction.
- Individual constituents affect change in enthalpy significantly. Ternary mixture CaO.CaF₂.SrO, CaO.SiO₂.SrO, and CaF₂.SiO₂.SrO is the most effective and has an increasing effect on enthalpy.
- Individual coating constituents of fluorspar, strontium oxide, and the binary mixture of CaO.SiO₂ has a significant and increasing impact on thermal conductivity. CaO.CaF₂.SiO₂, CaO.CaF₂.SrO, and CaF₂.SiO₂.SrO is the most effective ternary component, which positively affects thermal conductivity.
- The binary components of CaO.SrO and the ternary components containing SrO and SiO₂ (CaO.SiO₂.SrO, CaF₂.SiO₂.SrO) have an increasing impact on thermal diffusivity.
- The synergistic factor for specific heat shows that strontium oxide and ternary components containing strontium oxide (CaO.CaF₂.SrO, CaF₂.SiO₂.SrO) show an increasing and positive impact, while other components show a negative effect on specific heat.
- The contact angle having the most effective and increasing components are CaO.SrO, CaF₂.SrO, CaF₂.SiO₂, and SiO₂.SrO binary mixture. Contact angles play an essential role while measuring the wettability properties. The highly basic oxide has a strong tendency to produce free oxygen, which influences the contact angle. The contact angle reduces as the concentration of basic oxides increases.
- Surface tension effects significantly by individual ingredients and binary interaction of CaO.CaF₂. The binary mixture of CaO.SiO₂, CaO.SrO and CaF₂.SiO₂ show decreasing effect on surface tension.
- The regression analysis of spread area shows that primary mineral constituent has an increasing effect significantly. CaO.CaF₂.SiO₂ and CaO.CaF₂.SrO ternary interaction influence most effectively the spread area. When the contact angle decreases, the molten slag's height also decreases, which means that the molten pool of coating is becoming easier to spread out. The spread area is inversely proportional to the contact angles.
- Individual mineral constituents, along with CaO.CaF₂.SrO, CaO.SiO₂.SrO, and CaF₂.SiO₂.SrO ternary mixture is the most favourable and has an increasing effect on adhesion energy. CaO.CaF₂, CaO.SiO₂ and CaO.SrO binary interaction shows a decreasing effect.

6.3 Conclusions based on the study of IN617/304H dissimilar welds

- This investigation attempts to develop SMAW electrodes for IN617/304H DWJ's as an alternative to commercially available electrodes ENiCrCoMo-1. The designed electrodes performance has been demonstrated by extensive metallurgical and mechanical testing.

The welds fabricated using developed electrode have more chromium and less carbon content. When compared to ENiCrCoMo-1 electrodes, they perform comparative better in microhardness, tensile strength and impact toughness.

- Macrostructural examinations reveal that all welds were completely penetrating and showed no cracks under visual inspection using dye penetrant test. The developed electrodes have successfully fabricated weld with decent weld joint quality with no significant defects.
- Microstructural examinations reveal that different ranges of temperature experienced during the welding result in the formation of the heterogeneous microstructure at the 304-interface side. The 304H side of the weld interface fusion boundary observes unmixed zone (UZ), HAZ and delta ferrite formation. A significant increase in grain size was seen in the partially melted zone with fusion boundary IN617 with negligible HAZ was observed. The microstructure of the weld fusion zone confirmed the formation of secondary phases due to the segregation of various alloying elements at the end of the solidification. The EDS result showed that these secondary phases were enriched with Mo, Cr, and Ti. It also affects the mechanical properties.
- The tensile strength of the weld fabricated using laboratory developed electrodes improves 16.40% and 10.30% for weld E9M and E10M as compared to commercial electrode. The impact strength was found to improve by 37% and 22% for weld E9M and E10M respectively.
- The specimen subjected to molten salt mixes exhibited severe corrosion at elevated temperatures. The presence of chlorides in the molten salt, along with V_2O_5 , provides a more corrosive environment compared to molten salt containing chlorides.
- The weld specimen made using E10M electrode shows better hot corrosion resistance by gaining lesser weight (0.883 mg/cm²) as compared to the weight gain of the weld specimen (1.317 mg/cm²) produce using CE electrodes when exposed to SM1 environment at 850°C temperature. Similarly, when exposed to the SM2 environment at 850°C temperature the E10M fabricated weld specimen shows better hot corrosion resistance by gaining lesser weight (1.02 mg/cm²) as compared to the weight gain of the weld specimen (1.292 mg/cm²) fabricated using CE electrodes.
- The experimental combination E9M achieved a 24.57% reduction in the fume formation rate (FFR), while E10M exhibited a remarkable 44.72% reduction compared to its commercial counterparts.

6.4 Scope for future work

- The design and development of electrode coatings for CSEF ferritic steel to austenitic stainless steel, Ferritic-martensitic to austenitic stainless steel, and austenitic stainless steel to Ni-alloys dissimilar welds other than IN617/304 H can also be explored for power plant applications.
- Advanced mechanical characterizations like low cycle fatigue, wear and high temperature creep behavior of welds can also be explored.
- Modelling and simulation on fabricated welds can be also explored.
- Investigating the application of buttering layer on austenitic stainless base metal to enhanced structural integrity.
- The hot corrosion behavior of dissimilar welds in other aggressive molten salt environment can also be explored to establish the complete evaluation and utility of these welds when exposed to high temperature.