DESIGN AND DEVELOPMENT OF SMAW ELECTRODE COATINGS FOR DISSIMILAR METAL WELDS IN USC POWER PLANTS

A Thesis Submitted by

Sumit Mahajan

In partial fulfilment of the requirements for the award of the degree of

Doctor of Philosophy

Indian Institute of Technology, Jodhpur

Mechanical Engineering

July 2020

6
Conclusion & Scope for Future Work

6.1 Conclusions

The shielded metal arc welding electrodes were designed and developed to fabricate the dissimilar welds used in thermal power plant applications. These electrodes were designed on the basis of ternary phase diagrams using low carbon steel and Ni-based fillers. The comparative evaluation of the dissimilar welds fabricated using developed electrodes and commercial electrodes has been performed.

6.1.1 Conclusions based investigations of Physicochemical and Thermophysical properties for the developed electrode coatings

- Experimental investigations and regression analysis of the physicochemical and thermophysical properties shows that the individual mixture constituents have significantly decreasing effect on the density of electrode coatings. $SiO_2.Al_2O_3$ is the only binary mixture that has a significantly increasing effect on density. Ternary mixtures do not show any effect on the density of these coating formulations. The individual constituents have significantly increasing effect on the weight loss (%) of different coating mixtures while binary mixture $CaO.SiO_2$ has a significant decreasing effect on weight loss.
- Individual coating mixture ingredients do not have a significant effect on enthalpy. $CaO.CaF_2$, $SiO_2.CaO$ and $Al_2O_3.SiO_2$ binary mixtures have significant decreasing effect on the change in enthalpy, while other binary mixtures do not have significant affect.
- Individual coating ingredients do not have significant effect on the thermal conductivity. The binary mixtures show significantly increasing effect on the thermal conductivity except $CaF_2.Al_2O_3$ binary mixture. $CaF_2.Al_2O_3.SiO_2$ is the ternary mixture that shows significant decreasing effect on the thermal conductivity. Binary mixtures $CaF_2.Al_2O_3$, $CaF_2.SiO_2$, $SiO_2.Al_2O_3$ have significantly increasing effect on the thermal diffusivity. $CaF_2.Al_2O_3.SiO_2$ ternary mixture significantly decreases the thermal diffusivity of the coating mixtures. It was observed that $CaO.CaF_2.SiO_2$ ternary mixture significantly increasing the specific heat $CaF_2.Al_2O_3$ binary mixture has a significant decreasing effect on specific heat of coating mixtures
- Binary mixtures $CaF_2.SiO_2$ and $SiO_2.Al_2O_3$ have significant increasing effect on the contact angle. The coating compositions with a higher amount of $CaO.CaF_2$ (C1, C3, C13) having a low contact angle while the compositions with low $CaO.CaF_2$ and high $SiO_2.Al_2O_3$ possesses a high contact angle. This is due to the ability of the basic oxide to supply free oxygen, which controls the contact angle. As the contact angle decreases, the spreading area increased. Binary mixtures $CaO.SiO_2$, $CaO.Al_2O_3$, have a significant increasing effect on the spreading area, whereas binary mixtures $CaO.CaF_2$ and $CaF_2.Al_2O_3$ have significant decreasing effect. This is due to the presence of higher basic oxides in the mixtures, which reduces the melting point of the flux and increases its flowability.

- Using Young`s and Boni`s equations, the surface tension was calculated. Binary mixtures $CaO.CaF_2$, has a significant increasing effect on surface tension. Binary mixtures $CaF_2.Al_2O_3$ and $SiO_2.Al_2O_3$ show significantly decreasing effect on surface tension. SiO_2 reduces the free oxygen ions, which increases the interfacial tension. An increase in the surface tension was recorded when there is an increase in the CaO/SiO_2 ratio. As SiO_2 is replaced with CaO in the coating mixture, the surface tension slightly increases. As the contact angle decrease (larger spreading area), the adhesion energy increases. Binary mixtures $CaO.CaF_2$ and $CaO.SiO_2$ have significantly increasing effect on the adhesion energy. An increase in CaF_2 results in the increased adhesion energy. Binary mixture $CaF_2.SiO_2$ has significantly decreasing effect on the adhesion energy.
- Estimation of these properties will enable researchers to choose minerals in the right proportions to develop welding electrode consumables with optimized properties. The selection of these minerals appropriately leads to the good bead profile with desirable mechanical properties of developed welds.

6.1.2 Conclusions based on the study of P22/P91 dissimilar welds

- This research is an attempt to develop SMAW electrodes for P22/P91 dissimilar weld, which provide an alternative solution to commercially available electrodes E9018-B3. The performance of developed electrodes has been validated through extensive mechanical and metallurgical examination. The developed electrode`s welds have higher chromium-low carbon composition. They fare better in microhardness, impact, and lies in the same tensile strength as compared to commercial E9018-B3 electrodes.
- The tensile strength of the weld fabricated using laboratory developed electrodes matches with that of the commercial electrode. The impact strength was found to improve by 19% for laboratory developed electrode made welds as compared to the commercial electrodes.
- Microstructural investigations reveal the welds to have precipitation of bainite in dendritic morphology. The interphase between P91 and weld fusion zone has coarse grains with a clear formation of a carbon depleted and carbon enriched zone. This zone is also characterized by the precipitation of tempered bainite with fine grains. The transition zone between P22 and weld shows significant grain coarsening which further affects the mechanical behavior.
- The specimen exposed to molten salt mixtures experienced excessive corrosion at high temperature. The molten salt contains chlorides produces an aggressive environment as compared to molten salt containing V_2O_5.
- The weld specimen fabricated using laboratory developed electrodes possesses better hot corrosion resistance as compared to the commercial welds and base P22 in all the tested environments. The laboratory developed electrode (E2M) fabricated weld specimen gain 15.59% lesser weight as compared to the commercial electrodes fabricated weld specimen when exposed to SM1 at 750°C temperature. Similarly, 16.26% lesser weight gain was observed in E2M electrode weld specimens when exposed to SM2 at 750°C temperature.

6.1.3 Conclusions based on the P91/SS304L dissimilar welds

- Tensile strength of the welds fabricated using laboratory-developed electrodes were lower than the respective base metal P91 but higher than the base metal SS304L. Laboratory-developed electrode (E7M, E16M) welds possess better transverse as well as longitudinal weld tensile strength than welds fabricated with commercial electrodes (CE).
- Improvement of 24% in the impact value was observed in the case of E7M weld as compared to commercial electrode weld (CE).

- A sudden increase in the microhardness value was observed at the P91/FM 82 interface. Microhardness in case of E7M weld was lower value in all the regions of the welds as compared to the commercial weld.
- The weld specimen fabricated using E7M electrode shows better hot corrosion resistance by gaining lesser weight (0.893 mg/cm^2) as compared to the weight gain of the weld specimen (1.517 mg/cm^2) fabricated using CE electrodes when exposed to SM1 environment at 750°C temperature. Similarly, when exposed to the SM2 environment at 750°C temperature the E7M fabricated weld specimen shows better hot corrosion resistance by gaining lesser weight (2.1 mg/cm^2) as compared to the weight gain of the weld specimen (4.036 mg/cm^2) fabricated using CE electrodes.

6.2 SCOPE FOR FUTURE WORK

- The design and development of electrode coatings for Ferritic-Martenistic to Ferritic-Martenistic, Ferritic-Martenistic to Austenitic stainless steel, Austenitic stainless steel to Ni-alloys dissimilar welds other than P22/P91 and P91/SS304L can also be explored for power plant applications.
- Advanced mechanical characterizations like thermal fatigue and high temperature creep behavior of welds must be explored.
- The hot corrosion behavior of dissimilar welds in aggressive molten salt environment can also be explored to establish the complete evaluation and utility of these welds when exposed to high temperature.