

The growing energy demand and advancements in pipeline steel technology necessitate the development of specialized welding consumables. This study examines X70 pipeline steel welds using formulated SMAW electrode coatings, with a focus on consumable performance, weld undermatching, hydrogen effects, and ductile fracture modeling.

The flux formulation was targeted for high basicity, lower silica and rutile, substitution of CaO with BaO, low hydrogen (high CaF₂). Four major constituents were selected for investigation, CaF₂ – CaO – Al₂O₃ – BaO and CaO – SiO₂ – CaF₂ – BaO. Extreme vertices design approach was used for experimental design. The flux was investigated for contact angle, work of adhesion, and floatation coefficient, weight loss %, enthalpy change, thermal diffusivity, thermal conductivity, specific heat. Neural network models were developed for enhanced prediction accuracy. Increasing CaO and BaO raises the work of adhesion and lowers the floatation coefficient, while increasing Al₂O₃ and CaF₂ decreases the work of adhesion and raises the floatation coefficient. The structural analysis of as-quenched slag was done by XRD, UV-vis, and FTIR. The CaO and BaO act as network breakers and release non-bridging oxygen O⁻ at the expense of bridging oxygen O⁰. The contact angle decreases with the increase of CaO and BaO. The increase in individual constituents Al₂O₃ and CaF₂ increases the contact angle. The Al₂O₃ act as a network former in the melts. The CaF₂ present in the melt as Ca²⁺ and F⁻ due to higher CaF₂ concentration (~35%) which has positively affected the contact angle.

An increase in CaF₂ exhibits better thermal stability compared to the other minerals used. An increase in CaO and BaO has positive an influence, comparatively, BaO has more thermal stability. The primary cause of weight loss is due to moisture, crystallization water, calcination, and other volatile compounds present in the mineral. The thermal stability of flux while heating results in lower gaseous infiltration in the molten weld pool. Increasing alumina enhances thermal diffusivity, while an increase in calcite lowers thermal diffusivity. The solubility of water vapor in molten slag was estimated to range from 3.095 to 3.546.

A series of multi-pass bead-on-plate studies were conducted using laboratory-developed electrodes. The flux composition has shown a significant effect on all the responses. An increase in Al₂O₃, and BaO has shown a positive influence on nickel transfer, whereas an increase in CaO reduces nickel transfer. The slag detachability was found to be good for the ratio CaF₂:CaO:Al₂O₃:: 1.76:0.73:0.51.

Selection of better-performing electrode coatings was done. Two weldments were prepared using developed welding electrodes (AF_W, SF_W), and one using a commercial electrode E8018-G (CE_W) for comparison purposes. The mechanical, metallurgical, and hydrogen charging tests were performed. Even with the same electrode rod (ER80S-Ni1), both coating compositions have shown significant effects on the weld. The AF_W and SF_W welds have shown thin grain boundaries and acicular ferrite as compared to CE_W. The results were confirmed by a thermodynamic model that shows a reduction in ferrite and pearlite. Microhardness results are in agreement with phase fraction microhardness results. Due to fine ferrite morphologies, lower hydrogen embrittlement index for AF_W was achieved. Weld strength mismatch in decreasing order is SF_W, AF_W, and CE_W. The σ_{YS}/σ_{UTS} ratio of weld AF_W was better than the other welds.

Uniaxial tensile tests and single edge notch bend tests with $a_o/W = 0.50$ and $a_o/W = 0.25$ in-plane constraints were tested for X70 steel and weld (AF_W). The single edge notch bend pre-crack was prepared using electric-discharge machining. The test results of $a_o/W = 0.50$ were used to calibrate the GTN parameters using the design of experiment. The GTN model parameters were validated on $a_o/W = 0.25$ and flat notch tensile test experiments. The GTN model parameters were also validated on notch round bar and single edge notch tension test. The weld inhomogeneity was considered to simulate the pop-in behavior of single-edge notch bend tests. The simulations of single-edge notch bend tests with EDM-cut cracks and sharp cracks were studied, showing that the initial fracture toughness increases for EDM-cut cracks.