CHAPTER 2

LITERATURE REVIEW
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2.1. Effect on Weld Bead Geometry due to Weld Parameters

Gunaraj and Murugan (1999) suggested that submerged arc welding (SAW) is used extensively in industries to join metals for the manufacture of pipes of different diameters and lengths. In this work response surface methodology (RSM) technique of design of experiment (DOE) has been applied for the selection of the optimum input variables. The authors; Gunaraj and Murugan (2000); Gunaraj and Murugan (2000) developed mathematical models for penetration, width and reinforcement, area of penetration, area of reinforcement, percentage of dilution, total area of the weld bead and the total volume of the weld bead in terms of input process parameters; voltage, speed, wire feed rate and nozzle to tip distance and optimized these input process parameters for submerged arc welding on IS 2062 steel.

Murugan and Gunaraj (2005) suggested that mechanical strength of welds is influenced not only by the composition of the metal but also by the weld bead shape in SAW. So the selection of the process variables and control of weld bead shape has become essential.

In the experimental work, bead on plate has been taken on plates (IS 2062 carbon steel of 6mm thickness) with 3.15 mm diameter wire. Prediction equations were developed for penetration, reinforcement, bead width, PSF and RFF in terms of weld parameters; voltage, speed, wire feed rate and nozzle to tip distance.

Kaaoglu and Secgin (2008) carried out the sensitivity analysis of SAW parameters; welding current, welding voltage and welding speed for optimum weld bead geometry. The weld bead width, height and penetration were selected as design variables. A mathematical model was constructed using multiple curvilinear regression analysis. The
study revealed that the penetration is almost non-sensitive to the variations in voltage and speed.

The authors; Ghosh et al. (2011) suggested that in submerged arc welding process parameters play a significant role in determining the quality of a weld. So for such applications, optimum welding process parameters must be selected providing desired weld properties. In the work; beads were taken on 15mm thick plate by varying heat input and wire feed rate. Prediction equations were developed for penetration, reinforcement height and width using multi-regression method and artificial neural networks; a comparative study of both techniques has been also performed.

Chandel et al. (1997) developed theoretical predictions for the melting rate, bead height, bead width and weld penetration in terms of current, electrode polarity, electrode diameter and electrode extension in submerged arc welding. The authors concluded that in high-strength and higher toughness materials; the lowest possible heat input should be maintained during welding.

Datta et al. (2008) used Taguchi’s L9 OA by varying welding current and flux basicity index (BI) to obtain bead-on-plate weld on mild steel plates to obtain (single response) optimal parametric combinations to achieve desired weld bead geometry and HAZ dimensions.

Datta et al. (2008) optimized bead geometry (bead width, reinforcement, depth of penetration and depth of HAZ) using grey relational analysis. Taguchi’s L25 orthogonal array (OA) was used in the work for design of experiment and experiments were conducted to obtain bead-on-plate weldment on mild steel plates. Welding parameters were determined for bead width, reinforcement and depth of HAZ with lower-the-better and for depth of penetration with larger-the-better criterion.
The authors; Singh et al. (2013) proposed fuzzy expert system for the optimization of weld bead geometry parameters in terms of input parameters; voltage, wire feed rate, traverse speed and stick-out. In the proposed methodology; desirability function has been used to assign individual desirability values to responses; bead width, reinforcement, area of reinforcement and bead volume (lower-the better criterion) and depth of penetration, area of penetration and dilution percentage (higher-the-better criterion).

Narang et al. (2012) developed mapping technique for graphical representation of weld bead profile. The authors developed prediction equations for depth of penetration, bead height, HAZ width, bead width, bead contact angle, depth of HAZ and dilution for bead on plate on MS plates. It was suggested that bead contact angle is an important output response among weld bead shape parameters.

Taguchi’s L25 Orthogonal Array (OA) had been adopted for conducting experiments to produce bead-on-plate weld on mild steel plates by Nandi et al. (2010). Four bead geometry parameters: depth of penetration, reinforcement, bead width and percentage dilution have been determined in terms of voltage, wire feed rate, traverse speed and electrode stick-out. Two hybrid techniques; firstly, Taguchi method coupled with grey relational analysis; and secondly, Taguchi method in combination with desirability function approach had been applied.

The authors also described that in most of the cases; the optimization had been performed using single objective function. For solving multi-criteria optimization problem, it had been suggested to transform multiple objectives into an equivalent single objective function which may be assumed to be a representative of all the quality characteristics of the process, which is to be optimized.

In the study carried out by the Kim et al. (2005), RSM technique had been used for design and to obtain ‘near-optimal settings’ of welding process parameters in gas metal arc
(GMA) welding. The front bead height, back bead width and penetration were determined in this study. Controlled Random Search (CRS) suggested by Price (1977) was used to select the welding process parameters to obtain the desired weld bead geometry in GMA welding.

Biswas et al. (2012) discussed limitations of Taguchi method alone and discussed the other techniques such as grey relation theory, desirability function approach, utility theory etc. to solve multi-response optimization problems. Weighted Principal Component Analysis (WPCA) has been applied to eliminate response correlation in the study on optimization of multiple bead geometry parameters of submerged arc weldment using Taguchi method.

Experiments had been conducted based on Taguchi’s L25 Orthogonal Array design with combinations of process control parameters: voltage, wire feed, welding speed and electrode stick-out to optimize different bead geometry parameters: bead width, bead height, penetration depth and HAZ dimensions.

Murugan et al. (1993) carried out single wire surfacing by depositing 316L stainless steel onto structural steel plates IS 2062 of 20 mm thickness using central composite rotatable factorial design (CCD) conducting 31 experiments. The effect of welding parameters; open-circuit voltage, wire feed-rate, welding speed and nozzle-to-plate distance was investigated on the responses; penetration, reinforcement, width and dilution.

Gunaraj and Murugan (2002) suggested that in submerged arc welding (SAW), selection of appropriate values of process variables is essential in order to control heat-affected zone (HAZ) dimensions, get the required bead size and quality ensuring a predictable and reproducible weld bead. In the investigation, mathematical models were developed to study the effects of process variables and heat input on various metallurgical aspects; width of the HAZ, weld interface, grain growth and grain refinement regions of the HAZ.
From the study it was concluded that heat input and wire feed rate have a positive effect but welding speed has a negative effect on all HAZ characteristics. Width of grain growth and grain refinement zones increased but weld interface decreased with an increase in arc voltage.

Lee et al. (2000) discussed the effect of welding parameters on the size of the heat affected zone (HAZ) of submerged arc welding. The authors suggested that HAZ size indicates the grain coarsening and toughness; a larger/wider HAZ indicates larger grains in the HAZ and thus poor toughness whereas a narrower HAZ indicates a steeper thermal gradient and thus a faster cooling rate and shorter soaking time and hence finer grain size and better toughness. According to them an ideal fusion welding process is the one where a maximum percentage of supplied energy is utilized in fusing the filler/electrode and base metal and minimum energy is wasted in forming the heat affected zone. It was observed that for a given heat input, there is a decrease in HAZ size with an increase in welding current and welds made with higher heat input produced welds with larger HAZ.

Submerged arc welding of quenched and tempered HSLA steel was carried out under different heat input conditions using a welding wire and an agglomerated basic flux (basicity index = 3.1) by Basu and Raman (2002). Multiple regression analysis had been used in the work to correlate acicular ferrite (AF) content with different influencing parameters. It was concluded from the study that the correlation could be utilized to set up the trial welding parameters for similar grades of steel substrates and consumables with an aim to maximize the acicular ferrite (AF) content.

The authors discussed the work done by Farrar and Zhang (1995), Ricks et al. (1982), Abson and Dolby (1978), Bhadeshia (1990) and showed that intragranularly formed acicular ferrite in microstructure helps to achieve good low-temperature toughness.
Prasad and Dwivedi (2008) investigated the influence of the submerged arc welding process parameters on the microstructure, hardness and toughness of HSLA steel weld joints. Weld joints were prepared using high heat input (3.0-6.3 KJ/mm) by varying welding current (500-700 A) and welding speed (200-300 mm/min). It was concluded from the study that the grain structure coarsening and average hardness of both weld metal and HAZ decreased with increase in heat input. HAZ showed higher hardness than the weld metal and toughness increased with decrease in speed for a given welding current. Scanning Electron Microscopy (SEM) of fractured surfaces of impact test specimen was carried out to study the mode of fracture and revealed that the increase in the heat input encourages the ductile fracture.

Elangovan et al. (2012) developed a methodology to determine the optimum welding conditions that maximize the strength of joints produced by ultrasonic welding using response surface methodology (RSM) coupled with genetic algorithm (GA). The second-order regression models were developed to predict the weld strength using RSM-central composite design for spot and seam welding of 0.3mm and 0.4mm thick aluminum specimens.

Sharma et al. (2009) used ‘Best subset selection method’ and ‘Mallows criterion’ for development of model for deposition rate in twin-wire submerged arc welding. The deposition rate had been measured by varying process parameters; welding current, welding voltage, welding speed, contact tube to workpiece distance and wire-diameter for both DCEN and DCEP polarities. The authors concluded that welding voltage and welding speed have considerable effect on the deposition rate.

Nowacki and Rybicki (2005) analysed the influence of welding heat input on mechanical properties of weld joints using heat input from 2.5 to 4.0 kJ/mm for submerged arc welded of duplex steel. The study revealed that the heat input from 2.5 up to 4.0 kJ/mm has no
negative influence on mechanical properties of the joints in submerged arc welding of duplex steels.

Ghosh et al. (2011) used the digital image processing techniques in their work to assess the heat affected zone of submerged arc welding of structural steel plates through the analysis of the grain structure. It was concluded from the study that HAZ in submerged arc welding was of relatively less size due to 10% less grain growth.

Prasad and Dwivedi (2008) investigated the effect of heat input (controlled by welding current and welding speed) on the microstructure and tensile properties of high-strength low-alloy (HSLA) steel weldments for welding of 16mm thick 1.25Cr-0.5Mo steel plates. The weld joints were prepared by varying the welding current (500–700A) and welding speed (200-300mm/min). It is concluded from the study that the tensile strength decreased with increase in heat input while % elongation increased and SEM of tensile test fractured specimens exhibited ductile failure.

Sharma et al. (2010) studied the behavior of leading and trailing arcs in twin-wire submerged arc welding with help of transient heat transfer analysis. The model was simulated with different combinations of model parameters with an appropriate heat transfer model. The simulation indicated that the leading arc had a major share in producing penetration whereas the trailing arc was more responsible for melting.

The authors; Sharma et al. (2009); Li and Lu (2012) estimated the heat source model parameters for varying set of welding conditions. The study of Sharma et al. (2009) revealed that model parameters for twin-wire welding were dependent upon welding parameters and were different from the single-wire welding.
2.2. Effect on Weld Bead/Weld Joint Properties due to Weld Parameters and Flux Composition Variation

Datta et al. (2002) investigated the weldability properties of 20 mm thick plates using the shielded metal arc welding (SMAW) process. The authors suggested that susceptibility of steel to cold cracking is related to the carbon equivalent (CE) and its position in the Graville diagram. High strength, quench and tempered plates having yield strength of 670 MPa (carbon equivalent, CE: ~0.6) are susceptible to a crack-sensitive microstructure and cold cracking during welding.

Ramirez (2008) carried out welding operations using different welding processes such as FCAW, SMAW, GMAW with commercially available welding consumables. The objective of this study was to characterize the compositional and microstructural characteristics (nonmetallic inclusions) of HSS weld metals. The authors indicated that more work may be done in the developments of welding processes and consumables to produce weld metals with mechanical properties equivalent to the base metal in steel technology. To achieve this better understanding of chemistry and microstructural property relationships in HSS weld metals is required.

Jindal et al. (2012) reviewed structural integrity issues in submerged arc welding of HSLA steels. The most important problem in welding of HSLA steels is to prevent brittle fracture of welded joints due to increased strength of HSLA steels. The authors suggested that the welding fluxes should be developed providing welds with increased strength, toughness and minimizing diffusible hydrogen content to take full advantage of the HSLA steels.

Pandey et al. (1994) studied the influence of submerged arc welding parameters and flux basicity index on the weld chemistry and transfer of elements using five different fluxes and different values of the welding parameters to produce weld bead on a mild-steel plate. The work was aimed at studying the relative effect of welding parameters and fluxes on
the element transfer and weld composition. It was concluded that both composition of the flux and BI value completely characterize a flux for studying its effect on weld chemistry. Kanjilal et al. (2006) performed experiments using agglomerated fluxes, prepared by varying the ingredients CaO, MgO, CaF$_2$ and Al$_2$O$_3$ using extreme vertices design. Weld deposits were made on an 18mm thick low carbon steel plate using 3.15mm diameter filler wire by using formulated fluxes and varying welding parameters. The authors suggested that in submerged arc welding (SAW), the mechanisms are primarily affected by three factors: dilution of weld pool by the base plate (Davis and Bailey, 1980; Burck et al., 1990; Indacochea et al., 1985; Dallam et al., 1985), environmental contamination (Eagar, 1978; Chai and Eagar, 1982; Eagar, 1979; Davis and Coe, 1977) and the transfer of elements to or from the slag (Burck et al., 1990; Dallam et al., 1985; Mitra and Eagar, 1984). North (1977) had concluded that weld deposit chemistry had shown to be primarily dependent on flux composition and also on operating parameters.

Burck et al. (1990) evaluated the effects of CaF$_2$, CaO and FeO additions on weld metal chemistry on AIS11010, 1020 and 4340 steel base plates. Single pass, bead on plate welds were made with submerged arc welding process using three different flux systems; SiO$_2$-MnO-FeO, SiO$_2$ MnO-CaO and SiO$_2$-MnO-CaF$_2$.

Dallam et al. (1985) conducted bead-on-plate and double-V-groove submerged arc welds on a quenched and tempered niobium HSLA steel with two different heat inputs using twenty eight fused fluxes. The results showed negative delta values for manganese and niobium indicating a loss from the weld pool to the slag and the negative delta sulphur value indicated that the CaF$_2$-CaO-SiO$_2$ flux system was effective in sulphur control. Decrease in oxygen resulted in an improvement of the weld metal toughness due to the refinement of the weld metal microstructure.
Eagar (1978) suggested a model for oxygen contamination of submerged arc weld metal implying that oxygen level is controlled by $\text{SiO}_2$ decomposition in low acidic fluxes whereas the oxygen level of basic fluxes is controlled by the oxygen potential of the slag. The author also suggested minimum data requirement for complete characterization of slag metal reactions and to take $\text{CaF}_2$ as a neutral component while calculating BI of the flux.

In the research work by Paniagua-Mercado et al. (2007), submerged arc welding was performed on low carbon steel plates (ASTM A-36 grade) using three commercial fluxes (one neutral basic and two active basic fluxes) keeping the same welding conditions for all welds. Mechanical testing, chemical analysis, microstructure and microanalyses of inclusions of the welded samples were conducted. From the study it was concluded that the non-active flux promoted the formation of pearlite and ferrite in the weld having the highest toughness and ductility whereas the active fluxes promoted the formation of acicular ferrite (AF) and fine carbides in the welds showing the higher tensile strength and hardness (Sarma et al., 2009).

Kanjilal et al. (2005) developed a prediction model for acicular ferrite (AF) microstructure as a function of flux ingredients such as $\text{CaO}$, $\text{MgO}$, $\text{CaF}_2$ and $\text{Al}_2\text{O}_3$. Single pass bead-on-plate weld deposits were made on 18mm thick low carbon steel base plate using eighteen no. of formulated fluxes keeping fixed welding parameters. The authors concluded that flux ingredient $\text{CaO}$ tends to decrease whereas the binary mixtures of $\text{CaO}$ viz. $\text{CaO-CaF}_2$ and $\text{CaO-Al}_2\text{O}_3$ have binary synergistic (increasing) effect on weld metal acicular ferrite content. $\text{MgO}$ has not significant effect on AF of the weld metal.

Plessis et al. (2007) suggested that the diffusible hydrogen content of weld metal can be greatly reduced by flux chemistry modifications (Flanigan, 1947) i.e. by increasing the basicity index of flux and increasing the fluoride-containing compounds ($\text{CaF}_2$, $\text{NaF}$,
K$_2$TiF$_6$, or K$_2$AlF$_6$) in SMAW electrodes and by hydrogen trapping using Yttrium (Lensing et al., 2004). The authors, Plessis et al. (2007); Davidson (1998) suggested that despite extensive research, hydrogen assisted cold cracking remains prevalent in higher-strength steel welds. The work showed that the addition of CaF$_2$ up to 22% and addition of NaF in the flux reduced hydrogen content. Weld hydrogen content reduces with addition of calcite (CaCO$_3$) to the flux formulation up to certain limit.

The study of Chai and Eagar (1980) indicates that weld metal chemistry is primarily dependent on weld metal flux composition whereas operating parameters have insignificant effect on weld metal chemistry. The study also revealed that weld bead geometry is dependent on weld parameters only namely; welding current, voltage, travel speed, electrode diameter and electrode polarity and independent on flux composition.

The slag metal reactions were studied by Mitra and Eagar (1984) to predict the transfer of Cr, Si, Mn, P, S, C, Ni, and Mo between the slag and the weld pool for submerged arc welding of alloy steels. The experiments were performed with four fluxes; two fluxes were made by adding chromium oxide to two commonly used commercial fluxes while other fluxes were made from laboratory grade chemicals keeping the welding parameters constant.

It was observed during the study that the transfer of chromium was dependent on the type of flux used; lesser BI of the flux and higher initial chromium content of the electrode enhanced the chromium content in the weld metal. The manganese content of the weld metal depended mainly on the amount of manganese oxide in the flux and the initial manganese content of the electrode.

Moon et al. (2000) investigated microstructure and microhardness variations of HSLA-100 steel weldment fabricated through GMAW with an ultra-low-carbon welding consumable. Study revealed that the fusion zone mainly consisted of lath ferrite with fine lath
martensite, interlath retained austenite and oxide inclusions but no polygonal ferrite or solid state precipitates such as carbides or carbonitrides. The HAZ was the hardest region in each weldment and consisted predominantly of untempered lath martensite, which is susceptible to hydrogen cracking.

Maiti and Mandal (2005) established welding procedure for submerged arc welding enabling fabrication of sound welded butt joints on C-Mn steel plates of thickness 10mm and 12mm using a flux filled reusable backing strip. The combined effect of the welding parameters; voltage, current, speed along with the thickness of plate on weld penetration, bead formation, HAZ hardness and tensile strength of welded joint had been studied.

Kanjilal et al. (2007) developed a prediction model for mechanical properties as a function of flux ingredients; CaO, MgO, CaF₂ and Al₂O₃ using eighteen no. of formulated fluxes. Single pass bead-on-plate weld deposits were made on 18mm thick low carbon steel base plate keeping fixed welding parameters. The authors concluded that individual flux ingredient MgO is the most important whereas the binary mixtures of CaO with CaF₂ and Al₂O₃ have synergistic (increasing) effect on weld metal mechanical properties.

Dowling et al. (1986) analyzed inclusion phases and their role in the nucleation of acicular ferrite of submerged arc welds by electron diffraction and X-ray microanalysis. HSLA steel welds were made with three different fluxes and metallic additions of Ti, Mo, and Cr. It was concluded that inclusions act as inert substrate to nucleate acicular ferrite.

Bhole et al. (2006) discussed the effects of nickel (Ni), molybdenum (Mo) and Ni and Mo together additions to the weld metal on the impact toughness of an API HSLA-70 steel by submerged arc welding. The authors suggested that two major approaches have been pursued to improve the toughness of the weld metal (WM); one is to use different types of fluxes (Dallam et al., 1985; Fox et al., 1996); the other is to alter WM composition either by the use of newer filler metals (Krishnadev et al., 1999) or by metal powder additions in
Arnoldy, 1967; Barbangelo, 1990; Thornton and Webster, 1990; Bailey et al., 1987, Hakansson and Dixon, 1996). It was concluded from the study that impact toughness decreased due to suppression of the formation of acicular ferrite (AF) with the increase of Ni content whereas toughness increased with increase of AF microstructure with the increase of Mo content.

The effect of titanium addition on the SAW of API 5L-X70 pipeline steel was investigated by Beidokhti et al. (2009). From the study it was concluded that titanium-base inclusions improve impact toughness by increasing the formation of acicular ferrite in the microstructure and the best combination of microstructure and impact properties was obtained in the range of 0.02–0.05% titanium. On further increase of Ti content, the microstructure changed from a mixture of AF, GBF and WF to a mixture of AF, GBF, bainite and ferrite thereby the mode of fracture also changed from dimpled ductile to quasi-cleavage. No hydrogen induced cracking (HIC) susceptibility was found in the weld metals with titanium contents less than 0.09%.

Paniagua-Mercado et al. (2005) studied the effect of different fluxes on microstructure and tensile properties of submerged arc welded AISI 1025 steel with commercial fluxes at constant welding conditions. The presence of acicular ferrite was detected for welds of fluxes with the highest content of titanium oxide.

Ramakrishnan and Muthupandi (2013) carried out the experimental work to study the effect of process parameters and cold wire addition technology in tandem submerged arc welding of 140mm thick SA 299 material. It was concluded from the study that by using optimized cold wire addition led to increase in the deposition rate by 100%, decrease in percentage dilution by 100%, 30% reduction in HAZ, 40% reduction in the number of passes required to complete a joint and 30% savings in flux consumption as compared to conventional SAW.
Kanjilal et al. (2007) developed prediction model for change in element transfer due to flux ($\Delta$) in terms of flux ingredients; CaO, MgO, CaF$_2$ and Al$_2$O$_3$. Weld deposits were made on 18mm thick low carbon steel base plate using fluxes formulated with extreme vertices design at fixed welding parameters.

2.3. Literature Review on Flux Design

Crespo et al. (2007) developed a methodology to obtain the flux from five constituting compounds; MnO, SiO$_2$, CaO, Al$_2$O$_3$ and CaF$_2$. The authors used extreme vertices design for the design of experiment (DOE) for mixture design. It was suggested from the study that the region of the flux compound that responded with the most suitable results were characterised by an average ratio of MnO/SiO$_2$ = 1.42 and its components fall into the following ranges: MnO: 50.6–53, SiO$_2$: 35–38, CaO: 0–4.4, Al$_2$O$_3$: 0–3.6, CaF$_2$: 4.5–9

Adeyeye and Oyawale (2008) discussed the appropriate statistical tool for weld flux design and review of earlier work done by different authors has been also discussed. The authors suggested that factorial design may not work for weld flux design where only proportions matter and not the amounts; mixture design is more suitable in such cases. In the mixture design; the response is assumed to depend only on the relative proportions of the components rather than the total amount in the mixture. It was concluded in the study that constrained mixture designs or extreme vertices design is the most suitable mixture design technique.

Bhandari et al. (2012) discussed the issues and challenges such as solidification cracking, thermal fatigue and residual stresses for the systematic and scientific development of welding electrode coatings for bimetallic welds in SMAW. The primary requirement while deciding the percentage composition of various flux ingredients is that their melting temperature should be lower than that of base metals as the flux should melt first before
the base metals to be melted and should remain in the molten state even after the solidification of weldment so as to avoid the atmospheric contamination.

Jindal et al. (2013) developed flux mixtures using extreme vertices design for submerged arc welded V-groove butt joint on 18mm thick high-strength low-alloy steel plate for optimum weld properties. Mathematical models for ultimate tensile strength, percentage elongation and impact strength for weld joints versus flux constituents have been developed. Four solutions for flux mixtures were provided, giving optimized weld metal mechanical properties of weld metal of HSLA steel.

Adeyeye and Oyawale (2009) proposed a new methodology for optimization of weld-metal properties from welding flux ingredients. The authors utilized the earlier work done by Kanjilal et al. (2005); Kanjilal et al. (2007); Kanjilal et al. (2007) to provide single objective optimization values of flux mixtures.

Sakaguchi et al. (1994) investigated the effects of the addition of iron powder to agglomerated flux on welding performance and on the optimum welding conditions for high heat input welding. The study concluded that addition of iron powder to flux increased the deposition rate, improved welding efficiency and operability.

Bauné et al. discussed the development of different welding techniques for the welding of very high strength steels.

Datta et al. (2008) used the Taguchi method in combination with grey relational analysis for solving multiple criteria (objective) optimization problem in submerged arc welding (SAW). In the experimental work fresh unmelted flux was mixed with slag in different proportions of slag and fresh flux. Welding current, flux basicity and %composition of flux and slag were taken as process parameters. Study revealed that 10% slag-mix should be used (optimum amount) to achieve favorable quality weld in terms of bead geometry.
Pokhodnya (2003) reviewed history and present development strategies of welding processes and welding materials. The authors discussed that the important problem in welding HSLA steels is to prevent brittle fracture of welded joints due to increased strength of the weld. It was suggested that brittle fracture of welded joints is caused by structural transformations in the welded joint as well as in heat-affected zone (HAZ) and also by impurities dissolved in the metal mainly due to hydrogen.

Quintana et al. (2003) in their work determined the transfer coefficients, based on the laws of conservation of mass and on repartition. The study aimed at determining the transfer efficiency of alloying elements in SAW fluxes. The authors suggested that the two constituents of the flux aggregate; the matrix and the alloyed load by various processes with the help of agglomerating agents but agglomeration by granulation using liquid sodium and/or potassium glass is the most common. Ternary system: SiO$_2$–Al$_2$O$_3$–CaO, was utilized in their work to formulate agglomerate fluxes.

Paniagua-Mercado et al. (2003) carried out a study of the crystalline phases and the chemical characterization of the ions formed in agglomerated fluxes. Chemical analysis, X-ray diffraction (XRD) and differential thermal analysis (DTA) was carried out on three flux formulations prepared by using mineral oxides with agglomerating and sintering processes. The presence of crystalline phases such as Nepheline (NaAlSiO$_4$), Gismodine (CaAl$_2$Si$_2$O$_8$H$_2$O) and Vesuvianite (Ca$_{19}$Al$_{11}$Mg$_2$Si$_{18}$O$_{69}$(OH)$_9$) were observed during X-ray diffraction (XRD) analysis.

Jindal et al. (2013) studied the effect of flux constituents and BI on mechanical properties of submerged arc welded HSLA steel (SAIL Grade FE-540). The work was carried out using Taguchi’s L8 array to formulate eight fluxes with different BI by varying composition of three compounds; CaO, SiO$_2$ and CaF$_2$ each with two levels at constant welding parameters. It was concluded from the work that mechanical properties are not
affected by BI only but composition of flux in conjunction with BI plays role in deciding the same.

Kumar et al. (2012) evaluated the hardness of welded joints using developed agglomerated fluxes during submerged arc welding. Response surface methodology (RSM) technique was used to formulate the fluxes and it was observed that CaF$_2$ is not so prominent to improve the hardness.

Jindal et al. (2013) studied the resulting chemical composition of C, Si, Mn, P, S in the weld metal using formulated fluxes. The constrained mixture design; extreme vertices design has been used to formulate fluxes to study the effect of flux constituents. From the work it was concluded that CaF$_2$ was the most significant flux constituent and Al$_2$O$_3$ was the second most significant constituent among individual mixtures. CaO-MgO and CaO-Al$_2$O$_3$ binary mixtures are the most effective to change weld metal content.
2.4. Gaps Identified from the Literature Survey

After extensive study of the existing literature, following gaps were identified towards the design and development of SAW flux:

- Literature reveals that the researchers have carried out most of the work to study the effect of weld parameters on the weld bead geometry but little work has been done on flux composition and its effects on mechanical property estimation and chemical composition of the weld metal.
- Literature review reveals that the use of multi response optimization has not been explored for the optimization of process variables and flux compositions.
- Cold cracking is still the major issue in higher-strength steel welds. Limited work has been done on flux chemistry modification with an aim to minimize cold cracking.
CHAPTER 3

PROBLEM FORMULATION