2
Review of Literature

The Literature review gives an insight into the current research objectives of developing electrode coatings for dissimilar welding used in power plant applications. The issues related to dissimilar welding and their performance at higher temperatures are also discussed in this chapter. The gaps and scope in research have also been identified.

2.1 Energy requirement in India

India is the third-largest consumer of electricity. Energy demands in India have been increasing significantly over the past 20 years. The gross electricity consumption in the year 2000 was almost 500KW/capita, which has now increased to 1181 KW/capita in the year 2018-2019. The per capita consumption will almost double by 2040. Coal is India`s primary energy source and is used to generate more than 70% of the total electricity. The energy generated from the different sources in India and worldwide is presented in Figure 2.1.

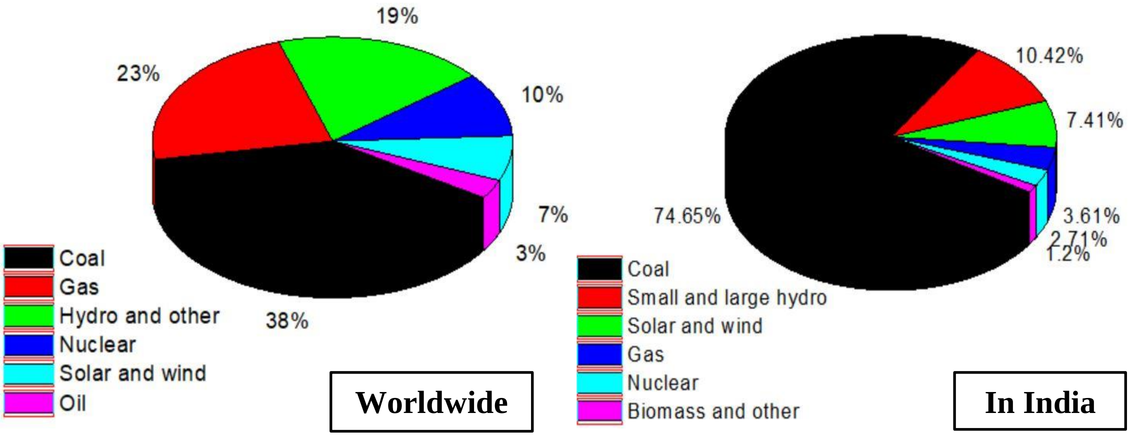


Figure 2.1: Electricity generation by source (www.iea.org/data-and-statistics)

A major concern of using coal as a primary source is CO_2 emission, which has a significant environmental impact. Therefore, India needs to adopt a clean coal-based technology that helps to minimize CO_2 emissions. A higher efficiency yields lower CO_2 and reduces coal requirement. (Chetal et al., 2015; Nicol, 2013, 2014)

2.2 Future of coal technologies

Coal technologies (clean coal) are in the developing phase worldwide because they would boost energy security by increasing the longevity of coal resources. Integrated gasification combined cycle (IGCC), Supercritical (SC), Ultra supercritical (USC), and Advanced ultra-supercritical (AUSC) are some of the clean coal technologies that are being developed in various countries. There is a need for higher efficiency and low CO_2 emission in the power plant operation, which can be attained by increasing superheater and reheater temperature. In India, supercritical technology has been successfully developed and adopted like other countries. Supercritical power plants offer improved efficiency by consuming less coal and emits lower CO_2. The USC and AUSC power plants are ready to be adopted and under the development phase with enhanced efficiency (Henderson, 2015).

2.3 Need for high strength materials for USC power plants

Coal-based power plants are prevalent, and coal-based power plants generate almost 50% of the world's electricity. The efficiency of these power plants is very low. The only effective way to increase the efficiency is to increase the steam parameters; thus selecting the material (that can withstand high temperature and pressure conditions) is an important aspect. Low alloy C-Mn and Mo based ferritic steels were used for first-generation pulverized coal combustion (PCC) power plants where the steam temperature is below 540°C and pressure are below 22.1 MPa. The use of improved 9-12% Cr steels was proposed with the development of SC and USC power plants due to their high corrosion resistance and creep resistance properties. It was reported that the efficiency of power plants could reach more than 50% if the stream temperature reaches above 700°C and it also reduces coal consumption significantly (Nicol, 2013). The different materials used in the power plant applications are presented in Figure 2.2.

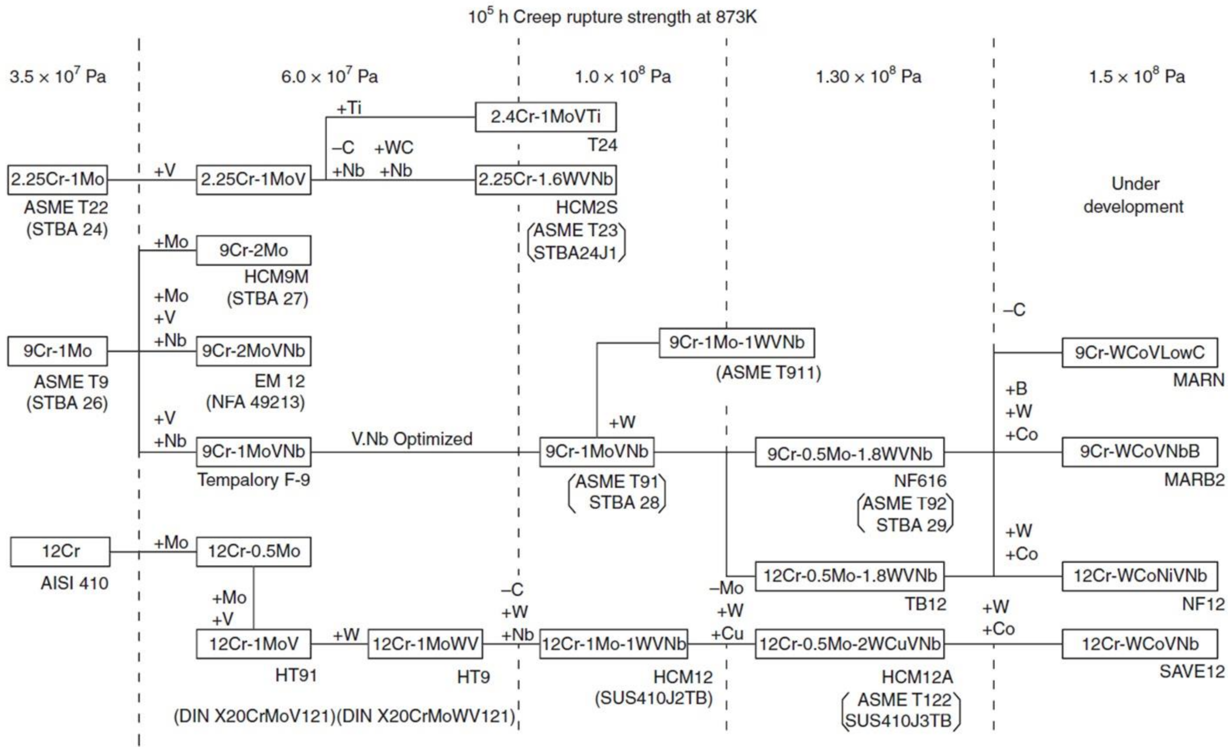


Figure 2.2: Boiler steel materials for power plant applications (Nicol, 2013, 2014; Chetal et al., 2015)

Low alloy ferritic steels are well known for their use when the steam temperature is below 550°C. The temperature limit for martensitic steels (9 to 12% Cr) is about 630°C. Nickel-based alloys are working well at 700°C and above, which is the main requirement for AUSC applications. The gap between the martensitic steel operating temperature and nickel-based alloys are generally filled with the austenitic stainless steels. These steels are working well up to 680°C with better corrosion resistance and creep strength. Materials generally used for high-temperature applications should possess good fabricability, weldability, creep rupture strength, fatigue resistance, and corrosion resistance properties.

2.4 Welding in power plant boilers

Power plant fabrication and maintenance is a complex process due to the extreme critical service environments. Transition joints are required to weld different components of power plants, which require different joining methods. Several joining techniques are commonly used to join different workpieces/components, which depends on the service and application. Mechanical fastening, adhesive bonding, and welding are some of the commonly used joining techniques in engineering applications. Weld joints have a high load carrying-capacity with better performance at high-temperature applications compared to other joining processes. Welding represents an essential element in the process of power plant equipment fabrication and maintenance. General components (Figure 2.3) which require welding repairs during their service are superheater, boiler header, steam pipes, water wall tubes, steam coil air heater flash tank, boiler heater, steam control valves, and boiler feed pump (Cerjak, 2008; David et al., 2013). Fusion welding is generally used for the fabrication and maintenance of power plant equipment.

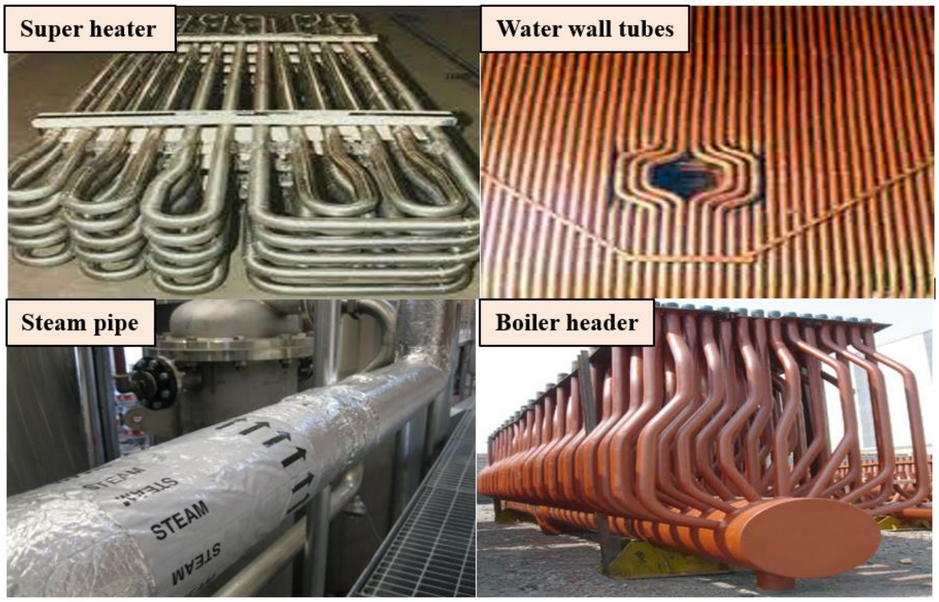


Figure 2.3: Power plant components require welding procedures during fabrication and service (Sorrentino, 2017)

2.5 Fusion welding

Fusion welding is a preferred method for welding small to large parts to construct power plant components. Fusion welding is defined as the localized melting and joining of two materials. Welding processes like shielded metal arc welding (SMAW), submerged arc welding (SAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), laser welding, plasma arc welding, electron beam welding, oxy-fuel welding, resistance spot welding falls under the category of fusion welding (Sorrentino, 2017). The research work present in the thesis concentrates on the welds fabricated using the SMAW process, a general and commonly used procedure.

2.5.1 Shielded metal arc welding

Shielded metal arc welding (SMAW), also known as manual metal arc (MMA) welding or informally as stick welding, is a process that uses a consumable electrode coated with flux to lay the weld. An electric current, in the form of either alternating current or direct current from a welding power supply, is used to initiate an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode decomposes, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the molten weld pool from the atmosphere (Figure 2.4).

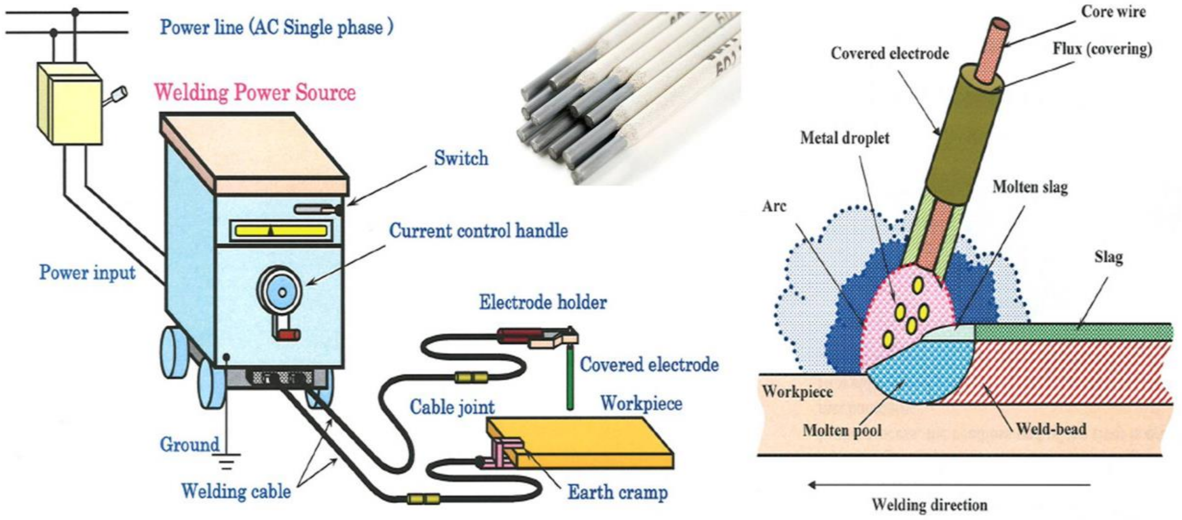


Figure 2.4: Shielded metal arc welding setup and operation (Parmar, 2015)

2.5.2 Flux coated welding electrodes

The welding electrode consists of two components, namely the core wire and the flux coating. The choice of core wire generally depends upon the base materials to be joined. The core wires are drawn from the large coils as per the desired diameter and cut to the proper length required. The selection of the electrode`s core wire depends upon the base materials composition. Flux coatings are generally made up of various oxide powders (minerals) that are used to facilitate the removal of harmful oxides and other undesirable substances from the weld pool. The essential functions of an electrode coating are summarized below.

- Electrode coating helps to refine the weld pool by eliminating the oxygen and nitrogen from the weld pool.
- It provides a slag blanket that protects the molten weld pool from the atmospheric impurities and contamination.
- It helps to improve the mechanical properties of the fabricated weld by providing required alloying elements to the weld pool.
- It helps to maintain arc and reduce spatter.

Electrode coatings impact weld metal quality. It affects the bead profile and shape geometry, which affects the load-carrying capacity of the weldments. It also affects the chemistry of the produced weld, which in turn influences the mechanical properties and corrosion resistance properties.

The flux coatings are classified into three types: basic, rutile, and cellulosic. The ones containing a high amount of cellulose (organic component) is called cellulosic coatings. They produce more smoke and have a rapid burn-off rate. Organic substances in cellulosic coatings increase the moisture absorption of coatings, which results in hydrogen assisted cracking of the welds. Rutile based electrodes are also called general-purpose electrodes because they can be used in all the welding positions with AC or DC power sources. Rutile coatings contain titanium oxide (TiO_2) as the primary component. These types of electrodes provide better arc stability, easy arc ignition, and lower spatter. Welds fabricated using rutile-based electrodes exhibit good bead geometry with self-detaching slags. Basic flux coated electrodes contain a higher amount of basic oxides (CaO, CaF_2, MgO). Basic oxides help in reducing the viscosity of the slag produced during the welding operation. Basic coated electrodes are very helpful in vertical and overhead position welding due to their fast freezing capability. They produce better quality welds with good mechanical properties.

2.5.3 Commonly used flux coating ingredients and their functions

Electrode coatings contain various different oxide minerals that perform functions to improve the final weld quality. Minerals like calcite (CaO), fluorspar (CaF_2), rutile (TiO_2), deadly burnt magnetite (MgO), calcinated bauxite (Al_2O_3), Silica (SiO_2), etc. are some of the very common minerals used in electrode coatings. These electrode constituents perform various functions, act as arc stabilizers, slag formers, alloying elements, binding agents, or slipping agents. Various minerals with their functions are summarized in Table 2.1. For better welding, the arc should be stable throughout the process, but the air is not sufficiently conductive to maintain a stable arc. Arc stabilizers are added to the electrode coatings to improve the arc stability during the welding process. Slag formers are used to provide sufficient slag during the welding process, which helps to protect the molten weld pool from impurities. The alloying powder is sometimes used in the electrode coatings to impart enhanced mechanical properties to the welds. Binding agents are used in the electrode coatings to prepare the wet mix, which holds the coatings. Binding agents also act as arc stabilizers due to the presence of potassium and silicate ions. Slipping agents in the electrode coatings are used to ease the extrusion process of electrodes. Gas forming materials are used in the electrode coatings to remove the harmful gases from the weld pool, which tend to deteriorate the weld quality (Bhandari et al., 2016a, 2016b)

Table 2.1: Electrode coating constituents and their functions

Constituent	**Functions of constituents**
Feldspar ($K_2O.Al_2O_3.6SiO_2$)	Slag former, Viscosity control, Arc stabilizer
Fluorspar (CaF_2)	Gasious protection, Deoxidizer, Viscosity control
Cellulose $(C_6H_{10}O_5)_x$	Gasious protection, Deoxidizer, Slipping agent
Calcium carbonate ($CaCO_3$)	Gasious protection, Deoxidizer, Slag former, Viscosity control, Arc stabilizer
Rutile (TiO_2)	Deoxidizer, Slag former, Viscosity control, Arc stabilizer
Silica (SiO_2)	Deoxidizer, Slag former, Viscosity control, Arc stabilizer
Mica (($KAl_2(OH)_2$)	Slipping agent, Arc stabilizer
Clay ($Al_2O_3.2SiO_2.2H_2O$)	Slag former, Viscosity control, Arc stabilizer, Binder, Slipping agent
Manganese powder	Slag former, Alloying agent
Iron oxide	Deoxidizer, Slag former, Viscosity control, Arc stabilizer
Ferroalloy powders	Deoxidizer, Slag former, Alloying agent
Iron powder	Arc stabilizer, Alloying agent
Sodium silicate ($Na_2SiO_3.nH_2O$)	Binder, Arc stabilizer
Talc ($2MgO.4SiO_2.4H_2O$)	Deoxidizer, Slag former, Viscosity control, Arc stabilizer, Slipping agent
Potassium Silicate ($K_2SiO_3.nH_2O$)	Binder, Arc stabilizer

2.6 Design and development of electrode coatings

2.6.1 Physicochemical behavior of electrode coatings

The effect of the flux coating ingredients on the physicochemical properties needs to be understood by the researchers to develop the electrode coatings. The physicochemical properties of the electrode coatings affect the weld pool chemistry significantly, which is always an essential consideration in the welding process. The molten flux must possess specific physical properties like viscosity, current carrying capacity, arc stability, which are decisive for their applications. So, the concentration of the constituents (CaO, CaF_2, SiO_2, MgO, MnO, Al_2O_3, TiO_2, Na_2O, Na_3AlF_6) must be restricted to certain limits. SiO_2 is generally used to obtain the desired viscosity. CaO/MgO is used as a slag former, which also improves the slag detachability with other chemical and metallurgical importance in the flux. It also makes the flux hydrophilic in nature, which causes porosity. Al_2O_3 also makes flux sensitive to moisture but improve slag detachability. MnO favors high welding speed and imparts deep penetration but decreases the current carrying capacity. The increase in MnO lowers the Si and C content in the weld metal. The amount of SiO_2 in the flux increases, the amount of MnO and FeO in the slag is also found to be increased with higher Si and O in the weld metal. Dissolved oxygen in the weld results in several problems like loss of fracture toughness, porosity and reduction in ductility. The weld metal oxygen significantly decreases with increasing the flux basicity index (BI) and CaF_2 concentration of the flux. The earliest form of a basicity index was expressed as ratio of basic oxides to acidic oxides used in the flux. In 1969, Tuliani S.S et. al. 1969 proposed a basicity index expression given by (Eq. 2.1):

$$BI = \frac{[CaO+MgO+CaF_2+Na_2O+K_2O+0.5(MnO+FeO)]}{[SiO_2+0.5(TiO_2+Al_2O_3)]} \quad (2.1)$$

CaF_2 can dilute the metal oxides, which helps to decrease the weld metal oxygen content. The ability of CaF_2 to reduce the oxygen content is dependent on the stability of the metal oxides present in the weld (Palm, 1972; Chai et al., 1982; Davis et al., 1991). Figure 2.5 shows the effect of flux oxide content on the weld metal silicon and oxygen content.

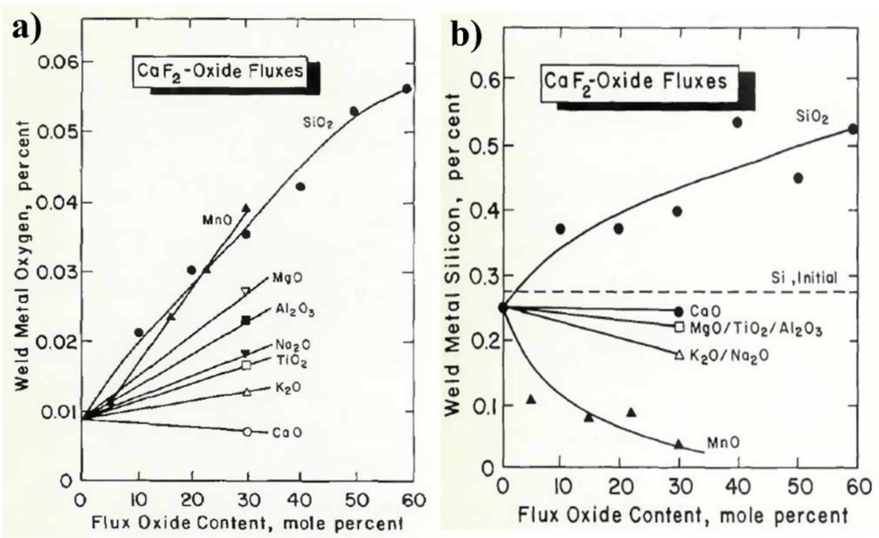


Figure 2.5: a) Weld metal oxygen vs. Flux oxide content b) Weld metal silicon vs. Flux oxide content, adapted from (Chai et al., 1982)

The addition of FeO (less than 10%), MnO, and SiO_2 is the primary source of oxygen inclusion in the weld. Calcite is a commonly used mineral which provides gaseous protection. Calcite decomposes into CaO and CO_2 at a high temperature, upon futher heating oxide ions are released. Fluorspar (CaF_2) significantly increases the silicon content in the weld metal because it reduces the oxidizing potential for SiO_2 by forming silicon fluoride (Eq. 2.2):

$$2CaF_2 + SiO_2 = 2CaO + SiF_4 \quad (2.2)$$

The welding electrode coatings have some important operational characteristics which impact the weld properties. The slag formation is required in the flux core electrode welding. The basic requirement of the slag is that it should be in the molten state and cover the molten weld pool during welding. The slag viscosity should be adequate so that it can completely cover and protect the molten weld pool. The adhesion of the slag to metal is also governed by the slag viscosity. If any welding slag has low viscosity, then its flowability is increased, which can affect the welding performance. If the viscosity is too high, it cannot cover the molten pool properly and reduce the diffusion rate, which impacts the slag-metal reaction at the weld/slag interface (Kalisz, 2013; Mitra et al., 1991a, 1991b). Higher slag viscosity increases the heat input per unit area, which confines the weld pool and results in deeper penetration. The vertical and overhead welding processes generally required dense welding slags to assist in reinforcing and protecting the weld pool. The range of slag viscosity is suggested to be between 22-35 poise at a temperature of 1400-1550°C (Petetskii, 1995). The higher amount of SiO_2 present in the flux reacts with CaO and form silicate ions (SiO_4^{4-}), which has a tetrahedron network structure. These silicate ions increase the viscosity of the slag due to its network forming capability. The addition of MnO and CaF_2 in the fluxes tend to reduce the slag viscosity by ionizing and breaking down the networks of silicate ions (Bhandari et al., 2016b; Mills, 2011; Olson et al., 1998).

Slag detachability in welding affects the weld quality of multipass weldments. It is defined as the ease with which the welding slag can be detached from the weld metal after the weld deposition. It depends upon the electrode coating constituent`s physical and chemical properties. There should be a significant difference in the coefficient of thermal expansion of the slag and the weld metal for easy removal of the slag (Qin et al., 2013; Wang et al., 2016b). The more difference in the coefficient of thermal expansion, the better is the slag detachability. It was reported that the electrode coatings with a higher amount of rutile possess excellent slag detachability. Rutile and rutile acidic based flux impart better slag detachability to the weldments. Slag detachability is difficult in basic flux coated electrodes. An increase in the acidic oxides like silica, alumina, corundum in the electrode coatings improves the slag detachability. The coatings containing higher CaF_2 results in the formation of cuspidine phases in slag after reacting with silica. The formation of cuspidine spinels and cordierite phases are difficult to remove from the weld metal (Bhandari et al., 2016a, 2016b). Along with better slag detachability, the stability of the welding arc is also an important factor for producing quality welds. The weld bead morphology is significantly affected by the initiation and maintenance of the arc during welding. If the welding arc is not stable, it impacts the electrode melting, and inconsistent deposition of weld metal results in defects and discontinuities in the final weld. The spatter observed in the welding process is due to the poor arc stability, which affects the production times due to the cleaning procedure of the spatter (Niagaj, 2002; Patchett, 1974; Suban, 2003). In the case of the electrodes with lower ionization potential, electrons are emitted at lower energies, which produce a stable arc. In the welding electrode coatings addition of potassium silicate, sodium silicate and rutile generally improves the arc stability because these minerals provide better electric conductivity (Sham et al., 2014; Natalie et al., 1986). Electrode coatings containing lime possesses better arc stability. It is also reported that the addition of CaO into the manganese silicate fluxes improves arc stability. The magnesium is added as an alloy to the fluxes, which improves the arc stability. The arc stability is significantly affected by the addition of CaF_2, which reduces the arc stabilization during welding (Farias et al., 1997; Olson et al., 1998; Rissone et al., 1997).

Mechanical and metallurgical properties of the welds are significantly affected by the weld metal chemistry. The composition of the final welds is a result of various physical and chemical interactions during the welding process (North et al., 1978; Palm, 1972; Polar et al., 1991). The dilution of base metals and filler metal controls the overall weld metal chemistry. The thermochemical reactions take place at the electrode tip, the detached droplet, the weld pool, and the solidifying weld pool. Oxygen inclusion in the fabricated weld is one of the decisive factors in weld quality. Near the welding arc, a high-temperature environment is present, which helps in decomposing various oxides and produce oxygen, as shown in Eq. 2.3:

$$SiO_2\ (g) = SiO\ (g) + \frac{1}{2} O_2\ (g) \tag{2.3}$$

Oxygen present in the weld increases the chances of oxide inclusions in the weld, and it also affects the element transfer efficiency from the electrode to the weld pool. The reactive elements should be removed from the weld pool in the form of slag. The stability of the various oxide, including MnO, MgO, SiO_2, Al_2O_3, TiO_2, K_2O, Na_2O, and CaO was observed by researchers. Some fluxes in arc plasma may dissociate into suboxides, which results in a high amount of oxygen in the weld metal and reduce the impact toughness. The addition of FeO, MnO and SiO_2 was found to be the primary source of oxygen contamination. The oxides with better stability have lower chances to decompose into suboxides; therefore, they produce lesser oxygen in weld metal (Eagar, 1978). The various chemical reactions were taking place between the slag and metal during welding, which results in compositional changes and impacts the weld properties. The slag metal reactions occurring during the welding process were studied by Mitra et al., 1984 in their research and proposed a kinetic model that describes the alloying element transfer. The authors divided the chemical interaction between slag and weld metal into three stages to understanding the reactions better, which are within (i) droplet (ii) diluted weld pool (iii) solidifying pool. The authors also stated that the solidification time plays an essential role along with the type of flux for weld oxygen content. The authors also performed various experiments to verify the kinetic models (Mitra et al., 1984, 1991a, 1991b). Various authors performed extensive experimentation to study the chemical and physical properties of the fluxes and their effect on the metallurgical and mechanical behavior of the welds (Chen et al., 1989; Fox et al., 1996; Jindal et al., 2013a, 2013b, 2014; Palm, 1972; Mercado et al., 2005; Petetskii, 1995; Polar et al., 1991; Sharma et al., 2018)

2.6.2 Flux coating development and its effect on weld performance

Electrode coatings play an essential role in the SMAW process. The ability to design and optimize welding electrode coatings is very crucial for any welding industry to compete in the global marketplace. With the increasing energies demand, advanced power plants with higher efficiency and low CO_2 emission are developing at the full pace. The construction of these power plants results in the development of new alloys and advances in their critical applications. To fabricate and repair these power plant components, there is a need for shielded metal arc welding electrodes. Therefore, it is important to study the effect of the electrode coating composition on the weld metal chemistry and mechanical behavior of the dissimilar welds.

Researchers have performed experimental investigations to examine the individual as well as the interaction of various coating ingredients on the weld quality during the welding process. SMAW consumables for offshore applications were designed by Osio A. et al., 1995. The main objective of this research is to minimizing porosity along with the precipitation of acicular ferrite in the weld fusion zone using suitable developed welding consumables. The fluxes were developed by mixing various minerals in a suitable proportion. A total of nine batches of electrodes with three series were developed and extruded on the E6013 core wire. It was observed that ferrotitanium (Fe-Ti) addition to the coatings increases the Si and Mn in the weld, which results in the increased hardenability. Fe-Ti and ferroboron (Fe-Br) are also known to be strong deoxidizers, which also reduces the weld metal oxygen. An addition of $CaCO_3$ up to 12.5 wt.% reduces the weld metal porosity. A higher amount of $CaCO_3$ results in an unstable arc and poor slag detachability (Osio A. S. et al., 1995).

Cruz-Crespo et al., 2010 developed CaO-CaF_2-TiO_2 flux system-based SMAW electrodes for hardfacing applications. The composition for all the minerals was selected using design of experiments approach. Seven groups of electrodes were developed and baked at 160°C for 2 hours. It was observed that with an increase in the CaF_2 content, the deposition rate is higher, whereas CaO and TiO_2 do not affect the fusion rate of electrodes too much. It was also observed that no compound alone could improve the performance of the electrodes, and a correct composition must be found to produce the desired outcome using multiple iterations (Cruz-Crespo et al., 2010).

Various researchers adopted mixture design approach to develop SAW fluxes and electrode coatings for different applications. In their work, various combination of minerals has been used to design and develop welding consumable to produce quality welds (Bhandari et al., 2016a, 2016b; Jindal et al., 2013a, 2013b, 2014; Kim et al., 2018; Qin, 2013; Wang, 2002).

Jindal et al., (2013a, 2014) design and developed CaO-Al_2O_3-CaF_2-MgO based SAW fluxes using a mixture design approach. The effect of each mineral and their interaction on the weld metal chemistry and mechanical properties were studied in their study. It was observed that an increase in CaO and CaF_2 individually deteriorates the impact toughness of welds but, in combination with MgO, it has a synergistic effect. The addition of CaO decreases the weld metal phosphorus and sulfur content. An increase in Al_2O_3 and MgO increases the ultimate tensile strength (UTS) but decreases the impact toughness (Jindal et al., 2013a, 2014).

Flux coated Nickel-based SMAW electrodes were developed by Qin, 2013. Sixteen types of electrode coatings were developed using $CaCO_3$, Na_2CO_3, and CaF_2 as the major constituents with varying addition of ferroalloys (Fe-Nb, Fe-Ti, Fe-Si) and alloying powders (Mn, Cr, Fe). SMAW process was used to deposit the multipass bead on a plate. The mass transfer of the electrodes was quantitatively evaluated in this research. It was found that the mass transfer of alloying elements follows the order: $\eta_{Cr} > \eta_{Mn} > \eta_{Nb} > \eta_{Si}$. The mass transfer coefficient of both Nb and Mn increases as their content increases in the coating. With the increase in the welding current mass transfer of Nb and Mn decreases, but for Cr and Si increases (Qin, 2013).

Sham et al., 2014 designed high-nickel electrodes for pressure vessel fabrication/repair in the power-generation industry. The coatings were formulated using three primary ingredients Na_3AlF_6, TiO_2, and $CaCO_3$. To improve the coating performance, other minerals were also added. A total of seven electrode coatings were developed with different code names. It was observed that an adequate amount of cryolite is important for weld cleanliness. Weld metal recovery calculations were also performed and found that the recovery rate of Cr is 95%, which is similar to the case of low carbon steel electrodes. Mn was found to be 60% recovered, which is much lower than the reported one (Sham et. al, 2014). The CSM final coating electrodes possess better arc stability with good extrudability and welding characteristics.

Wang et al., 2016a developed Nickel-based SMAW electrodes using CaO-CaF_2-SiO_2 based flux system. It was found that the slag detachability is improved with a decrease in the SiO_2 content in flux coating. A 10.9 % of SiO_2 with 28.3 % CaF_2 results in the best slag detachability. The best slag detachability was achieved when $CaO:CaF_2:SiO_2$ :: 1.7:1.8:1 and the worst slag detachability appeared at $CaO:CaF_2:SiO_2$ :: 1.3:0.9:1 (Wang et al., 2016a).

The effect of the flux coating ingredients on the welding performance, weld quality, and mass transfer coefficient of alloying elements were studied by Wang et al., 2016b. The electrodes were prepared using CaF_2-CaO-SiO_2 and TiO_2-SiO_2-SrO flux systems. It was found that the electrode made using CaF_2-CaO-SiO_2 flux system possesses a better deposition rate, smaller spatter, and fumes with better slag fluidity as compared to the other system electrodes. The slag detachability and larger penetration were observed in the TiO_2-SiO_2-SrO based electrode welds. The impurities like S, P, and O were relatively lower in the CaF_2-CaO-SiO_2 based weld deposits due to the presence of higher CaO and CaF_2 content in the slag (Wang et al., 2016b).

Stainless steel-based SMAW electrodes were developed using TiO_2-SiO_2-CaO-CaF_2 flux-based system by Bhandari et al. 2016a. The austenitic stainless-steel based electrodes were developed to join bimetallic joints used in nuclear power applications using extreme vertices design methodology. In this research, the effect of constituents and their interaction on the mechanical properties were established. The coating ingredients CaO, CaF_2, and Ni tend to increase the ultimate tensile strength of weld while SiO_2 shows the opposing trend. Higher SiO_2 in electrode coating formulations results in higher silicon and dissolved oxygen along with lower manganese and carbon in weld metal. Higher SiO_2 in electrode coating formulations results in higher silicon and dissolved oxygen along with lower manganese and carbon in the weld metal. A higher SiO_2 content also shows a decreasing effect on impact toughness and microhardness values of the weld (Bhandari et al. 2016a).

Bhandari et al., 2016b developed mild steel-based SMAW electrodes to join bimetallic weld of ferritic steel to austenitic steel. The electrode coatings were developed using CaO-CaF_2-SiO_2 basic flux system with an addition of Ni alloying powder by extreme vertices design methodology. Twenty-one were prepared, and the effect of coating ingredients and their interactions on the weld metal chemistry was observed. It was observed that CaO, CaF_2 and SiO_2 tend to decrease the Ni and P content in the weld. SiO_2 and the binary interactions of CaO have a decreasing effect on the carbon content. CaO, CaF_2, Ni, and all the binary interactions of Ni tends to increase the tensile strength of the welds while SiO_2 decreases the tensile strength. The impact toughness was observed to increase with increasing Ni, CaO, and CaF_2 content in the coatings. CaO picks up the carbon from weld due to which the microhardness was reduced due to the increase in $CaO.CaF_2$ and $CaO.SiO_2$ binary mixtures in coatings. Binary mixtures of Ni improve the corrosion resistance of the welds (Bhandari et al., 2016b).

In one of the studies, the rutile-based flux coatings were developed by Kim et al., 2018. The effect of compositional variations in rutile-based electrode coatings on viscosity, wettability, and electronegativity was studied. Welded specimens were machined and mechanically tested to fundamentally identify the relationship between the flux composition and mechanical properties such as tensile strength and micro-Vickers hardness. Thermo-physical properties such as wettability and viscosity were calculated and measured to identify the covering area on the bead and the degree of polymerization at high temperatures using the flux containing 6 wt pct Na_2O as a fusing agent. All welding fluxes spread on a Pt-10Rh plate with full wetting instantly when the temperature reached 1773 K. This meant that the covering effect was equal for all fluxes (Kim et al. 2018).

The welding electrodes were developed by Kashchenko et al., 2017 for welding transmission pipelines and marine equipment. To improve the efficiency of microalloying, the weld metal produced with the new electrodes the rare-earth metals (oxides of cerium and lanthanum) were added to the complex component of the coating – minerals. The composition of the rare-earth metal oxides in the form of powders with a particle size of 250 µm, added to the composition of the minerals. Plates of the low-alloy steel of the strength categories K80, X70 with V-shaped edge preparation were welded with experimental electrodes. The welds produced using these basic coated electrodes shows reduced diffusible hydrogen content. It was shown that microalloying with oxides of cerium and lanthanum through the mineral alloys in the given component system of the coating results in the formation in the weld metal of a finegrained homogeneous structure with the uniform distribution of the globular or non-metallic inclusions with clean intergranular boundaries (Kashchenko et al., 2017).

Rutile based electrodes were developed with different basicity index (L100 with B.I. 1.4 , L127 with B.I 1.2 and L208 with B.I 1.1) for the welding of super duplex steel by Liraz et al. 2020. ER2205 core wire was used to develop electrodes and two plates of SS304L were welded using these developed electrodes. It was observed that as the basicity index of the coating increases, the level of impurities decreases. The auhtor also observed that the colling rate of the welds depends upon heat input and the location in the weld metal. The cooling rate in the weld metal can be ranked as follows: L100 = L127>>>L208. The study demonstrates that the sigma phase cannot be avoided in welds. However, the secondary austenite can be avoided, by employing an adequate "low heat input policy". The higher the austenite levels in the weld, the higher the elongation properties of the weld (Liraz et al. 2020).

The mineral waste added SiO_2–CaO–CaF_2–TiO_2 flux system based electrodes were developed by Waris et al., (2020a; 2020b) for offshore applications. The electrode coatings were developed using extreme vertices design methodology. The developed electrode coatings were extruded on the SS309L core wire. The multipass beads were deposited on super duplex stainless steel 2507 grade using SMAW process. The beads show acceptable microstructure and micro hardness values, confirming the utility of red ochre in developing electrode coating. It was observed that high iron content in ochre improves current carrying capacity and arc stability of the developed electrodes. Binary mixtures $CaO.CaF_2$, $CaO.TiO_2$ and $TiO_2.SiO_2$ along with tertiary mixture of $CaO.CaF_2.TiO_2$ have significant effect on increasing the chromium content. Microhardness is an important mechanical property and the quadratic regression model developed here shows that it increases with $CaO.TiO_2$ and $TiO_2.SiO_2$ (Waris et al. 2020a; 2020b).

Waris et al., 2021 developed SiO_2–CaO–CaF_2–TiO_2 flux system based electrode coatings and extrude it to the austenitic 309L filler wire to fabricate welds for offshore structures. Multipass weld beads were deposited on the super duplex 2507 grade. It was observed that deleterious elements (Phosphorus and sulphar) in the weld zone can be controlled by altering the electrode coating compositions. Calcite and rutile lowers the sulphur content by forming sulphides and releasing free oxygen. Phosphorus content in the weld zone increases by the binary interactions of $CaO.CaF_2$, $CaO.SiO_2$, and $CaF_2.SiO_2$ (Waris et al., 2021).

2.7 Dissimilar metal welds

Components like superheaters, reheaters, water wall tubes require materials and weld joints, with improved oxidation resistance with high creep strength. Ferritic steels (P22, P91) and austenitic stainless steels (SS304, SS347) are very common and popular materials for such applications. Carbon migration from low to high alloy steels, which generally takes place during the high-temperature exposure, results in the formation of a softer zone (carbon depleted zone) and harder zone (carbon-rich zone). Different methods have been employed to control carbon migration. This impacts the service life of dissimilar welds significantly. Buttering of the low Cr steels with nickel base material prior to welding helps to reduce the carbon migration (Chhibber et al., 2006). The carbon migration can be reduced by using the filler material of the intermediate chemical composition of the two materials to be joined. To fabricate dissimilar joints used in power plant boilers having different Cr content, the selection of filler is very important. Literature reveals the following criteria for choosing appropriate welding filler (DuPont, 2012; Fuchs et al., 2010; Mvola et al., 2014; Toshiharu, 2002):

- Welding consumable matching with low-Cr steel
- Welding consumable matching with higher-Cr steel
- Low-Cr, Low-C weld metal welding consumable with strong carbide formers
- Welding consumables having intermediate Cr content
- A nickel-based welding consumable (IN-617, IN-625)

Consumables matching with the low-Cr steels are low in cost as compared to the high-Cr and nickel-based consumables. Failures in DMWs can occur prematurely at service times below the expected creep life of either base metal and well below the design life of the plant. The failures can generally be due to the following reasons (Avery, 1991; Bhaduri et al., 1994; David et al., 2013; Lundin, 1981):

- The difference in the coefficient of thermal expansion: different steels can have a different thermal coefficient of expansion, as shown in Figure 2.6.
- Carbon diffusion: carbon diffuses across DMW from areas of high carbon concentration to areas of low carbon concentration.
- Steam side oxidation resistance: differences in resistance to steamside oxidation between two steels can create localized oxidation.

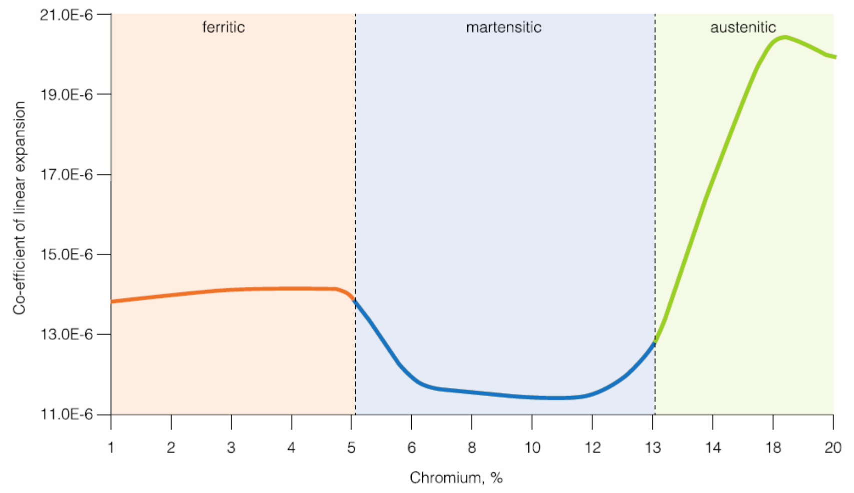
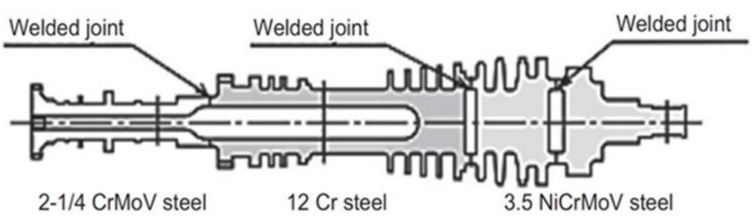


Figure 2.6: Coefficient of thermal expansion for various steels (Nicol, 2013, 2014)

2.7.1 Dissimilar welding of (Ferritic-Martenistic to Ferritic-Martenistic) and (Ferritic-Martenistic to Austenitic stainless steels)

Dissimilar welding of low-Cr ferritic steels, high-Cr martensitic steels, and austenitic stainless steels are generally used in transition between the membrane and headers, thermowell or between turbine rotor sections, as shown in Figure 2.7.



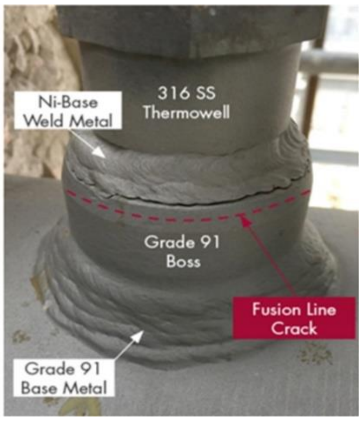


Figure 2.7: Layout of a welded rotor and thermowell (Sorrentino, 2017)

SMAW and GTAW welding processes were generally used to fabricate these joints due to the ease of these operations. The components used in supercritical/ultra-supercritical plants generally undergo cyclic stresses at high temperatures. The materials required should possess better creep and fatigue resistance properties at higher temperatures with enhanced high-temperature corrosion resistance. The materials like P22, P91, and SS304 and their weldments are specifically focused in this present investigation as these materials are commonly used for the construction of power plants equipment.

You et al., 2001 studied the carbon migration in the dissimilar welding of the modified 9Cr-1Mo steel fabricated using different electrodes. It was observed that the carbon migration is primarily driven by elemental differences between the weld metal and the base metal. The joint was fabricated using E9016-B3, TS-502, E308L-16, E309L-16, and ENiCrFe-3 electrodes. It was concluded that the Ni-base (ENiCrFe-3) electrodes are an effective way to control the carbon migration, and authors recommended these electrodes as the best-suited ones to join modified 9Cr-1Mo steel and austenitic stainless steels (You et al., 2001).

Sudha et al., 2006 fabricated the dissimilar weld joints between P22 and P91 low alloy steels. The P91 steel matching electrodes were used to fabricate the joint using the SMAW process. The microstructure and chemistry of this dissimilar joint were investigated after the post weld heat treatment (PWHT). The formation of the soft zone in the low Cr side was observed due to the diffusion of carbon across the weld interface. The carbide rich hard zone was also identified adjoining the soft zone in the high-Cr side of the weldment, as shown in Figure 2.8. An indirect method was used to estimate the carbon content and the average carbon content of 0.39% was found in the hard zone (Sudha et al., 2006).

The characteristics of the dissimilar welds T23/T91, T24/T91, and P23/P92 were observed by (Fuchs et al., 2010). The filler material which is matching with low-Cr steel was used to join these dissimilar steels. It has been observed that the presence of carbide forming elements V, Nb, and Ti in steels T23, T24, and P92 reduce the degree of C-diffusion, which has a positive effect on the creep strength of the dissimilar welds.

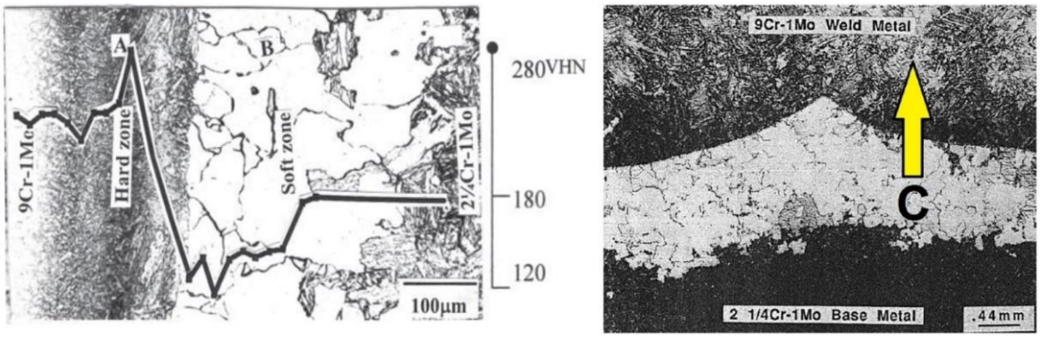


Figure 2.8: Formation of soft zone and hard zone due to carbon migration in P22/P91 DMW`s, adapted from (Mayr et al., 2018; Sudha et al., 2006)

Tammasophon et al., 2011 studied the effect of PWHT on the microstructure and hardness of P22/P91 TIG weldment. The Inconel 625 filler was used to fabricate this weld. The joint was provided with PWHT at 750°C for 2, 4, and 6 hours. It was observed that the post weld heat treatment provides a more homogeneous microstructure and reduced hardness differences in welded microstructure which improves the weld crack resistance of the welds operating at higher temperature. It was also suggested that the PWHT at 750°C for 2 hours is most suitable for the P22/P91 dissimilar welds. This PWHT condition provides the minimum hardness difference across the dissimilar joint (Tammasophon et al., 2011).

Sultan et al., 2017 studied the microhardness profile and microstructure behavior in a dissimilar weld of P22/P91 fabricated using E9018-B9 electrodes followed by PWHT from room temperature to 770°C. It was observed that the width of the carbon migration zone increases as the PWHT temperature is increased. The width of the carbon enriched zone is smaller than the width of the carbon depleted zone (Figure 2.9). Carbon has migrated from a larger area of P22 steel and has enriched a smaller area in the weldment. Higher PWHT temperature provides better tempering of the steel and decreases the microhardness. A temperature of 730°C is suggested as the optimal PWHT temperature to avoid over tempering and under tempering of the dissimilar joint (Sultan et al., 2017).

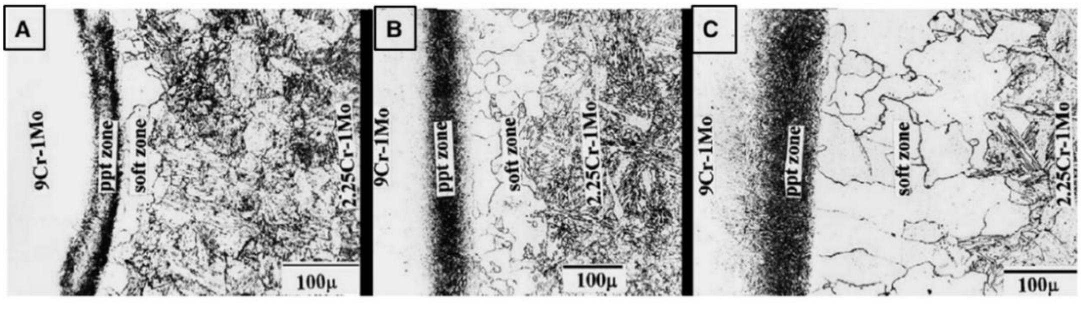


Figure 2.9: Microstructure of the fusion line between P22/P91 DMW`s representing various zones after PWHT at 750°C a) For 1 h b) For 2 h c) For 10 h (Sudha et al., 2002)

Kulkarni et al., 2018 fabricated P22/P91 dissimilar joint using activated-TIG (A-TIG) process. The activated fluxes used were SiO_2, TiO_2, Cr_2O_3, MoO_3, and CuO. No carbon enriched or depleted zones were observed after welding, but after PWHT, a narrow band of soft zone and hard zone were observed. A-TIG welding reduces the problem of carbon migration as compared to the multi-pass weld made with filler metals (Kulkarni et al., 2018).

The issues in dissimilar ferritic welds are not only limited to carbon migration. There is a number of other factors that impact the performance of dissimilar welds. Weldability of the alloys is also a concern due to their susceptibility to reheat cracking during welding or repair. The presence of carbide forming elements Nb, Ti, and V are also crucial in a filler material that stabilizes carbon. The choice of PWHT parameters also accelerates the dissolution of carbides and provide the necessary free carbon for migration in service. Welding geometry and design also impact the weld performance in various applications (Avery, 1991; David et al., 2013; Fuchs et al., 2010; Hänninen et al., 2006; Mayr et al., 2018). To fabricate the dissimilar welds between low Cr and high Cr steels for power plant applications, different approaches have been examined by various researchers as summarized in Figure 2.10.

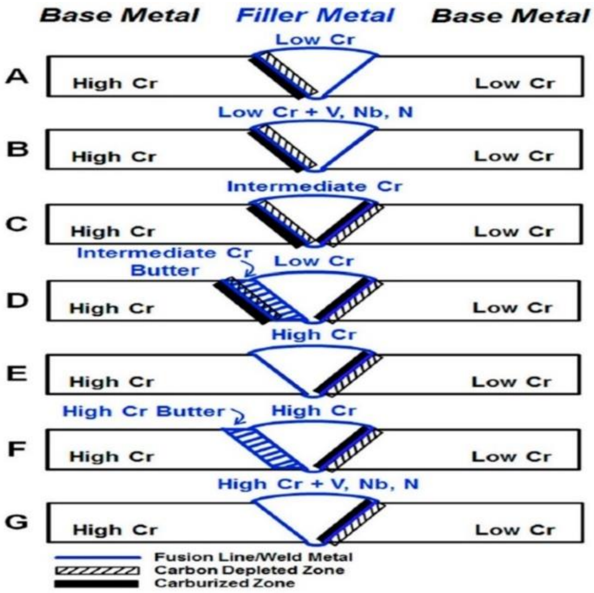


Figure 2.10: Possible approaches for dissimilar welds between low and high chromium steels (Mayr et al., 2018)

Ferritic and austenitic stainless steel has been commonly used in fossil fuel power plants for the construction of boilers and heat exchangers. Transition joints between these steels are required in power plant applications. The problem of cracking in the Ferritic to austenitic steel dissimilar welds has been reported by various researchers while servicing at a higher temperature. Generally, cracking has been observed in the heat-affected zone of ferritic steels of dissimilar welds (Bhaduri et al., 1994). Schaeffler's constitution diagram is used by the researchers for the selection of welding filler to join dissimilar metals, as shown in Figure 2.11. This diagram shows the relationship between the weld metal constitution and structure as well as possible problems. To estimate the microstructure of a deposit, the nickel and chromium equivalents are calculated from the composition.

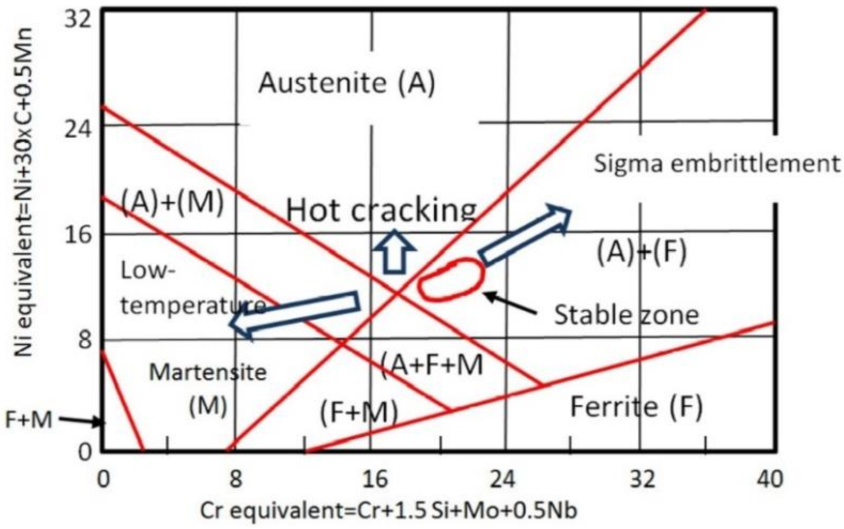


Figure 2.11: Schaeffler diagram and problem associated with dissimilar welding (Mvola et al., 2014)

Rowe et al., 1999 performed a series of experiments in which dissimilar welds were deposited on A36 steel by using ER308, ER309LSi austenitic stainless filler, and ERNiCr-3 nickel-based filler. Cracking was observed in all filler wires. The most severe cracking was observed in the ER308 filler wire, and the least cracking was observed in nickel-based fillers (Rowe et al., 1999). The dissimilar joint between carbon steel and austenitic steel was fabricated using various approaches by Toshiharu, 2002. In this study, stainless steel is joined with carbon steel by four different approaches. The excellent properties were observed in the case when carbon steel is first buttered with Inconel alloy, and weld was made using Inconel filler. The carbon migration is reduced, low thermal stresses, high corrosion resistance, and no sign of cracking was observed. On the other hand, the joint made with stainless steel filler experience cracking and carbon migration with low corrosion resistance. The author suggests the use of Inconel alloy as the best possible filler material to join carbon steel to austenitic steel (Toshiharu, 2002).

The joint between P22 and SS316 stainless steel with and without the Inconel buttering was fabricated. The PWHT was carried out at 725°C for 1h for the buttered ferritic steel to relieve stresses. It was observed that the joint fabricated using Inconel-82 buttering possesses a lower amount of residual stresses as compared to without buttering joint. Therefore, buttering of the low alloy steel is a beneficial approach to minimize residual stresses to avoid failures due to these types of stresses (Joseph et al., 2005). In one of the studies, the ferritic steel is joined with austenitic steel using two different fillers. One joint has been fabricated using stainless steel filler ER-309L, and another joint was fabricated using ERNiCr-3 nickel-based filler. The hardness gradient from the ferritic base to the fusion zone was substantial in the case of stainless-steel filler as compared to the nickel-based filler. Similar trend has been observed by various researchers in their studies performed on ferritic to austenitic dissimilar welds (Brentrup et al., 2013; DuPont, 2012; King et al., 1977; Lundin et al. 2016; Sharma et al., 2017; Slaughter, 1962). In another study, microstructural and mechanical properties of the A335 low alloy steel/347 austenitic stainless-steel dissimilar joint was investigated by Hajiannia et al., 2013. The dissimilar joint was fabricated using two different fillers ER309L and ERNiCr-3, respectively. It was observed that the joint failed from the HAZ of A335 low alloy steel. The ductile fracture was observed by the impact test results in all the welds. The carbon migration was observed from HAZ to the interface of the A335/309L weld interface. A martensitic zone was formed with high hardness value in the case of ER309L filler but was not observed in the case of ERNiCr-3 filler. Weld fabricated with ERNiCr-3 filler possess better impact energy as compared to the ER309L filler. To achieve the optimum mechanical properties of A335/SS347 dissimilar weld ERNiCr-3 filler was suggested as the best solution by the authors (Hajiannia et al., 2013).

Rathod et al., 2015, 2016a, 2016b suggested the use of Inconel buttering while joining ferritic steel to austenitic steel. In this study, the dissimilar weld between SA508/SS304L was fabricated with and without a buffer layer in buttering. The metallurgical and mechanical investigations were carried out. It was observed that the buffer layer restricts the carbon migration from the ferritic steel to the Ni-Fe alloy (buffer layer buttering) due to the absence of chromium (Rathod et al., 2015, 2016a, 2016b).

Sireesha et al., (2000a, 2000b, 2002) fabricated a dissimilar weld between Alloy 800/SS316LN using different welding consumables. Four consumable ER316, 16-8-2, IN-82, and IN-182 were used to fabricate the dissimilar weld. The welds were fabricated with SMAW using IN-182 and ER316 consumables and using TIG with 16-8-2 and IN-82 consumables. The welds made out with IN-182 fair out better amongst all the weld because its coefficient of thermal expansion lies in between both the base metals. Weld made with IN-82/182 consumables possesses superior mechanical properties as compared to the ER316 and 16-8-2. PWHT at a temperature of 760°C for 2 hours was applied to the welds made with IN-82/182 consumables, and no carbon diffusion was observed from the ferritic steel to weld metal (Sireesha, 2000a; 2000b; 2002). A comparative evaluation of P91/SS347H dissimilar weld was performed, which were fabricated using different welding consumables. It was observed that the needle shape martensitic structure is formed in the HAZ of P91, which is mainly the reason for higher hardness. The welds made with the TIG welding process using ERNiCr-3 consumable provide better mechanical properties as compared to the other consumables and SMAW welding process welds (Mittal et al., 2015a). The similar and dissimilar welds of India specific 304HCu stainless steel were fabricated using different welding consumables as per ASME Section IX requirements. The mechanical properties like creep strength and microstructure were evaluated for the Indian AUSC program. The ER304HCu filler wire was suggested as the best option for similar welding, and ERNiCrCoMo-1 filler wire was best suited for dissimilar welding with alloy 617M (Srinivasan et al., 2016). A dissimilar joint between P91, and SS316LN was made using TIG and SMAW process by employing IN-82/182 filler. A complex microstructure was observed in P91 and IN-182 buttering and the unmixed zone was also developed at the interface of the IN-182/82 weld metal and SS316LN. A nonuniform microhardness profile was observed for the welds (Karthick et al., 2018). Thakre et al. 2019, performed investigations on the P91/SS304L dissimilar joints prepared using the TIG welding process. The joint was prepared using a P91 matching filler. In this investigation, the uneven distribution of hardness is also observed along the dissimilar weld. The minimum hardness was obtained in the HAZ of the P91 side. The PWHT at 760°C for 2 hours results in the improvement of the ductility of the welded joint. Variations in the impact toughness were also observed along the dissimilar welds. The Charpy toughness value of 45J, 80J, and 82J was recorded at room temperature for the weld fusion zone, P91 HAZ, and SS304L side HAZ, respectively (Thakre et al. 2019).

2.8 Hot corrosion investigations on Ferritic-Martenistic to Ferritic-Martenistic steel welds and Ferritic-Martenistic to Austenitic stainless-steel welds

Hot corrosion is a mode of degradation where alloy experiences accelerated oxidation in the presence of fused salt mixtures or a gaseous environment (combustion product or other oxidizing gases). Highly corrosive conditions may develop when fused salt films condense on the surface of the metals as the gases are cooled. The surface of the metal reacts with the sulfur present in the gas phase and leads to fireside corrosion of the boiler tubes (Rapp, 1987, 1990, 2002). The condensed alkali metal salt like Na_2SO_4 is a prerequisite to hot corrosion. These salts come from different sources like absorbed sea salt in a marine environment, combustion of fuel containing both sulfur and sodium. Sodium vanadyl vanadate ($Na_2O.V_2O_4.5V_2O_5$) melts at a very low temperature (550°C) and is the most common salt in boiler steel. In energy conversion process, sulfur released from the coal reacts with alkali salts to form alkali sulfides and dissolves the protective oxides, which allows the base metal to react with sulfates ions forming sulfide ions and non-protective oxides. NaCl comes directly from seawater and chlorides lower the first melting temperature, which produces an extreme corrosion environment. The cyclic hot corrosion studies create the severest conditions for testing, which simulate the conditions prevailing in the actual service environment of the superalloy components, where breakdown/shutdown occurs frequently. The purpose of imposing cyclic conditions was to create an accelerated environment as observed in actual cases for hot corrosion testing. The cyclic conditions were used by many researchers to investigate the hot corrosion behavior of various alloys and their welds. (Laverade 2004; Kumar, 2007, 2009, 2016; Arivazhagan, 2009, 2012; Appala, 2014; Mittal, 2015b) Available sulfur in low- grade coal mixed with NaCl and water vapors forms Na_2SO_4 at high temperatures in coal-based power plants. Vanadium may also be present as an impurity when combining with Na_2SO_4. This results in low melting eutectoids, which provides an extremely corrosive environment at high temperatures. $FeCl_2$ has been observed at the metal/oxide interface of boilers, which makes the oxide layer above these chlorides very porous and loose (Grabke et al., 1995; Patel et al., 2017). In the past decade, substantial losses in the power plant industries were recorded due to the hot corrosion problem. Operating temperature conditions in these applications are usually high. This requires materials having high corrosion resistance. Low alloy steels are always a preferred choice for power plant applications due to their excellent properties at high temperatures with low cost involved (Singh et al., 2007; Skrifvars et al., 2008, 2010). Cr-Mo steels are widely used because of better corrosion resistance properties and excellent weldability, which enables them to be used in a variety of applications that involves elevated temperatures. There are various molten salt environments which provide extreme corrosion condition for the alloys at higher temperature. Alloys experience accelerated corrosion in the presence of molten fluoride salts, molten nitrate salts, molten chloride salts, and molten sulphate salts. In the thermal power plant boilers, the significant molten salt environment that impacts the hot corrosion behavior of alloys are molten sulphate and molten chloride salts (Patel et al., 2017). Various studies were performed on the hot corrosion behavior of ferritic/austenitic steels along with their similar and dissimilar weldments. Authors predicted the oxidation kinetics using thermogravimetric analysis and characterization of the corrosion layers were performed using X-ray diffraction (XRD) and scanning electron microscopy (SEM) in conjunction with energy dispersive spectrometry (EDS).

Kumar et al. (2007, 2009, 2016) fabricated a weld joint of P11, P22, and P91 alloy using SMAW and TIG welding processes. The cyclic studies were performed in molten salt (Na_2SO_4 + 60% V_2O_5) and air for 50 cycles. Each cycle consisted of 1 hour of heating at 900°C in the silicon carbide tube furnace followed by 20 minutes of cooling at room temperature. The specimens were kept in alumina boats, and then the boats were placed inside the furnace. The SMAW welds show more weight gain as compared to the TIG welds. The weight gain in both the base metal and weld specimen follows the parabolic law in molten salt environment. Maximum cracking was observed in the case of SMAW welds. The weight gain per unit area for the base metal and HAZ was higher than for the weld metal. The specimen exposed to molten salt gain higher weight as compared to specimens exposed to air. Thicker oxide scaling was observed in the molten salt exposed specimens. The weight gain was in the order of P11 > P22 > P91. Arivazhagan et al. (2009, 2012) fabricated a dissimilar weld of AISI 4140 low alloy steel with AISI 304 stainless steel using friction welding. These weld specimens were exposed to the 40% Na_2SO_4 + 40% K_2SO_4 + 10% KCl + 10% NaCl and K_2SO_4 + 60% NaCl salt mixtures for 50 cycles. The hot corrosion behavior of welds was studied at 500°C, 550°C, 600°C, and 650°C temperatures. A noticeable weight gain was observed in the dissimilar welds. The weight gain of salt coated specimens follows parabolic law and parabolic rate constant increases with an increase in exposure temperature. The oxide scale on the welds was found to be porous, which provides an easy diffusion path for the corrosive elements. Fe_2O_3, Cr_2O_3, $NiCr_2O_4$, and FeNi intermetallic are found to be the major phases detected by XRD in the oxide layer. There was some material loss observed which occurs due to the formation of Fe and Cr. Hot corrosion studies on P11/P22 dissimilar welds were performed by Appala et al., 2014. The welds were made using the SMAW process with a P22 matching filler. The weld specimens were exposed to Na_2SO_4 + 48% NaCl molten salt mixture and air environment at 650°C and 800°C for 50 cycles. The thermo-gravimetric analysis showed that the weld and weld interface are more prone to corrosion as compared to the base metal in both air and molten salt environment. The air oxidation showed the lowest weight gain as compared to the molten salt (Na_2SO_4 - 48%NaCl) environment. SEM/EDS and XRD analysis have indicated the presence of Fe_2O_3 as a predominant phase in the molten salt environment and Fe_2O_3, Fe_3O_4, a predominant phase in the oxidation. The high-temperature behavior of different regions of P22 steel and P91 steel weldments in $SO_2 + O_2$ environment was investigated by Ghosh et al., (2014, 2015). The welds were fabricated using tungsten inert gas welding and exposed to $SO_2 + O_2$ (ratio 2:1) environment at 700°C for 120 h. The reaction kinetics and corrosion growth rate of different regions of weldment in isothermal conditions are evaluated. The post corrosion scales of the different specimens are studied using SEM, EDS, and XRD. The results indicate that the weld metal shows a higher corrosion rate followed by HAZ and the base metal. The higher rate of corrosion of weld metal is mainly attributed to the least protective inner scale of Cr_2O_3 with minimum Cr content. This is due to the formation of delta ferrite, which leads to the precipitation of the Cr-based secondary phases and depletes the free Cr from the matrix. The thermal cycles during welding at high temperatures are favorable for the formation of delta ferrite. On the other hand, in the absence of delta ferrite, the base metal and HAZ regions of the weldment show lower corrosion rate than weld metal. The difference in corrosion rate in the three regions of the weldment is supplemented by post corroded scale characterizations. The higher corrosion rate of the heat-affected zone in P22 weld is due to the formation of $Cr_{23}C_6$ secondary precipitates leading to depletion of the protective inner scale of the Cr-rich oxide during welding. The studies on the high-temperature corrosion of the dissimilar metal welds are necessary for longer service of the weldments in the corrosive medium. Mittal et al., 2014 report the performance of microstructurally different regions, namely heat-affected zone (HAZ), weld metal (WM), and base metal (BM) of dissimilar metal weldment of T22/T91 in the molten salt (Na_2SO_4-60%V_2O_5) environment under cyclic studies. The T22 HAZ, WM, and T91 HAZ were observed to oxidize at higher rates and develop more scale thickness than other regions in the weldment. The presence of chromium carbides and intermetallic in unoxidized T22 HAZ region and martensitic structure with the presence of delta ferrites in the un-oxidized T91 HAZ region was observed to be the major cause behind the weak corrosion resistance of the respective HAZs. The higher oxidation rate of T22 HAZ may be attributed to the absence of a protective scale of Cr_2O_3 and the presence of Fe_3O_4 phases. Similarly, the higher oxidation rate of the T91 HAZ region can be attributed to the lesser availability of Cr due to the tendency of the development of delta ferrite in the martensitic structure (Mittal et al., 2014).