Preface

The main drivers for the alternate energy search are population growth, economy, technology, and agriculture. The standard of living of the people of any country is considered to be proportional to the energy consumption by the people of that country. In one sense, the disparity one feels from country to country arises from the extent of accessible energy for the citizens of each country. Unfortunately, the world energy demands are mainly met by fossil fuels today. The geographical non equi-distribution of this source and also the ability to acquire and also control the production and supply of this energy source have given rise to many issues and also disparity in the standard of living. As has been seen, petroleum serves as an extensive source for the energy need as well as feed stock for the spectrum of industries. Petroleum is a non-renewable natural resource and the industry is faced with the inevitable eventual depletion of the world’s oil supply. By the very definition of non-renewable resources, oil exploration alone will not save off future shortages of the resources. Resource economists argue that oil prices will rise as demand increases relative to supply, and that this will spur further exploration and development. However, this process will not increase the amount of oil in the ground, but will rather temporarily prolong production as higher prices make it economical to extent oil that was previously not economically recoverable. Natural gas has emerged as promising fuel due to its environment friendly nature, efficiency, and cost effectiveness. Natural gas is considered to be most eco-friendly fuel based on available information. Economically natural gas is more efficient and it does not need to be generated from other fuels. Natural gas is easy to handle and convenient to use and energy equivalent basis, it has been price controlled below its competitor-oil. It is also suitable chemical feedstock for petrochemical industry. Hence natural gas can substitute oil in both sectors namely fuels (industry and domestic) and chemicals (fertilizer petrochemicals and organic chemicals). Natural gas works more efficiently and emits less pollution than other fossil fuel power plants. Due to economic, environmental, and technological changes, natural gas has become the fuel of choice for new power plants. Bringing of natural gas from remote locations requires a safe and economic mode of transportation. The pipe line is the most economic and safe mode of transportation of the natural gas from the remote locations.
Since modern gas pipelines require operation at high pressure, it has become imperative to use high strength steel line pipes to sustain high operation pressures without increasing the line pipe wall thickness. Until recently, API X-70M was the highest grade that was used as the main workhorse for transportation of natural gas (onshore). However, over the last few years a number of long distance gas transmission projects in North America, Europe and China have applied API-5L X-80M grades line pipes. Key notable world references are Transco (UK), Cheyenne Plains (USA), Rockies Express (USA), Second West-East Pipeline (China). In view of the ever increasing length of pipe line networks and ever increasing operating pressure, it is very essential to develop high strength steel for manufacturing line pipes. The governing parameters of any pipe line project are project cost, operating cost and operating life. The variables affecting the project cost are mainly the tonnage of steel and the welding consumables. The development of high strength low alloy steel makes a significant contribution to pipe line project cost reduction. Recent experiments show that X-100M steel could give investment cost savings of about 7% with respect to X-80M and by using X-100M instead of X-70M, the cost saving can be higher. When we use X-120M steel the cost saving may be much higher over X-70M material. In other words the clean fuel may be delivered at lower price to the end users in today’s competitive market.

The welding and forming procedures for manufacturing the line pipe for critical applications is needed to be developed. Advancement in welding and materials science technology has resulted in greater improvements in the reliability of the weld.

As far as welding of API-5L Grade X-120M steel pipe lines is concerned, several weldability criterion have to be dealt with like $H_2$ induced weld cracking, proper use of low hydrogen ($H_2$) welding consumables, toughness of material and weld at sub zero temperature, fracture behavior at sub zero temperatures, microstructural control, plate chemistry etc. other issues like formability at different stages of pipe manufacturing to achieve uniform strength and dimensional accuracy are also important, such as control of forming operations, control of welding operations, control of expansion operations. During welding, control of macro and microstructure, weld pool shape, competitive epitaxial dendrite growth is
also important factor to get the desired optimal results. The welding variables are to be designed to get 
the optimum penetration and defect free elliptical weld pool shape having competitive epitaxial dendrite 
growth to avoid the center line segregation of the weld. The macro and micro examination for 
solidification behavior, dendrite growth pattern, bainitic/ ferrite /and acicular ferrite structure, effect of 
different micro alloying elements to be studied to get the desired properties of the weld and heat affected 
zone (HAZ) by optimization of welding variables, plate chemistry and welding consumables. The 
welding procedure to be established with different welding consumables having alloying element like 
Ti, B, Ni, Zr, Cr, Mn, and Mo wires. Effect of heat input will be studied on the toughness and fracture 
resistance of weld and heat affected zone (HAZ) with different heat input levels.

In present work, API-5L X-120M longitudinal double submerged arc welded line pipe has been 
manufactured through J-C-O-E route. The first step was to develop the specification for plates through 
thermomechanical control processing and accelerated cooled route to manufactured LDSAW line pipes. 
The plates have been rolled as per the specification laid down and subsequently checked for the 
conformance to the specification. The second step to manufacture the LDSAW line pipe during the 
present study was to establish the optimum heat input level of submerged arc welding to get optimum 
HAZ toughness and fracture resistance at sub zero temperature. The third step to manufacture the 
LDSAW line pipe during the present study was to develop submerged arc welding wire to get required 
strength level of X-120; sufficient toughness and fracture resistance in the weld of line pipe at sub zero 
temperature. The forth step to manufacture the LDSAW line pipe during the present study was to 
develop the required tooling to form the line pipe at various stages like crimping press, ICO press and 
mechanical expander to get the desired shape/profile of line pipe during the manufacturing process.

Present study is organized into the following chapters:

Chapter-I

This chapter deals with the general introduction (need for high strength steel line pipe X-120M) which 
comprises of brief description of line pipe and different manufacturing techniques of line pipe, brief 
history of line pipe, research objective, experimental setup and the scope of present study.
Chapter-II

In this chapter, steel making through blast furnace, plate rolling from slabs by thermomechanical controlled processing and accelerated cooled process, and different on-line and off-line characterizations/testing techniques has been discussed in brief. The base material used in the present work to manufacture X-120M line pipe is TMCP and accelerated cooled steel plates for ultra high strength line pipe X-120M of API-5L and its behaviour during the line pipe manufacturing has also been discussed.

Chapter-III

This chapter comprises of brief history of microalloyed steel and the detailed TMCP and accelerated cooled steel plate specification for manufacturing of API-5L X-120M line pipe. The full scale testing of plates has been performed to verify the compliance to the laid down specification for TMCP and accelerated cooled steel plate for the present study. The testing performed on steel plates before further processing of the plates are chemical analysis, tensile testing in rolling as well transverse to rolling direction, charpy V-notch testing, drop weight tear testing, Vicker’s hardness testing and microstructural characterization by light and electron microscopy to establish the required strength, toughness and target microstructure as required to get required toughness and strength of X-120M for manufacture of the API-5L X-120M line pipe.

Chapter-IV

This chapter deals with the optimization of the heat input of submerged arc welding to minimize the effect of heat on the toughness and fracture behavior of heat affected zone (HAZ) on the longitudinal double submerged arc welded (LDSAW) line pipe weld. The experimental procedure in the chapter describes the test coupon preparation; submerged arc welding (SAW) on the test coupons at various levels of heat input. The testing performed on test coupons before further processing of the plates are charpy V-notch testing, crack tip opening displacement (CTOD), Vicker’s macro and micro hardness testing and microstructural characterization by light and electron microscopy to establish the required
toughness and target microstructure of X-120M in the HAZ of LDSAW weld for manufacture the API-5L X-120M line pipe.

Chapter-V

This chapter deals with the development of the LDSAW wires. The experimental procedure in the chapter describes test coupon preparation, SAW on the test coupons with various SAW wires. The testing performed on plate test coupons are charpy V-notch testing, crack tip opening displacement (CTOD), Vicker's macro and micro hardness and microstructural characterization by light and electron microscopy to establish the required strength, toughness and target microstructure as required to obtain toughness and strength of X-120M in the LDSAW weld for manufacturing the API-5L X-120M line pipe.

Chapter-VI

This chapter deals with the development of the formation tools to form the LDSAW line pipe to get the desired shape/profile at various stages of the manufacturing. The most important stages are edge milling of the plate which affects the weld quality during the final submerged arc welding and this step also decides the plate width which in turn decides the percentage of expansion. Second critical formation step is plate edge crimping which decides the shape/profile around the weld of LDSAW line pipe. Third critical step is J-C-O formation which decides the overall shape/profile of the LDSAW line pipe. Last critical step is mechanical expansion which controls the shape/profile and final dimensions of the LDSAW line. The tooling has been designed and established in this chapter before the actual X-120M LDSAW line pipe manufacturing.

Chapter-VII

This chapter describes the step by step manufacturing of X-120M LDSAW line pipe based on the results derived from Chapters # III, IV, V and VI. The LDSAW line pipe manufacturing steps involved as described in this chapter are visual and dimensional inspection of the TMCP and ACC plates, run-in and run-out tab joining, ultrasonic scanning of TMCP and ACC plates, plate edge milling, plate edge
crimping, JCO formation, continuous tack welding with GMAW followed by submerged arc welding, visual inspection followed by real time radiography, mechanical expansion, end beveling of LDSAW line pipe, hydrostatic testing, final ultrasonic testing of the weld and HAZ, spot radiography and magnetic particle testing of ends as well as the weld of X-120M LDSAW line pipe. After completing the manufacturing steps and on-line non-destructive testing, samples has been drawn for off-line testing to confirm the LDSAW line pipe to the API-5L X-120M specification. The off-line testing performed on LDSAW line pipe are charpy V-notch toughness, crack tip opening displacement (CTOD), Vicker’s macro and micro hardness testing and microstructural characterization by light and electron microscopy to establish structure; properties relationship between strength, toughness and target microstructure to have toughness and strength of X-120M in the base, HAZ and weld of LDSAW line pipe.

Chapter-VIII

This chapter summarizes the results derived in the present work of development and optimization for manufacturing of API-5L, X-120M steel line pipe through J-C-O-E technique with respect to the target properties. A systematic approach for the work has been adopted by the study of TMCP and ACC steel plates for X-120M, influence of submerged arc welding heat input on the said steel plates and establishment of the optimum heat input level to get the best toughness in the heat affected zone of the weld, development of submerged arc welding consumables through structure-property relationship method. The line pipe formation toolings have been developed and optimized for successful manufacturing of API-5L, X-120M line pipe. This chapter also derives the conclusion of the present study and future plan of the study.

The references are numbered in square bracket in the text and are listed at the end of respective chapters.