The following conclusions were arrived from the investigations after analyzing various aspects of the stainless steel cladding of low carbon structural steel by FCAW process in the sequence in which they were discussed in the previous chapters.

8.1 DESIGN OF EXPERIMENTS (CHAPTER - 4)

1. The working ranges of the FCAW process variables for austenitic stainless steel 316L flux-cored wire were established considering the quality of the bead. The upper limit and the lower working range of voltage were found to be 38V and 30V respectively. Similarly the upper and the lower range of the wire feed rates were found to be 9 m/min and 17 m/min respectively. Also the feasible welding speed range was found to be 0.18 to 0.5 m/min considering the width and reinforcement of the bead.

2. It was found that higher NPD causes long arc and inadequate sealing resulting ingress of nitrogen into the weld metal. Since nitrogen is a strong austenizer, the clad metal contains lesser amount of ferrite than what is to be expected.

8.2 DEVELOPMENT OF THE MATHEMATICAL MODEL (CHAPTER - 5)

1. The response surface methodology was found to be powerful tool for developing mathematical models to predict the direct and interaction effects of the welding variables. The two-way interaction effect can be easily studied with the help of perspective surfaces and contour diagrams.

2. As the developed mathematical models were simple quadratic equations, of first and second order, these could be easily and effectively applied for cladding to achieve the low dilution, heat input and desired bead dimensions.

3. When the experiments were conducted as per the design matrix, the maximum and minimum heat input conditions were obtained corresponding to 21\textsuperscript{st} and 13\textsuperscript{th} trial run conditions.

4. It was observed that voltage has negative effect on reinforcement but wire feed rate has positive effect. The reinforcement was maximum when both voltage and welding speed were at their low levels.

5. It was found that when the voltage and wire feed rate increase the penetration also increases.
6. The width of the bead decreases considerably with increase in welding speed and nozzle to plate distance.
7. When the welding speed increases reinforcement drastically decreases.
8. It is observed that when the wire feed rate and welding speed increase the dilution increases. Out of the five influencing variable welding speed was found to be significant as far as the dilution was concerned.
9. It was found that delta ferrite decreases when the wire feed rate and welding speed increase.
10. The dilution increased with rise in voltage and decreased when NPD was increased.
11. The increase in penetration due to increase in voltage is significant when the nozzle to plate distance is high.
12. The lowest dilution can be achieved when the voltage is at low level and the electrode angle is kept at the highest level.
13. The accuracy of the mathematical models developed were tested by conformity test which showed the accuracy of all the models as 96%.
14. For constant heat input the penetration increases significantly when V, F and S are increased.
15. For a constant heat input it is observed that voltage and wire feed rate has a positive effect on dilution.

8.3 OPTIMIZATION AND SENSITIVITY ANALYSIS (CHATER - 6)
1. The optimization module available in the MATLAB software package was found to be an easy and effective tool for optimizing the weld bead parameters.
2. Sensitivity analysis gave complete information about the interdependencies of the bead parameters.
3. It was found that maximum value of penetration was 0.795 mm when other bead parameters were fixed at acceptable limits to get sound cladded joint.
4. By optimization for a maximum high bead width of 26.22 mm is obtained which gives high production rate
5. It was found that the increase in the value of reinforcement from 4.6 mm to 5 mm had no effects on width and dilution
6. Increase in the value of penetration from 0.3 mm to 0.7 mm had significant positive effects on reinforcement and width.
7. The optimum value of the dilution was 10 % and the corresponding process variables are arc voltage =36.35V olts; wire feed rate = 9.42 m/min; welding speed = 0.328 m/min; NPD = 20.3 mm; electrode angle = 9.2 deg
8.4 METALLURGICAL ANALYSIS, EVALUATION OF THE SHEAR STRENGTH OF THE OVERLAY AND CORROSION RESISTANCE (CHAPTER -7)

1. The chemical composition of the clad depends upon the dilution and heat input, which in turn depends upon the process variables and welding processes. Hence the clad chemistry can be controlled by varying the process variables.

2. The carbon content of the single layer cladding deposited at desired level of dilution was found to be 0.041 and double layer as 0.033 percentage, which are within the acceptable limit. It was also observed that as the heat input increases the carbon content level also increases.

3. If the carbon content is greater than 0.25% then the clad will have low corrosion resistance. But from table 7.1 it was observed that the carbon content was much less than the 0.25%, which offered good corrosion resistance.

4. Also it is found that when the heat input decreases the microhardness of heat affected zone and fusion zone decreases. The microhardness of high heat input specimen F4 was found to be high (455VHN) due to the transfer of carbon from the base metal. The maximum microhardness of the clad structure with optimum dilution was just 232VHN, which indicates the absence of any hard phase and hence offered good ductility.

5. The hardness of the two-layer overlay was also found to be uniform, which indicates the absence of the sigma phase and carbides.

6. Five methods are used to find the amount of delta ferrite present in the overlay. The variation in the measured values found to be within the permissible range.

7. The colour metallographic technique was an effective tool in finding out the primary and secondary microstructures especially in stainless steel.

8. The solidification modes assessed based on Schaeffler, WRC-1992, and Espy equivalents are found to be consistent.

9. The solidification structure of the optimized clad is cellular and cellular dendritic. Small amount of ferrite with skeleton morphology is also present.

10. The microhardness value in the weld metal zone was not affected much by the process parameters and was almost equal to that of unaffected base metal.

11. In the case of low heat input the metal cools quickly resulting in fine and soft structure. Fine-grained metals have higher strength and more ductile. But in the case of high heat input the metal cools slowly resulting in coarse grained and brittle structure.

12. It is found that the HAZ increases with increase in heat input, which confirm the findings of Christensen.

13. Heat input does not directly affect ferrite content of weldments, but it affects through nitrogen pickups, which can influence the ferrite level.

14. The shear strength of single layer cladded performed at optimum dilution was found to be 410 MN/m², which indicates that the bond strength between base metal and overlay was sufficient.
15. The visual observation at the interface showed no pores and inclusions, which indicated good structural integrity.

16. When the optimized overlay was subjected to 180° bend test there was no fissure or fracture on the surface indicating that the overlay had good ductility, which was an essential requirement for the fabrication.

17. Double loop EPR test used to detect sensitization in stainless steel was found to be a very effective, repetitive nondestructive, rapid and highly reliable method. It was also found that it was very sensitive to the temperature of the electrolyte.

18. The ratio of peak currents in the reactivation and activation loops was found to be a good measure of degree of sensitization.

19. The reactivation ratio \( I_r/I_a \) is found to be low for low heat input specimen.

20. It is observed that high heat input specimen F4 has large hysteresis loop which indicates a poor resistance to pitting corrosion. A specimen, resistance to pitting corrosion shows low hysteresis loop. This concept is observed in the case of specimens F13 and F23, which are having good pitting resistance.

21. It is also observed that when the pitting and protection potential are high, pitting corrosion resistance is also high.

22. It is observed that higher \( \text{Cr}_{\text{equi}}/\text{Ni}_{\text{equi}} \) ratio and resultant ferrite mode of solidification gives maximum resistance to chloride pitting.

23. The variation in area of hysteresis loop (logarithmic scale) and pitting potential due to increase in heat input are found to be linear.

### 8.3.1 SCOPE FOR FUTURE WORK

There are potential for future work in the following aspects of stainless steel cladding:

1. The shielding gas carbon dioxide can be mixed with argon at various proportions and its effect on bead parameters, heat input and ferrite content can be studied.

2. The effect of various heat treatments on the overlay may be studied.

3. The effect of process parameters on the modes of solidification may be analyzed.

4. The influence of stress corrosion cracking on the stainless steel overlay can also be further studied.

5. The influence of various concentration of sodium chloride on pitting corrosion can be studied.

6. The variation in microstructure and corrosion resistance after some specific heat treatment can also be analyzed.

7. Mathematical model could be developed connecting the process variables and corrosion rate.