CHAPTER 6

CONCLUSION AND FUTURE SCOPE

The research work was aimed to develop a suitable surfacing material, methods and processes with minimum cost, maximum corrosion resistance and minimum wear resistance to suit high pressure valve applications. The experiments were conducted in substrate of low carbon steel (ASTM A216) as below:

The mathematical models were created for weld bead geometry, dilution and penetration for hardfacing of clad materials with low carbon. With the aid of mathematical modelling, the experiments were conducted by Gas Tungsten Arc Welding Process with argon as shielding gas. The deposited clad material with the substrate was further post heat treated for stress relieving and refined crystal boundary.

i. The thermal spray coating process was applied to the steel substrate eliminating pre heat treatment, post heat treatment and post machining processes on the clad surface due to hardfacing. The experiment has been conducted on coating the steel substrate by Plasma Spray coating with prepared nano-powder of tungsten carbide – cobalt (WC-12%Co) powder, zirconium and titanium.

ii. The nano-coating process was introduced for minimizing thermal stress formed during the surface of the substrate by hardfacing and thermal spray coating. Zirconium and molybdenum were identified as nano coating materials to enhance hydrophobic property of the
substrate by sol-gel dip coating process and electrophoretic deposition process.

Experiments were conducted to achieve the above objective in three phases as discussed in the following paragraphs:

Experiments on harfacing of the steel substrate with the flux cored arc welding wire of stellite 6 (cobalt based alloy), FW2 and FW3 (nickel Based alloys) are carried out with the aid of mathematical modelling. To undertake the experiments initially the base materials are preheated to 300°C. The clad materials are pool welded by building the layers up-to 8.0 mm thickness and allowed to solidify. The hardfaced specimen was further subjected to post heat treatment and the weld pool is machined to 2.0 mm thickness from 8.0 mm and wire-cut for further investigations corrosion and wear studies. Since the specimen was subjected to hardfacing, the corrosion test were conducted by weight loss method and wear by sliding wear mechanism.

To eliminate pre heat treatment and post machining operations, the thermal spray coating was carried by plasma spray coating with prepared nano-powder of tungsten carbide – cobalt powder, zirconium and titanium. The process involves layering heating of the specimen in the concentrated area and shielding gas is used to control the brittle fracture and cracks over the surface. The thickness of the coating is maintained to 0.5 mm.

Nano-coating of the steel substrate had been carried out, to further improvise the process and fuse the clad material without application of heat, the sol gel dip Coating process and electrophoretic deposition processes were identified to carry the processes. Zirconium and molybdenum were prepared to form sol and exhibits the hydrophobic properties. The results of nano-coating
with better corrosion and wear properties provides an alternative to hard facing techniques.

The results were summarized in the following sections and the report was concluded by making summary on the contributions and findings of the research and suggestions for future enhancements.

### 6.1 CONCLUSION

The A216 steel specimens were subjected to welding (hard facing), thermal (plasma) spray coating and nano-coating with various transition materials. The results are indicated in Figure 6.1

![Comparison of Wear rate and corrosion rate of hardfaced, plasma spray coated and nano-coated specimens](image)

**Figure 6.1** Comparison of wear rate and corrosion rate of hardfaced, plasma spray coated and nano-coated specimens

It is evident that the corrosion resistance is higher for specimens hardfaced with FCAW St-6. The results in order of high corrosion resistance of hardfaced specimen, plasma spray coated (TS) and Nano-coated (NC)
substrates are in the order of TS-WC-12% Co with 0.0169 mills / Year, FCAW – St6 with 0.178 mills / Year, NC-Mo with 0.21 mills / Year, FW3 with 0.2684 mills / Year, FW2 with 0.575 mills / Year, NC-Zr with 1.06 mills / Year, TS-Zr with 3.3 mills / Year, TS-Ti with 4.5 mills / Year.

Though hardfacing techniques provide the less corrosion rate compared to thermal spray coating and Nano-coating, the major disadvantage with the conventional hardfacing techniques that the as indicated in Table 5.4, it requires 8.0 mm (which is recommended by American Petrochemical Industries, API) build surface to clad thickness of 2.0 mm for obtaining minimum porosity and thermal bonding between the steel substrate. Hence, the build area is to be hard machined (up to 6.0 mm), which would increase the cost and requires certified welder and qualify the WPS. To have the alternative the Plasma Spray coating (TS WC-12%Co) coating responds well but again, there is a thermal barrier between the surfaces due to the enormous heat produced between the surfaces. To reduce the thermal barriers the Nano coating is preferred the Molybdenum coating gives the better results of 0.21 mills/ year.

The steel substrate was not only subjected to corrosion testing, but also subjected to wear testing Figure 6.1 indicates that there is minimal wear rate for hardfaced specimens, nano-coated zirconium and thermal sprayed titanium specimens respectively. The order of specific wear rate in mm$^3$/N-m is given by FCAW – St6 with 0.00025, FW2 with 0.00063, FW3 with 0.00142, TS –Ti with 0.0026, NC –Zr with 0.0053, TS –Zr with 0.0106, NC –Mo with 0.0160 and TS-WC-12% Co with 0.1200

In the cited above corrosion and wear results, the following points have to be addressed:
1. Literature studies and research findings indicate that the flux cored wire FCAW St 6 alloys are preferred for high pressure steam application and FW2 alloys are preferred for petrochemical applications. The disadvantages with these techniques are it require a skilled welder with AWS/ IWS certification and WPS for hardfacing the substrate.

2. The adjunct operations of hardfacing are pre heating, post heat treatment, stress relieving and machining, which is time consuming and there is thermal distortion and high dislocation of particles and boundary on the Heat Affected Zone.

3. In plasma spray coating, ceramic materials are coated on steel substrate, the better results were obtained for prepared powder (coating material) than the commercial available powder. The drawback with the coating is non-line of sight are difficult to coating. Similar to hardfacing there is thermal distortion between the surfaces and the amount of carbon evaporated during the processes. To eliminate the cited difficulties it was preferred to carry the experimentation at different set-ups or process by nano-coating.

4. In sol gel process and electrophoretic deposition process is preparation of sol, selection of precursor, reacting agents and chemical equilibrium condition. The nano-powders are to be synthesized before coating. Hence it is preferred to nano-coat the substrates for mass batch production.

It is concluded that the coated materials are selected based on optimum wear and corrosion rate as in Figure 6.1 which indicates the substrate with the order of hardfaced FCAW ST-6, hardfaced FW3, nano-coating of molybdenum coating and Nano coating of zirconium fits the best. On considering least lead time and best corrosion rate the WC-12% Co fits the best.
6.2 FUTURE SCOPE

On the basis of the studies and the investigations carried out in this research, as an extension of this work the following points are suggested.

- Hardfacing operation shows best so far and it is followed as per API standard, the difficulties encountered is high surfacing and machining with high porosity. To avoid this, the processes may be extended with low temperature welding techniques / welding with the interface layer to form three layered processes, substrate- intermediate layer- hardfacing material.

- Inconel, Monel and Hastalloys were in the base element is a combination of Nickel and Cobalt proves to be better to improve both corrosion and wear properties, research activities on hard facing techniques can be undertaken for these materials based on the application.

- Thermal spray coating proves to be costlier, and the penetration is good, hence effects can be made to minimize the cost of coating. The provision of masking and coating of non-line of sight may be studied for coating the substrate.

- The sol gel processes or electrophobic deposition processes is that on mass production the materials may be subjected to hydrogen blisters due to the presence of H+ ions in the process or addition of zinc. The process may be optimized by selecting proper precursors and degassing the unit and control atmosphere.
The preliminary experimentation had been carried with the sputtering a PVD technique in the process for zirconium and molybdenum and showed the best bonding with very minimal corrosion and wear, the drawback faced is the carbon content increased from 0.25% to 3.0% and the area of coating is minimal there are HAZ above the coated surface and takes considerable time. Research may be carried to further optimize the processes by designing and production of Nano-powder suitable for PVD or CVD processes.