The important outcomes of the present investigations regarding the behavior of the uncoated and HVOF sprayed coatings on T91 steel in molten salt (Na$_2$SO$_4$-60%V$_2$O$_5$) and actual coal fired boiler environments are presented in this chapter. The usefulness of post treatment of the coatings has also been highlighted. The salient conclusions from the present investigation are summarized as follows:

1. HVOF spraying process has been successfully used to deposit NiCr and Cr$_3$C$_2$-NiCr coatings on T91 boiler steel substrates in the range of 270–320µm thickness; the coatings have nearly uniform, adherent and having dense microstructure.

2. The porosity value of the HVOF sprayed NiCr and Cr$_3$C$_2$-NiCr coatings have been found to be less than 2%. Post treatment of both the coatings by the method of heat treatment and sealing resulted in decreasing the interconnected porosity of the coatings.

3. The average microhardness value of 287 Hv and 850 Hv were measured for NiCr and Cr$_3$C$_2$-NiCr coating respectively. The microhardness of both the coatings has been found to be higher than the substrates steel. The average microhardness value for the substrate steel has been found to be 244 Hv. A slight increase in the microhardness of the substrate at the coating-substrate interface might be due to work hardening effect of sand blasting and HVOF spray.

4. Both the coatings exhibited uniform and dense splat-like structures, with long axis of the splats oriented parallel to the substrate surface. NiCr coating revealed more dense and lamellar structure. Some voids and inclusions are also observed in the microstructure.

5. The cross-sectional EDS analysis of both the coatings revealed the formation of oxide stringers along the splat boundaries and at the places of porosity after heat treatment of the coatings. Further, these oxide stringers are richer in Cr and depleted of Ni in comparison to the coatings nominal composition. This suggests that these oxide stringers are oxides of Cr. The top surface revealed the presence
of Ni and Cr along with traces of oxygen, which suggest the formation of oxides and spinals of Ni and Cr on the top surface after heat treatment of the coatings.

6. The bare steel underwent intense spalling, sputtering and peeling-up of its oxide scale, and the weight gain was enormous during the cyclic hot corrosion studies in molten salt (Na\(_2\)SO\(_4\)-60\%V\(_2\)O\(_5\)) environment at all the three temperatures of study i.e. 600 °C, 700 °C and 900 °C. The significant increase of corrosion rate occurred at 900 °C.

7. The oxides formed during hot corrosion of bare steel are thick, porous and non-protective, with plenty of Fe in the disintegrated oxide layers. The formation of numerous layers influenced detachment and spallation of the oxide scale, resulting in reduction of the oxidation resistance at higher temperature.

8. As revealed by XRD and EDS analysis, the scale of bare steel after hot corrosion mainly consists of Fe\(_2\)O\(_3\), which is considered to be non-protective. The thickness of scale was observed to increase with the increase in temperature of testing.

9. In general HVOF sprayed NiCr and Cr\(_3\)C\(_2\)-NiCr coatings in both as-deposited and post treated condition were found useful in providing necessary resistance to T91 boiler steel against molten salt (Na\(_2\)SO\(_4\)-60\%V\(_2\)O\(_5\)) corrosion at 600 °C and 750 °C for 50 cycles. Oxide scale, formed on the surface of the coated samples, was compact and adherent to the substrate in general. The oxidation behavior was found to be governed by parabolic rate law in almost all the cases.

10. The parabolic rate constants of the coated steel were small when compared with that of bare steel, indicating the protective nature of NiCr and Cr\(_3\)C\(_2\)-NiCr coatings against molten salt corrosion.

11. The presence of oxides and spinels of nickel and chromium contributed for the better hot corrosion resistance of the NiCr and Cr\(_3\)C\(_2\)-NiCr coatings in the molten salt environment.

12. At 900 °C temperature of testing in molten salt environment, as-deposited NiCr and Cr\(_3\)C\(_2\)-NiCr coatings experienced two stages of hot corrosion i.e. initiation stage and propagation stage. Once the coatings entered the propagation stage, the protective scale (scale rich in oxides of Ni and Cr) rendered ineffective and
substrate became vulnerable to hot corrosion, thereby resulting in intense spalling, sputtering and peeling-up of its oxide scale.

13. Post treatment of coatings by the method of heat treatment and sealing proved to be effective in improving the hot corrosion resistance of the coatings on T91 steel substrate at all the three temperatures of study i.e. 600 °C, 700 °C and 900 °C in molten salt environment for 50 cycles.

14. Heat treatment resulted in clogging the pores of the coating by rapid formation of oxides at the coating splat boundaries and within open pores, thereby stopping ingress of corrosive species towards the substrate. Better performance of heat treated coating in the given environment has also been attributed for its tendency to form protective dense oxides of chromium, nickel and their spinels.

15. Sealing treatment has improved the corrosion resistance of the as-deposited coating-substrate system and provided the best protection to the substrate steel by decreasing the interconnected porosity to the substrate.

16. Application of Cr₂O₃/Al₂O₃ as top coats on NiCr/Cr₃C₂-NiCr coating has not proved very useful in improving hot corrosion resistance of the NiCr/Cr₃C₂-NiCr coating on T91 steel in the given molten salt environment and has shown only marginal improvement in the hot corrosion resistance of the coatings.

17. At 900 °C temperature of testing in Na₂SO₄-60%V₂O₅ environment as-deposited NiCr/Cr₃C₂-NiCr coatings and duplex coating systems consisting Cr₂O₃/Al₂O₃ as top coat experienced internal corrosion, cracking and oozing out of material from beneath for both NiCr and Cr₃C₂-NiCr coatings.

18. Cracks perpendicular to the coating surface were observed in both the coatings due synergic effect of thermal shock due to mismatch in thermal expansion coefficients of the coatings and substrate, and due to penetration of corroding species to the substrate material through interconnected porosity/intersplat boundaries of the coating.

19. Bare T91 steel suffered extensive oxidation attack in the boiler environment, with the oxide scale penetrating deeply into the substrate. Inferior resistance of bare T91 steel might be attributed to the formation of pores and loosely bounded oxide scale rich in Fe₂O₃.
20. HVOF sprayed NiCr and Cr$_3$C$_2$-NiCr coatings in both as-deposited and post treated condition were found useful in providing necessary high temperature oxidation resistance to T91 boiler steel in the coal fired boiler environment.

21. Amongst the NiCr and Cr$_3$C$_2$-NiCr coatings in as-deposited conditions in actual boiler environment, NiCr coating showed maximum resistance to E-C in the actual environment.

22. Amongst the post treatment techniques, heat treatment and sealing were found to be useful to enhance the E-C resistance of the NiCr and Cr$_3$C$_2$-NiCr coatings on T91 steel in actual boiler environment.

23. The application of Cr$_2$O$_3$/Al$_2$O$_3$ as top coats on NiCr/Cr$_3$C$_2$-NiCr coating could not improve the E-C performance of the NiCr/Cr$_3$C$_2$-NiCr coating in actual boiler environment.

24. The superior erosion-corrosion resistance of the heat treated coatings in the actual boiler environment might be attributed to the formation of Cr$_2$O$_3$ phase along with the spinel of NiCr$_2$O$_4$.

25. Amongst the NiCr and Cr$_3$C$_2$-NiCr coatings on T91 steel in both as-deposited and post treated condition, sealed NiCr coating showed maximum resistance to erosion-corrosion in the actual boiler environment followed by sealed Cr$_3$C$_2$-NiCr coating.

26. Amongst both the coatings, the order of erosion-corrosion rates based upon thickness lost data (mpy) after the exposure to the actual boiler environment for 1500 hours has been observed as follows.

Sealed NiCr > Sealed Cr$_3$C$_2$-NiCr > Heat treated NiCr > Heat treated Cr$_3$C$_2$-NiCr > as-deposited NiCr > as-deposited Cr$_3$C$_2$-NiCr > NiCr with Al$_2$O$_3$ top coat > Cr$_3$C$_2$-NiCr with Al$_2$O$_3$ top coat > NiCr with Cr$_2$O$_3$ top coat > Cr$_3$C$_2$-NiCr with Cr$_2$O$_3$ top coat > Bare T91 steel

27. The embedment of ash particles has been observed in the uncoated and coated steels after exposure to boiler environment.