CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 SUMMARY

En 52 and 21-4N are two important valve steel materials used for I.C. engine valves. In the present work cryogenic treatment is considered as a supplementary process to conventional heat treatment of these steels. However the cryogenic treatment parameters need to be optimized specific to the material to have the maximum benefits in terms of optimal combination of tensile strength, hardness and wear resistance of the material. The effects of the cryogenic treatment on their mechanical properties that are of high premium for the effective functioning of valves are studied. The observations are analyzed for the optimization of cryogenic treatment parameters using grey-Taguchi technique. The optimal deep cryogenic treatment cycle has been evolved and the benefits have been quantified experimentally through a confirmation test. The changes in the microstructure of the treated materials are also analyzed by conducting a characterization study so that the underlying mechanisms for the improvement could be understood.

Based on the study the following conclusions are drawn.

7.2 CONCLUSIONS

7.2.1 Optimal Deep Cryogenic Treatment Parameters

- The Taguchi method coupled with the grey relational analysis is successfully applied to optimize the multiple performance characteristics of DCT of En 52 and 21-4N valve steels.
• The optimal deep cryogenic treatment cycle for the En 52 valve steel has a cooling rate of 1 °C/min, a soaking temperature of -130 °C, a soaking period of 36 hrs, and tempering temperature of 650 °C. For the 21-4N valve steel the optimal treatment parameters are 1.5 °C/min cooling rate, -185 °C soaking temperature, 36 hrs soaking period and 700 °C aging temperature.

• The results of ANOVA indicate that the soaking period is the significant factor in influencing the multiple performance characteristics of En 52 valve steel, to the extent of 50 %. However for the 21-4N valve steel, the aging temperature influences significantly the multi performance characteristic to the extent of 40 %. This helps us to understand that no compromise could be made on these while designing the cycle.

7.2.2 Wear resistance

• The wear resistance of En 52 and 21-4N valve steel has improved by 47 % and 28 % respectively due to the DCT, when compared with that of the CHT.

7.2.3 Hardness

• The hardness of the En 52 and 21-4N DCT sample has improved by 11% and 15% over the CHT samples respectively.
7.2.4  **Tensile Strength at room temperature**

- The ultimate tensile strength of the En 52 and 21-4N DCT samples has improved by 12 % and 8 % respectively over the CHT sample.

- The yield strength of the En 52 DCT samples exhibit an enhancement of 11 % over the CHT samples. The average yield strength values of the SCT and DCT samples are more than that of the CHT samples by a factor of 6 % and 11 % respectively for the 21-4N material.

7.2.5  **Tension strength at Elevated Temperature**

- The ultimate tensile strength of the En 52 DCT sample tested at 400 °C has improved by 8 % over the CHT sample. The ultimate tensile strength of the 21-4N DCT sample tested at 650 °C has improved by 7 % over CHT sample.

- The yield strength of the En 52 DCT sample tested at 400 °C has an improvement of 11 % over that of the CHT samples. The yield strength of the 21-4N cryo-treated samples exhibits a small variation when compared with that of the CHT samples.

7.2.6  **Microstructural Analysis**

- In the micrographs of the DCT samples a large amount of fine carbides of micron size are precipitated throughout the structure. Fine carbides precipitated in the martensitic matrix can strengthen the structure. The fine carbides precipitated
through cryogenic treatment tie up with certain elements and hinders the motion of dislocation of atoms, which can be the reason for the improvements realized.

### 7.2.7 Impact Test

- The average impact energy of the En 52 DCT sample has 23% improvement when compared to that of the CHT samples. For the 21-4N valve steel, the DCT samples absorb more energy than the CHT samples. The 21-4N DCT sample has an improvement of 22% than that of the CHT sample.

### 7.2.8 Thermo-mechanical Analysis

- The En 52 and 21-4N valve steels has an average of 16% and 17% lower coefficient of the thermal expansion for the DCT specimens, which indicates that the dimensional stability is better for the DCT samples when compared to that of the CHT sample.

The effects of the cryogenic treatment on the En 52 and 21-4N valve steels are studied through various mechanical and characterization tests. The study concludes that the deep cryogenic treatment imparts better effects than SCT and CHT in improving the overall characteristics of both the materials. The precipitation of ultra fine carbides in the DCT enhances the properties of the En 52 and 21-4N valve steel materials. After studying the microstructure of the cryogenically processed valve steels, it is concluded that the formation of very small carbides dispersed in the tempered martensite structure along with retained austenite transformations are the main reasons for the enhancement of certain mechanical properties.
It is concluded that cryo-processing not only facilitates carbide formation, but also

- increases the precipitation of fine carbides.
- increases its volume fraction in the martensitic matrix.
- aids the homogeneous distribution of the carbides in the martensitic matrix.

7.3 SCOPE FOR FURTHER WORK

- Instrumented impact studies can be carried out to study the dynamic fracture toughness of the material after various treatments.

- A TEM analysis and X-ray diffraction analysis of the En 52 and 21-4N valve steel samples can be conducted to know more about the potential causes for the carbide precipitation, carbide size and carbide distribution before and after cryogenic treatment.

- A Thermal fatigue study can be carried out to analyze the fatigue behavior of the cryo-treated En 52 and 21-4N valve steel materials.