Chapter 5
Conclusions

Based on the experiments carried out on the untreated specimens i.e. base material, hard chrome plated, thermal sprayed using alumina powder, and plasma nitrided specimens of three different categories and the analysis undertaken, the following conclusions have been drawn:

- The data generated is clearly distinguishable between the different categories of surface treatments which have positive and negative effect on rotating bending fatigue strength of AISI 4340 steel. Accordingly, the treatments can be divided in two groups as given below:

  Categories, which increase fatigue strength are

  - Plasma nitrided with compound layer < 10 μm
  - Plasma nitrided without any compound layer

  Categories, which decrease fatigue strength are

  - Hard chrome plated
  - Thermal sprayed using alumina powders, and
  - Plasma nitrided category of compound layer > 10 μm

- Based on detailed study on plasma nitriding, the following conclusions are drawn:

  For the plasma nitrided categories with compound / white layer thickness of less than 10μm and with absence of compound layer, the Fatigue Stress Modification Factors (FSMF), $(\theta_{coat})_i$ are greater than one whereas for plasma nitrided category with compound layer thickness of more than 10μm the FSMF value is less than one. The plasma nitrided category without any compound layer shows the highest increase in the Fatigue Stress Modification Factor. The higher values of FSMF are desirable for greater endurance limit and in turn enhanced fatigue life of any material. Similar trend is observed for Cycle Modification Factor, Ψ_i as well.

  The difference in the fatigue strength of compound layer greater than 10 μm and less than10 μm, respectively, is essentially associated with interaction effects of phases present in compound layer with the state of residual stress. It is known that compound layer with Fe_4N and $Fe_{2-3}N$ tend to have principal residual stresses in the compressive & tensile mode respectively. Further, the probability of fatigue crack nucleation in compound layer is directly proportional to the volume of compound layer. Below a threshold thickness of compound layer the residual stress can switch to the compressive mode leading to enhanced fatigue strength. Thus, for larger thickness of compound layer, the probability of crack nucleation will be higher and will decrease as the thickness of the compound layer reduces.

- FEA studies reveal that up to a thickness of 10 µm of white layer the peak normal fiber stress is about 25% lower than the peak normal fiber stress in the base material. However, beyond a thickness of 10 µm, the stress in the white layer rapidly switches over to a value which is nearly 30% higher than the peak normal fiber stress in the base material. Lower the value of peak normal stress, better is the fatigue life of the material.

  As mentioned earlier, the post- plasma nitriding residual stress in the white layer of $Fe_{2-3}N$ constitution is of tensile nature while that in the Fe_4N phase is of compressive nature. Thus, presence of tensile normal stress in the $Fe_{2-3}N$ layer, (in white layer with thickness greater than 10µm) "adds-on" to the externally applied bending stress creating further stress intensification, finally resulting in further degradation of fatigue life. In contrast, the compressive nature of normal stress in Fe_4N white layer of thickness less than 10µm, gets subtracted from the externally applied bending stress and results in reduction in stress intensification, helping in increasing the fatigue life.

- An important finding of this work is that in contrast to the commonly held notion that the presence of compound / white layer (in any thickness) will degrade the fatigue life, the present study shows that this is not completely true. The presence of compound layer is not always detrimental to fatigue life. As far as compound layer is free from $Fe_{2-3}N$ phase, the fatigue is not adversely affected. The results obtained clearly show that the presence of compound layer up to 10 µm thickness enhances the fatigue strength and fatigue life of the material and the drop in fatigue strength starts only when the compound layer thickness is greater than 10 µm.

- Besides improving fatigue life, the plasma nitriding leads to an improvement in the wear and corrosion resistance of the material and thus offers an added benefit.

Suggestions for future work

- Looking into the nature of dependency of fatigue life on thickness of compound layer, it is suggested to further study the nitriding process with variation in process parameters to further improve fatigue life. This can be achieved by avoiding formation of ε-nitride.
- It is also suggested to study the characteristics of compound layer through fracture mechanics approach. This is for better understanding of fatigue failure mechanism of phases like ε-nitride and γ'-nitride.