CHAPTER 7
MAJOR CONCLUSIONS

The study focuses extensively on the aspects related to surface roughness, tool wear, turning forces, parametric optimization and economical feasibility in hard turning using multilayer-coated carbide inserts. Therefore based from the findings of the research on hard turning, following conclusions may be drawn.

1. Under present experimental configuration from the preliminary investigation as observed uncoated carbide tools suffer catastrophic failure due to poor surface strength and thermal properties during turning D2 steel. However, TiN coated tool sustains the machining process due to high hardness, wear resistance and low coefficient of friction. It is observed that the tool life of multilayer TiN coated carbide insert is almost thirty times higher than that of uncoated tool in machining D2 steel under speed of 200m/min.

2. Comparing the surface roughness obtained by uncoated and multilayer TiN coated carbide tools a work surface roughness of 3.6 micron is reached within a minute for uncoated tool as compared to only 2.02 micron roughness over a long span of 32 min for coated insert. The improved surface roughness obtained from coated carbide may be attributed to the retained cutting edge geometry with better hardness, wear resistance and low friction properties.

3. From the analysis of variance (ANOVA) it is observed that the feed is the most significant influencing parameter to surface roughness in turning D2 steel as compared to cutting speed and depth of cut.

4. From the preliminary investigation during hard turning of AISI 4340 steel (47 ± 1 HRC) for selection of range of cutting parameters, multilayer TiN coated carbide inserts have shown higher tool life compared to ZrCN tools. The cutting forces for
uncoated carbide inserts are higher compared to TiN and ZrCN tools. Such a poor result for uncoated tool can be attributed to the quick dulling of the tool tip, which is clear from the surface roughness obtained by the respective tools. Both the coated tools performed effectively at cutting speed as high as 150 m/min with normal feed and depth of cut. A 4$^3$ full factorial design of experiment was proposed for performance analysis of both the coated tools in the adopted experimental setup, based on cutting parameters speed, feed and depth of cut. The limits of the parameters were selected based on the results of preliminary investigation.

5. From the chemical analysis of work-piece material AISI 4340 steel found to contain Ni, Cr and Mo as the major alloying elements.

6. The wears of tools were primarily due to abrasion and micro chipping. In addition grooving wear and notch wear were also observed at the flank surfaces of the tools. At low feed (0.05 mm/rev) and depth of cut (0.2 mm), the flank wear observed to progress steadily when cutting speeds are increased from 60 to 150 m/min. However, at highest speed 150 m/min, the tool wear for multilayer ZrCN tool was rapid. As the feed rate was increased to the highest value of 0.2 mm/rev and depth of cut to 0.5 mm, TiN coated tool has shown tool failure by fracture as compared to ZrCN tool to suffer such a phenomenon at a speed of 60m/min only. Chipping and catastrophic failure are observed to be the primary mode of failure at higher speeds, feeds and depth of cut. However, TiN coated tool has shown its longer tool life compared to others.

7. So far the quality of surface produced in hard turning, multi layer TiN coated carbide tools produced better surface quality than ZrCN coated inserts. The roughness of the order of 1.6 micron comparable with that of surface grinding has been obtained. Such a high quality surface has been obtained under a low feed (0.05 mm/rev) and high speed (150 m/min) which is in well agreement with previous researchers. At higher feed, depth of cut and lower speeds the surface quality has been observed to deteriorate. However, multi layer TiN coated tool continues to give good quality surface as compared to ZrCN tools even beyond a feed rate of 0.1 mm rev. But good quality surface for ZrCN tool was limited to the low feed up to 0.1 mm/rev and high speed (120-150 m/min) in hard turning.
8. From the chip morphology it has been observed that the colour of chips produced by TiN coated tools are mostly metallic and burnt blue for ZrCN coated tools indicating a higher temperature. This confirms the lower heat generation with lubricious properties of TiN coated carbide tool as compared to ZrCN coated tool.

9. From the ANOVA analysis, it has been observed the cutting speed is more significant parameter followed by depth of cut and feed for tool wear. Feed is most influencing parameter on surface roughness followed by cutting speed. Depth of cut is the least significant parameter for surface roughness. It is concluded that, the cutting speed and feed are the significant factors affecting the tool wear and surface roughness.

10. From the force analysis, thrust force (Fy) is the largest followed by tangential force (Fz) and the feed force (Fx) in finish hard turning experiments. The reason may be attributed to the smaller depth of cut (0.2 mm) and feed compared to the nose radius of the cutting tool (0.8mm). It has been observed that, the thrust force is 1.5 to 2 times higher than the cutting force in hard turning. Magnitude of thrust force was found to be in the range of 31-231 N. There is not much difference in forces has been observed between TiN and ZrCN coated tools. Reduction in cutting force at higher cutting speed has been observed and may be attributed to softening of work-piece materials and reduction in material’s strength because of high heat generation. A rise in cutting force under high feed and depth of cut is normal due to higher resistance to uncut chip area. However, the drop of thrust force at higher depth of can be attributed to the expanding cutting edge beyond the nose radius to principal cutting edge.

11. Grey relational analysis coupled with Taguchi method for multi-responses has been used to obtain optimizing parametric combination. The optimal parametric combinations were found to be d1(0.2 mm) -f1(0.05 mm/rev) -v3 (120 m/min) and d4(0.5 mm)-f1(0.05 mm/rev)-v2 (90 m/min) for multilayer TiN coated carbide inserts and multilayer ZrCN coated carbide insert respectively. Improvement in grey relational grade has been noticed in both cases. Feed is the most significant factor for multi-responses followed by cutting speed for multilayer TiN coated and ZrCN coated carbide insert during hard turning. The measured tool life have been found to
be 47 min and 31 min for multilayer TiN and ZrCN coated carbide insert at their optimal levels. The improvement of tool life of TiN coated carbide insert has been found to be 1.5 times or 34% higher than the ZrCN coated carbide inserts at optimal parametric conditions in hard turning.

12. The economic analysis carried for multilayer coated tool on its optimal parametric conditions. It has been observed that, the TiN coated tool gives a better and economical process of machining giving us a machining cost saving of the order of 12.9% having a 1.5 times higher tool life compared to ZrCN tool.

13. A higher saving in machining costs has been obtained for multilayer TiN coated inserts i.e. 93.4% compared to uncoated carbide and 40% compared to multilayer ZrCN coated carbide inserts respectively in hard turning at higher cutting speed.

14. Comparing the performance of multilayer TiN coated carbide tools with respect to uncoated carbide, ZrCN coated, CBN-TiN coated and CBN coated with chip breaker carbide tools and PCBN inserts, it has been observed that, cost savings of the order of 92%, 35%, 81.7%, 7.4% and 80% respectively achieved in hard turning processes. Though the tool life of TiN coated carbide inserts is 2.5 times less than CBN-TiN coated carbide inserts and 4 times less than PCBN insert, the lower initial cost associated with this, makes TiN coated carbide inserts economically more favored.

15. From the experimental investigation and observations from the experimental results on tool wear, surface roughness, chip morphology, cutting forces in hard turning with uncoated, multilayer TiN coated and ZrCN coated carbide tools, it has been concluded the TiN coated tool out performs over the range of parameters chosen compared to other tools. ZrCN coated carbide tools have shown potential at low speed and feed ranges. ANOVA and grey relational analysis have clearly indicated the optimal parametric level.
7.1 Scope for Future Work

Based on the research study that has been carried out, several recommendations for further work can be made. Further research will concentrate on the following issues:

1. Future work will involve analysis of extended cutting parameters, different tool geometries and tool materials. Some additional variables, such as cutting tool nose radius, cutting time and hardness of work materials should be taken into consideration for further research in hard turning to investigate the progression of flank wear, surface roughness and cutting forces.

2. The findings of the results can be utilized to develop a mathematical model for better predictions using response surface methodology and artificial neural network.

3. To compare the results of flank wear, cutting force and surface roughness using wiper geometry coated carbide insert under same cutting environments.

4. Study of effects of minimum quantity lubrication on coated carbide tool performance in hard turning. Combinations of soft and hard coated carbide insert should also be tried to judge the performance in hard turning.

5. Using various high end software’s, a finite element model of hard turning can be developed for understanding the fundamentals of hard turning process and for the prediction of cutting forces, chip morphology, tool stresses, temperature and residual stresses.

6. Vibration related studies should be carried out to study the effect of the vibration of the machine on the responses like cutting force components, surface roughness and chip morphology.