CHAPTER 5
CONCLUSION

The turning process is carried out by machining with different work tool combinations, such as the AISI 1045 steel with the CNMG 120412-5 TN2000 multi-coated carbide insert, and the AISI 316 stainless steel and Titanium alloy with CNMG 120404 MP 431 KC 5010 PVD coated carbide inserts. The machining operations were carried out in different machining environments for all the workpiece materials. They are: dry machining, conventional wet machining with soluble oil as the coolant, and cryogenic CO₂ and LN₂ machining. The effect of cryogenic cooling with CO₂ and LN₂ as the cutting coolants is studied and compared, with dry and conventional wet machining in terms of the cutting temperature, cutting force, chip thickness, chip form, chip morphology, surface roughness, shear angle and tool wear. The major conclusions in machining the different workpiece materials under different machining environments are:

1. Cryogenic machining is an effective alternative method, to reduce the cutting temperature arising during the machining process.
2. The cryogenic machining process, especially when CO₂ was used as the cutting fluid, helped to reduce the cutting forces more significantly than the other machining environments.
3. Better chip breakability with reduced chip thickness was obtained, when a cryogenic CO₂ coolant was used.
4. Better chip control was also obtained in cryogenic machining, than in the conventional wet machining process.

5. The surface finish of the workpiece was improved when cryogenic coolants were used for machining.

6. The shear angle calculated under cryogenic machining conditions was greater, when compared with that under dry and wet machining.

7. Tool wear was reduced drastically in respect of crater and flank wear during the turning operation, when cryogenic CO\textsubscript{2} and LN\textsubscript{2} were used as coolants.

5.1 PERFORMANCE OF CRYOGENIC COOLING IN TURNING AISI 1045 STEEL

The turning of the AISI 1045 steel workpiece was carried out, using a multi-coated carbide insert CNMG 120412-5 TN2000 at different speed-feed combinations under different cutting environments. The major conclusions of this investigation are:

1. The cryogenic CO\textsubscript{2} coolant reduced the cutting temperature in the range of about 3 – 13% while the cryogenic LN\textsubscript{2} coolant reduced the cutting temperature in the range of about 9 – 27%, when compared to wet machining.

2. The cutting force reduced in the range of about 17 – 38% in cryogenic CO\textsubscript{2} cooling while a reduction of about 8 – 34% was seen in cryogenic LN\textsubscript{2} cooling under similar cutting conditions.
3. The cryogenic CO\textsubscript{2} coolant was favourable in reducing the cutting force in the range of about 2 – 12% when compared with the LN\textsubscript{2} coolant.

4. Feed force and radial force were reduced in the range of about 17 – 26% and 9 – 22% with the cryogenic CO\textsubscript{2} coolant, and up to 11% with the cryogenic LN\textsubscript{2} coolant, when compared to wet machining.

5. The cryogenic CO\textsubscript{2} coolant reduced the thickness of the chips in the range of about 25 – 33% and 8 – 23% and LN\textsubscript{2} in the range of 19 – 33% and 5 – 20%, when compared to dry and wet machining respectively.

6. Chips of a shorter form and smaller size were produced in cryogenic machining, on the application of cryogenic coolants. Better chip breakability and chip control was also observed.

7. Surface finish improved significantly on the application of cryogenic coolants. Especially, when cryogenic CO\textsubscript{2} was used, the advantage in the improvement of the surface finish was found to be about 37 – 56%, 4 – 24% and up to 14% when compared with dry, wet and cryogenic LN\textsubscript{2} machining.

8. Tool wear was reduced to a greater extent in cryogenic machining when compared to dry and wet machining. The application of cryogenic CO\textsubscript{2} as the cutting coolant offered the highest benefit in the reduction in the crater wear of up to 67% and flank wear in the range of about 76 – 88%, 72 – 76% and 41 – 61% when compared to dry, wet and cryogenic LN\textsubscript{2} machining conditions.
5.2 PERFORMANCE OF CRYOGENIC COOLING IN TURNING AISI 316 STAINLESS STEEL

The turning of the AISI 316 stainless steel workpiece was carried out, using a PVD coated carbide insert CNMG 120404 MP 431 KC 5010 at different speed-feed combinations under different cutting environments. The major conclusions of this investigation are:

1. The cryogenic CO\textsubscript{2} coolant reduced the cutting temperature in the range of about 34 – 43% and 8 – 35%, while the cryogenic LN\textsubscript{2} coolant reduced the cutting temperature in the range of about 39 – 53 % and 16 – 46 % when compared with dry and wet machining respectively.

2. The cryogenic LN\textsubscript{2} coolant was favourable with the least cutting temperature, due to its extreme low temperature, and it reduced the cutting temperature in the range of about 8 – 17% when compared to cryogenic CO\textsubscript{2} machining.

3. The cutting force reduced significantly with the cryogenic CO\textsubscript{2} and LN\textsubscript{2} coolants, when compared to dry and wet machining. CO\textsubscript{2} favoured the reduction of the cutting force in the range of about 41 – 63% and 35 – 55%, and LN\textsubscript{2} coolant in the range of about 30 – 55% and 26 – 45%, when compared with dry and wet machining respectively.

4. The cryogenic CO\textsubscript{2} coolant reduced the feed force and radial force in the range of about 34 – 56% and 25 – 54% and the cryogenic LN\textsubscript{2} coolant reduced the feed force and radial force in the range of about 23 – 49% and 9 – 43% when compared to wet machining respectively.
5. Better chip control and breakability was observed during the process of cryogenic machining. Chip thickness was reduced up to 19% and 14% in cryogenic CO$_2$ and LN$_2$ machining, when compared to wet machining.

6. Surface finish improved in the range of about 38 – 67% and 13 – 53% in cryogenic CO$_2$ coolant machining, and 36 – 64% and 11 – 47% in cryogenic LN$_2$ coolant machining, when compared to dry and wet machining respectively.

7. The CO$_2$ coolant offered a maximum advantage of a reduction in the crater wear in the range of about 47 – 60%, when compared with LN$_2$ machining. It reduced the flank wear up to 91%, 62% and 72% when compared to dry, wet and LN$_2$ machining.

5.3 PERFORMANCE OF CRYOGENIC COOLING IN TURNING TITANIUM ALLOY

The turning of the Titanium alloy workpiece was carried out, using a PVD coated carbide insert CNMG 120404 MP 431 KC 5010 at different speed-feed combinations under different cutting environments. The major conclusions of this investigation are:

1. The cutting temperature obtained in cryogenic CO$_2$ and LN$_2$ machining reduced up to 43% and 52% over dry machining respectively and in the range of about 13 – 36% and 23–46% over wet machining respectively. Further, it was found that there is a reduction of the cutting temperature in the range of about 9 –20% on the application of LN$_2$ compared to the cryogenic CO$_2$ coolant.
2. The cutting forces were reduced in the range of about 21 – 41% and 9 – 22% in cryogenic CO$_2$ and cryogenic LN$_2$ machining respectively, when compared to wet machining.

3. Feed force and radial force reduced in the range of about 14 – 40% and 14 – 43% with the cryogenic CO$_2$ coolant, and in the range of about 6 – 22% and 5 – 28% with the cryogenic LN$_2$ coolant, when compared to the wet machining process.

4. Acceptable forms of fine chips were produced in both cryogenic CO$_2$ and LN$_2$ machining with reduced chip thickness.

5. Improved surface finish in the range of about 16 – 35% and 35 – 63% respectively was observed in cryogenic LN$_2$ and CO$_2$ machining, compared with wet machining. The cryogenic CO$_2$ coolant improved the surface finish in the range of about 13 – 48% when compared to cryogenic LN$_2$ machining.

6. The use of the cryogenic CO$_2$ coolant reduced the crater and flank wear up to 57% and 61% respectively, when compared to wet machining. The cryogenic LN$_2$ coolant reduced the crater and flank wear up to 45% and 35% respectively, when compared with wet machining.

Based on the investigation of the experimental results, it was observed that cryogenic cooling had a substantial benefit in reducing the cutting temperature, cutting force, chip thickness, surface roughness and tool wear. The cryogenic CO$_2$ cooling, in particular, performed better when compared with the other machining conditions for different work-tool combinations.
5.4 FUTURE SCOPE OF THE RESEARCH

1. The optimization of machining parameters, such as the cutting velocity, feed rate and depth of cut can be done for the maximum material removal rate at a low machining cost.

2. Different techniques of applying the cryogenic coolants to the cutting zone can be carried out.

3. A parametric variation of the cryogenic coolants’ flow can be investigated through experimental work.

4. The optimization of the process parameters can be done for an economical supply of the cryogenic coolants.