CHAPTER 6

CONCLUSION

Incremental forming of cone and pyramid shapes of IS: 513 CR3 deep drawing quality steel, IS: 277 Galvanized steel and AISI 304 stainless steel sheets through a series of local plastic deformations applied incrementally.

Accordingly incremental forming trails have been conducted using different tool rotational speed, table feeds and step depth. The process status was assessed by monitoring the surface roughness, final thickness, Vickers microhardness, thickness distribution, formability and the microstructure of formed cone and pyramid shaped specimens. Besides the process parameters optimization techniques was developed using response surface methodology through the software Design Expert (Version 9.0.2.0) to predict the surface properties of the incrementally formed specimens. Confirmation experiments were conducted to evaluate the validity of the results of optimization techniques. Apart from process characterization and optimization, finite element analysis was carried out using the software ABAQUS (Version V 6.10.1) to predict the forming characteristics of the incrementally formed specimens. The results of the finite element analysis were compared with the experimental results.

Based on the experimental, optimization and finite element studies on incremental forming for cone and pyramid shapes on steel sheets IS 513
CR3 deep drawing quality steel, IS 277 Galvanized steel and AISI 304 stainless steel, the following conclusions have been drawn.

- Incremental forming is a feasible method for forming steel sheets into various shapes for small batch production.

- For a constant step depth both table feed and tool rotational speed influences the formability and final thickness of the formed component for all the steel sheets were studied during incremental forming.

- Hardness increased for all the steel sheets studied with increasing tool rotational speeds, table feeds and step depths.

- Surface Roughness increases with the increase in tool rotational speed for the cone and pyramid shapes of steel sheets during incremental forming. The increase in the roughness between 40 to 45% was observed.

- Increase in step depth and feed rate has less influence on surface roughness. For the lower values of step depth the surface roughness is less and similarly for increased in feed rate leads to increase in the surface roughness of the sheet during forming of both cone and pyramid shapes.

- Increase in step depths and feed rates leads to variation of approximately 30 to 35 % and 25 to 30% on surface roughness of cone and pyramid shapes respectively.

- During forming of IS 513 CR3 deep drawing quality steel the following conditions yielded better results.

  - Higher formability was achieved for cone shape at lower tool rotational speed with moderate feed rate and step depth.
Higher formability was achieved for pyramid shape at moderate speed, feed rate and step depth.

The final thickness of incrementally formed cone shape was about 46% reduction in original thickness.

The final thickness of incrementally formed pyramid shape was about 44% reduction in original thickness.

The value of hardness increase during forming of cone shape and pyramid shape were around 20% and around 24% respectively.

The microstructure of the cone and pyramid shaped specimens revealed a change in pearlite and ferrite phase due to cold working during incremental forming.

Increase in feed rates resulted in an increased thickness of ferrite and pearlite layer on the formed surfaces for both shapes.

During forming of IS 277 galvanized steel the following conditions yielded better results.

Higher formability was achieved for cone shape at higher tool rotational speed and step depth with lower feed rate.

Higher formability was achieved for pyramid shape at lower tool speed and feed rate with moderate step depth.

The final thickness of incrementally formed cone shape was about 41.7% reduction in original thickness.

The final thickness of incrementally formed pyramid shape was about 37.7% reduction in original thickness.
- The value of hardness increase during forming of cone shape and pyramid shape were around 36% and 33% respectively.

- The microstructure signifies elongated pearlitic grains in a matrix of ferrite in both cone and pyramid shapes.

During forming of AISI 304 stainless steel the following conditions yielded better results.

- Higher formability was achieved for cone shape was achieved at moderate tool rotation speed and lower feed rate with higher step depth.

- Higher formability was achieved for pyramid shape at moderate tool rotational speed and higher feed rate with higher step depth.

- The final thickness of incrementally formed cone shape was about 45.3% reduction in original thickness.

- The final thickness of incrementally formed pyramid shape was about 43% reduction in original thickness.

- The value of hardness increase during forming of cone shape and pyramid shape were around 75% and 74% respectively.

- Incremental forming results in a transformation to the martensite phase at the full depth (around 40mm).

- The percentage of austenite and martensite was approximately 96% and 4%, respectively.

- Increase in step depth results in increased density of martensite.
Response surface methodology technique exhibits good correlation on surface roughness and final thickness between experimental results and predicted results.

The results on the thickness distribution during incremental forming of cone and pyramid shapes for all the steel sheets agrees reasonably well with the predicted value by finite element analysis with a variation of 10%.

The FEA results are useful to analyze and predict the forming behavior of incremental forming on steel sheets into various shapes.

6.1 SCOPE FOR FURTHER WORK

Investigation of formability behaviour of high strength and low alloy steels during incremental forming.

The influence of process variables such as tool diameters, sheet thickness, forming angle on forming force and process optimization during incremental forming of steels can be studied.

Failure prediction and deformation mechanism of single point incremental forming of sheet metal.

Forming behaviour of coated tools under different tribological conditions.