CHAPTER 7

CONCLUSIONS AND SCOPE FOR FUTURE WORK

7.1 CONCLUSIONS

The following conclusions are made by the simulation outcomes and experimental investigation.

7.1.1 Sheet Hydroforming

- Numerical analyses of the hydroforming process conducted with DEFORM 3D code, using correct material properties and material model, were able to capture the failure and wrinkling characteristics.

- The numerical results are found to be in good agreement with the experimental results and accurate thinning distributions have been predicted.

- By comparing experimental results without fluid pressure to the corresponding numerical results, an accurate numerical modeling capability to predict wrinkle formation in sheet metals was established.

- Using this same model and expanding it to simulate hydroforming it was found that sheet hydroforming could be used as a viable alternative forming process not only capable
of preventing wrinkles, but also of increasing the formability and drawing depths for the final required shape.

- It should be emphasized that the success of the process requires a specially derived fluid pressure profile to prevent both wrinkling and rupturing instabilities from occurring.

- In the process, an experimental test rig for the sheet hydroforming process was constructed and was used successfully to produce super alloy cups. Super alloy of high strength can be formed under the condition of very high chamber pressure. The experiments show that Inconel alloy 625 has better formability.

- The drawing ratio reaches 2.6 for super alloy work pieces with hydro forming process compared to a drawing ratio of 1.7 using conventional forming process.

- The experimental results show that the chamber pressure should be in safe working zone for successful drawing. This was achieved by interfacing the punch travel with the chamber pressure.

- Uniform thickness strain distribution is also one of the main features of this process in which there is no need for die but only punch with geometry of cross section similar to the drawn cup.

- The lower and upper limits of the optimum fluid pressure-punch stroke path for the sheet hydroforming of Inconel 625 sheet metal were determined using the numerical model developed. The upper and lower limits were proven experimentally.
Experiments designed based on the orthogonal array of the Taguchi method were used to identify the most significant forming parameter affecting the hydroformability. It was concluded that the greatest effects on thinning ratio in this process is contributed by internal pressure. The results from this work open the avenue of determining the optimal internal pressure range for better quality products.

7.1.2 Tube Hydroforming

- A tube hydroforming test machine with four independent controls of two axial feeding punches, an internal pressure, and a counter punch was developed. Experiments on T-shape protrusion forming using Inconel 625 were conducted to test the formability.

- Different loading paths and the corresponding thickness distribution of the formed product were discussed. A loading path, which can generate a sound product, was obtained.

- The protrusion heights of the formed products with and without a counter punch were also compared to verify the merit of using a counter punch during tube hydroforming.

- The hydroforming of T-shapes requires proper selection of many process parameters, i.e. the internal pressure, the axial feeds, and the counter punch force. All these parameters are crucial to the success of the hydroforming operation. In order to reduce the trial-and-error effort in the designing of the process parameters, in this work analytical model were developed and that can be used to estimate valid process parameter values.
• It was also shown experimentally that the geometric parameter tube length, affects the obtainable protrusion height.

• FEA simulations show a good correlation with the results from experiments, which indicates that the cost can be reduced in the experimental work greatly by avoiding large number of trails.

• It is very important to pre-form useful wrinkles that can be flattened by enough high liquid pressure in the calibration stage, and harmful wrinkles should be avoided in the pre-forming stage. Through simulation, it is also shown that following the increase of the internal pressure in the pre-forming stage, the wall thickness in the expanding area will be more uniform and the variation of wall thickness is not large.

• It could be concluded that the software HyperForm can be used for more complex and intricate tube hydroforming parts.

### 7.2 SCOPE FOR FUTURE WORK

The following aspects of sheet and tube hydroforming of Inconel alloy are identified for future work:

• Tool design, process design and tool redesign for thermal hydroforming of Inconel alloy.

• Thermo mechanical coupled FEA simulation.

• Combination of deep drawing a double blank and hydroforming process in one stroke.

• Hydroforming of tailor welded blanks of different thicknesses.