CHAPTER 6

Conclusion and Scope of Future Work

6.1 Conclusions

The present work is carried out to develop rubber based sheet hydroforming process for metals and alloys. The lab scale RBSH setup is designed and fabricated to perform experiment and evaluate the process parameters. provisions have been made in the setup to monitor real time variation in loads and hydraulic back pressure during forming. The experiments are done in a sequential manner. In first stage, the effect of rubber diaphragm is studied on formability of the trial component. In 2nd stage, the effect of different rubber diaphragms vis. Natural, Nitrile and Silicone rubber on forming of hemispherical have been studied. Finally in the third stage, hydraulic pressure has also been applied and study of variation in load and hydraulic pressure during forming have been carried out. The numerical simulation using FEA is performed for each case to develop the suitable model. In Stage I, study was carried out for both the cases of 'Shallow forming' and 'Deep Drawing'.

1. Under shallow forming (Height to Diameter ratio$<$0.5), the following points are observed

    (a) In case of forming Stainless Steel 304 cup having thickness 1.5mm, the rise in principle stresses in conventional forming are found more that rubber assisted forming. In this case 'Hydraulic back pressure' has not been applied. This trial was done using polyurethane rubber diaphragm.

    (b) The next trial was carried out SS304 blank having thickness of 0.8mm and natural rubber is used. The rise in hardness in case of conventional forming is more than rubber assisted forming. As hardness is directly proportional to the strength of the material, hence stresses generated in case of conventional forming is on the higher side than that of rubber assisted forming which would delay in necking and fracture in rubber assisted forming. The microstructure study also gives the fair idea that grain deformation in rubber assisted forming is minimal.

(c) The trial carried out in point No 2 is repeated with pure copper blank having thickness of 0.8mm. The similar observation in hardness pattern and microstructure is observed as above. Hence rubber assisted process improves the formability of both SS304 and Pure copper.

2. Under Deep drawing (Height to Diameter ratio > 0.5), the following points are observed

    (a) The experiment was carried out to draw the cone made of pure copper (84 deg) using convention route (without rubber) and rubber assisted forming (with rubber). The formability was measured in terms of percentage thinning and it was observed that there is 15 % improvement of thinning in rubber assisted forming case.

    (b) The above experiment was repeated for hemispherical cup made of pure copper. It was found that improvement up to 5 percent has been observed in rubber assisted forming. It can also be inferred that rubber has better effect on formability in complex shapes such as cone in compared with simple shapes such as hemisphere.

    (c) The improvement in formability was further studied using grid analysis and measurement of major strain and minor strain. It has been observed that in case of conventional forming (without rubber), the maximum major strain was 0.2914 (stretching zone) whereas it was 0.21142 in case of rubber assisted forming. Hence, component is more prone to fracture in conventional forming.

3. In Stage II, study was carried out to study the effect of different rubber diaphragms on formability. The rubbers were manufactured in-house in such a way to achieve harness in the range of 55-60 A (shore hardness). The thickness of rubbers is kept as 3mm to maintain uniformity.

    The hemispherical cup made of pure copper was drawn under three rubbers as explained above. It was found that percentage of thinning is almost same in case of rubbers although rubbers have different strength and young's modulus. It can be inferred that as long as developed strain values during forming are within the limit of max permissible strain value, the effect of any rubber on formability would remain same.

4. In Stage III, the experiment are performed to study the combined effect of rubber diaphragm and hydraulic back pressure on formability of the material. The lab scale rubber based hydroforming set up is developed along with data acquisition system. The set up is mounted in the existing press of 20 Tons capacity. The load cell of 5 Ton is integrated with punch and two hydraulic power packs are integrated to control pressure in the inlet and exit of set up. Correspondingly, two pressure transducers are also integrated at the inlet and exit of the set up.

5. The experiments are carried out under various conditions as discussed in chapter 3. Following are the outcomes of the experiment

   (a) It is observed that the monitored values are very close to the theoretical calculated values of load and pressure. Hence it can be concluded that this set up can predict the required load and hydraulic pressure for forming of any shape.

   (b) The maximum peak load observed in case of rubber assisted forming is less than that of conventional forming.

   (c) The maximum peak load during rubber assisted hydroforming is found almost close to conventional forming.

   (d) The maximum peak load observed in case of nitrile rubber is lower than that of natural rubber as nitrile rubber has lower Young's modulus.

6. The numerical simulation is carried out for 3 cases namely forming of SS304 cup, forming of copper cone and forming of hemispherical cup. The conclusion for each case is given below

   (a) The results of simulation of SS304 cup indicate that there is better uniformity in distribution in von-mises stresses in case of rubber assisted forming especially in the region supported by rubber diaphragm. This has been further confirmed by microstructure analysis. The variation in plastic strain in almost same. The experimental measured thickness data is matching closely with simulation data.

(b) Following are the main conclusion of FE Simulation for Copper Cone

i. For forming cup with smaller cone angle, the sheet process should be done in number of stages, so as to get the final product without fracture.

ii. The thickness along the cup wall decreases with the increase in cone angle for all the forming processes studied.

iii. The thickness build-up near the holder region is small for rubber assisted forming process as compared to conventional forming process.

iv. The von-Mises stress increases with the decrease in cone angle causing failure at the higher cone angles.

v. With the increase in fluid pressure for rubber assisted forming process, the von-Mises stress decreases. But there exists a critical cone angle after which the von-Mises stress again rises.

(c) The simulation of complete rubber assisted sheet hydroforming was carried out and Fem model was established. The experimental pressure variation data during forming was given as input in simulation. The simulated thickness variation is matching closely with experimental thickness variation data.

(d) The simulation model of Non-symmetric shape is also established in Abaqus. It has been established that non-symmetric can also be formed without failure.

6.2 Scope for future research

1. In present work, the forming has been carried out at low strain rate (1mm/s). Further investigations can be carried out under high strain rate conditions (>1mm/s).

2. The present rubber assisted sheet hydroforming set up may be scaled up for

study the effect of ultra-high strength materials such as Inconel, 11-10 PH and other precipitation hardened steels.

3. As titanium alloy especially Ti6Al4V is exhibits low formality, the present work may be evaluated for this alloy.

4. Blank holder force is another critical parameter during forming. There is scope for integrating the load cells with blank holder in order to study the effect of blank holding force during forming.

5. The set up may be further improved so as to calibrate and control the blank holding force and chamber pressure during forming.

6. The effect of friction between rubber and metals may be studied especially when back pressure is in action.

7. A commercial version of RBSH setup may be developed for industry application.

8. Multi-features sheet forming may also be done with this process.