CHAPTER 7

Conclusion and Future Scopes

7.1 Conclusions

In the current study, setups of RAISF and RAISHF have been developed from scratch in production lab at IITBHU. Once the setups were developed, different axis symmetric and non-axis symmetric shapes on AA6061 based on the parameters optimized by straight groove test. The following main conclusions are drawn from this work:

(1) Straight groove test has been conducted to optimize the input parameters of tool speed, tool diameter and step depth. It has been found from regression analysis that the best combination of maximum strain, minimum spring back and minimum forming time are achieved with tool speed, tool diameter and step depth of 77.75 mm/s, 10 mm and 0.42 mm respectively. All the experiments have been conducted on these parameters only.

(2) An analytical model has been developed to predict the forming forces during incremental sheet forming. The mathematical equations have been developed in a polar 3D coordinate system. All six stress components have been taken into consideration initially, before neglecting $\tau_{\theta z}$. Analytical formulae have been developed for all the stress components. The contact area has been modeled analytically before finally developing the equations for all forces. The three force components for which the equations have been developed are F_r, F_θ, and F_z. The resultant of the three force components is the total force represented as F_t. The resultant of F_r and F_θ is the resultant force in the r-θ plane, represented as F_p. The process has been modeled in FEA using the same experimental

parameters, and the force components F_z and F_p have been calculated before finally calculating the total force (F_t). Finally, the process has been carried out on a six-axis industrial robot, and forces have been measured using a tool dynamometer. The data obtained from the analytical model and FEA have been validated by the experimental results. The validation has been done for a 45° cone. The results obtained from the analytical model and FEA are in good agreement with the experimental result. The maximum error in the analytically calculated total force is found to be 4.25%. Similarly, the results obtained from the FEA model are also in agreement with the experimental results. The maximum error in evaluated total force from the FEA model is found to be 4.89% with respect to the experimental results

(3) Series of experiments have been carried out on RAISF and RAISHF and the results have been compared. It is found that in maximum formable wall angle and forming depth increased by 6.67 % and 28.47% respectively in RAISHF process that that in RAISF process. Additionally, spring back is reduced by 77.14% in case of RAISHF in respect of RAISF.

(4) Due to hydrostatic nature of fluid pressure from back, more uniform thickness distribution has been observed in case of RAISHF than that of RAISF. The average sheet thickness of the cone formed by RAISHF was 12.09% more than that formed by RAISF. It has been further observed that the range of deviation of thickness values from average value varied from -9.87% to 17.27% in case of RAISF; whereas in case of RAISHF the variation lied in the range of -7% to 5%.

(5) Uniaxial tensile tests have been conducted on the samples taken from the sheets before and after deformation. It has been revealed from the tensile test that

strength of the formed cone is higher due to strain hardening. Strength of the cone formed by RAISHF is found to be marginally less than that formed by RAISF. Ductility in sample taken from cone formed by RAISHF was more due to pressure-induced ductility.

(6) Measurement of R_a revealed that surface finish of the surface in contact of tool is better from RAISHF than from RAISF. An increase of 10.56% has been observed in the surface finish of the formed cone by RAISHF than by RAISF. AFM images revealed that surface topology of hydroformed sample is more uniform in comparison with incrementally formed samples. Hence, static fluid pressure from back can improve the surface quality of the formed product which is a major issue in incremental sheet forming.

(7) It has been revealed from FLC of RAISHF and RAISF that more formability can be achieved in the RAISHF.

(8) Micro hardness of the samples was measured and it was found that the sample in the middle region is hardest. Microhardness in case of RAISF was higher than that in RAISHF.

(9) XRD analysis has been carried out to find out the residual stresses in the samples taken from undeformed and formed samples by RAISF and RAISHF. The residual stress in both the cases was tensile in nature. Relatively higher residual tensile stress was observed in case of RAISF.

(10) EBSD analysis has been carried out for studying the microstructural evolution in the undeformed and formed by RAISF & RAISHF. It was observed that significant grain refinement occurred from RAISF and RAISHF. Finer grains were present in case of RAISF than in RAISHF. High density LAGBs were present in case of both RAISF and RAISHF samples. Majority of LAGBs in

case of RASIF belonged to the group of 5^0-15^0 and in case of RAISHF majority of LAGBs belonged to the group of 2^0-5^0.

(11) As ISF offers higher formability than conventional bi-stretching, hence Limiting Dome Height test has been conducted in which hemispherical dome is made on a hydraulic press and has been compared with dome made by RAISHF. The measurements of dome height revealed that there is a rise of 186% in height of the dome made by RAISHF. This rise is because of the nature of localized deformation and propagation of the same to a new location which leads to either suppression or delay of necking.

(12) Multi stage RAISHF has been conducted on AA6061 to examine the effect of multi stage on process outcomes of RAISHF especially surface finish as it is one of the limitations in single stage RAISF. To study the multi-stage RAISHF, VWASCF sample was presented.

(13) Multi-stage RAISHF can be helpful in getting steeper wall angle and additionally can ensure more uniform strain distribution than that observed in single stage RAISHF. The maximum deviation from average thickness went down to 16% in multi stage RAISHF to 24% in single stage RAISHF.

(14) A significant increase in the surface quality of both sides of the formed cone was observed in multi stage RAISHF than in single stage RAISHF. It has been observed that inner side of the cone formed by multi stage RAISHF had 64.86% better surface finish than that formed by the single stage RAISHF.

(15) The waviness of the formed surface can be significantly reduced by performing multi stage RAISHF.

(16) As the no of forming stage increased to form VWASCF, the surface finish became better and a linear decrease from 0.534 μm to 0.32 μm was observed as wall angle varied from 55^0 after 2^{nd} stage to 75^0 after 5^{th} stage.

(17) In order to study the effect of forming temperature in RAISF, cold and warm RAISF has been conducted. For warm RAISF, the heating of the sheet has been done by using hot air gun.

(18) Warm forming significantly reduced the forming forces.

(19) Warm forming enhanced the formability of the sheet, as is evident from the larger wall angle of the cone formed by WISF.

(20) The strength of the product formed by CISF was higher than that formed by WISF; however, ductility increased in WISF, and WISF can achieve a higher formability than CISF.

(21) The uniformity of sheet thickness was found to be better in WISF than in CISF.

(22) The measurement of Ra, Rz, and Rq values revealed that WISF adversely affected the surface quality of the formed component; hence, some post-processing can be required.

(23) WISF can be beneficial as it does not require addition of any sophisticated mounting, and properties of the products are enhanced.

7.2 Future scope

RAISHF is a relatively new forming process whose study was undertaken in current thesis. Some potential future scopes of the current work are

(1) Integrating Artificial intelligence and Machine Learning for shape genearation with accuracy and precision.

(2) Study of tool wear should be done.

(3) Generalized program using robot software has been developed which should be checked for getting complex shapes.

(4) The validation of analytical model should be done for range of wall angles.

(5) TEM can be done to understand the mechanism of deformation during RAISF and RAISHF.