

Contents

<i>Contents</i>	<i>Page No.</i>
Certificate	iii
Declaration	iv
Acknowledgements	v
List of Abbreviations	xxi
Preface	xxiii
1 Introduction and Literature Review	1
1.1 Introduction	1
1.1.1 Deep drawing process	3
1.1.2 Sheet anisotropy	8
1.1.3 Failure Criteria for Sheet Metal Hydro-forming	10
1.1.4 Hydro-forming deep drawing process	13
1.2 Rubber Based Sheet Forming Process (RBSF)	14
1.2.1 Guerin process	16
1.2.2 Marform Process	17
1.2.3 Verson Hydroform Process	17
1.2.4 Maslennikov's process	17
1.3 Advantages and Disadvantages of RBSF Processes	19
1.3.1 Advantages	19
1.3.2 Disadvantages	19
1.4 Literature Review	20
1.4.1 Numerical Simulation	21

1.4.2	Effect of Process Parameter	23
1.4.3	Recent Developments	23
1.4.4	Design and Development of Rubber based forming setup	24
1.5	Objectives of the Present Research	26
1.6	Organization of Thesis	27
2	Work Material Characterization and Elements of Rubber Based Forming Process	29
2.1	Material Properties for Pure Copper Sheet	29
2.1.1	Forming Limit Curve (FLC) for pure copper	31
2.2	Material Properties for Stainless Steel (SS-304)	34
2.3	Material Properties for Rubber	36
2.3.1	Steps in Rubber Manufacturing	38
2.3.2	Material Characterisation	40
3	Design and Fabrication of Rubber-based Sheet Hydro-forming Setup	45
3.1	Introduction	45
3.2	Essentials factors of product design	46
3.3	Detailed Design of RBSH Test-Setup	49
3.3.1	Theoretical Study	50
3.3.2	Design considerations for development of test set up	52
3.4	Fabrication of Test Setup	54
3.5	Data Acquisition System	67
3.5.1	Load Cell	67
3.5.2	Pressure Transducer	67
3.5.3	Data Acquisition Module	69
3.5.4	Data Acquisition Software	70
3.6	Experimental Setup and analysis	71
3.6.1	Experiment Table and Outcome	72
3.6.2	Experimental Data Analysis	76

4	Study of Conventional and Rubber-Assisted Forming Processes	85
4.1	Introduction	85
4.2	For height to diameter ratio less than 0.5 (Shallow Forming)	85
4.2.1	Study for Cup made of SS-304	85
4.2.2	Study for Cup made of Pure Copper	95
4.3	For height to diameter ratio greater than 0.5 (Deep Drawing)	105
4.3.1	Study for Cone made of Pure Copper	105
4.3.2	Study for Hemispherical Cup made of Pure Copper	109
4.4	Formability study using Grid Method	113
4.4.1	Grid marking and measurement of Principal Strains	113
4.4.2	Generation of theoretical Forming Limit Curve for Pure Copper	114
4.4.3	Generation of Forming Limit Diagram from Measured Principal Strains	117
4.4.4	Comparison of FLD for both processes	119
4.5	Effect of Rubber type on the Formability of Hemispherical Cup	123
4.5.1	Experimental Plan	123
4.5.2	Comparison of percentage thickness variation in radial direction	123
5	Numerical Simulation of Rubber-assisted Forming Process	127
5.1	Introduction	127
5.2	Simulation for Stainless Steel 304 Cup using FEA	129
5.3	Simulation of Copper Cone using FEA	139
5.3.1	Loads and Boundary conditions	140
5.3.2	Validation of Numerical Model	140
5.3.3	Results and Discussion	141
5.4	Simulation of Hemispherical Copper Cup using FEA	149
5.4.1	Plasticity Model and Boundary Conditions	149
5.4.2	Validation of Numerical Model	150
5.5	Simulation of Non-symmetric shapes using FEA	155

5.5.1	Load and Boundary Conditions	155
5.5.2	Results and Discussion	156
6	Conclusion and Scope of Future Work	159
6.1	Conclusions	159
6.2	Scope for future research	162
	References	165
	Bibliography	175
	Appendix	177
A	Component Drawings	177
B	Formulation for Dynamic Explicit Finite Element Analysis	193
C	List of Publications	195