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COMPARATIVE FORMABILITY STUDY OF NATURAL RUBBER, B-NITRILE RUBBER AND SILICON RUBBER IN RUBBER ASSISTED FORMING OF HEMISPHERICAL COPPER CUP

ABHISHEK KUMAR[1], SANTOSH KUMAR[2] & DASHARATH RAM[3]

[1]*Research Scholar, Department of Mechanical Engineering, IIT BHU, Varanasi, Uttar Pradesh, India*

[2]*Professor, Department of Mechanical Engineering, IIT BHU, Varanasi, Uttar Pradesh, India*

[3]*Scientist, Defence Research & Development Laboratory, Kanchanbagh-PO, Hyderabad, Telangana, India*

ABSTRACT

Rubber assisted sheet metal forming has always been the subject of research for last 50 years. Rubber diaphragm is primarily used to improve the formability of the sheet metal components having complex features. In this paper, three varieties of rubber viz. Natural rubber, B- nitrile rubber and Silicon rubber are used to form the hemispherical part made out of pure copper. The rubbers are manufactured in such a way to achieve the same hardness level so that proper comparison could be made. The same part is formed under three rubber diaphragms and thickness reduction is compared. The present paper gives the detail account of rubber chemical composition, forming set up and comparison of thickness reduction in the part after forming.

KEYWORDS: Formability, Grid Analysis & Natural Rubber

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Original Article

INTRODUCTION

In recent years, sheet flexible-die forming processes have been widely used in industries such as automotive and aerospace factories [1]. The flexible forming process is employed in many operations like deep drawing, bending and stamping. It consists of using an elastomeric material, usually rubber, between the punch and the sheet or between the sheet and the die. As the punch advances, and the rubber acts somewhat like a hydraulic fluid in exerting nearly equal pressure on all work piece surfaces as it is pressed around the form block or punch [2]. These soft materials are used to remove surface scratches on the sheet during forming. Flexible forming with rubber has many advantages compared with conventional forming [3]. In this kind of process, the same soft tool may be used for several types of parts. Also the alignment problems with punch-die are eliminated and rubber improves the surface finish of formed parts [4]. Several researchers studied the forming process with flexible tools [5][6]. In this paper rubber assisted forming is carried out for forming of hemispherical copper cone. The process is similar to Marform process, Guerin process, and Verson-Wheelon process but it has some differences in its design and analysis. Thiruvarudchelvan S.,[4][7]in his review paper stated that rubber use as flexible tool started at the beginning of the 20^{th} century in bulging processes. But only in the sixties with the introduction of the polyurethanes such elastic means began to be largely used due to their much higher hardness and resistance to wear and to chemical attacks by lubricants. Many academic researchers use polyurethane as a rubber material[8]. N. Alberti, A. Forcellesez, L. Fratini and F. Grabrielliz (1998) have described Urethane as a polymer which shows nonlinear elastic stress-strain behavior [9]. The polyurethane rubber is a hyperelastic material, and generally, it is assumed as nearly incompressible during deformation [10]. Xiao Wang proposed that rubber is similar to the liquid which has good flow property [11]. If compressed in one direction, it will expand in the other direction, and delivering pressure. David and Emil [12] presented an experimental study of the rubber forming process in order to produce sheet metal components.

Although polyurethane has remained the research object in past, other type of rubbers have not been tired out. In present work, rubber assisted forming is attempted with natural rubber, silicon rubber, and nitrile rubber, because these are having good elongation and strength.

THEORETICAL STUDY OF RUBBERS

Determination of its Mechanical Properties and Applications

Characterisation of rubber is first thing to be carried out before to be used as rubber diaphragm. Geiger and Sprenger (1998) has conducted a study on the characterization of polyurethane pad sand experimental bending using elastomer pads [8]. Most of the application uses polyurethane as Rubber Material for operations because of its elastic nature and long life. However, Natural Rubber, silicon rubber, B-nitrile rubbers can also be a potential candidate for deep drawing operations. Natural rubber derived from the tree *Heveabrasiliensis* is the prototype of a wide range of materials which have a high extensibility combined with an ability to recover from extension. It is usual to refer to these materials as highly elastic, and to group their properties as high elasticity [13]. Natural rubber exhibits high tensile strength and elastic property at room temperature. The major constituent of this natural Rubber is Cis1,4Polyisoprene. The uniqueness of natural rubber lies in its physical properties of extensibility and toughness, i. e., its ability to be stretched repeatedly to seven or eight times than its original length. In the absence of tensile (stretching) stress, the polymer chains assume an amorphous, or disordered, arrangement. On being stretched, however, the molecules readily align into an ordered crystalline arrangement. Crystallinity lends greater strength to the material therefore natural rubber is considered to be “self-reinforcing” [14]. Silicon rubber is the best among all the elastomers for both high and low temperature. It has excellent ozone, weather resistance, and electrical insulation. Mechanical properties such as tensile strength, are low but changes very little when measured at higher temperatures. Applications include aerospace, medical, food contact, and automotive ignition cable [15]. B-nitrile rubber is the workhorse of the marketplace for its oil resistant properties. This rubber is known as acrylonitrile butadiene, Buna-N & simply nitrile according to the chemist, to other & Industrial firm respectively. It is a better heat aging resistance. Special compounding ingredients can be added to increase heat aging resistance. Like SBR, NBR needs reinforcing fillers to give good mechanical properties [15].

The rubber pads (silicon, natural and nitrile rubbers) of thickness 3mm are manufactured to obtain hardness in 55-60 A range. The mechanical properties are determined by using the tensile test as per ASTM D412 standard[16]. The plot of Stress vs. Strain is shown in figure 4. Table 5 lists out the mechanical properties of rubbers. It is very much clear from the plot that these rubbers have good Ultimate Tensile Strength and strain. This is the actual requirement for any deep drawing operation.

Composition of Rubbers

Figure 1: Natural Rubber

Table 1: Natural Rubber

SI.No.	Ingredients	PHR	Actual Weighed	Property/ Composition
1	ISNR5, SBR	80×23	1840	Rubber
2	1502	20	460	Rubber
3	TMQ	1	23	Anti-oxidant
4	6PPD	2	46	Anti-oxidant
5	Zinc Oxide,	5	115	Activators for
6	Stearic acid	2	46	curing
7	CI Resin	3	69	Hardness,
8	HAF Black	36	828	strength,
9	Naphthenic oil	7	161	softness
10	MBTS,	1.2	27.6	Curing
11	TMTD,	1.5	34.5	chemicals
12	Sulphur	1	23	

Figure 2: Nitrile Rubber

Table 2: Nitrile Rubber

SI.No.	Ingredients	PHR	Actual Weighed	Property/ Composition
1	Krynac 2645F	100×36	3600	Nitrile raw
2	6PPD	1.5	54	rubber
3	TMQ	1	36	Anti-oxidants
4	Sulphur	0.8	28.8	Activators for
5	Zinc Oxide	5	180	curing
6	Stearic acid	1	36	Hardness,
7	SRF Black	20	720	strength,
8	DBP(oil)	2	72	elongation
9	CI Resin	3	108	Curing
10	MBTS,	1	36	chemicals
11	TMTD	1.2	43.2	

Figure 3: Silicon Rubber

Table 3: Silicon Rubber

SI. No	Ingredients	PHR	Actual Weighed	Property/ composition
1	ELASTOSIL 60	100×46	4600	(silicon+silica filler)
2	Red Oxide	2.5	115	Heat resistance, color
3	Di Cumyl Peroxide	0.5	23	Curing chemicals

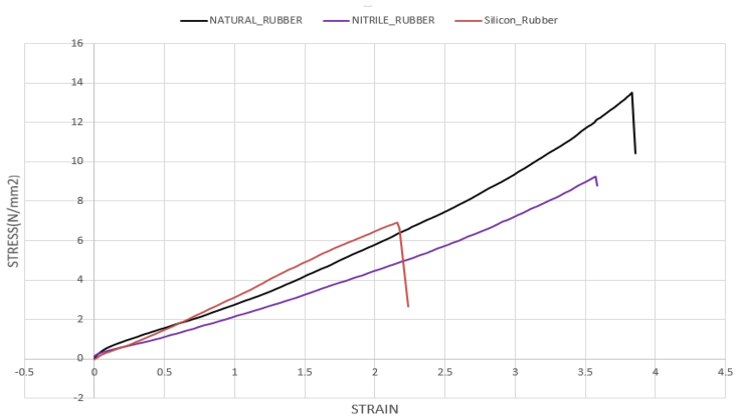

Figure 4: Comparison Stress-Strain Curves for Three Rubbers

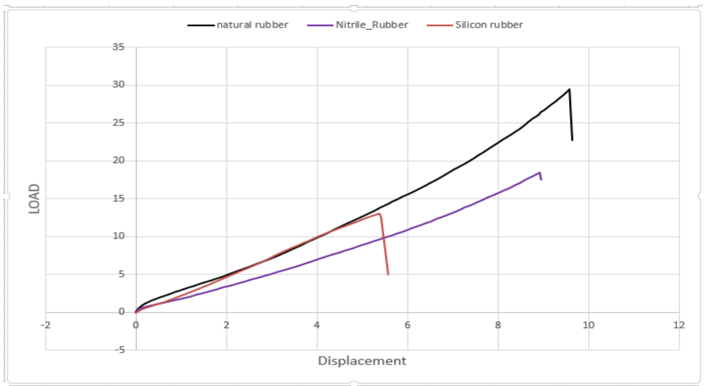

Figure 5: Comparison of Load Displacement Curve for Three Rubbers

EXPERIMENTAL WORK

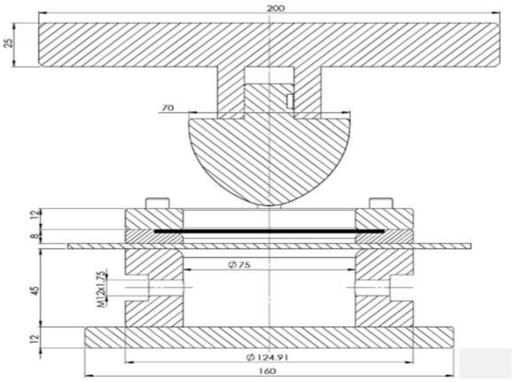

Figure 6: Experimental Setup for Rubber Assisted forming of Hemispherical Cup

An Experiment is performed to determine the formability of hemispherical copper cup in rubber assisted forming with natural rubber, silicon rubber and B.-nitrile rubber. Figure shows a schematic diagram of the experimental setup used in this study. The experiment has been carried out on a hydraulic press machine. The die clamped to the base and punch is placed at the top of the press machine. The copper sheet is placed on the upper surface of the die. The copper sheet is flat and is formed in hemispherical part as of the shape of punch. Below the die block the rubber sheet is placed, the sheet metal and rubber are pressed together by the punch. The hydrostatic compressive stress is generated by deformed rubber which can contribute towards improving formability. The elastomer incompressibility is exploited by deforming at constant volume as it exerts a hydrostatic pressure on the sheet metal [17]. The blank holder is held tightly by C-clamps so that it presses the sheet firmly. Velocity is provided to the punch during the process so that the punch presses the sheet results in sheet deformation which help to conform the final shape of the punch. The experiment is carried out with three rubbers. The clearance between the components is controlled closely to minimize the movement of the part and to avoid wrinkle. The punch and the die radii are sufficient so that it does not tear the copper sheet. The same tool setup can be used for forming different materials and different thicknesses. Low hardness of rubber material provides less wear of sheet metal as compared to conventional deep drawing. In rubber assisted forming, the amount of pressure exerted by rubber is limited by the strength of rubber itself.

Material Characterization of Pure Copper and Rubbers

The tensile test for pure copper, in annealed condition, has been carried out as per ASTM E8/M[18]standard. Yield stress, strain hardening exponent and strength coefficient are three critical forming parameters for deep drawing application. Strength coefficient is true stress value at strain value of 1[19]. As copper has strain-hardening exponent of 0.44, it can be definitely used for drawing of hemispherical cup having H/ D ratio > 0.5 without failure. The calculated forming load is less than 5 Tons. Hence, press capacity of 20 Tons is used for carrying out deep drawing of hemispherical cup.

Table 4: Material Properties for Pure Copper Sheet

Property	Value
Yield Stress (Y)	78 N/mm^2
Ultimate Tensile Strength (UTS)	239 N/mm^2
Strain Hardening Component (n)	0.44
Strength Coefficient (K)	470
Density	8.96 E-9 kg/mm^3
Young's Modulus	117 GPa
Poisson's Ratio	0.33

Table 5: Mechanical Properties of Rubbers

S. No	Properties	Natural Rubber	Silicon Rubber	Nitrile Rubber
1	Thickness (mm)	3	3	3
2	Hardness(Shore-A)	61~62	57~60	57.5~57.8
3	UTS (MPa)	13.07	6.75	9.25
4	Elongation at break(%)	378	209	358

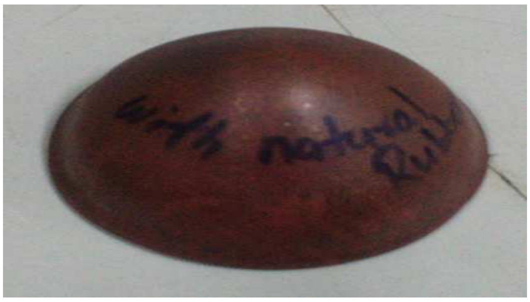

Figure 7: Hemispherical Cup Formed by Natural Rubber

Figure 8: Hemispherical Cup Formed by Nitrile rubber

Figure 9: Hemispherical Cup formed by Silicon Rubber

RESULTS AND DISCUSSIONS

Table 6, Table 7, Table 8 & Table 9 show the comparison of thickness variation and percentage of thinning for hemispherical cup in rubber assisted forming with three rubbers (silicon rubber, natural rubber, and nitrile rubber).

The hemispherical cup has been divided into two sections X and Y and the thickness has been measured according to the distance from the cup center in both the sections. This process is carried out for all three rubbers. Finally percentage of thinning in a hemispherical cup for three rubbers in both X and Y sections are compared.

Table 6: Thickness Variation of Hemispherical Cup with Different Rubbers in X-Section

S.No	Distance (mm)	Thickness Variation (mm)		
		Natural	Nitrile	silicon
1	0	1.85	1.83	1.84
2	2.5	1.71	1.71	1.71
3	7.5	1.78	1.76	1.77
4	13	1.87	1.88	1.91
5	18.5	1.95	1.93	1.96
6	24.5	2.02	1.99	2.01
7	32	2.13	2.1	2.12

Table 7: Thickness Variation of Hemispherical Cup with Different Rubbers in Y-Section

S.No	Distance (mm)	Thickness Variation (mm)		
		Natural	Nitrile	Silicon
1	0	1.85	1.83	1.84
2	2.5	1.71	1.71	1.73
3	7.5	1.77	1.77	1.79
4	13	1.89	1.88	1.91
5	18.5	1.96	1.93	1.95
6	24.5	2	1.99	2.01
7	32	2.12	2.11	2.13

Table 8: Percentage of Thinning of Hemispherical Cup with Different Rubbers in X-Section

S.No	Distance (mm)	Percentage of Thinning (%)		
		Natural	Nitrile	Silicon
1	0	7.5	8.5	8
2	2.5	14.5	14.5	14.5
3	7.5	11	12	11.5
4	13	6.5	6	4.5
5	18.5	2.5	3.5	2
6	24.5	-1	0.5	-0.5
7	32	-6.5	-5	-6

Table 9: Percentage of Thinning of Hemispherical Cup with Different Rubbers in Y-Section

S.No	Distance (mm)	Percentage of Thinning (%)		
		Natural	Nitrile	Silicon
1	0	7.5	8.5	8
2	2.5	14.5	14.5	13.5
3	7.5	11.5	11.5	10.5
4	13	5.5	6	4.5
5	18.5	2	3.5	2.5
6	24.5	0	0.5	-0.5
7	32	-6	-5.5	-6.5

Thickness Variation in Hemispherical Cup

Deghani and Salimi [20]carried out measurement of thickness variation to predict the formability of material. In present work also, the percentage of thinning is used as a parameter to measure formability.

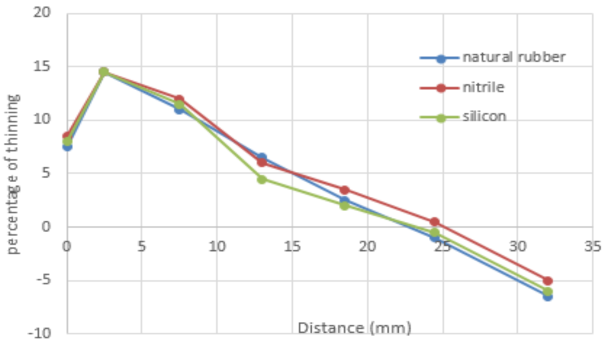

Figure 10: Comparison of Percentage of Thinning for Three Rubber in X-Section

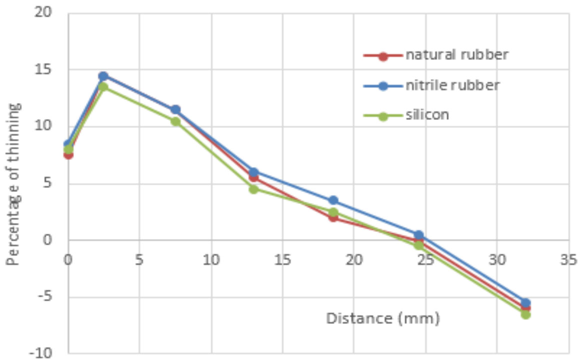

Figure 11: Comparison of Percentage of Thinning for Three Rubber in Y-Section

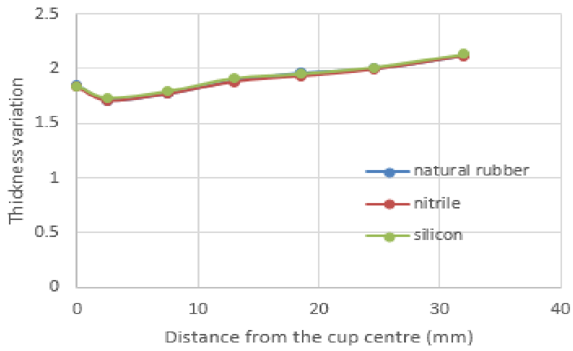

Figure 12: Distance from the Cup Centre (mm)

It was assumed that as rubbers have different stress strain behavior, it may affect the formability of component. However, the obtained experimental results are new of its kind. As expected, the region of more thinning is nearest to the cup center. Figure 10 & Figure 11 show the comparison of the percentage of thinning between three rubbers (natural, silicon and nitrile rubbers). It can be observed that the percentage thinning of hemispherical cup decreases as going away from the cup center in three rubbers. However, percentage thinning is almost equal at any cross-sectionof cup in all three cases. It can be inferred that as long as developedstrain values during forming are within the limit of max permissible strain value, the effect of any rubber on formability would remain same.

CONCLUSIONS

In this paper, the formability study of natural rubber, silicon rubber and nitrile rubber for drawing of hemispherical cup in rubber assisted forming processhas been studied. Rubbers are manufactured to obtain hardness in the range of 55-60 A by selecting proper mixture of constituents. Forming experiments are carried out on pure copper sheet metal blank.

The formability study has been carried out in terms of percentage thinning for each rubber separately. The percentage thinning of the hemispherical cup for three rubbers is compared. From the comparison, it is observedthat percentage thinning in all three cases are almost same. It can be inferred that as long as the developed stresses and strains in rubber are within the limits of that particular rubber, the effect on formability will remain same.

REFERENCES

1. *Maziar Rmezani, and Zaidi Mohd Ripin., "Rubber-pad forming processes Technology and applications,," in Chapter-1.3, Introduction to sheet metal forming processes, Flexible-die forming, new delhi, Woodhead publishing, 2012., p. 5.*
2. *E. Battikha and D.J. Browne,, "Experimental rubber-pad forming of aluminum sheet, Proc. 9th Conf.," Irish Manufacturing Committee,, no. University College Dublin, pp. 479-487., (1992).*
3. *L. Belhassen, S.Koubaa, M.Wali and F.Dammak., " Numerical prediction of spring-back and ductile damage in rubber-pad forming process of aluminum sheet metal.," International journal of Mechanical sciences 117,pp. 218-226., (2006).*
4. *Thiruvarudchelvan S., " Elastomers in metal forming," : A review. J Mater Process Technol,pp. 39:55-82., 199.*
5. *BrowneDJ,BattikhaE, " Optimization of aluminumsheetformingusinga flexibledie,".JMateProcessTechnol, p. 55:218–23.,.1995;.*
6. *Dirikolu MH, Akdemir E.;, "Computeraidedmodellingof flexible forming process," JMaterProcessTechnol, p. 148:376–81.,.2004.*
7. *Thiruvarudchelvan S.,, "Free forming of near hemispherical shells using a urethane pad,," Journal of Materials Proc. Technology,,pp. 18:5-15., 1989.*

8. *M. Geiger, A. Sprenger,,, "controlled bending of aluminum extrusions, Ann. CIRP 47–1," p. 197–202, (1998).*

9. *N.Alberti, A. Forcellesez, L. Fratini and F. Gabrielliz, " Sheet Metal Forming of Titanium Blanks Using Flexible Media,",CIRP Annals - Manufacturing Technology; 47 (1) pp, p. 217–220., (1998),..*

10. *Rhim SH, Son YK, Oh SI,, "Punching of ultra-small size hole array.," CIRP Ann-Manuf Technol, p. 54(1):261–4., (2005).*

11. *Xiao Wang, Yaoqiang Yuan, Zongbao Shen, Chunxing Gu, Qiang Zhang, and Huixia Liu),,, " Investigation of the forming pressure and formability of metal foil by laser-driven multi-layered flyer," Journal ofOptics & Laser Technology 58 pp, p..151–160, (2014.*

12. *Browne David j, Battikha Emil, "Optimisation of Aluminum sheet forming using a flexible die.," J mater Process Technol., pp. 218-23, 1998.*

13. *Deshpande, Neela, et al. "Experimental investigation on strength characteristics of concrete using tyre rubber as aggregates in concrete." International Journal of Applied Engineering Research and Development 4.2 (2014): 97-108.*

14. *M.J.R. Loadman. Analysis of Rubbers and Rubber like Polymers, "Analysis of Rubbers and Rubber like Polymers," in Chapter-1, Introduction-The Nature of Materials, KluwerAcademicPublishers, 1998.*

15. *"Polyisoprene". Encyclopædia Britannica. Encyclopædia Britannica Online. Encyclopædia Britannica Inc. http://www.britannica.com/science/polyisoprene," [Online].*

16. *Dey, S. A. R. M. I. S. H. T. A., P. B. Mazumder, and S. B. Paul. "Effect of copper on growth and chlorophyll content in tea plants (Camellia sinensis (l.) o. kuntze)." Int J Res Applied Natural Social Sci 2.5 (2014): 223-230.*

17. *Andrew Ciesielski. An introduction of Rubber Technology.*

18. *ASTM D412, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension..*

19. *Sala G,, "A numerical and experimental approach to optimise sheet stamping technologies," {part II } aluminium alloys rubber-forming, Journal of Material and Design (22),,pp. 299-315., (2001),.*

20. *ASTM E8/M, "Standard Test Methods for Tension Testing of Metallic Materials".*

21. *"Abaqus Manual Version 6.8. SIMULIA,," 2008.*

22. *FarshidDehghani, Mahmoud Salimi., "Analytical and experimental analysis of the formability of copper-stainless steel 304L clad metal sheets in deep drawing.," Int J AdvManufTechnol, pp. 82:163-177., 2016*