Deep drawing of 304 L Steel Sheet using Vegetable oils as Forming Lubricants

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ABSTRACT

The study involves the evaluation of deep drawing process using two non edible oils, Pongam (*Pongammia pinnata*) and Jatropha (*Jatropha carcass*) as metal forming lubricants. Experiments are conducted on 304L steel sheets under the raw and modified oils with suitable punch and die on a hydraulic press of 200 ton capacity. The punch load, draw-in-length and wall thickness distribution for deep drawn cups are observed. The drawn cups are scanned using laser scanning technique and 3D models are generated using modeling package. The wall thickness profiles of cups at different sections (or height) are measured using CAD package. Among the two raw oils, the drawn cups under Jatropha oil, have uniform wall thickness profile compared to Pongam oil. Uneven flow of material and cup rupturing is observed under methyl esters of Pongam and Jatropha oil lubricated conditions. However, the results are observed under epoxidised Jatropha oil with uniform metal flow and wall thicknesses compared to mineral and other versions of vegetable oils.

Keywords : Forming, *Pongammia pinnata*, *Jatropha Curcass*, Lubricant

1 INTRODUCTION

Deep drawing is the process by which sheet metal is forced to flow between the surfaces of a punch and die. A flat sheet is formed into cylindrical, conical or box shaped part [1]. It is one of the most widely used processes in metal working industry with high rate of production [2]. Pure radial drawing between die and blank holder, bending and sliding over the die profile, stretching between die and punch, bending and sliding over the punch profile radius and stretching and sliding over the punch head take place while drawing a cup [3]. The most important factor deciding on the success of deep drawing operation is initiating the metal flow. Deep drawing besides its importance as a forming process it also serves as a basic test for sheet metal formability.

In general, the formability of a blank depends on blank holder force, lubrication, punch corner radius, die corner radius, clearance (Fig.1), speed of punch, limiting drawing ratio and so on [4,]. Material properties like strain hardening and anisotropy also affect the deep drawing process. Of all these parameters, the blank holder force and friction influences strain distribution [5] in the sheet, play a major role on the flow characteristics of the blank [6]. Nevertheless, the role of lubricant is vital in initiating the metal flow, which dictates the quality of the component. Also, the presence of an effective lubricant film between contact surfaces in deep drawing process increases the drawability, reduces tool wear, and improves the quality of product [7]. During the process, different lubrication condition exists. It is from hydrodynamic lubrication in the blank holder [8], [9], [10] to boundary lubrication at the drawing radius.

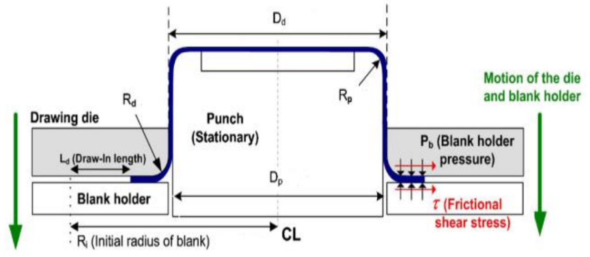

Fig.1 Schematic representation of deep drawing operation [11]

The quality of the drawn cup is decided by the wall thickness profile and the surface roughness. Uneven distribution or flow of material generates thicker and thinner walls and the latter leads to rupturing of the cup [11]. Proper lubrication and blank holding force between the blank and die are the critical parameters to obtain uniform thickness profile of the cup. Deep drawing/stamping operation has many applications in Automotive, Marine and Aerospace industries. Currently, in industry, petroleum based lubricating oils are used. With the introduction of environmental legislation series, the scope of increasing the use of vegetable based lubes has increased in manufacturing sector [12].

Vegetable oils consist of primarily of triglycerides, which are glycerol molecules with three long chain fatty acids attached at the hydroxyl groups via ester linkages [13]. It is reported that triglyceride structure provides desirable qualities for boundary lubrication due to their long and polar fatty acid chains. It provides high strength lubricant films that interact strongly with metallic surfaces, reducing both friction and wear [14]. However, the two performance issues, low oxidative stability and poor temperature properties hinder the use of vegetable oil as lubricant for industrial applications. This problem is addressed by structural modification of oil. The transesterification and epoxidation are the two such methods to improve stability of the oil. The performance of Sunflower, Corn, Soybean and Olive oils are evaluated as forming lubricants on steel sheets under stamping operation [15]. Lower dynamic friction values are reported during the experiments under these oils compared to mineral oil. A study [16] revealed that the interfacial friction characteristics under Canola oil and boric acid powder (5 %wt.) lubrication, was dropped by 44 percent compared to a transmission fluid during deep drawing operation. Further, the combination (R_a = 0.58) provided substantially better separation between the surfaces. Linseed oil is used to lubricate Aluminum sheets for stamping operation [17]. High friction and adhesive wear is reported under this oil, which could be overcome by increasing the oil thickness. A modified rapeseed oil with a Zirconia carbide coated punch and die show lower punch force and low tool wear [18].

The two vegetable oils, Pongam and Jatropha, are non-edible and plentifully available in Indian scenario. For the present study, formulated Pongam and Jatropha oils are chosen as forming lubes for deep drawing of Steel sheets because of their higher thermal and oxidative stability and favourable fatty acid composition (Table1). High thermal stability of oil provides wide range of operation. However, oxidative stability is considered for the consistent formation of oil layer at operating temperature for the whole life of the oil.

The alloy 304 L stainless steel used for the present investigation, is a variation of the 18% Chromium – 8% Nickel Austenitic alloy, the most familiar and frequently used alloy in the stainless steel family. This alloy may be considered for a wide variety of applications and exhibits good corrosion resistance, ease of fabrication, excellent formability and high strength with low weight [19].

2 METHODOLOGY

The two vegetable raw oils, Pongam (PR) and Jatropha (JR) are chemically modified. Transesterification process is followed to produce Pongam oil methyl ester (PME) and Jatropha oil methyl esters (JME) under carboxyl group modification method. Epoxidation process is followed to produce Jatropha raw epoxidised oil (JREP) under fatty acid chain modification method. The physico-chemical properties of raw and modified oils such as viscosity, viscosity index, pour point, iodine values and others are tested as per the ASTM standards (Table 2). The extent of modification of oils is observed through the changes in properties of the oils. Thermal stability studies (Table 3) are conducted for both the versions of oils using Thermo gravimetric analyzer (TGA). A sample TGA curve for Pongam raw oil is depicted in Fig.2.

TABLE 1
FATTY ACID COMPOSITION OF PONGAM AND JATROPHA OIL

Compound Name	Pongama raw oil (%)	Jotrapha raw oil (%)
Lauric acid (C 20:0)	00.94	00.30
Myristic acid (C14:0)	-	00.09
Palmitic acid (C16:0)	11.00	15.50
Stearic acid (C 18:0)	05.94	06.00
Arachidic acid(C20:4)	01.40	00.22
Palmitoleic acid(C16:1)	-	01.10
Oleic acid (C 18:1)	50.40	38.20
Linoleic acid (C18:2)	20.60	38.30
Linolenic acid (C18:3)	03.93	00.30

Experiments are conducted on 304 L Steel sheets under the raw and modified oils with suitable punch and die on a hydraulic press of 250 ton capacity, double acting with maximum stroke of 500 mm (Fig.3). The process parameters like punch load, punch travel and blank holding force are measured. The wall thickness profile, an indication of uniform friction between drawing surfaces and draw-in-length, the diameter of blank before and after the draw are studied to asses the behaviour of lubricant.

The thickness profiles of deep drawn cups are observed with raw and modified oils as lubricants. The drawn cups are scanned using laser scanning and 3D models are generated using modeling package. The thickness profiles of cups at different sections (or heights) are measured using a CAD package.

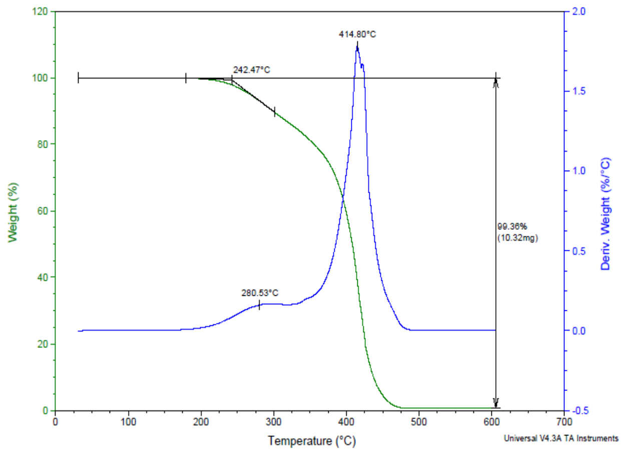

Fig.2. TGA curve for Pongam oil

TABLE 2

PHYSICO-CHEMICAL PROPERTIES OF RAW AND MODIFIED OILS

Properties	PR	PME	JR	JREP	JME	MR
Kinematic viscosity @ 40^0C (cSt)	53.65	17.07	35.36	63.65	09.51	32.20
Kinematic viscosity @ 100^0C (cSt)	13.90	09.26	11.70	19.97	03.65	11.70
Viscosity index	163.58	202.95	177.23	178.10	256.26	180.6
Total acid value (mg KOH g^{-1})	00.73	01.06	01.91	01.28	02.07	01.86
Flash point (0^0C)	268.00	168.00	284.00	>350	170.00	190.0
Pour point (0^0C)	02.00	-04.00	-5.00	-06.00	-05.00	-08.0
Iodine value (mg l g^{-1})	80.44	75.59	101.44	20.00	94.41	07.52

TABLE 3

ONSET TEMPERATURE OF THERMAL DEGRADATION OF RAW AND MODIFIED OILS

Testing oil	Onset temperature (^{o}C)
Mineral oil	257.25
Pongam raw	242.47
Pongam methly ester	146.00
Jatropha raw	220.07
Epoxidised Jatropha raw	234.08
Jatropha methly ester	108.00
Epoxidised Jatropha methly ester	215.19

Fig.3 Experimental setup

3 RESULTS AND DISCUSSION

3.1 Thermal stability

TGA curve represent the percentage weight loss of the oil against temperature. The weight of the oil remains constat till the decomposition starts. The test is carreied out under Nitrogen environment. The thermal stability is determined from the onset temperature of decomposition [20]. The onset temperature of thermal decomposition for both vegetable and mineral oils are studied. Results revealed that, the onset temperature of raw vegetable oils and their esters are lower compared to mineral oil. Further, the methyl esters of two vegetable oils, showed lower onset temperature comapred to their raw versions.

3.2 Punch Load

The load required to draw the cups under different modes of lubrication is depicted in Fig.4. Lower the punch load, better is the lubrication between the drawing surfaces. It is noticed that, in the initial stages of drawing, about 77 % and 60 % of higher loads are encountered under PR and PME modes respectively compared to mineral oil.Also, JR and JME showed 30 % higher loads when compared to petroleum based oil. This may be due to transfer of accumulated or compressed material, which may be generating higher friction between blank and die. However, the load requirement under JREP is almost similar to that of loads under mineral oil.

As the punch reaches mid of the total stroke, still higher loads are obesrved under PR, PME, JR and JME compared to petroleum oil as there are bulky wall thicknesses encountered by the punch

At around 80 % of stroke, the trend is continued for PR, PME, JR and JME oils. However, mineral and epoxidised Jatropha oils have similar load conditions.

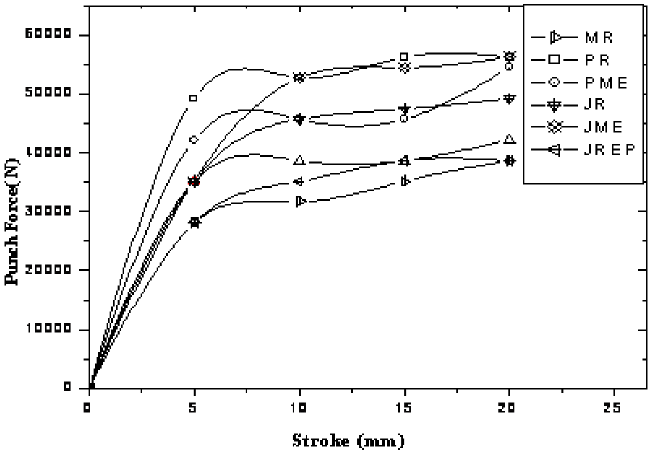

Fig.4 Variation of Punch load with punch travel

3.3 Draw-in-length

The draw-in-lengths indirectly indicate the effect of co-efficient of friction between blank and die. As the length increases, lower friction is encountered during the operation. Fig. 5 shows the draw-in-lengths under different lubricated conditions. It is noticed that about 1.39 and 1.26 times more metal flow is achieved under JR and JREP mode of lubrication respectively compared to mineral oil. However, under PR and PME mode, only 1.17 times more material flown in. Consequently, under all vegetable versions of lubricants, better flow is observed compared to petroleum oil. Particularly, JR and JMEP versions made more material to flow during the operation.

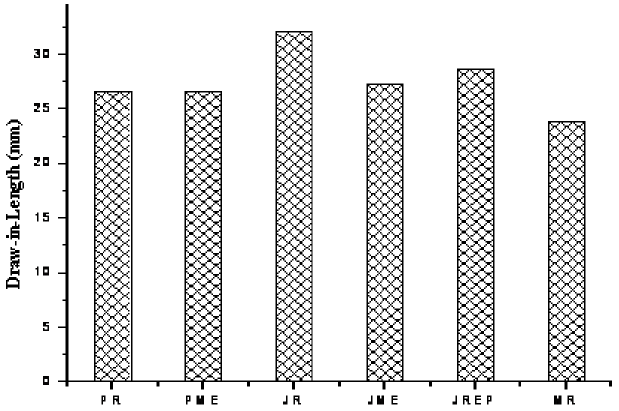

Fig.5 Variation of Draw-in-length for different lubricants

3.4 Thickness profile

The 3D image of the deep drawn cup is shown in Fig.6. The wall thickness distribution under various lubricants is shown from Fig.7 through Fig.12. Fig. 7 represents the cross section of cup drawn with Pongam raw oil. Thinning followed by a rupture is observed at the bottom of cup under this oil. Under Pongam methyl ester (Fig.8), even distribution of material is noticed on one side and rupture on other side. Uniform wall thickness profile from flange to bottom of cup is noticed under Jatropha raw and its epoxidised version oils (Figs.9 and10). Nevertheless, more thinning is observed under Jatropha methyl ester (Fig.11) from flange to bottom of cup followed by a rupture. The profile under mineral oil (Fig 12) shows trends similar to profile fashion under Pongam methyl ester.

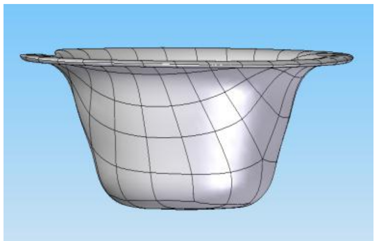

Fig 6. 3D image of drawn cup

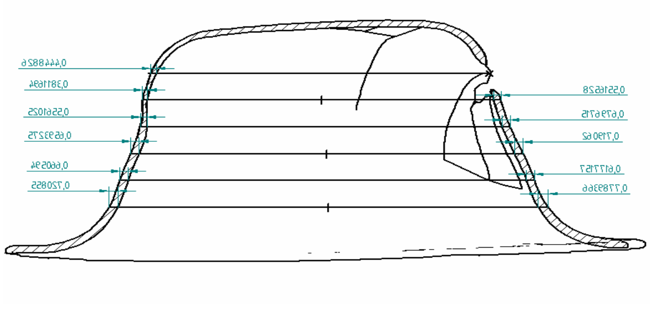

Fig.7 Pongam raw

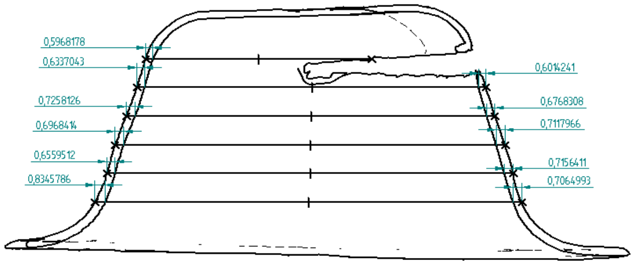

Fig.8 Pongam methyl ester

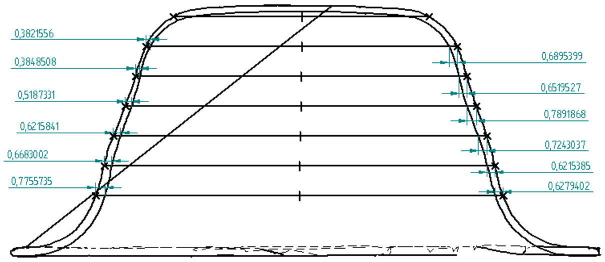

Fig.9 Jatropha raw

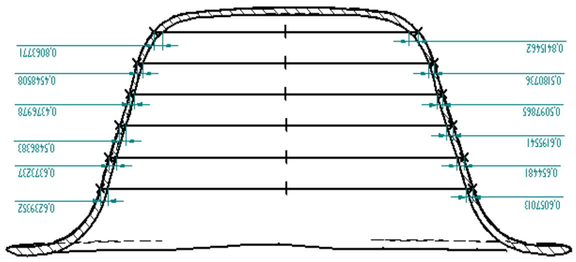

Fig.10 Epoxidised Jatropha raw

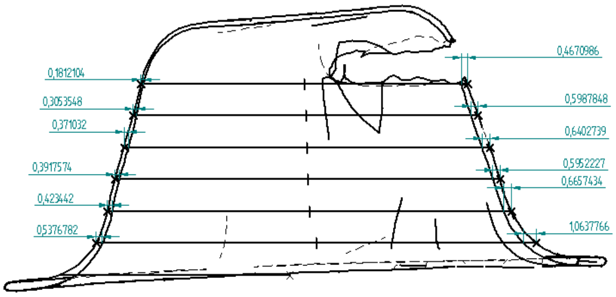

Fig.11 Jatropha methyl ester

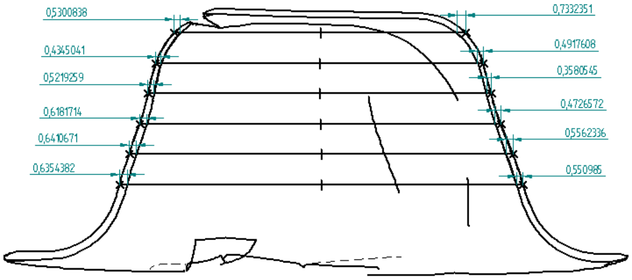

Fig.12 Mineral oil

Uniform wall thickness proile from flange to botttom of the cup, indicates better lubrication between the surfaces of drawing. The variation of cup wall thickness with punch travel under different lubricants are shown in Fig.14.The results show that, in the initial stages of drawing under Pongam, epoxidised Jatropha and Mineral oils, there is no much variation of wall thicknesses. As the drawing progresses and when the punch reaches around 50 % of the total stroke, side wall thicknesses of cupss drawn with PR, JR and JREP oils showed different thickness values compared to mineral (around 45 % higher under PR & JR oils and around 23 % higher under JREP compared to petroleum based oil).This may be due to higher viscosity values of vegetable oils compare to mineral oil.

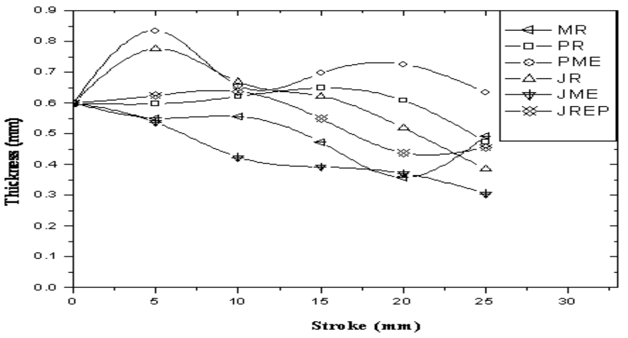

Fig.14. Variation of wall thickness with punch travel for different lubricants

except under JR and JREP oil modes, cups drawn under all other oils are encountered with necking followed by a rupture. Further, large variation in profile thickness as compared to mineral oil is noticed under methyl esters of Pongam and Jatropha oils during all stages of draw.

4 CONCLUSION

A better thermal stability is observed for raw and epoxidised Jatropha oils compared to their ester versions. Lower punch loads are encountered under mineral oil and epoxidised Jatropha oil compared to other vegetable oils. Better material flow/draw-in-length is noticed under vegetable oil mode of lubrication, particularly under Jatropha and its epoxidised mode where as under mineral oil, early rupture is observed. Uniform thickness profiles are observed with Jatropha and its epoxidised version of lubrication.

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