EVALUATION OF SOME NIGERIAN VEGETABLE OILS AS LUBRICANTS IN DEEP DRAWING OPERATIONS

'BY

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A thesis submitted to the Postgraduate School, Ahmadu Bello University, Zaria, in partial fulfilment of the requirements for the award of the degree of Master of Science in Production Engineering.

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THESIS APPROVAL

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DEDICATION

This work is dedicated to the affectionate memory of my late Grandmother, Madam Hannah Ajike-Babaagba

AND TO

Almighty God for His guidance and protection in all my life endeavours.

DECLARATION

I hereby declare that this work is wholly the authors and has not been part of any presentation for any other qualification.

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ABSTRACT

The Swift simulative formability "test was employed. in this research work for the assessment of some locally-produced vegetable oils viz: Palm oil, Palmkernel oil, Cottonseed oil and Groundnut oil as lubricants in deep drawing operations.

The assessment of these local oils was based on Swift test parameters; the limiting drawing ratio and the maximum drawing load. The higher the limiting drawing ratio, the better the lubricant. Also, the lower the maximum drawing load, the better the lubricant.

Two cold rolled low carbon steels namely Galvanized Mild Steel and Plain Carbon Steel were deep drawn. The effect of material thickness variation on the performance of each of the lubricating oils was investigated in relation to a particular tool geometry. The total geometry employed for each set of lubrication condition was varied using punches of different profile radius.

The Swift tast parameters obtained under each set of lubrication condition of these local oils were then compared with those obtained using the widely used high grade industrial lubricant E.P. 140 oil, and Paraffin oil as a lower standard for comparison.

The newly developed Kaftanoglu f»rmability test in deep drawing operation for the estimation of the limiting

drawing ratio was carried out for each of the lubrication condition8 under a particular tool geometry* for comparison with the Swift test results.

Analysis of the Kaftanoglu deep drawing tests confirmed the consistency of the Swift test results.

The Results •btained from the Swift formability deep drawing test showed that Cottonseed oil and Palm oil are the host lubricating oils, giving better performance than E.P. H4O oil. Groundnut oil and Palmkernel oil also gave favourable results compared with E.P. 140 oil.

Based on the results of the chemical analysis by Ajala (1981), the local oils were found to he relatively stable and less susceptible to deterioration. They are easy to decrease in an alkaline medium, and because fof their low viscosities-, they are easier to apply. The local oils are easy to degrease in an alkaline medium as indicated by their saponification values. The local oils' potential to compete with the imported deep drawing lubricants will save the country some foreign exchange earnings.

On the foregoing-, it is concluded that the use of these local oils as lubricants in deep drawing operation is justified. It is therefore recommended that;

(a) Part-blends with mineral oils should be encouraged, as a short-term measure, before the country can be self-sufficient in the production of these local oils.

(b) Chemical additives such as chlorine, sulphur and phosphorus, to these local oils, could he used to enhance the viscosity of these local oils if they are to be used for the severest deep drawing operations. However, Cognisance need be taken of the reaction of these additives with the metal surfaces concerned,

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ABBREVIATIONS

LDR	Limiting Drawing Ratio
E.P. oil	Extreme Pressure oil
D_b	Blank Diameter
Dcr	Limiting Blanksize
h	Bulge Depth
M	Empirical constant
Exp	Exponential
N	Empirical constant
d	Punch Diameter
Db1, Db2, Db3	Blank Diameter in tests 1.2 and 3 respectively
h_1, h_2, h_3	Bulge Depth in tests 1, 2 and 3 respectively
μ	Coefficient of Friction
μ_1	between blankholder and workpiece
μ_2	Coefficient of Friction between Die and Workpiece
σ_1	Principal Radial Stress
σ_2	Principal Circumferential Stress
σ_3	Principal Thickness Stress
$\sigma_{1,i}$	Current principal radial stress of element in the material

r	Current radius of blank
r_i, r_{i+1}	Current radii of elements in the material
dr	radius increment
σ_1	increment of principal radial stress
t	Cup Wall thickness
R	Position of element before drawing commences
R_o	Blank outside radius
$d\phi$	angle of segment of cup
r_c	Punch radius
r_b	die throat radius

CHAPTER 1

INTRODUCTION

1.1 General

Sheet metal forming process occupies a significant position in the metal forming techniques. Like many other modern manufacturing processes, sheet metal forming is based on high capital investment (in presses and dies) and low unit cost through the large number of the same article produced. It is a process whereby sheet metal is formed into a variety of shapes by deformation between a pair of matched dies. The wide range of application of this manufacturing process is due to its immense versatility and the relative strength of its product as well as the speed of its operation. Thus it is hardly possible to live in an industrialized society without being in constant contact with one sheet metal product or another from motor vehicles to typewriters, refrigerators, television sets, radios, cooking utensils, cans and so forth, all of which consist either entirely or partly of sheet metal products.

It is well known that sheet metal forming operations are resolveable into two principal kinds of deformation; deep drawing and stretching, but it is only in recent years that attempts have been made to define these aspects clearly and quantitatively. In stretch-forming, a part is made from a blank by drawing where the flange of the blank is constrained whereas in deep-drawing the flange of the blank is allowed to draw in. However, whichever

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process is adopted will depend upon many factors, from economics to the final service application.

1.2 Mechanics of Deep Drawing Operation

Deep drawing is a sheet metal forming operation whereby a flat blank is formed into a cup or shell-like part by forcing a punch against the centre portion of a blank that rests on the die ring. The deep drawing operation can be divided into three important regions as shown in figure (1.1).

Radial Drawing Region

This is a region over the die where the sheet metal is in contact with the die and blankholder. Here the radial stress is tensile while the circumferential stress is compressive. During deformation, because of this circumferential compressive stress in the flange of the blank, the material thickness increases non-uniformly and the material workhardens. This non-uniformity in material thickness in this region is a defect known in sheet metal forming as wrinkling which can be supressed by a suitable application of a blankholder. In this region, the friction between the workpiece and die, and also between the workpiece and blankholder is significant as it contributes to the rapid increase in drawing load during the early stages of deep drawing operation. However, as drawing progresses, the area of contact between the work and the die continually decreases while the frictional force also decreases.

Effective lubrication is therefore necessary in this region to reduce the load required for the deep drawing operation.

Between the Punch and Die

In this region the material is subjected to a biaxial tensile stress as it undergoes bending and sliding over the die profile radius. The die profile radius is a critical region where friction exists. If metal 'pick-up' should occur, it will often develop towards the end of the die profile radius where lubricant is squeezed out to the greatest extent. Therefore selection of a suitable lubricant which is viscous enough with good adherence property should be sought to reduce the wear.

Stretching Over the Punch

The material in this region is first in contact with the punch. As drawing progresses, the material is bent and wrapped around the punch profile radius. The material is then stretched and slides over the punch profile radius. The total amount of stretching depends on the punch travel and also upon the punch profile radius. High friction is highly concentrated in this region, and because of the nature of the stresses developed, this area of the shell bottom becomes the thinnest portion of the cup. This thinning is often called the 'neck' which is usually the first place to fracture in an unsatisfactory drawing operation. The application of a suitable lubricant is important in this region as it helps to distribute the stresses more evenly within the region thereby increasing the depth of draw at which fracture can occur.

1.3 Stress and Strain Distribution in Deep Drawing Operation

In deep drawing operation, the state of stresses and strains in the various parts of the formed cup varies from one point to another due to changes in contour of the forming tools as well as changes in the process variables. There are three main zones of deformation namely the flange, the die profile radius, and the punch profile radius as illustrated in figure (1.1).

Radial Drawing in the Flange

The flange of the material workpiece is first in contact with the die. During deformation, elements in the flange are subjected to radial tensile stresses and attendant circumferential compressive stresses. The flange rim thickness increases during radial drawing whereas elements within the flange thicken to amounts somewhat less because of the radial tensile stress. Because of this thickness variation, Swift and Chung (1951) naturally assumed that the whole of the blankholder force is concentrated on an infinitely narrow band of material around the rim and that deformation of the flange takes place under a state of plane stress. The state of stress is shown in figure (1.2). The equilibrium of forces acting along the radial direction gives

$$d\sigma_1 = \frac{(\sigma_2 - \sigma_1)}{r}dr + \frac{2(\mu_1 + \mu_2)\sigma_3}{t}dr$$

$$\text{or} \quad \sigma_{i,i+1} = \sigma_{1,i} + \int_{ri}^{ri+1} (\sigma_2 - \sigma_1)dr + \int_{ri}^{ri+1} \frac{2(\mu_{i1} + \mu_2)\sigma_3}{t}dr$$

The stresses and strains in the material during the drawing process can be determined by the application of the plasticity theories.

It is therefore desirable to apply suitable lubricant between the workpiece/tool interface to minimize friction, thereby reducing the radial stress required to overcome the blank-holding pressure.

Drawing at the Die Radius:

As the material of the flange is drawn into the die throat, it undergoes bending and sliding under tension over the die profile radius. The condition of drawing in this region is quite different from that of flange drawing in that the blankholding force is no longer significant. In this region, high friction exists between the workpiece and the die surface and even in the presence of a lubricant, the lubricant has great tendency to squeez out thereby allowing for metal-to-metal contact. A drawing stress must therefore be introduced to overcome the effect of die profile friction. This is one area where effective lubrication and optimization of tool surface finish can be effective in reducing the total drawing load. The state of stress is illustrated in figure (1.3).

Stretching Over the punch Profile Radius:

At the start of the punch movement, the material in the central zone must necessarily conform to the punch profile because of the action of the radial drawing stress; consequently, a state of biaxial tension exists throughout

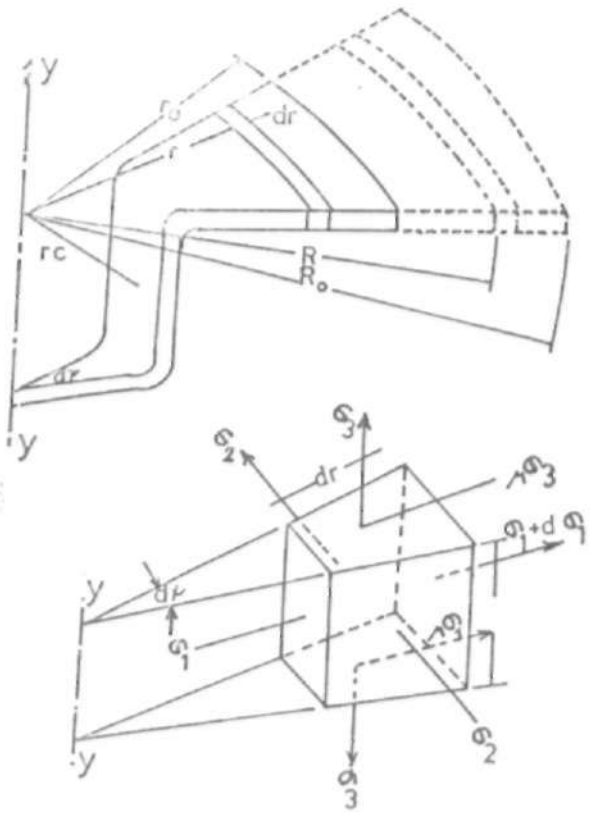


Fig1·2Radial drawing stresses

this zone. The metal in contact with the flat base of the punch thins uniformly while the metal at the punch radius bends under the influence of this biaxial stress system causing local thinning. The degree of stretching, and hence the subsequent thinning over the nose, depends, to a large extent upon the conditions of friction between punch and blank. From a typical formed cup, it is known that two zones of local thinning can occur. The thinning associated with the punch profile radius is normally refered to as the primary 'neck' and the thinning caused by the bending under high tension, of relatively undeformed material over the die radius is refered to as the secondary 'neck'. Instability followed by fracture can develop in either of the locally thin zones if an attempt is made to draw an oversize blank. The state of stress in this region is illustrated in figure (1.4).

Suitable application of a lubricant with high viscosity that would resist squeezing out of the workpiece/tool interface is desirable to assist in distributing evenly the stresses in the material so as to prevent undue local thinning that could lead to premature failure.

1.4 Material selection for Deep Drawing Operations

1.4.1 Selection of Low Carbon Steel Sheets

Steel sheets can be produced in a variety of types, grades, qualities and mechanical properties depending on end part requirements. At the present time, most steel for the

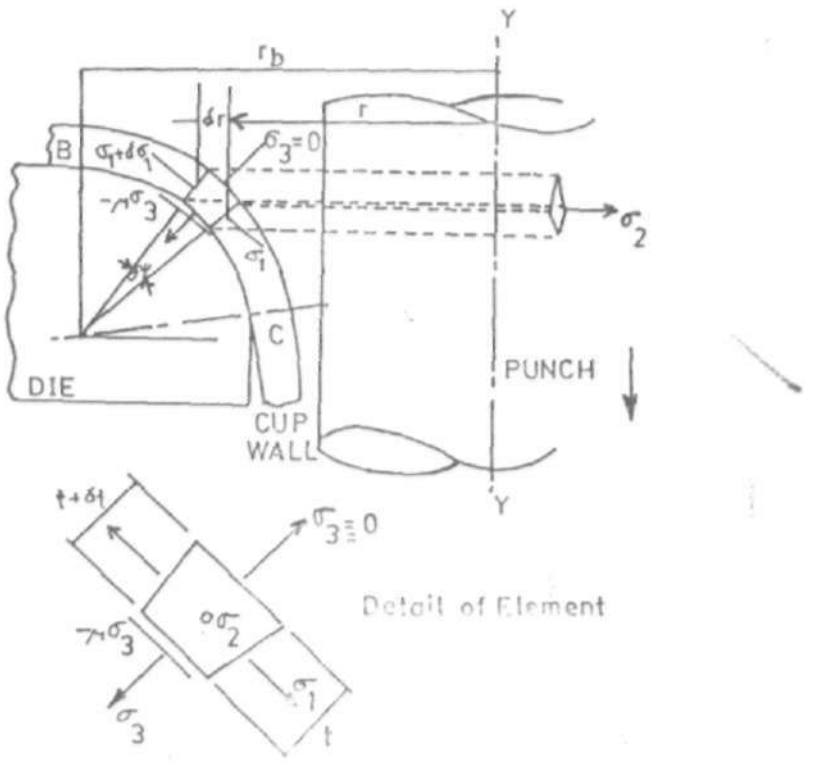


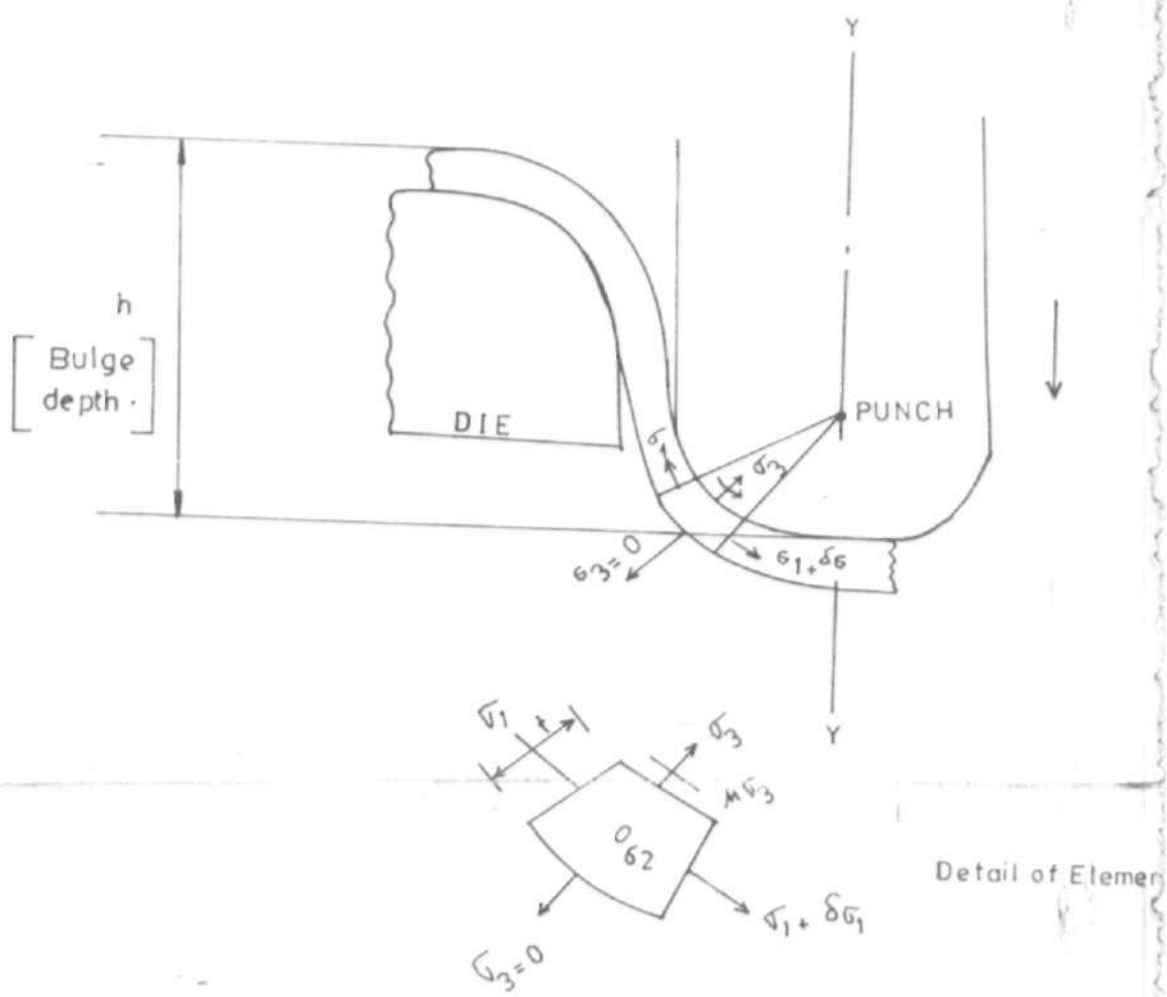
Fig 1·3 Stresses Due to Die profile friction

production of sheets is made by the basic oxygen, or open hearth or electric furnace process. The TYPE of steel refers to the deoxidation practice used in making the steel, such as rimmed, capped or special killed Steels.

Rimmed steel is formed when steel is poured into an ingot mould without addition of de-oxidants. Rimmed steels possess surfaces free of defects, and have softer edges with harder centres. They are good for moderate drawing operations.

Capped steel is a modification of rimmed steel where the rimming action is halted after a short time by the use of a metal plug in the ingot top. The rim is thinner and a more uniform segregation characteristic is obtained than rimmed steel. It has high hardness value and only suitable for mild deformation.

Killed steel can be formed by addition of strong de-oxidant to tie up dissolved oxygen in the steel ingot mould. The most commonly used de-oxidant is aluminium. Apart from the use of de-oxidant and other additives, killed steel can also be produced by vacuum degassification process. In this case, the steel melt is contained in an air-tight tank with an outlet connected to a vacuum pump. Evacuation of the space within the tank, as a result of operation of the vacuum pump, causes gas inclusions to escape from the steel, with an accompanying boiling action. The killed steel is the best choice for formability by virtue of its superior mechanical properties, its uniformity in terms of composition as well as its non-aging characteristics.



Detail of Elemen

Fig. 1·4. Stresses due to punch profile friction.

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The GRADE of steel refers to chemical composition of the steel, while the QUALITY refers to properties imparted to the product by manufacturing operations such as strength hardness, dimensional accuracy etc.

In deep drawing operations, the principal factors affecting the selection of grade and quality of low carbon steels are severity of draw, thickness of sheet, shape of the part, flange requirements, ironing requirements, speed of drawing operations, grainsize of workpiece, desired surface finish, availability of material, and cost.

There are three principal classes of available low carbon steels for deep drawing operations. They are commercial quality, drawing quality, and aluminium killed quality. All the three classes are available in the cold rolled and hot rolled conditions. However, by size classification according to recommendations in ASTM A568 and AISI Product Manual, hot rolled sheets are obtainable only within the size range of 1.1405 to 12.7000mm whereas cold rolled products are of the size ranging from 0.3607 to 12.7000mm.

Commercial Quality:

This is ordinarily produced from rimmed or capped steel with a maximum carbon content of 0.15 percent. The minimum requirement being that the steel will bend flat on itself in any direction. It is used for mild deep drawing operations.

Drawing Quality:

This is ordinarily produced from rimmed steel with a carbon maximum of 0.06 percent. By the use of specially produced or selected steels in combination with special processing, drawing quality is furnished with better and more uniform drawing properties than commercial quality. It is used for more severe drawing applications.

Special Killed Drawing Quality:

This is produced from aluminium killed steel. Based on its superior mechanical properties and good uniformity in terms of composition, and its non-aging characteristics, it is therefore used to make parts involving the most difficult draws or where a minimum of aging or non-aging characteristics are required.

For hot rolled sheets, the mill oxide on the surface is detrimental for deep drawing, because it impairs the flow of metal and increases tool wear. Special surface can be obtained for any of the three qualities by method of pickling. In addition, the prickled surfaces of hot rolled steels are oiled thereby increasing its final cast.

The primary consideration in selection between hot and cold rolled steel for deep drawing is availability of the material sheet thickness. Steel sheets falling within the range of 1.1405mm and below are only obtainable in the cold rolled condition. The cold rolled grade provides the advantage of greater uniformity of properties throughout

shipment, a result of closer process control of annealing temperatures, compared with finishing temperature in hot rolling. Another influential factor is that the cold rolled sheet has a more uniform thickness extending to the edges of the sheet. Roll wear on the hot mill sometimes makes close thickness tolerance at the edges difficult to maintain. Therefore, where thickness accuracy and superior surface finish is desired, cold rolled sheet is specified.

The choice between commercial and drawing quality in either the hot or cold rolled sheets depends on the severity of draw. For mild deformation, the commercial quality is generally specified whereas for severe draws, the drawing quality is prefered because with a nominal extra cost, the required drawability is guaranteed.

When drawability requires freedom from aging or if the design specifies severe forming such as flanges, ironing, sharp corner radii, extra cup depth, or lack of symmetry, special killed quality is specified.

1.4.2 Selection of Material for Deep Drawing Dies

The selection of die materials is such that the desired quality and quantity of parts produced will be at minimum tooling cost. Die performance is determined by the amount of wear or galling during production time. This rate of wear increases with increasing thickness of work material, decreasing die profile radius, and increasing quantity of parts produced.

For mild deep drawing of steel sheets, best resistance to wear is obtained from chromium plated aluminium bronze dies, for short-run production. For long-run production, sintered carbide, air-hardening tool steels are used.

For severe drawing operations, alloy cast iron, alloy cast iron with air-hardening tool inserts are used.

1.4.3 Selection of Materials for Deep Drawing Punches

The selection of punch material for deep drawing depends on the size of punch and the drawing pressure required to make the cup. Increase in sheet thickness produces increase in drawing pressure for a fixed punch diameter.

As the resulting punch pressure increases from low to maximum values, the selection of punch material for short-runs changes in the following order: Carburized mild steel, alloy cast iron, water-hardening tool steel, oil-hardening tool steel, and carburized shock-resisting steel.

For long-runs, the selection as pressure increases is as follows: water-hardening tool steel, oil-hardening tool steel, and high carbon high-chromium steel.

1.4.4 Selection of Materials for Deep Drawing Blankholder

In deep drawing operations, the blankholder pressure is applied to surpress wrinkling of the workpiece. Thick

material will wrinkle less than thin stock. As a result, the pressures required to prevent wrinkling are no greater, and may even be less, than those required for thin work. Wear resistance requirements for blankholder material is therefore generally low. For short-runs, unhardened mild steels are used while for long-run production, air-hardening tool steels are used.

1.5 Influence of Friction and Lubrication in Deep Drawing Operations

The margin between success and failure encountered in deep drawing operation is greatly influenced by the friction existing between the workpiece and the tool interface.

Friction is to some extent an undesirable element in deep drawing operation. The higher the friction, the greater the load required to produce a particular deformation. Based on the fact that deformation process under high normal pressures is always accompanied by local temperature development resulting from friction at the workpiece/tool interface, locallized welding which gives rise to 'pick-up' on the tool and the subsequent 'scoring' of the product occurs. This is largely responsible for tool wear and the debris caused by the breakdown of the welds contribute to the abbrasive wear action.

Friction, however, has some beneficial effects in deep drawing operation. To prevent the onset of necking during deformation, there should be high friction on the punch and low friction against the die. While a reduction in die

friction will improve drawability by reducing the drawing load, the presence of high friction on the punch nose tends to improve drawability. The balance between these two opposing effects gives the changes in drawabilities under different frictional conditions.

A fundamental way by which friction is controlled in deep drawing operation is therefore, by applying and maintaining a sufficiently thick film of suitable lubricant at the workpiece/tool interface system so as to prevent intermetallic contact between the sliding surfaces. This, in essence, will reduce wear and frictional forces between the workpiece and the tool, and also provide an overall reduction in deformation load despite the adverse effect of the low friction that will be maintained at the nose of the punch.

In combating the adverse effect of friction in sheet metal forming operation in general and deep drawing operation in particular, a number of lubricants have been developed for use. However, selection of lubricants depends on factors such as the material of the workpiece, material thickness, severity of forming, and tool geometry. Other factors are properties of the lubricating oils such as viscosity, ease of removal, ease of application, stability, odour and toxicity, flash point, pour point, fire point, neutralization number, demulsibility and oxidation resistance.

The Iron and Steel industries are fast growing and the importance of sheet metal forming has motivated the

Federal Government into integrating the flat sheet rolling mill into her existing rolling mills. It is worth mentioning that all lubricants presently used in the country are imported.

A survey of the Nigerian market revealed that there is a number of locally produced vegetable oils having lubricating potentials in forming operations in general and sheet metal forming in particular. Of particular interest in this regard are vegetable oils such as Palm oil, Palm kernel oil, Cottonseed oil, and Groundnut oil. The suitability of each of these oils as a deep drawing lubricant is being investigated in the present research effort. The various local oils are evaluated on the basis of the simulative formability test known as the Swift test (1954). The Swift test evaluation is based on two test parameters; the limiting drawing ratio (LDR) and the maximum drawing load. The value of using this Swift test procedure is that it enables lubricant specification to be stated precisely in respect of the material workpiece, and the material thickness in relation to a particular tool geometry.

In evaluating the performance of these locally produced vegetable oils, two cold rolled low carbon steels namely Galvanized mild steel and Plain carbon steel were deep drawn. The effect of material thickness variation on the behaviour of each of the lubricants was investigated by employing different thicknesses of the materials in

relation to a particular tool geometry. A variation in tool geometry was made possible using punches with different profile radii. Under each set of lubrication conditions, the Swift test parameters were evaluated thus allowing for evaluation of each of the local oils in respect of the material deep drawn, the thickness of the material and also the geometry of the punch used in the deep drawing operation.

To set a standard for comparison, the performance of each of the locally produced oils as lubricant in the deep drawing operation was compared with a widely used high grade industrial lubricant - Extreme Pressure lubricant (E.P. 140 grade), and Paraffin oil as a lower bound/standard were used in accordance with Butler and Pope (1968).

CHAPTER 2

LITERATURE REVIEW

2.1 Drawability Tests

The ability of a material to be deep drawn successfully without fracture is known as drawability. Drawability is expressed as the ratio of the depth of cup formed to the punch diameter. Failure in deep drawing is either by tension resulting in splitting or by compression resulting in buckling or wrinkling. The likelihood of failure in deep drawing operation has been studied by Low (1940) by tensile testing or by simulative formability tests.

In tensile testing in general, the conventionally shaped specimen is pulled to failure in a tensile testing machine, and the load versus extension graph plotted. From the graph, the uniaxial tensile mechanical properties such as elastic modulus, yield strength, tensile strength, elongation, strain ratio, and strain hardening exponents are determined. Attempts have been made by Low (1940) to predict drawability in respect of the limiting drawing ratio from the tensile test results but such tests have failed to incorporate the various process variables encountered in practical deep drawing operations and as such can only provide a sufficient basis for the control and investigation of the metallurgical properties concerned in drawability.

The cup drawing formability test has been used as simulative test, enabling the incorporation of process variables such as speed, strain rate friction, etc., to be studied in a deep drawing operation.

Kaftanoglu (1974) invented a method for estimating the limiting drawing ratio in deep drawing using oversize blanks with standard diameters. The new method attempts to fill the gap between a highly theoretical approach and the experimental or trial and error type of determination of the limiting drawing ratio. He plotted the bulge depth(h) at fracture against initial blank diameters (D_b) of oversize blanks thereby producing a smooth curve whose characteristics he approximated by an exponential relationship of the following type:

$$D_b = M \exp(-Nh) + Dcr$$

where M, N and Dcr (limiting blank diameter) are constants. Computation of the limiting drawing ratio (ratio of the limiting blank diameter to punch diameter) results from his theory were found to compare very favourably with the experimental ones.

2.2 Mechanism of Lubrication

The primary objective of any lubricant, whether liquid or solid, is to separate the sliding surfaces which are represented by the tool and the workpiece. When comparatively thick layer of a liquid lubricant separates the surfaces, the lubrication is of the fluid type. This is a perfect lubrication system and it is seldom experienced in deep drawing operations.

With high pressures and low sliding speeds it is difficult to maintain fluid conditions and the lubricant

layer is reduced to a film of molecular dimensions. The thin film is susceptible to breakdown resulting in metal-to-metal contact between asperities of the two sliding surfaces. With this condition prevailing the metal surfaces can be separated by a lubricant film of only a few molecules thick and lubrication is therefore of the boundary type. In deep drawing operations, this type of lubrication regime is dominant. However, there is evidence to indicate that in deep drawing, both types of lubrication regimes can occur. This was clearly illustrated in the work done by Coupland (1957) on the effects of speed in deep drawing. Irrespective of the lubrication regime there is that tendency for complete breakdown to occur according to Coupland (1978).

2.3 Lubricant Assessment

2.3.1 Simulative Formability Tests

The assessment of lubricants for deep drawing operation has been based on simulative formability tests which combine the effects of material properties and process variables such as tool geometry and friction conditions. The Swift test which is one of the well known simulative formability tests, is used to evaluate the criterion of performance of lubricants in deep drawing operations.

In the context of the Swift test, a circular specimen is drawn through a circular die by a punch of 50mm diameter. A series of blanks, increasing in diameter by 2mm increments are drawn, until a specimen fails. The blank size prior to that of failure is the limiting blank size and the limiting

drawing ratio is given as follows:-

$$\text{Limiting drawing ratio} = \frac{\text{Limiting blank diameter}}{\text{Punch diameter}}$$

The results of the test have been found to be highly dependent upon the lubrication of the specimen. This test has been found to be of use in determining the properties of lubricants and in this case the maximum drawing load or the limiting drawing ratio are used as test parameters.

PERA (1956) also investigated and classified a useful range of lubricants using tools that were of similar size to those used by Swift although the punch radius was 6.35mm. The tests were carried out at practical speeds of 304, 203, and 106mm per second. Both the limiting drawing ratio and maximum drawing load criteria were used but PERA found only a small degree of correlation between the results. This lack of correlation was suspected to be due to interaction between frictional conditions at the flange and punch nose regions. It was analysed that maximum drawing load results are far more sensitive criteria to be adhered to. However a note of caution was introduced, when the use of limiting drawing ratio is contemplated. In addition, the punch should be hot blasted to eliminate frictional changes over the punch.

A test by Gibson (1974) based on the depth to which an oversize blank can be drawn to fracture has been developed for hydrostatic lubrication in radial drawing. A heavy blankholder load was used to make the test more sensitive

to flange lubrication. This test was used for the assessment of conventional lubricants. Since it can be shown that the depth at fracture for a given oversize blank can be related to the limiting drawing ratio, there may be some justification for using this depth to fracture as a rapid sorting test for lubricants.

Wolftowics (1953) introduced a test based on the energy consumed in drawing a 50mm wide strip from between two opposed dies pressed against each side of the strip with known adjustable load. There was no plastic deformation of the strip and it could not therefore be said to simulate pure stretching or drawing. Several lubricants were investigated using this method.

Gibson (1974) used a similar test but the performance was based on the force required to withdraw the strip from between the dies. The results from this test on several lubricants were compared with Swift Test results and the performance of the lubricants on a commercial type pressing. A lack of correlation was observed between the two tests. Lubricants arranged in order of increasing Swift Test drawing load did not show a corresponding trend of increasing friction in the strip draw test. Comparison of the Swift test results with those for a commercial pressing was found to be reasonable. However the Swift test was analysed and considered to give good indication of performance for simple press forming operation. For those involving higher pressures and difficult drawing conditions, correlation of results was difficult.

The major point emerging from various works described above is that no single test can be used to rate lubricants in press working of sheet metal. However, the Swift test is found to be reliable but attempts have to be made to compare results with performance on industrial pressings.

2.3.2 Chemical Analysis

Several attempts have been made to update the knowledge about lubrication in relation to sliding metal surfaces in general. Such efforts were geared towards the analysis of the chemical and physical properties of the lubricating oil involved.

The local oils under the present investigation are fatty oils which consist predominantly of fatty acids in glyceride molecules.

Fatty oils are polar substances having very long carbon chains with one or more chemically active/polar groups at one end. Both the chemical and physical properties of these oils are determined by their fatty acid radicals which may contain some saturated (unreactive) and unsaturated (reactive) acids. The unsaturated fatty acids are the polar groups that adhere strongly to the work metal and tool surfaces, causing the long chain to be oriented at approximately right angles to the metal surfaces. These oriented films of polar substances, which are several molecules thick, minimize metal-to-metal contact and friction thereby reducing wear.

According to Evans (1948), the relative amount of these polar substances in fatty oils has been found to be a measure of degree of unsaturated fatty acids in the oil. Hence the iodine value of an oil which is defined as that weight of iodine that is absorbed by 100 grams of oil, gives a numerical value indicating the amount of reactive or polar radical in the oil.

Clarke (1961) also suggested the lubricating mechanism in dry soap films as having a boundary metal soap layer with polar attachment to a composite layer containing hydrated crystalline structure - the polar attachment being a derivative from the unsaturated fatty acid content of the fatty oil used for the soap manufacturing

Lee (1975) highlighted the role of viscosity on the performance of lubricants during deep drawing operations. He reported that low viscosity lubricants reached a shear state more readily than oils of high viscosity, and are therefore more easily ruptured under high loads resulting into metal-to-metal contact. Highly viscous lubricants do not rupture easily thereby minimizing friction and wear.

Newby (1976) reported the presence of some chemicals such as Sulphur, Phosphorus or Chlorine capable of improving lubricity of many lubricating oils. These elements react chemically with metal surfaces under heat by forming metallic soaps which help to resist metal-to-metal contact even when the oils is in a reduced state. In some cases they help to maintain the adhesion properties on to metal and tool surfaces.

Ajala (1981) carried out the chemical analysis of locally produced vegetable oils that are being investigated in the present research efforts. From his analysis the chemical composition of the oils were evaluated (See Appendix 2(A)). The saponification value, percentage free acid value, iodine value and percentage phosphorus content of each of the local oils were also evaluated (See Appendix 2(B)). The stability of each of the oils was determined by its percentage free acid value while the saponification value indicates the ease by which the oil can be degreased effectively in an alkaline medium. The iodine value indicates the amount of reactive or polar radicals in each of the local oils, and is also a measure of the level of unsaturated fatty acid contained in them.

2.4 Lubricant Selection

The final selection of any lubricant involves the determination of the test parameters based on the simulative formability tests as well as determination of several other properties to establish whether or not it will meet the requirements. The following are some of these properties of lubricating oils and greases as listed by McGannon (1971).

Viscosity:

This has an important influence on the effectiveness and suitability of a lubricant for a specific operation. Generally, lubricants of high viscosity are used for severe deformation while lubricants of low viscosity are for mild deformation.

Method of Application:

Viscosity is a parameter to be considered in this respect since it dictates the method by which the lubricant will be applied whether by dip, spray, roller, drip feed or brush. The time of application will definitely affect the final cost of the process.

Toxicity, Odour and Stability:

Some lubricants become rancid on standing, producing foul odour and gummy deposits after exposure for some time. However, deterioration is less troublesome in lubricants used in deep drawing operations because the interval between application and subsequent removal of forming lubricant is very short.

Ease of Removal:

Stains and corrosion products may be left behind work metal if the lubricant is not completely removed after the deep drawing operation.

Pour Point:

Pour point is another property of an oil that is important if the oil is to be used to lubricate machinery that operates in unheated buildings or out-of-doors during cold weather. It is the lowest temperature at which a given oil will pour or flow when it is chilled without disturbance at a fixed rate.

Oxidation Resistance:

The constituents of lubricating oils, which are a complex mixture of hydrocarbons, will combine more or less

slowly with oxygen in the air especially if subjected to heat. The products of oxidation have no lubricating value in themselves and even may affect seriously the performance of the remaining unoxidized lubricant.

Flash Point:

Flash point is the temperature at which a flash (momentary ignition) occurs at any point on the surface of an oil when a flame is passed over it, but the oil does not continue to burn.

Fire Point:

The fire point is the temperature at which ignition occurs at any point on the surface of an oil when a flame is passed over it and the oil continues to burn.

Demulsibility:

When water enters a lubricating system and is mixed up with the oil, an emulsion is formed that has poor lubricating properties. If the oil is clean, it will separate from the emulsion if the latter is allowed a rest period. This characteristic is known as the demulsibility of the oil. Demulsibility is good if the oil separates slowly. The presence of products of oxidation may retard or even prevent the operation process.

Neutralization Number:

High acidity makes oil detrimental to bearing surfaces, and may be indicative of undesirable chemical changes that are taking place in a lubricant. The

neutralization number is the number of milligrams of potassium hydroxide necessary to neutralize the acid content of one gram of oil under standard test conditions.

Cost and Final Selection:

The cost of the lubricant considered with the aforementioned parameters help in the final selection of the lubricant for the deep drawing.

Based on the aforementioned selection factors, a good lubricant should obviously fulfil the following functional requirements:-

(a) Provide the desired frictional resistance in all regions of the deep drawing by having the correct shearing characteristics at the prevailing temperature and pressure.

(b) Reduce metal-to-metal contact by having adequate adhesive properties should the finite film be reduced to boundary conditions at the asperity plateaux.

(c) Reduce tool wear by removing debris formed as a result of particles, dirt, scale, etc. especially in the case of high production rate forming operation.

(d) Produce the desired surface finish and metallurgical characteristics on the deep drawn component.

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1 Equipment

The main equipment used for this work is the 400 KN Universal Sheet Metal testing machine. This machine is, simply, a hydraulic press with electronic equipment to measure load versus displacement in a deep drawing operation. A circular blank (lubricated/unlubricated) was positioned in the machine and a primary clamping load sufficient to supress wrinkling was applied. The material was then deformed by movement of the 50mm diameter punch at a press speed of 400 mm/min. The load versus punch displacement curve was then plotted on the Hille graph paper by the X-Y recorder.

3.2 Blank Preparation

From the sheet materials under investigation (Two Galvanized Mild Steel Sheets which are 0.82mm and 1.55mm thick and Plain Carbon Steel which is 0,61mm thick), square blanks with sides of 10mm more than the diameter of the required circular blanks were cut using the shearing machine. A manually operated circular blanking machine was then used to cut the square blanks into circles. The edges of these blanks were then ground to the final size to remove the edge-work hardening effects and to secure a standard edge condition. Deburring of the edges of the blands was carried out using a hand file.

Before the blanks were lubricated, their surfaces were thoroughly cleaned with white cotton wool soaked in

methylated spirit. This was followed by dipping into appropriate bath of the lubricating oil, and subsequent removal from the bath to allow the excess oil to trickle off. Handling was careful enough to prevent surface staining of the test blanks.

3.3 The Swift Test Method

The Swift test was used to evaluate the limiting drawing ratio and maximum drawing loads for each of the lubricating oils under test, namely Palm oil, Palm kernel oil, Cottonseed oil, Groundnut oil, E.P. 140 oil, and Paraffin oil. In the test, 0.82mm and 1.55mm thick galvanized mild steel sheets, and 0.61mm thick plain carbon steel were deep drawn. Specifically, punches of profile radii 3mm, 10mm, 15, and 18mm were used under various lubrication conditions.

A total of 224 circular blanks were prepared from each of the material thickness for use in the deep drawing tests for the evaluation of the oils under investigation.

For the estimation of the limiting drawing ratio; starting circular blank size with initial drawable diameter was selected. With other blanks increasing in diameter by 2mm increment, an average of seven blanks were drawn until failure occured. Actually for the 0.61mm thick plain carbon steel and 0.82mm thick galvanized mild steel blanks, an initial blank size of 110mm diameter was selected while for the 1.55mm thick galvanized mild steel, an initial drawable blank of diameter 104mm was employed,

PLATES I-VI show the pictures of successfully drawn cups and bottom rupture of the materials used while deep drawing with 3mm punch-profile radius.

The blanksize prior to failure was then used to determine the limiting drawing ratio for each selected punch of a given profile radius using each of the lubricating oils as well as the dry condition. A total of 196 circular blanks were therefore deep drawn in the determination of the limiting drawing ratio for each of the thicknesses using two punches of profile radius 3mm and 15mm for all the oils under investigation including dry condition.

For the estimation of the maximum drawing load, 28 circular blanks were tested for each material thickness. Each lubricating oil including dry condition was tested by fully deep drawing the selected size that ensured a successful draw. A blanksize of 110mm diameter was selected for 0.82mm thick galvanized mild steel and 0.61mm thick Plain carbon steel while 104mm diameter blank was selected for 1.55mm thick galvanized mild steel. From the plot of drawing load versus punch displacement by the X-Y recorder, the maximum drawing loads of these selected sizes were estimated. Each of the lubricating oils as well as the dry condition was tested using punches of four profile radii viz: 3, 10, 15, and 18mm.

3.4 Kaftanoglu Test Method

The newly developed Kaftanoglu test method for the

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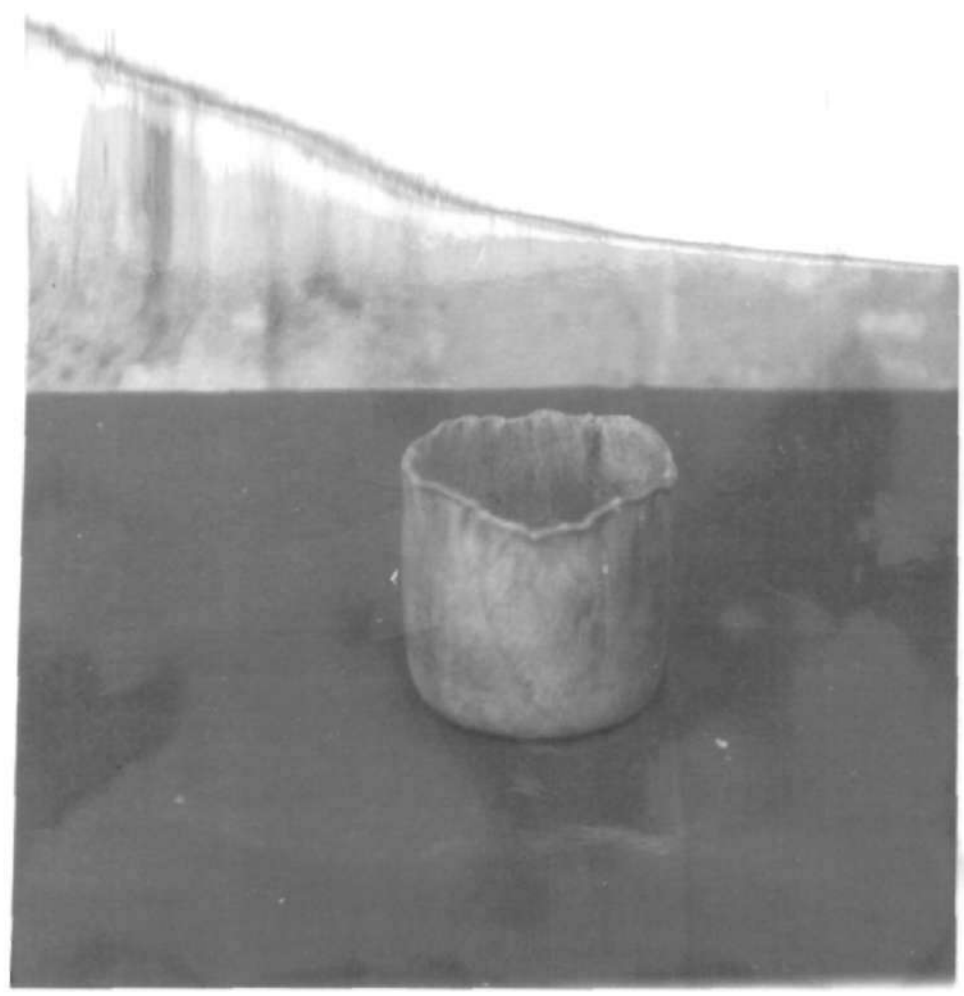


PLATE I: Successfully drawn cup of 0.82mm galvanized mild steel using 3mm punch profile radius

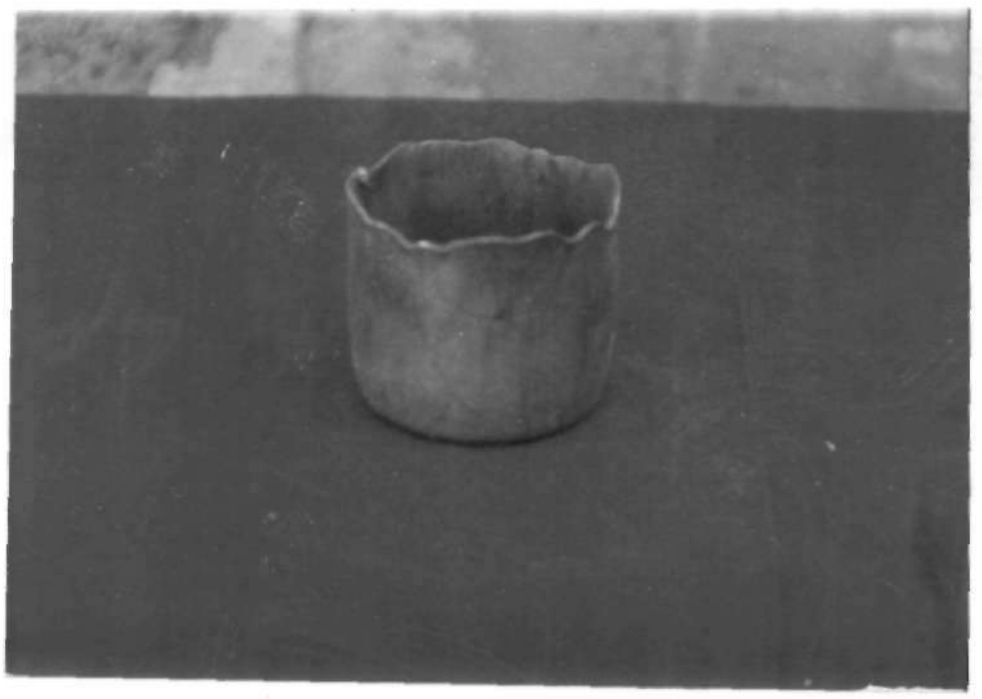


PLATE III: Successfully drawn cup of 1.55mm galvanized mild steel with a punch of 3mm profile radius



PLATE IV: Bottom rupture in deep in deep drawing 1.55mm galvanized mild steel using 3mm punch-profile radius.



PLATE V: Successfully drawn cup of 0.61mm plain carbon steel with a punch of 3mm profile radius



PLATE VI: Bottom rupture in deep drawing 0.61mm plain carbon steel using 3mm punch-profile radius.

determination of the limiting drawing ratio, was employed using each of the oils under investigation namely Palm oil, Palm kernel oil, Cottonseed oil, Groundnut oil, E.P. 140 oil, Paraffin oil as lubricants and under dry condition in the deep drawing of 1.55mm thick galvanized mild steel using a punch of 15mm profile radius.

The idea was to test the validity of this new approach by comparing results obtained by this method with those of swift test for evaluating limiting drawing ratio, under the same set of deep drawing conditions.

A total of 21 oversize circular blanks were prepared for the deep drawing operation.

For each of the lubricating oils including dry condition, 3 oversize blank diameters of 146, 136 and 126mm were used. An oversize blank under a given lubrication condition was deep drawn at a press speed of 400 mm/min and when a hairline crack occured on the bottom of the cup along the radius of the punch, the machine was stopped immediately. The crack occured in this region because of the biaxial tensile stresses developed coupled with the high concentration of friction around the punch profile radius. Fig. 1.4 shows the formed cup indicating the bulge depth.

The bulge depth at fracture was recorded against the size of the blank. The experiment was repeeted for other oversize blanks under the same lubrication condition. When the three tests were carried out, the blank diameter and

bulge depth data obtained were used in equations (2-8) [See Appendix 3(A)]. A computer programme based on these formulae [See Appendix 3(B)] was used to estimate the limiting blank diameter and hence the limiting drawing ratio.

After the computation of the limiting blank diameter (Dcr), diameter of blanks one increment (0.025 of LDR) oversize and one increment undersize were computed.

3.5 Viscosity Test

The viscosity of a lubricating oil is defined as the ability of the oil to resist flow or shear. This property of a lubricant is important in sheet metal forming operations as it plays a significant role in these operations. In deep drawing operations in particular, relatively high loads and pressures are involved. Any lubricant selected for such operations is not to shear too easily, thereby allowing for rupture or failure leading to considerable metal-to-metal contact. Accordingly, one is dependent on high viscosity lubricant.

Also, viscosity must be considered in relation to the method of lubricant application onto the workpiece as well as the effects on handling of the blanks and the formed parts.

As a laid down procedure by the Institute of Petroleum, according to Evans (1948), the viscosity of the oils under investigation were determined at room temperature of 27°C and at 60°C using the Redwood viscometer.

The numerical value for representing the viscosity of the oils using Redwood's viscometer represents the number of seconds required for 50 millilitres of the oil to offlux through a standard orifice under a standard falling height at a particular temperature and the unit is expressed in Redwood seconds.

CHAPTER 4

RESULTS

The results of the Swift test in relation to the limiting drawing ratio (LDR) and maximum drawing load of each of the lubricating oils under test are illustrated in tables and figures for the various materials used in relation to the tool geometry employed. Also, the result of the Kaftanoglu test showing the limiting drawing ratio of the lubricating oils under test are represented in a table and a graph, correlating test results with those of Swift ones for a given material deep drawn with a particular tool geometry. Measured values of the viscosity of the lubricating oils at room temperature of 27°C and at 60°C are presented in a table.

4.1. Swift Test Results

4.1.1 Limiting Drawing Ratio Results

Table 4.1 shows the limiting drawing ratio values obtained while deep drawing the various materials under the lubrication conditions under test using various tool geometries.

4.1.11 LDR Results While Deep Drawing 0.82mm Thick Galvanized Mild Steel

Considering the local oils as lubricants, LDR values obtained while deep drawing with 3mm punch-profile radius show that Palm and Cottonseed oils gave a higher value of 2.36 while Palm kernel oil and Groundnut oil gave a lower value of 2.32. Deep drawing with a punch profile radius

TABLE 4.1 (CONT'D)

MATERIAL USED	MATERIAL THICKNESS (mm)	LUBRICATING OIL	LIMITING DRAWING RATIO USING PUNCH-PROFILE RADIUS OF:	
			3mm	15mm
Plain Carbon Steel	0.61	Dry Condition	2.32	2.32
		E.P. 140 oil	2.40	2.40
		Paraffin oil	2.36	2.36
		Palm oil	2.36	2.40
		Palm kernel oil	2.36	2.40
		Cottonseed oil	2.40	2.44
		Groundnut oil	2.40	2.40

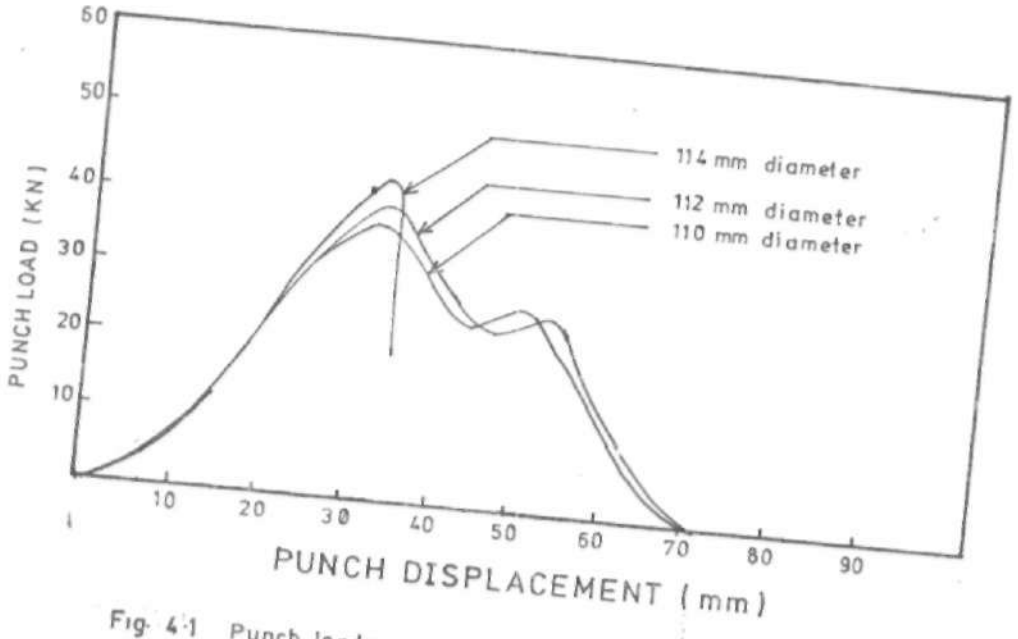


Fig. 4·1 Punch load versus punch displacement relations for drawing of various blank diameters, under dry conditions from 0·82mm thick galvanized mild steel using 3mm punch-profile radius..

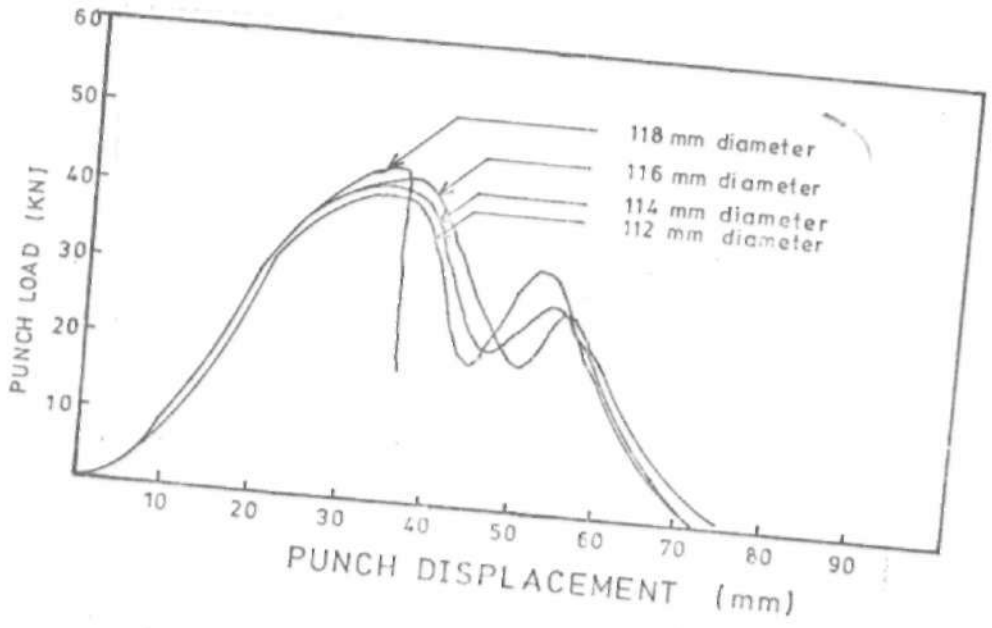
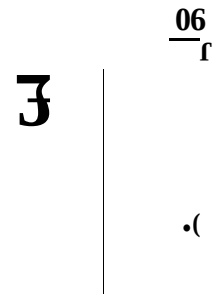


Fig 4·2 Punch load versus punch displacement relations for drawing of various blank diameters, lubricated with E-P. 140 oil, from 0.82mm thick galvanized mild steel using 3mm punch-profile radius



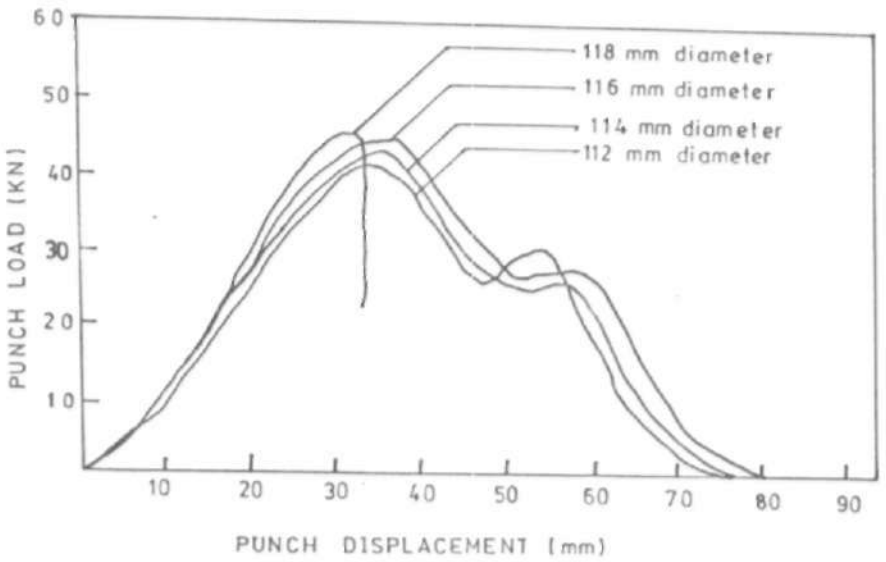


Fig 4·5 Punch load versus punch displacement relations for drawing of various blank diameters lubricated with palmkernel oil from 0·82 mm thick galvanized mild steel using 3mm punch-profile radius.

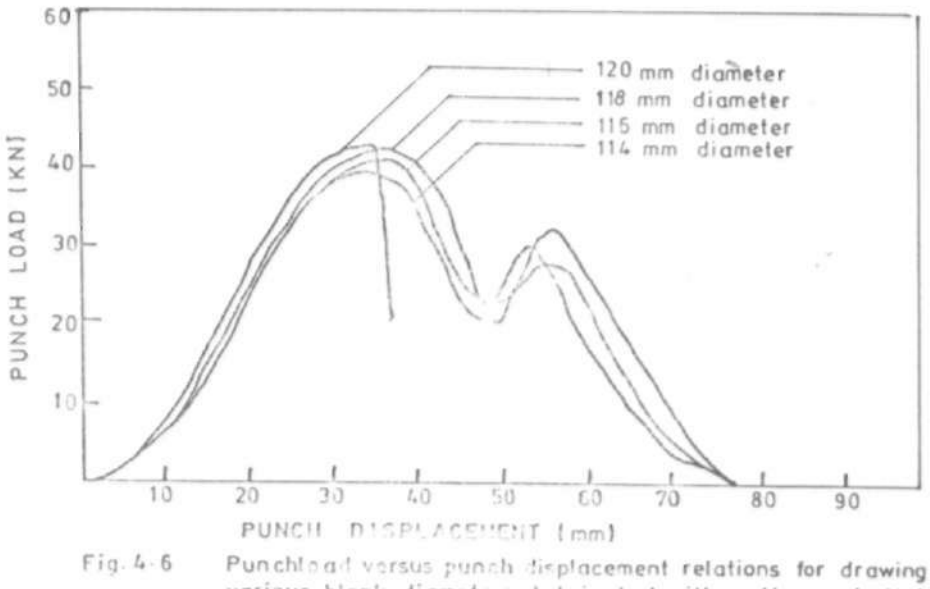


Fig. 4·6 Punchload versus punch displacement relations for drawing of various blank diameters lubricated with cottonseed oil from 0.82mm thick galvanized mild steel using 3 mm punch-profile radius.

The critical blanksizes under the dry condition, E.P. 140 oil, Paraffin oil, Palm oil, Palm kernel oil, Cottonseed oil and Groundnut oil are 114, 116, 114, 118, 116, 118 and 116mm respectively.

4.1.13 LDR Results While Deep Drawing 0.61mm Thick Plain Carbon Steel

Cottonseed oil and Groundnut oil gave a higher LDR value of 2.40 while Palm oil and Palm kernel oil gave a lower value of 2;36 when deep drawing with 3mm punch-profile radius. Using 15mm punch-profile radius, Cottonseed oil gave a higher value of 2.44 while Palm oil, Palm kernel oil and Groundnut oil gave the same lwer value of 2.40.

Figures (4.17), (4.18), (4.19), (4.20), (4.21), (4.22), and (4.23) show curves of punch load versus displacement relations while drawing various diameters using 3mm punch-profile radius, until failure occured. The critical blanksizes under dry condition, E.P. 140 oil, Paraffin oil, Palm oil, Palm kernel oil, Cottonseed oil, and Groundnut oil are 116, 120, 118, 118, 118, 120, and 120mm respectively.

4.1.2 Maximum Drawing Load Results

Table 4.2 shows the maximum drawing load results obtained while deep drawing the various materials under the lubrication conditions under test using various tool geometries.

4.1.21 Deep Drawing 0.82mm Thick Galvanized Mild Steel

Deep drawing with 3mm profile radius punch, Palm oil gave the lowest drawing load of 36.0 KN while Palm kernel oil

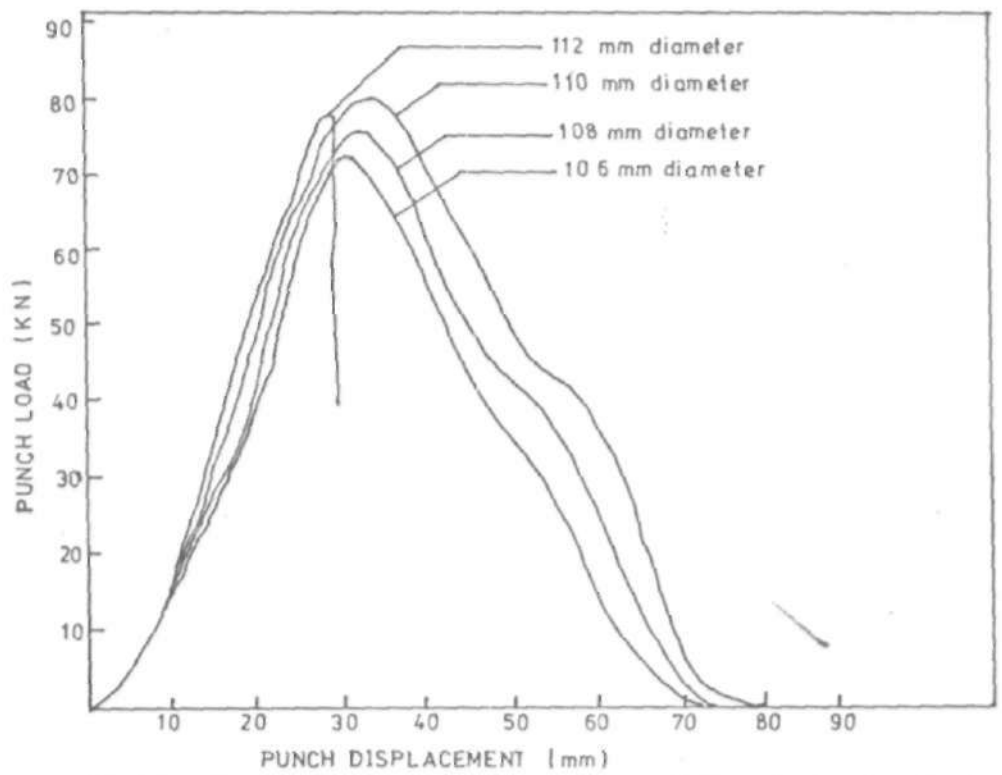


Fig. 4-11 Punch load versus punch displacement relations for drawing of various blank diameters, lubricated with parafin oil from 1·55 mm thick galvanized mild steel using 3mm punch profile radius

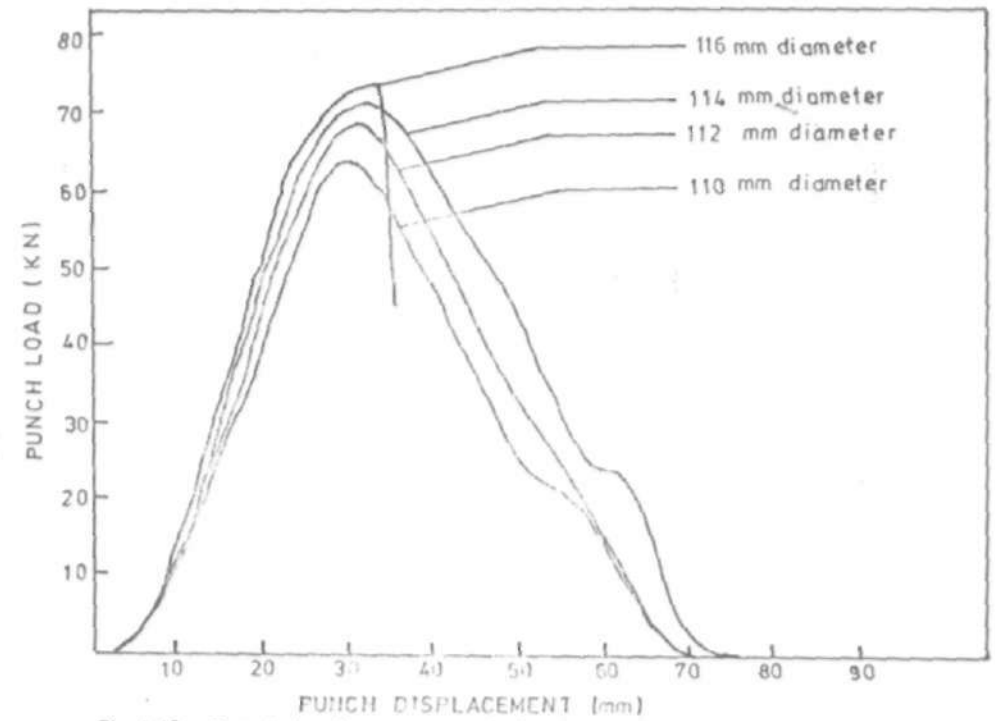


Fig 4-12 Punch load versuspunch displacement relations for drawing of varius blank diameters, lubricated with palm oil from 1·55 mm thick galvanized mild steel using 3mm punch profile radius

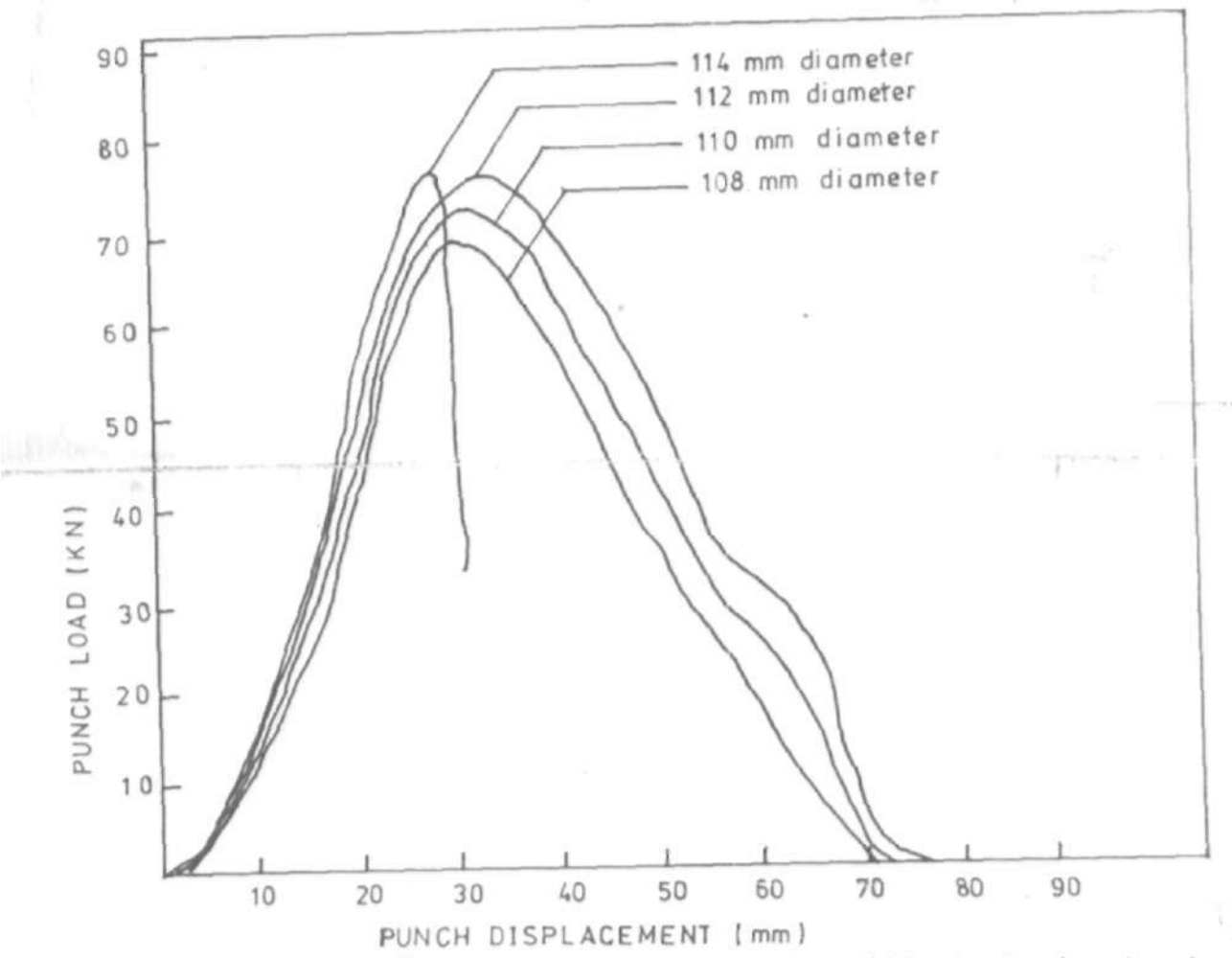
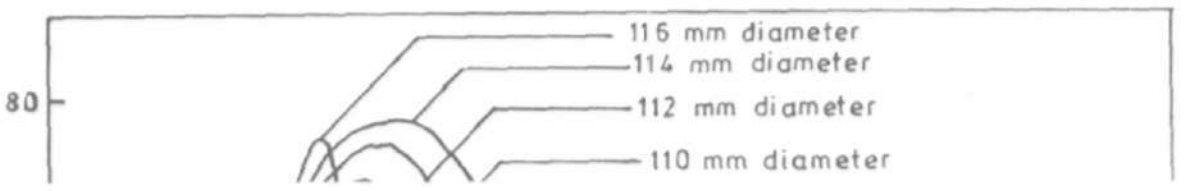


Fig 4-13 Punch load versus punch displacement relations for drawing of various blank diameters, lubricated with palm kernel oil, from 1·55 mm thick galvanized mild steel using 3mm punch- profile radius.



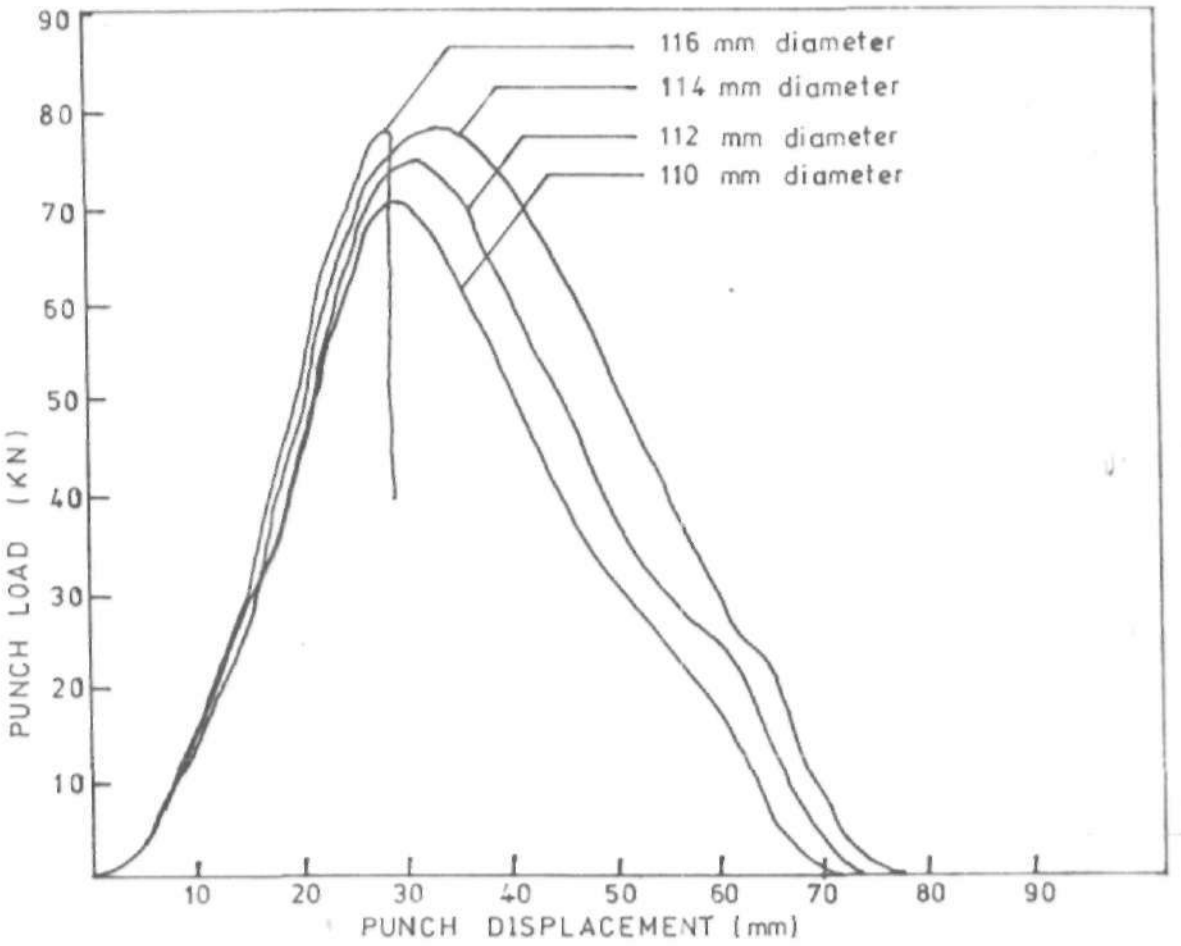


Fig 4-15 Punch load versus punch displacement relations for drawing of various blank diameters, lubricated with ground nut oil, from 1·55mm thick galvanized mild steel using 3mm punch-profile radius.

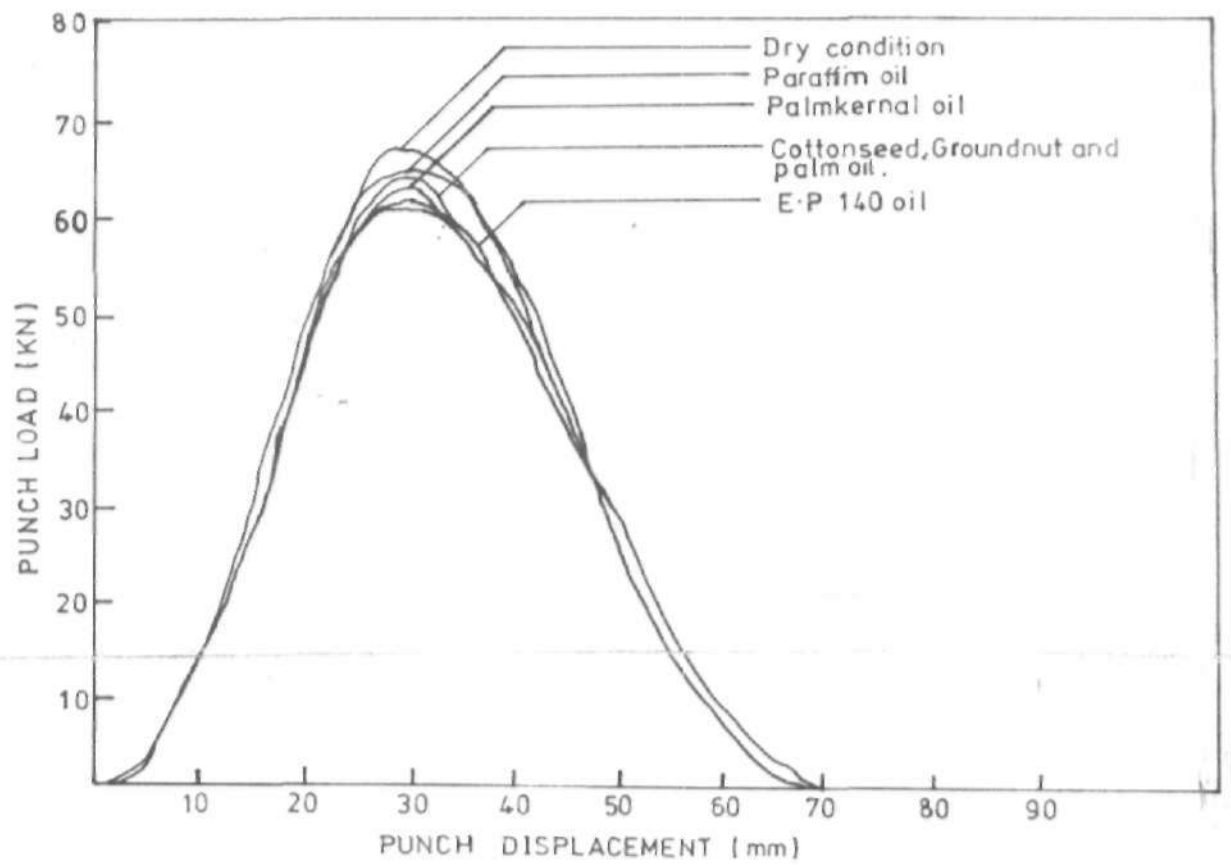


Fig 4-16 Punch load versus punch displacement relations for drawing 104 mm blank diameters using 3mm punch-profile radius from 1·55mm thick galvanized mild steel under various conditions of lubrication

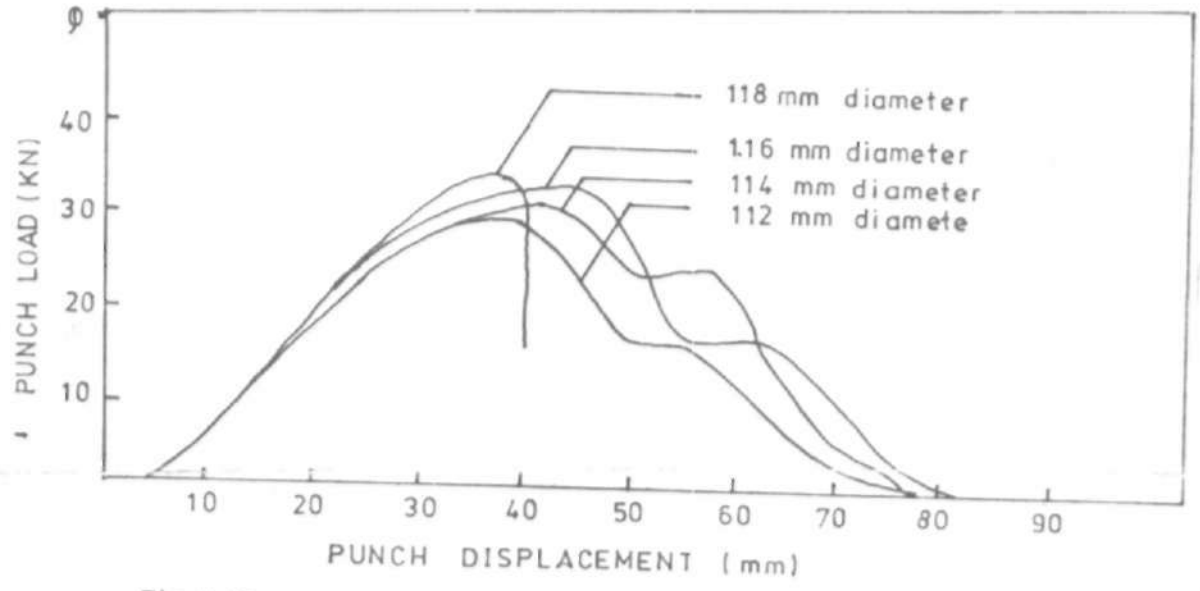


Fig 4·17 Punch load versus punch displacement relations for drawing of various blank diameters, under dry conditions, from 0·61 mm thick plain carbon steel using 3 mm punch-profile radius.

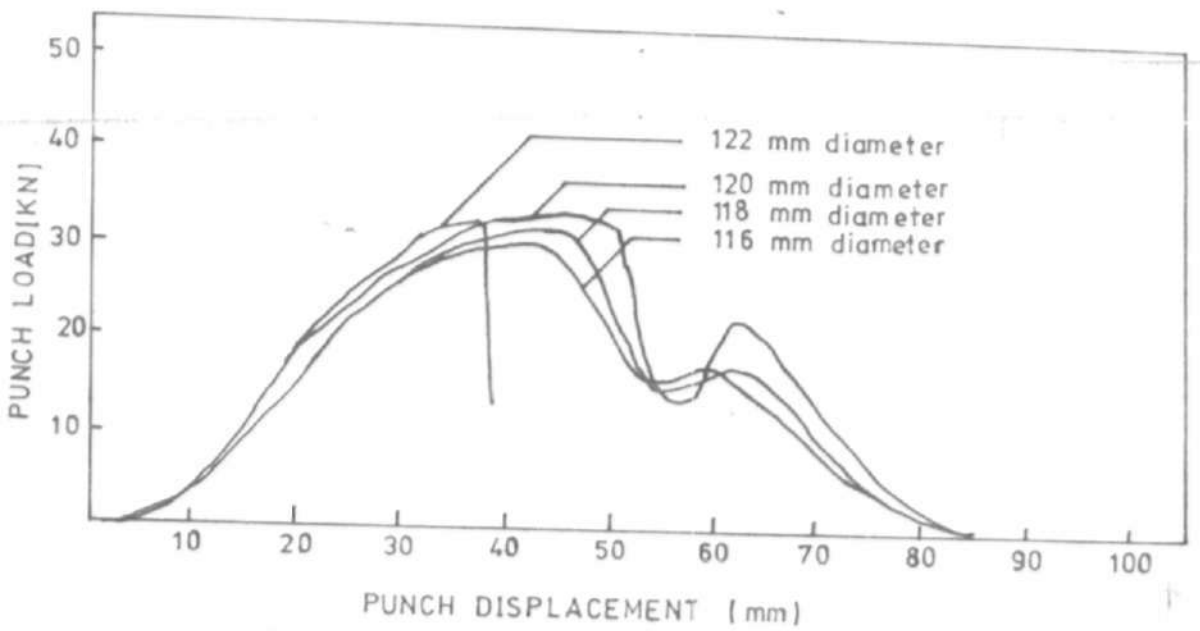


Fig 4·18 Punch load versus punch displacement relations for drawing of various blank diameters lubricated with E-P 1·40 from 0·61 mm thick plain carbon steel using 3 mm punch - profile radius.

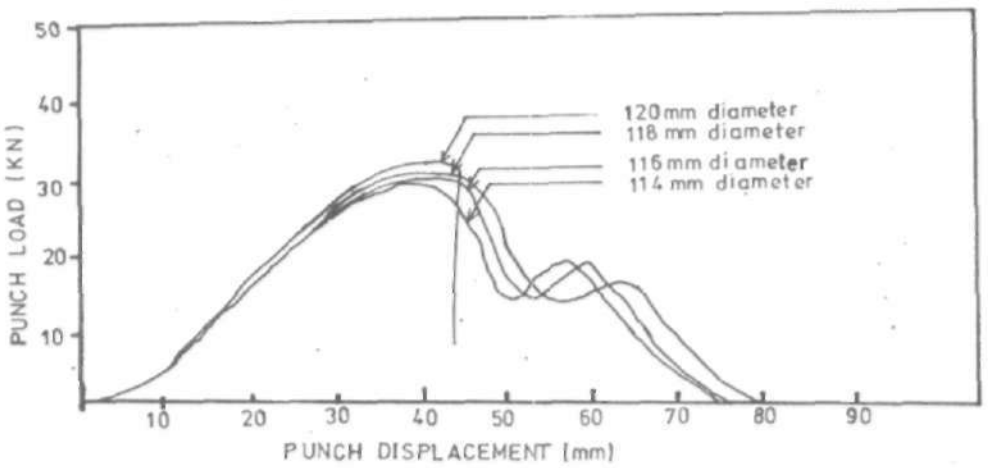


Fig 4·21 Punch load versus punch displacement relations for drawing of various blank diameters lubricated with palmkernel oil, from 0·61 mm thick plain carbon steel using 3mm punch profile radius.

Palm Kernel

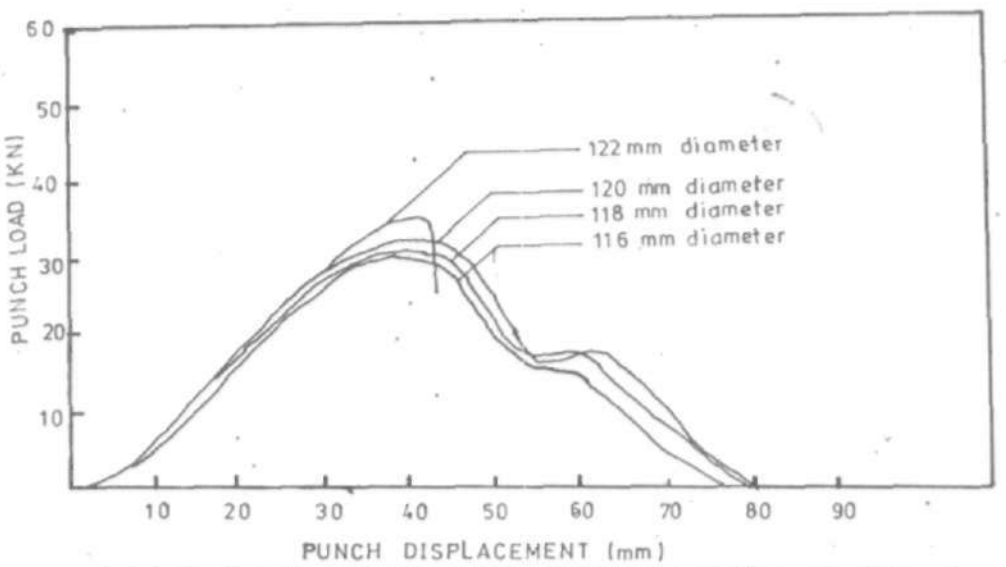


Fig 4·22 Punch load versus punch displacement relations for drawing of various blank diameters, lubricated with cottonseed oil, from 0·61mm thick plain carbon steel using 3mm punch profile radius.

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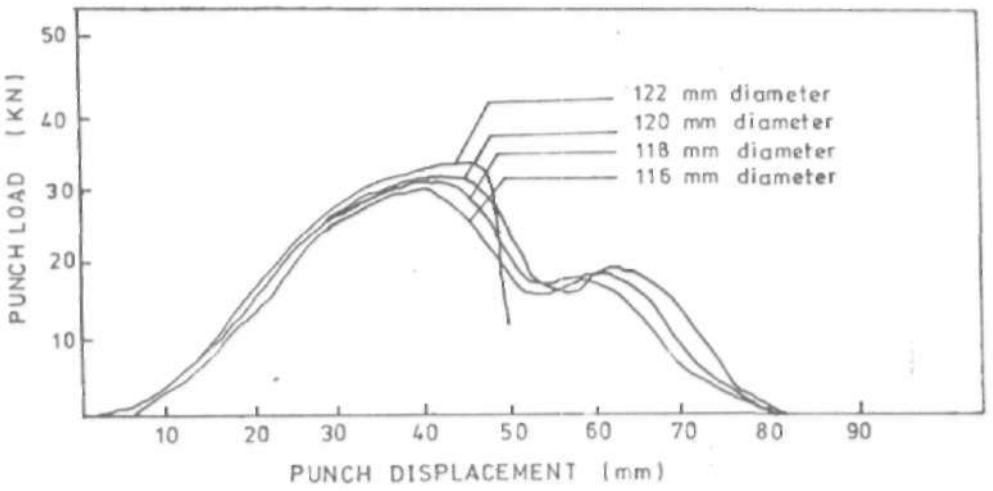


Fig 4·23 Punch load versus punch displacement relations for drawing of various blank diameters lubricated with groundnut oil, from 0·61mm thick plain carbon steel using 3mm punch-profile radius.

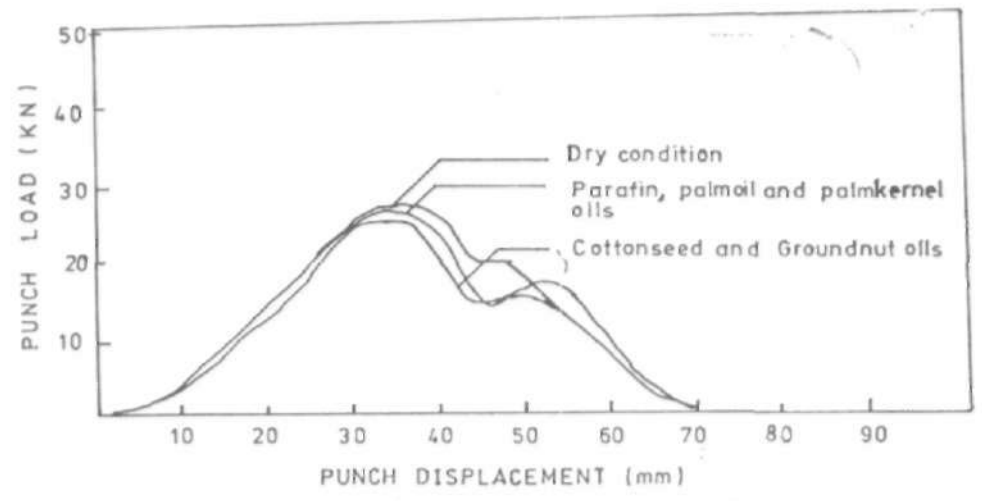


Fig 4-24 Punch load versus punch displacement relations for drawing 110mm diameter blank using 3mm punch profile radius from 0·61mm thick plain carbon steel under various lubrication conditions.

gave the highest drawing load of 38.0 KN. However, with 10mm punch-profile radius, Palm oil and Cottonseed oil gave the lowest value of 36.0 KN while Palmkernel oil gave the highest drawing load of 37.0 KN. Deep drawing with 15mm punch-profile radius, Palm oil gave the lowerst drawing load of 34.5 KN while Palm kernel oil gave the highest value of 36.5 KN. With an 18mm punch-profile radius, Palm oil gave a lower drawing load of 35.0 KN while Palmkernel oil, Cottonseed oil and Groundnut oil gave a higher value of 36.0 KN.

Figure (4.8) shows curves of punch load versus punch displacement relations from drawing of 110mm diameter blanks using 3mm punch-profile radius with various oils under investigation as lubricants. The maximum drawing loads under dry condition, E.P. 140 oil, Paraffin oil, Palm oil, Palmkernel oil, Cottonseed oil and Groundnut oil are 39.0, 38.0, 38.5, 36.0, 38.0, 36.5 and 38.0 KN respectively.

4.1.22 Deep Drawing 1.55mm Thick Galvanized Mild Steel

Considering the local oils under investigation, Palm oil gave the lowest drawing load of 61.0 KN while Palm kernel oil gave the highest value of 63.0 KN when deep drawing with 3mm punch-profile radius. Deep drawing with 10mm punch-profile radius shows that Palm oil and Cottonseed oil gave a lower drawing load of 59.5 KN while Palmkernel oil and Groundnut oil gave a higher value of 61.0 KN. Using 15mm punch-profile radius shows that

Cottonseed oil gave a lower value of 57.5 KN while Palmkernel oil gave the highest value of 60.0 KN. With 18mm punch-profile radius, however, Palm oil gave a lower drawing load of 56.0 KN while Palmkernel oil, Cottonseed oil and Groundnut oil gave a higher value of 57.0 KN.

Figure (4.18) shows curves of punch load versus punch displacement relations obtained while deep drawing 104mm diameter blanks using 3mm punch-profile radius with the various oils under investigation as lubricants. The maximum drawing loads under dry condition, E.P. 140 oil, Palm oil, Paraffin oil, Palm oil, Palmkernel oil, Cottonseed oil, and Groundnut oil are 66.0, 62.5, 63.0, 61.0, 63.0, 61.5 and 61.5 respectively.

4.1.23 Deep Drawing 0.61mm Thick Plain Carbon Steel

During the deep drawing operation using 3mm punch-profile radius, Cottonseed oil gave the lowest drawing load of 25.0 KN while Palmkernel oil gave the highest value of 26.0 KN. Deep drawing using 10mm punch-profile radius shows that Groundnut oil gave a lower drawing load of 25.0 KN while Palm oil, Palmkernel oil and Cottonseed oil gave a higher value of 25.5 KN. Using 18mm punch-profile radius, Palm oil, Cottonseed oil and Groundnut oil gave a lower drawing load of 24.0 KN while Palmkernel oil gave a higher value of 24.5 KN.

Figure (4.24) shows curves of punch load versus punch displacement relations from drawing 110mm diameter blanks

using 3mm punch-profile radius with oils under investigation as lubricants. The maximum drawing loads under the dry condition, E.P. 140 oil, Paraffin oil, Palm oil, Palmkernel oil Cottonseed oil and Groundnut oil are 27.0, 26.0, 26.5, 25.5, 26.0, 25.0 and 25.5 KN respectively.

4.2 Kaftanoglu Test Results

Table 4.3 shows the results of the Kaftanoglu test method indicating the computed limiting drawing ratio for each of the oils under investigation in the deep drawing of 1.55mm thick galvanized mild steel employing a punch of 15mm profile radius. The empirical constants, M, N and critical blank diameter for the exponential equations are presented for each of the lubrication conditions. For comparison purposes, limiting drawing ratio obtained from the standard Swift test method using the various oils as lubricants are presented, thus enabling correlation of results between the experimental Swift test and the Kaftanoglu test for the determination of limiting drawing ratio.

Table 4.4 shows the bulge depth versus initial blank diameters of oversize blanks obtained from Kaftanoglu test while deep drawing 1.55mm thick galvanized mild steel employing 15mm punch-profile radius, under the various lubrication conditions under investigation. The computed critical blank diameters for each of the lubrication conditions are also presented in the table.

Figure (4.25) shows the graphs of bulge depth versus initial blank diameters of oversize blanks while deep drawing

1.55mm thick galvanized mild steel using a punch-profile radius of 15mm with various oils as lubricants.

4.3 Viscosity

Table 4.5 shows the viscosity at a room temperature of 27°C, and at 60°C of the various oils under investigation expressed in Redwood seconds. Of all the various oils investigated, Cottonseed oil has the highest viscosity value of 255 Redwood seconds, while Palmkernel oil has the lowest value of 191 Redwood seconds at 27°C. The same trend was observed from the viscosity measurements at 60°C.

TABLE 4.2 MAXIMUM DRAWING LOAD RESULTS OBTAINED WHEN DEEP DRAWING UNDER VARIOUS LUBRICATION CONDITIONS AND TOOL GEOMETRIES.

MATERIAL USED	MATERIAL THICKNESS (mm)	LUBRICATING OIL	MAXIMUM DRAWING LOAD (KN) USING PUNCH PROFILE RADIUS OF: 3mm	10mm	15mm	18mm
Galvanized mild Steel	0.82	Dry Condition	39.0	39.0	37.5	36.5
		E.P. 140 oil	38.0	36.5	36.0	36.0
		Paraffin oil	38.5	37.0	37.0	36.5
		Palm oil	36.0	36.0	34.5	35.0
		Palm kernel oil	38.0	37.0	36.5	36.0
		Cottonseed oil	36.5	36.0	36.0	36.0
		Groundnut oil	38.0	36.5	36.0	36.0
Galvanized mild Steel	1.55	Dry Condition	66.0	62.0	62.0	61.0
		E.P. 140 oil	62.5	61.0	60.0	57.0
		Paraffin oil	63.5	62.0	62.0	61.0
		Palm oil	61.0	59.5	58.5	56.0
		Palm kernel oil	63.0	61.0	60.0	57.0
		Cottonseed oil	61.5	59.5	57.5	57.0
		Groundnut oil	61.5	61.0	59.5	57.0

TABLE 4.2 (CONT'D)

MATERIAL USED	MATERIAL THICKNESS (mm)	LUBRICATING OIL	MAXIMUM PUNCH 2mm	DRAWING PROFILE 10mm	LOAD RADIUS (KN) OF: 15mm	USING 18mm
Plain Carbon Steel	0.61	Dry Condition	27.0	27.0	-	25.5
		E.P. 140 oil	26.0	25.5	-	24.0
		Paraffin oil	26.5	26.0	-	25.0
		Palm oil	25.5	25.5	-	24.0
		Palm kernel oil	26.0	25.5	-	24.5
		Cottonseed oil	25.0	25.5	-	24.0
		Groundnut oil	25.5	25.0	-	24.0

TABLE 4.3: LIMITING DRAWING RATIO RESULTS OBTAINED FROM KAFTANOGLU DEEP DRAWING TESTS OF 1.55mm THICK GALVANIZED MILD STEEL USING 15mm PUNCH-PROFILE RADIUS UNDER VARIOUS LUBRICATION CONDITION

LUBRICATING OIL	SWIFT LIMITING DRAWING RATIO	EMPIRICAL CONSTANTS FOR THE EQUATION $Db=N\exp(-Nh)+Dor$			COMPUTED LIMITING DRAWING RATIO	WITHIN AN INCREMENT OF 0.025 ON LDR	
		M	N	Dor(mm)		UNDERSIZE BLANK (mm)	OVERSIZE BLANK (mm)
DRY CONDITION	2.28	100980.45	0.26107	115.138	2.303	113.888	116.388
B.P. 140 OIL	2.32	149385.75	0.26107	115.138	2.303	113.888	116.388
PARAFFIN OIL	2.28	115060.94	0.26107	115.138	2.303	113.888	116.388
PALM OIL	2.36	4470581.98	0.36022	122.045	2.441	120.795	123.295
PALM KERNEL OIL	2.32	640830.84	0.32081	119.820	2.396	118.570	121.070
COTTONSEED OIL	2.36	1036889.37	0.32081	119.820	2.396	118.570	121.070
GROUNDNUT OIL	2.32	1217293.85	0.32081	119.820	2.396	118.570	121.070

TABLE 4.4: BULGE DEPTHS VERSUS BLANK DIAMETERS OBTAINED WHILE DEEP DRAWING 1.55mm THICK GALVANIZED MILD STEEL USING 15mm PUNCH-PROFILE RADIUS UNDER THE VARIOUS LUBRICATION CONDITION.

LUBRICATING OIL	BLANK DIAMETER (Db) (mm)	BULGE DEPTH (h) (mm)	CRITICAL BLANK DIAMETER (Dcr) (mm)
DRY CONDITION	146 136 126	31.0 32.5 35.0	115.138
E.P. 140 OIL	146 136 126	32.5 34.0 36.5	115.138
PARAFFIN OIL	146 136 126	31.5 33.0 35.5	115.138
PALM OIL	146 136 126	33.5 35.0 38.5	122.045
PALM KERNEL OIL	146 136 126	31.5 33.0 36.0	119.820
COTTONSEED OIL	146 136 126	33.0 34.5 37.5	119.820
GROUNDNUT OIL	146 136 126	33.5 35.0 38.0	119,820

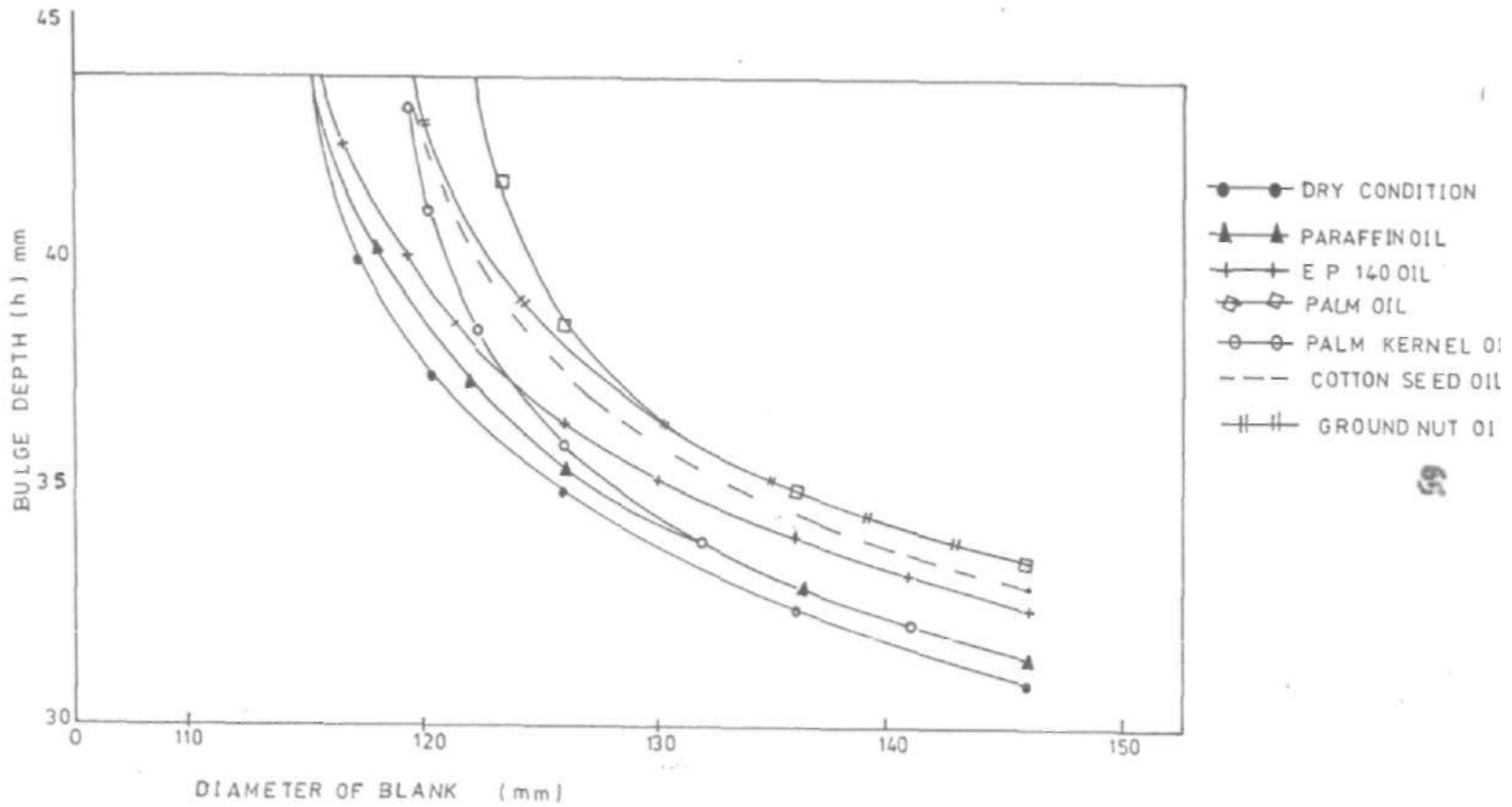


Fig. 4.25 BULGE DEPTH VERSUS BLANK DIAMETER WHEN DEEP DRAWING 1·55 mm GALVANIZED MILD STEEL USING 3mm PUNCH–PROFILE RADIUS (VARIOUS LUBRICATION CONDITIONS EMPLOYED.)

TABLE 4.5: VISCOSITY VALUES FOR THE VARIOUS LUBRICATING OILS UNDER INVESTIGATION AT ROOM TEMPERATURE (27°C) AND AT 60°C

LUBRICATING OIL	VISCOSITY (REDWOOD SECONDS) AT: 27°C	60°C
E.P. 140 OIL	4,440	1,130
PARAFFIN OIL	525	170
PALM OIL	245	115
PALM KERNEL OIL	191	90
COTTONSEED OIL	255	122
GROUNDNUT OIL	225	108

CHAPTER 5

DISCUSSION OF RESULTS

The properties of each of the local oils under investigation in respect of the numerical values obtained from the Swift deep drawing formability test parameters have been used as a major criterion for the oils assessment as lubricants in deep drawing. The limiting drawing ratio (LDR) and the maximum drawing load are the Swift test parameters used to assess the performance of the local oils. The higher the value of the limiting drawing ratio, the better the lubricant while the lower the deep drawing load, the better the lubricant. However, to set a standard for comparison, the results obtained for the local oils in respect of these Swift test parameters were compared with those obtained for the widely used high grade industrial lubricant - E.P. 140 oil. The lower performance characteristics of these local oils in deep drawing operations have been evaluated by comparing test results with Paraffin oil - a lower grade oil used in sheet metal forming operations.

The newly developed Kaftanoglu test was used for the determination of limiting drawing ratio of each of the oils under investigation, including dry condition by selecting one sheet material using a particular tool geometry to enable comparison of results obtained from this new approach with those of Swift tests.

5.1 Lubricant Assessment by Swift Test Method

5.1.1 Limiting Drawing Ratio Results

The results of the limiting drawing ratio obtained while deep drawing the various materials with the investigated oils as lubricants using two different tool geometries are presented in table 4.1.

5.1.1.1 Deep Drawing 0.82mm Thick Galvanized Mild Steel

Deep drawing with 3mm punch-profile radius, the limiting drawing ratio results show that Cottonseed oil and Palm oil gave LDR value of 2.36 thereby showing better lubrication performance than E.P. 140 oil. Groundnut oil and Palmkernel oil gave the same LDR of 2.32 as the E.P. 140. All the lubricants performed better than Paraffin oil with an LDR of 2.24.

Deep drawing with 15mm punch-profile radius shows that Cottonseed oil and Palm oil having an LDR of 2.44 are more superior lubricants than E.P. 140 oil. However, Palmkernel oil and Groundnut oil gave similar performance with Paraffin oil and E.P. 140 oil having LDR of 2.36.

5.1.1.2 Deep Drawing 1.55mm Thick Galvanized Mild Steel

Results show that while deep drawing with 3mm punch-profile radius, Palm oil, Groundnut oil and Cottonseed oil having an LDR of 2.28 are better lubricants than E.P.140 oil. Palmkernel with an LDR of 2.24 gave a similar result

with E.P. 140 oil. All the lubricants performed better than Paraffin oil with an LDR of 2.20.

Limiting drawing ratio results using 15mm punch-profile radius in the drawing operation reveals that Palm oil and Cottonseed oil with LDR of 2.36 are the best lubricating oils. Palmkernel oil and Groundnut oil have the same performance as E.P. 140 oil with LDR of 2.32. All the local oils performed better than Paraffin oil having an LDR of 2.28.

5.1.1.3 Deep Drawing 0.61mm Thick Plain Carbon Steel

Limiting drawing ratio results obtained from the deep drawing operation using 3mm punch-profile radius reveals that Groundnut oil and Cottonseed oil have the same LDR of 2.40 as E.P. 140 oil, thereby showing best lubrication performance. Palmkernel oil and Palm oil having an LDR of 2.36 are less superior to E.P. 140 oil but gave similar performance to Paraffin oil.

Using 15mm punch-profile radius, Cottonseed oil with LDR of 2.44 gave the best lubrication performance. Palmkernel oil gave the same performance as E.P. 140 oil having an LDR of 2.40. All the local oils performed better than Paraffin oil with an LDR of 2.36.

5.1.2 Maximum Drawing Load Results

The results of the maximum drawing load obtained while deep drawing with various oils under investigation as lubricants using four different punch-profile radius are presented in table 4.2.

5.1.2.1 Deep Drawing 0.82mm Thick Galvanized Mild Steel

Best lubrication performance was obtained from Palm oil with a drawing load of 36.0 KN while deep drawing with 3mm punch-profile radius, followed by Cottonseed oil with 36.5 KN. Groundnut, Palmkernel oils and E.P. 40 oil gave the same lubrication performance with a drawing load of 38.0 KN. All the lubricants performed better than Paraffin oil with a maximum drawing load of 38.5 KN.

When drawing was carried out using 10mm punch-profile radius, the maximum drawing load results show that Palm oil, Cottonseed oil and Groundnut oil, with 36.0 KN are more superior lubricants than E.P. 140 oil. E.P. 140 oil having a maximum drawing load of 36.5 KN was found to be more superior than Palmkernel oil with 37.0 KN. All the local oils except Palmkernel oil performed better than Paraffin oil with 37.0 KN drawing load.

Deep drawing with 15mm punch-profile radius, Palm oil having a drawing load of 34.5 KN was found to be the best lubricating oil. Groundnut oil and Cotton-seed oil each having a drawing load of 36.0 KN gave the same performance as E.P. 140 oil. Palmkernel oil was less superior to E.P. 140 oil but has the same rating as Paraffin oil with a drawing load of 37.0 KN.

Maximum drawing load results using 18mm punch-profile radius show that Palm oil was the best lubricating oil, having a drawing load of 35.0 KN. Palmkernel oil,

Cottonseed oil and Groundnut oil having a drawing load of 36.0 KN. rated same as E.P. 140 oil. All the lubricating oils were found to be superior to Paraffin oil having a drawing load of 36.5 KN.

5.1.2.2 Deep Drawing 1.55mm Thick Galvanized Mild Steel

Deep drawing operation using 3mm punch-profile radius shows that Palm oil was the best lubricating oil with a drawing load of 61.0 KN. Cottonseed oil and Groundnut oil with a drawing load of 61.5 KN were found to be more superior lubricants than E.P. 140 oil. Palmkernel oil having a drawing load of 63.0 KN was less superior to E.P. 140 oil but gave a better performance than Paraffin oil having a drawing load of 63.5 KN.

When 10mm punch-profile radius was employed in the deep drawing operation, Cottonseed oil and Palm oil each having a drawing load of 59.5 KN were found to be the best lubricating oils. Palmkernel and Groundnut oils gave the same performance as E.P. 140 oil with a drawing load of 61.0 KN. All the local oils performed better than Paraffin oil with a drawing load of 62.0 KN.

Maximum drawing load results using 15mm punch-profile radius reveals that Cottonseed oil was the most superior lubricant having a drawing load of 57.5 KN. Palm oil and Groundnut oil with drawing loads of 58.5 and 59.5 KN respectively performed better than E.P. 140 oil, Palmkernel

oil and E.P. 140 oil have the same rating with a drawing load of 60.0 KN. All the local oils performed better than Paraffin oil with a drawing load of 62.0 KN.

Deep drawing with 18mm punch-profile radius, Palm oil gave the most superior performance with a drawing load of 56.0 KN. Palmkernel oil, Groundnut oil and Cotton-seed oil gave the same rating as the E.P. 140 oil having a maximum drawing load of 57.0 KN.

5.1.2.3 Deep Drawing 0.61mm Thick Plain Carbon Steel

Results of maximum drawing load using 3mm punch-profile radius show that Cottonseed oil was the best lubricating oil with a drawing load of 25.0 KN. Groundnut and Palm oils having a drawing load of 25.5 KN were found to be more superior than E.P. 140 oil. Palmkernel oil gave the same performance as E.P. 140 oil with a drawing load of 26.0 KN. All the local oils performed better than Paraffin oil having a drawing load of 26.3 KN.

When drawing was carried out using 10mm punch-profile radius, a maximum drawing load of 25.0 KN was obtained for Groundnut oil making it the best lubricating oil under this condition. Palm oil, Cottonseed oil and Palmkernel oil gave similar lubrication performance as E.P. 140 oil having a drawing load of 25.5 KN. All the local oils gave a more superior performance than Paraffin oil having a drawing load of 26.0 KN.

Deep drawing using 18mm punch-profile radius shows that Palm oil, Cottonseed oil and Groundnut oil are best lubricants having the same drawing load of 24.0 KN, as E.P. 140 oil. However, all the local oils were found to be more superior than Paraffin oil that gave a drawing load of 25.0 KN.

5.2 Lubricant Assessment by Kaftanoglu Test Method

Table 4.3 shows the computed limiting drawing ratio results obtained from the Kaftanoglu test against those of Swifts while deep drawing 1.55mm thick galvanized mild steel employing 15mm punch-profile radius.

Palm oil was found to be the most superior lubricant with an LDR of 2.441, followed by Groundnut oil, Cottonseed oil and Palmkernel oil each having LDR of 2.396. All the local oils were found to be superior to E.P. 140 oil which gave the same LDR of 2.303 as Paraffin oil.

Limiting drawing ratios obtained for dry condition, E.P. 140 oil, Paraffin oil and Cottonseed oil show that a high degree of correlation exists between the two test methods. However, Kaftanoglu's LDR value for Palmkernel oil and Groundnut oil, of 2.396 was higher than 2.32 obtained from Swift method.

Discrepancies are expected between the results of the two test methods due to differences in their limits of accuracy.

Figure (4.25) shows the curves of bulge depth versus blank diameters in the Kaftanoglu test. The bulge depth is the depth of travel of the punch up to the point of initiation of the hairline crack at the bottom around the punch profile radius.

The figure shows that a greater bulge depth was achieved with a good lubricant than that of a poorer one. It could be seen therefore from the figure that, as the exponential curve shifts upwards, the better the lubricant. Hence for the dry condition, the curve is lowest whereas the curve for Palm oil having the highest LDR is at the top.

5.3 Viscosity

It is well known that viscosity plays a significant role in sheet metal forming operation in general, and deep drawing in particular. In view of the prevailing condition of high loads and pressures involved in deep drawing operation, the selection of a lubricant of high viscosity, which will not shear too easily and allow rupture of the lubricating oil film, and subsequent failure of the material workpiece to occur, is of paramount importance.

From the room temperature ($27^{\circ}C$) viscosity of the oils under investigation as shown in table 4.5, the mineral oils have the highest viscosity numbers; E.P. 140 oil having a viscosity of 4,440 Redwood Seconds and Paraffin oil with a viscosity of 525 Redwood Seconds.

The local oils under investigation have relatively low viscosities ranging from Palmkernel oil which has the lowest viscosity of 191 Redwood Seconds to Cottonseed oil having the highest viscosity of 255 Redwood Seconds. The low viscosity obtained for Palmkernel oil must have necessitated easy rupture of its lubricating film, thereby allowing for failure to occur at shallow drawing depth compared with Cottonseed oil of higher viscosity failing at much higher drawing depth. The viscosity numbers of these oils at 60°C justify the temperature dependence of these oils under investigation. It is worth mentioning that the trend of increasing viscosity as observed from viscosity data obtained at the room temperature of 27°C, was found to be in same manner as the data obtained at 60°C.

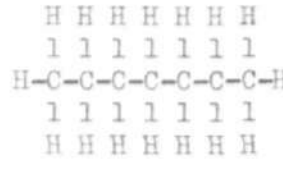
Even though the viscosity numbers obtained for these local oils are very low compared with mineral oils, the local oils still performed favourably as indicated by the Swift test results.

Cottonseed oil and Palm oil with the highest viscosity numbers of 255 and 245 Redwood Seconds respectively, gave the most superior lubrication, followed by Groundnut oil with a viscosity of 225 Redwood Seconds while the poorest was Palmkernel oil with a viscosity of 191 Redwood Seconds. The performance of these oils was therefore found to be in accordance with their increasing viscosity. All the local oils are easy to apply onto workpiece because of their low viscosities.

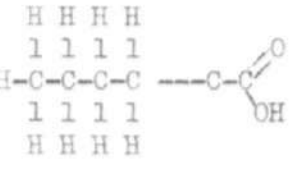
514 Chemical Analysis

The chemical analysis of each of the local oils showing their fatty acid composition, percentage of free acid content, iodine value, phosphorus content and saponification value are presented in Appendix 2A and 2B.

The action of fatty oils in reducing friction under boundary condition has been attributed to their molecular adherence to metal surfaces. The fatty acid content of the fatty oils adheres to the surface with sufficient strength to resist being turn off when the rubbing surfaces slide over each other. Molecules of fatty acids have carboxyl groups (the active end of the molecule) that attach themselves to the metal surface. Ordinary mineral oils like the Paraffins do not have this polar (active) group because they have a chain structure that is in equilibrium. Sometimes they are described as being made up of saturated molecules. The structure of fatty acid and Paraffin oil are shown below:



Paraffin oil



Fatty acid.

The structure of fatty acids bears a marked resemblance to the Paraffins but has the addition of an OH (hydroxyl) and an O (oxide), which form the unsaturated carboxyl group. The fatty acid molecules orient themselves

with the carboxyl groups at the metal surface. This results in the formation on the surface a film of fatty acid molecules all standing up from the surface. The forces of adhesion are sufficiently strong to resist removal of the fatty acid molecules. The layers actually isolate the surface forces of the two metals, and the friction, which would be high in the absence of a lubricant, is substantially reduced.

5.4.1 Fatty Acid Composition

The saturated fatty acid content of the local oils are myristic, palmitic, stearic, caprytic, capric, lauric, arachidic, beharic and lignoceric acids. However, with the presence of carboxylic groups, these acids help in maintaining a strong molecular adherence of the fatty oils to metal surfaces thereby minimizing friction.

The unsaturated fatty acid contents are the oleic and linoceric acids. These acids are by themselves reactive in addition to the presence of carboxylic groups. They therefore contribute more to the molecular adherence of the local oils onto metal surfaces. It is therefore not suprising to note that Cottonseed oil has the highest percentage of linoceric acid (46%) while Palmkernel oil has the lowest (2%) in conformity with their lubrication performance.

5.4.2 Iodine Value

The iodine value is a measure of the degree of unsaturated fatty acids in the oil. It indicates the

amount of reactive radicals present in them. These reactive radicals react under the prevailing conditions of high loads and pressures as encountered in deep drawing operations, thereby forming metallic soaps. These metallic soaps are formed at the workpiece/tool interface preventing metal-to-metal contact, thereby enhancing deep drawing operations.

Iodine value results show that Cottonseed oil has the highest value of 111.15 while Palmkernel oil has the lowest value of 18.67. The high iodine value of Cottonseed oil must have contributed to its improved deep drawing performance. However, a direct correlation between lubrication performance of these local oils and their corresponding iodine values gave no positive result.

5.4.3 Phosphorus Content

Phosphorus, like other reactive elements such as sulphur and chlorine have been extensively used over the years, either singly or in combination, to improve the lubrication performance of oils. Phosphorus reacts with metal surfaces to form metallic soaps thereby preventing metal-to-metal contact between work and tool. The presence of phosphorus in the local oils under investigation in relatively small amounts must have enhanced their lubrication performance. Cottonseed oil has the greatest phosphorus content of 0.105%, while in the other local oils, the phosphorus content ranges from 0.048 to 0.065%.

5.4.4 Free Acid Content

The percentage of free acid content in fatty oils indicates the ease at which the oil will turn rancid after exposure to the atmosphere for some time. It is therefore used as a measure of the stability of an oil. The free acid content of the local oils under investigation falls within the range of 0.11 to 5 percent for Cottonseed oil, Groundnut oil and Palmkernel oil. Palm oil has a free acid content ranging from 7 to 31%. The use of fatty oils with percentage free acid content over 16% is considered very prone to corrosion attack on the workpiece during sheet metal forming operation if effective degreasing system is not employed (Newby, 1976).

5.4.5 Saponification Value

This indicates the ease with which an oil can be effectively degreased in an alkaline medium. The higher the saponification value, the more difficult it is for the oil to be degreased. Cottonseed oil, Palm oil and Groundnut oil have saponification values ranging from 227-227 while Palmkernel oil has the highest saponification value of 285.55.

CHAPTER 6

SUMMARY AND CONCLUSION

The Swift simulative formability test has been employed in the present research work for the assessment of locally produced oils viz: Palm oil, Palmkernel oil, Cottonseed oil and Groundnut oil as lubricants in deep drawing operations.

As reported by Roberts (1978), the early use of fatty oils as lubricants in sheet metal forming operation dates as far back as prior to World War II, when Palm oil was the most widely used lubricant for cold rolling operations. Neckervis and Evans (1948) reported that 16% free acid content in Nigerian Palm oil provided better lubricity than the same oil refined until its free fatty acid content was reduced to 0.55 percent. However, the shortage of this oil resulting from its increasing domestic consumption rate spurred the search for substitute materials. This research led to the use of tallows, castor oil, Olive oil and a large number of other fatty oils of both animal and vegetable origins. These were gradually replaced with mineral oils which are readily available over a wide range of viscosities for use in metal forming operations.

Fatty oils are organic compounds consisting of predominantly fatty acids in a glyceride molecule. The fatty acids are of very long carbon molecules with carboxyl (polar) groups attached at one end. These polar

groups which are several molecules thick adhere strongly to work and tool surfaces thereby causing the long carbon chain to be oriented at approximately right angles to metal surfaces, thus minimizing metal-to-metal contact and friction.

Roberts (1968) reported that the mineral oils, like the Paraffin oil, on the other hand, do not possess high lubricity as the fatty oils because their compcnent hydrocarbon molecules are saturated. They do not therefore possess this polar group which help to maintain firm molecular adherence onto metal surfaces. However, Campbell (1932) claimed that there is some evidence to show that Paraffin hydrocarbons react with different metal surfaces but in a very mild manner by forming metallic soaps which help to minimize metal-to-metal contact and friction. The major parameter responsible for the lubricity provided by the mineral oils is viscosity. The high viscosity helps to disallow rupture of the lubricating film thereby preventing metal-to-metal contact and reducing friction.

Extreme Pressure (E.P.) Lubricants are typical examples of the use of mineral oils as coolants as well as carriers. These E.P. oils, like the E.P. 140 oil being investigated, are selected grades of mineral oils of high viscosity blended with organic compounds containing either sulphur, chlorine or phosphorus. Through chemical reactions with the metal surfaces, these additives form

solid surface films of metallic chlorides, sulphides or phosphides. These boundary films have a relatively low shearing strength so that rubbing between the interacting surfaces occurs in the additive film and thus protects the underlying metal.

The assessment of the local oils under investigation as lubricants in deep drawing operations was based on the Swift test parameters viz: the limiting drawing ratio, and the maximum drawing load. The resulting parameters were compared with those obtained for the widely used high grade industrial oil-Extreme Pressure (E.P. 140 oil) oil, and Paraffin oil as a lower standard.

Limiting drawing ratio results obtained showed that Cottonseed oil and Palm oil are the best lubricants amongst the local oils under investigation giving better performance than the high grade E.P. 140 oil. Groundnut oil and Palmkernel oil also gave favourable results compared with E.P. 140 oil.

Maximum drawing load results similarly confirmed above results indicating the excellent lubrication performance of Cottonseed oil and Palm oil as a more superior lubricant than E.P. 140 oil. Palmkernel oil and Groundnut oil also compared favourably with E.P. 140 oil. In most cases, however, Palmkernel oil gave the poorest lubrication performance.

The potentialities of these local oils as lubricants in deep drawing operations, having been studied in relation to the two different materials investigated, using different thicknesses and various tool geometries, showed consistent results. It was therefore concluded that irrespective of the tool geometry employed in the deep drawing operation, or the thickness of the material selected, the performance of the local oils as excellent lubricants is guarranteed in comparison with E.P. 140 oil.

Also, the consistency of the results of the Swift test was confirmed by employing the newly developed Kaftanoglu formability test in the deep drawing operation for the estimation of the limiting drawing ratio for each of the lubricating oils under a particular condition of tool geometry. Results from both tests gave good correlation.

However, the final evaluation of the local oils as lubricants in deep drawing operation was not only based on the Swift test results, but also on major factors such as method of application, toxicity and stability, ease of removal, and cost.

The relatively low viscosities of these oils at room temperature afford the opportunity of easier application onto a work and makes handling of work and finished product easier than is the case with the highly viscous E.P. 140 oil.

The tendency for deterioration of these local oils when exposed to the atmosphere is indicated by their percentage of free acid content. The free acid contains unsaturated hydrocarbons which are very reactive and on exposure to the atmosphere get oxidized. The products of oxidation results in deterioration of the oils leading to lowering of the lubricity of the oils. The local oils were found to possess high stability because of their relatively low free fatty acid content.

The local oils are easily degreasable in an alkaline medium as confirmed by their relatively low saponification values.

In view of the fact that lubricants presently used in the country in the various sheet metal forming industries are imported, foreign exchange will be saved if they are substituted with the locally available oils. Also the agriculturists will be encouraged to revive and boost the production of these oils.

In the present context, consideration is given to only the important lubricant selection factors peculiar to deep drawing operations. Factors such as fire point, flash point, pour point, cloud point etc as earlier mentioned (see Chapter 2) are not critical factors that could be considered in deep drawing operations using the local oils under the present investigation. The local oils under investigation are edible oils. Therefore

temperatures attained during cooking are quite practically unattainable during deep drawing of sheet metal and as such factors such as fire point, flash point, cloud point do not play a critical role. Pour point bears a little role in lubricant application, because solid lubricants can be applied onto workpiece by methods such as brushing, swabbing etc. Also, since deep drawing lubricant are not recycled for re-use, other factors were considered not critical.

On the foregoing, it is thereby concluded that the use of the local oils as lubricants in deep drawing operations is justified. It is however considered necessary that as a short-term measure, before the country can fully be self sufficient in the production of these oils, part-blends with mineral oils should be encouraged. This will not only enhance the lubricity of the currently used mineral oils, but will also save the country some foreign exchange as against the the present scheme of 100% importation. By this blending, the pour point, saponification value, and iodine value will even be lowered than when 100% local oils are used, thus implying easier application, easier degreasing and thus less tendency for deterioration.

Also, the use of chemical additives such as compounds of sulphur, chlorine or phosphorus could be used to assist in maintaining the viscosity of the local oils if they are to be used under the severest deep drawing operations. However, the choice of any particular additive should take cognisance of its reaction with metal surface as rightly suggested by Lee (1975).

On the foregoing, the research work is considered to have added a new dimension towards reviving the nation's economy by identifying and confirming the potentiality of some locally available materials for use in our sheet metal forming industries.

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APPENDIX 2(A): CHEMICAL COMPOSITION OF LOCAL OILS

FATTY ACIDS	CHAIN LENGTH	% IN COTTON SEED OIL	% IN PALM OIL	% IN GROUND-NUT OIL	% IN PALM-KERNEL OIL
MYRISTIC	14	1.0	1	-	17
PALMITIC	16	21.5	48	7.5	8
STEARIC	18	2.0	4	4.5	2
CAPRYTIC	8	-	-	-	3
CAPRIC	10	-	-	-	4
LAURIC	12	-	-	-	51
ARACHIDIC	2	-	-	3	-
BEHARIC	22	-	-	2	-
LIGNOCERIC	24	-	-	2	-
OLEIC	18	24	38	62	13
LINOLEIC	18	46	9	20	2

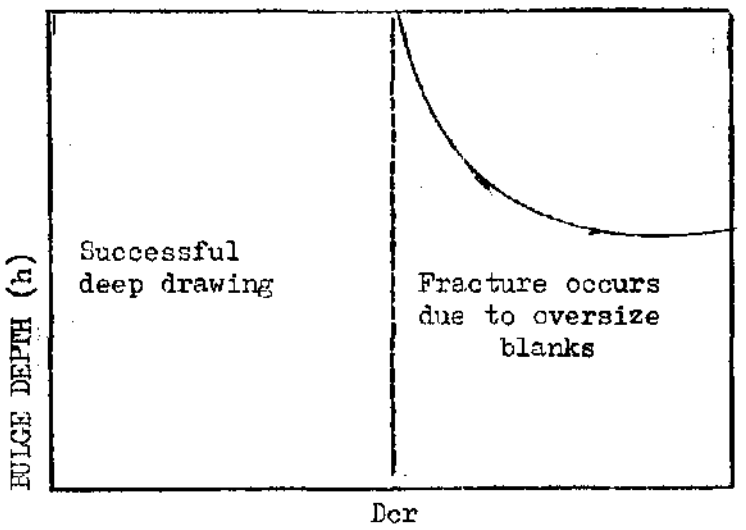
APPENDIX 2(B): FREE ACID VALUE, SAPONIFICATION VALUE, IODINE VALUE AND PHOSPHORUS CONTENT OF EACH OF THE LOCAL OILS UNDER INVESTIGATION.

LUBRICATING OIL	% FREE ACID	SAPONIFICATION VALUE	IODINE VALUE	% PHOSPHORUS CONTENT
PALM OIL	26.99-31.99	225.41-227.56	64.5	0.048
PALMKERNEL OIL	4.63	286.95	18.67	0.065
GROUNDNUT OIL	0.11-0.24	223.04-230.23	106.01	0.067
COTTONSEED OIL	0.11-0.32	221.39-227.84	111.15	0.105

APPENDIX 3(A)

KAFTANOGLU'S METHOD OF ESTIMATING LIMITING DRAWING RATIO (LDR)

In deep drawing, if oversize blanks are used, fracture would occur over the punch head before the drawing of a full cup, at a certain punch travel or bulge depth. Bulge depths, when plotted against initial blank diameters of oversize blanks would produce a smooth curve as shown below.



DIAMETER OF BLANK (D_b)

Variation of bulge depth with blank diameter,

The above characteristics curve can be approximated by exponential relationship of the following type:

$$D_b = M \exp(-Nh) + Dcr \quad - - - \qquad (1)$$

Where M, N and Dcr (Limiting blank diameter) are constants. It is observed that when: $h \rightarrow \infty$

then $D_b \longrightarrow Dcr$

In equation (1) there are three unknowns, namely M, N and Dcr. These can be determined if three points are known from experiments on the characteristic curve. Hence, the three sets of D_b and h values when substituted in equation (1) produce the following equations:

$$D_b,1 = M \exp(-Nh_1) + Dcr \quad \text{---------- (2)}$$

$$D_b,2 = M \exp(-Nh_2) + Dcr \quad \text{---------- (3)}$$

$$D_b,3 = M \exp(-Nh_3) + Dcr \quad \text{---------- (4)}$$

Substracting equation (3) from equation (2):

$$D_b,1 - D_b,2 = M \left[\exp(-Nh_1) - \exp(-Nh_2)\right] \text{ --- (5)}$$

Substracting equation (4) from equation (2)

$$D_b,1-D_b,3 = M\left[\exp(-Nh_1) - \exp(-Nh_3)\right] \text{ --- (6)}$$

Dividing equation (5) by equation (6):

$$\frac{D_b,1-D_b,2}{D_b,1-D_b,3} = \frac{\exp(-Nh_1) - \exp(-Nh_2)}{\exp(-Nh_1) - \exp(-Nh_3)} \text{ ------- (7)}$$

In equation (7) the only unknown is N, since the three values for D_b and h are known from experimental results. The equation can be solved for N by a trial and error computation. Using this value of N, M can be calculated from either of equations (5) or (6). With these values of M and N, Dcr can be computed from one of equations (2), (3) or (4).

Thus:

$$\text{Limiting drawing ratio (LDR)} = \frac{Dcr}{d}$$

Where d = Punch diameter.

APPENDIX 3(B): Computer Programme based on Kaftanoglu's method of estimating Limiting Throwing Ratio (LTR). See attached computer print-outs.