SUITABILITY OF LOCAL VEGETABLE OILS FOR COLD EXTRUSION OF ALADJA ST60-2 STRUCTURAL STBEL.

BY

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A Thesis submitted to the Postgraduate School, Ahmadu Bello University, Zaria, in partial fulfillment of the requirements for the award of the degree of Master of Science (M.Sc) in Metallurgical Engineering.

DECLARATION

I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It has not been accepted in any previous application for higher degree. All quotations are distinguished by quotation marks and the sources of information are acknowledged by means of references.

G. B. Nyior

CERTIFICATION

This thesis entitled, "Suitability of local vegetable oils for cold extrusion of Aladja ST60-2 structural steel" by G. B. Nyior, meets the regulations governing the award of the degree of Master of Science (M.Sc.) (Metallurgical Engineering) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

The performance of some vegetable oils (palm oil groundnut oil, soya bean oil, and shea butter oil) as lubricants in the cold extrusion of Aladja ST60-2 structural steel has been investigated in the direct extrusion of 13mm diameter slugs with different initial billet lengths at various extrusion ratios and speeds.

The performance criteria employed are the coefficient of friction, surface finish of extrudates and hardness values taken radially along the cross section of extruded billets. To set a standard for comparison, the test results (coefficient of friction, surface finish and hardness values) obtained for the oils were compared with those obtained for the standard zinc phosphate/sodium stearate lubricant.

Based on frictional values, at lower reductions and speeds, the vegetable oils especially soya bean oil and groundnut oil gave a performance almost at par with the standard zinc phosphate/sodium stearate lubricant. The other vegetable oils too gave a favourable performance compared to the standard lubricant. At the higher reductions and extrusion speeds all the oils performed better than the standard lubricant. On the basis of frictional values obtained at higher reduction and speed, the performance of the oils as lubricants for extrusion in descending order is, soya bean oil, groundnut oil, shea butter oil, palm oil and zinc phosphate/sodium stearate.

From the results obtained, the surface finish varied in the same direction as the coefficient of friction. The order

of performance of the oils in terms of surface finish was therefore similar to that for the frictional condition.

The variation in hardness from the edge of the extruded billets to the centre is not much different for the various lubrication conditions. the variation from the edge to the centre is found to decrease as the extrusion ratio increases.

The correlation of performance with physico-chemical properties of the oil shows that the order of performance of the vegetation oils using the parameters of friction coefficient and surface finish is in the same direction as their iodine value. The higher the iodine value of an oil, the better its lubrication performance. In terms of hardness, it has been observed that the higher the iodine value of an oil the lower the hardness obtained on the extruded billet.

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NOTATIONS

μ	=	Coulomb's Coefficient of Friction
τ	=	Tangential or Shear Stress
ρ	=	Pressure
m	=	Shear Factor
L	=	Length of Land of Die
R_o	=	Original (initial) Radius
R_f	=	Final Radius
α	=	Semi Die Angle
$f(\alpha)$	=	Function of Semi Die Angle
σ_o	=	Yield Stress
σ_{xb}	=	Back Push Stress
σ_{xf}	=	Front Pull Stress
K	=	Shear Yield Stress
Y	=	Normal Yield Stress

CHAPTER ONE

INTRODUCTION

1.1 Historical Development Of The Extrusion Process:

The permanent deformation accomplished by applying mechanical forces to a metal surface has, as one of its primary objectives, the production of specific shapes or sizes. Among the well known shape producing methods is extrusion. Extrusion can be defined as the technological process in which a block of material is forced to flow by compression through an orifice or holes of smaller cross-sectional area for the purpose of obtaining a product which consists approximately of similar shape and size. The work material may be of solid metal, sintered alloy, plastics or other materials.

Extrusion has a long history. The concept of extrusion as a forming process can be traced back to a patent granted in 1797 to Joseph Bramah a famous British Engineer, for a machine to manufacture pipes from lead and other soft metals. There is no evidence though that Bramah's machine ever produced pipes. By the 19th Century, great success had been achieved in the extrusion of lead, first in the production of pipes. Methods by which a lead sheath could be directly extruded on to electric cables were also developed in 1879 by Borel in France and Wesslau in Germany (Pearson and Parkins, 1960). According to Radford and Richardson (1978), Copper alloys were first extruded in 1894 by Dick, a

founder of the Delta metal company. The extrusion of copper alloys was the turning point in the development of the process and made extrusion one of the major methods of metal working.

As is well known, the operation of cold extrusion is not new. It was first carried out more than 100 years ago for the manipulation of soft ductile materials particularly lead and aluminium, and to this day extrusion is used, to a considerable extent, for the manufacture of aluminium products for pharmaceutical, packaging in general and the radio industry; in fact, it seems highly likely that the very existence of the process has served to influence some designers to conceive products that would take advantage of the process.

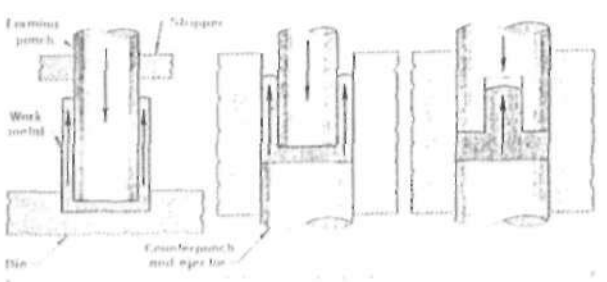
As far as steel is concerned, the process was originally developed in Germany during the 1930's and after the end of the war, attention was focused on it for both military and civilian applications particularly in America, Germany and Great Britain.

Since the process of cold extrusion of steel first received world wide prominence, much has been written about it and a considerable amount of research and development effort has been expended in order to provide answers to many of the problems involved in plastically deforming steel into various shapes.

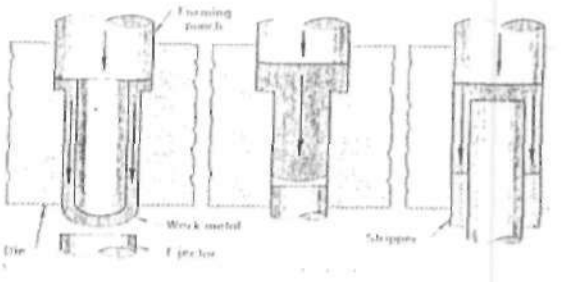
1.2 Extrusion Methods:

In the process of extrusion, a billet (slug) is placed in an enclosed chamber. The chamber has an opening through which the excess material escapes as the volume of the chamber is reduced by the pushing of a ram at the back of the billet. The escaped material has a uniform cross-section identical with that of the opening.

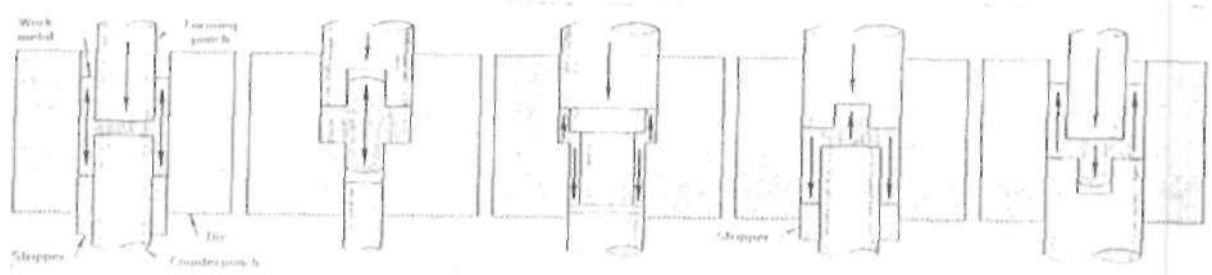
Three basic methods are employed to produce extrusions. In all these methods, the volume of metal remains unchanged during the change in shape from slug to finished part. The pressure required depends primarily on the materials mechanical properties, the reduction in area and the efficiency of lubrication.Extrusion involves forward or (direct), backward or (indirect) or combined backward-and -forward displacement of metal by plastic flow under steady though non uniform pressure.



(a) Backward Extrusion



(b) Forward Extrusion



(c) Combined backward and forward extrusion

Fig.1.1 Displacement of metal in extrusion

(a) Backward, (b) Forward, and (c) Combined backward and forward extrusion.

1.2.1 Forward Extrusion:

In forward extrusion schematically shown in Fig.1.1 (b) metal is forced to flow in the same direction as punch movement. A slug is placed in a die cavity (container) having a diameter slightly larger than that of the slug and pressure is applied to the top of the slug by a punch entering the die cavity. In pure forward extrusion the punch closely fits the upper part of the die cavity to prevent backward flow of the metal. Instead the metal is forced to flow ahead of the punch through an orifice immediately under the die cavity, thus producing a part that is smaller in diameter than the original slug. Metal leaves the die orifice at a speed greater than that of the punch and flows a considerable

distance beyond the end of the punch. The increase in speed of the metal is proportional to the reduction in cross-sectional area. Forward extrusion is generally used to produce bolts and screws, stepped or tappered-diameter solid shafts, or thin-walled tubular parts having thick flanges.

1.2.2 Backward Extrusion:

In backward extrusion (some times called reverse or indirect extrusion), the material is forced to flow in a direction opposite to the direction of punch movement as shown in Fig.1.1 (a). A slug of the material is placed in a stationary die cavity and pressure is applied to the top of the slug by means of a press-ram actuated punch. Metal is displaced upwards through the annular opening between punch and die which is called the die orifice and rises along the punch.

Configuration and size of the punch controls the desired external shape and dimensions of the part being extruded. The die cavity shape controls the external contour of the part and the clearance between the punch and die determines the wall thickness. Thickness of the bottom or web is established and maintained by the distance the punch travels (stroke of the press) and is independent of the wall thickness. Backward extrusion is an ideal method for producing shells, tubular parts or other symmetrically shaped hollow components having closed bottoms or a web at one end of the part. Circular, oval,

square, rectangular or other shapes of cross-sections can be produced and ribs can be formed on the external and internal walls.

In backward extrusion there is generally little change in outside diameter (from slug to finished part) but the length is increased in proportion to the reduction in cross-sectional area. It is possible to backward extrude parts having steps to different diameters on their peripheries and also a wide range of cross-sectional shapes.

1.2.3 Combination Extrusion (Impact Extrusion):

Sometimes both forward and backward extrusion methods are combined so that some of the work metal flows backwards and some forward as shown in Fig.1.1 (c). The conventional process of impact (piercing) extrusion is basically a rapid form of backward extrusion characterised by a shallow die and minimum contact between the work and die (Fig. 1.1 (a)). The impact extrusion is used in the production of non-ferrous collapsible tubes and similar components.

While reduction in area possible with combination extrusion is less than obtained with either forward or backward extrusion alone, intricate parts that could not be made with either method singly can be formed in a single operation.

1.2.4 Hot and Cold Extrusion

As a result of the magnitude of the forces involved in the extrusion process, it is often necessary to heat up the billet prior to extrusion. This is to decrease the deformation resistance of the metal. Based on the initial temperature of the billet, the extrusion process may be divided into hot and cold extrusion.

In hot extrusion, metals are extruded at high temperatures so as to take advantage of the decrease in flow stress. The upper hot working temperature depends on the temperature at which hot shortness occurs or for pure metals the melting point. Many of the components produced by cold extrusion can also be produced by other processes such as hot forging, machining and sometimes casting. However, cold extrusion is used when the process is economically attractive because of:-

(1) Savings in material,

(2) Reduction or elimination of machining and grinding operations because of good surface finish and dimensional accuracy of cold extruded parts,

(3) Elimination of heat treatment operations because of increase in mechanical properties of cold extruded parts.

Extrusion in general is an attractive process for numerous reasons. Many shapes can be produced by extrusion including those containing re-entrant angles or longitudinal holes. No draft is required thereby enabling the saving in material. Since extrusion is

compressive in nature, the amount of reduction in a single step is limited only by the capacity of the equipment. Billet-to-product area ratios in excess of 100:1 have been quite common with weak metals. In addition extrusion dies are relatively inexpensive. Since major changes require only a single die change, small quantities of a desired shape can be produced economically by extrusion. The major limitation of the process is the requirement that the cross-section must be the same for the entire length of the product extruded.

The ease with which a metal may be extruded is determined by its ability to undergo plastic deformation without failure and its resistance to deformation since this governs the capacity of the equipment. The magnitude of the reduction possible before failure occurs is dependent on a number of factors such as lattice structure, temperature, thermal conductivity, alloying constituents, occurrence of phase changes, presence of localized stresses etc, and on mechanical factors such as tool and workpiece configuration, rate of deformation, lubrication etc. This thus brings us to the question of ability to efficiently extrude a given metal i.e extrudability.

Extrudability according to Mondolfo et al, (1975) is one of those complex properties that have different meanings to different people. To some, the term 'good extrudability' means the ability to push complicated shapes with low pressure; to others it means achievement

of high production rates. A third group is mainly concerned with the fidelity of reproduction and surface finish of the extruded shape; and in some cases, absence of cracking is the paramount criterion.Before any measure of extrudability can be carried out, it is necessary to define the property to be measured.

The application of the zinc phosphate-sodium stearate system of lubrication in cold extrusion is very expensive in terms of capital outlay and running costs. The system requires a skilled attendant in order to check the strength of the various chemicals at regular intervals if steady efficient results are to be maintained at all times. This project is therefore being undertaken with a view to exploring possibilities of obtaining a cheaper and simpler lubrication system for the cold extrusion of steel. Specifically palm oil, groundnut oil, soya bean oil and shea butter oil which are vegetable oils produced locally are being investigated as cold extrusion lubricants.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 MECHANICS OF METAL EXTRUSION:

Historically, the originator of the scientific study of extrusion was Tresca (1864). The first systematic researches on this subject are considered to be those of Siebel and Fangmeier (1931) and Eisben and Sachs (1931). Their work was comprehensive and is repeatedly quoted even today.

The analysis of extrusion process was based on the so called "total strain theory" until the appearance of Hill's work (1948) using slip line theory.

As slip line field techniques were found fairly effective techniques in understanding the extrusion process (especially in accounting theoretically for its inhomogeneous nature) Green (1955) and principally Johnson (1954) thereafter applied it to various plane - strain problems.

A vast amount of experimental work has been done to date. Most of it however, pay no attention to recent theoretical achievements. The monograph of Johnson and Kudo (1962) however gave explanations of the analytical procedures, summarized and discussed the results of recent theoretical work on the mechanics of the extrusion process. Attention was paid to the correlation of practical or experimental observations and theory.

In recent times, analytical study of the process has been undertaken. Frisch and Thomson (1959) studied the effect of die opening design on extrusion pressure. Thomson et al (1954) studied the detailed flow characteristics of the metal and analysed the strain and stress fields. Studies with a view to predicting the extrusion stress through the upper bound approach were undertaken by Kudo (1960). Yang (1962), and Avitzur (1965).

Steel extrusion was not commercially practicable until 1930, but it has advanced very rapidly, particularly with the introduction of molten glass lubrication by Sejournet. This is a considerable improvement on lubrication with graphite, giving lower extrusion pressures, better die life and the possibility of using longer billets. Most carbon and stainless steels are now extruded at about 1,200°C with glass as the lubricant though other materials are beginning to compete with glass.

There has in recent years been a revival of interest in cold extrusion, which is now possible even with steels using an impact technique. There may be very large differences in section in the same product and the whole slug can be used; for example, making a tube with a heavy flange in one operation.

At present the theory is applicable only to the simpler processes. Stress evaluation is of little value in predicting extrusion loads because the reductions of

area are very large necessitating large die angles, often 180°, which introduce considerable inhomogeneity in the deformation. There is appreciable redundant work in all practical extrusions. Plane-strain solutions apply to a small proportion of real extrusion problems, but the type of equation deduced from slip line fields can be applied also to extrusions of round bars. Many extruded sections can be represented approximately by equivalent flat strips or round bars for load calculations. The flow pattern predicted by slip-line fields also closely resemble practical patterns in both flat strip and round bar. Upper-bound theory has been extensively applied to extrusion of various types. As in drawing there is an optimum die angle for a given set of extrusion parameters but the uncertainty in the frictional contribution makes prediction of the angle less accurate for extrusion. However, it is possible to depart considerably from the optimum without seriously increasing the pressure and other factors such as lubricant retention may determine the choice of die angle. Theory is of much use in extrusion for predicting working loads and, with less accuracy, deformation patterns.

The basic characteristic of any extrusion process is normally presented in the form of curves relating punch load or extrusion pressure with punch travel or displacement. The idealized curves for direct and indirect extrusions are shown in Fig.2.1. The figure, according to Watkins et al (1958), can be considered as

consisting of five stages. In stage I the material is compacted until it fills the extrusion chamber; it is further compressed at increasing pressure in stage II until material begins to flow through the die. Throughout stage III, the material continues to extrude and pressure required progressively decreases during the direct process but remains constant during the indirect process.

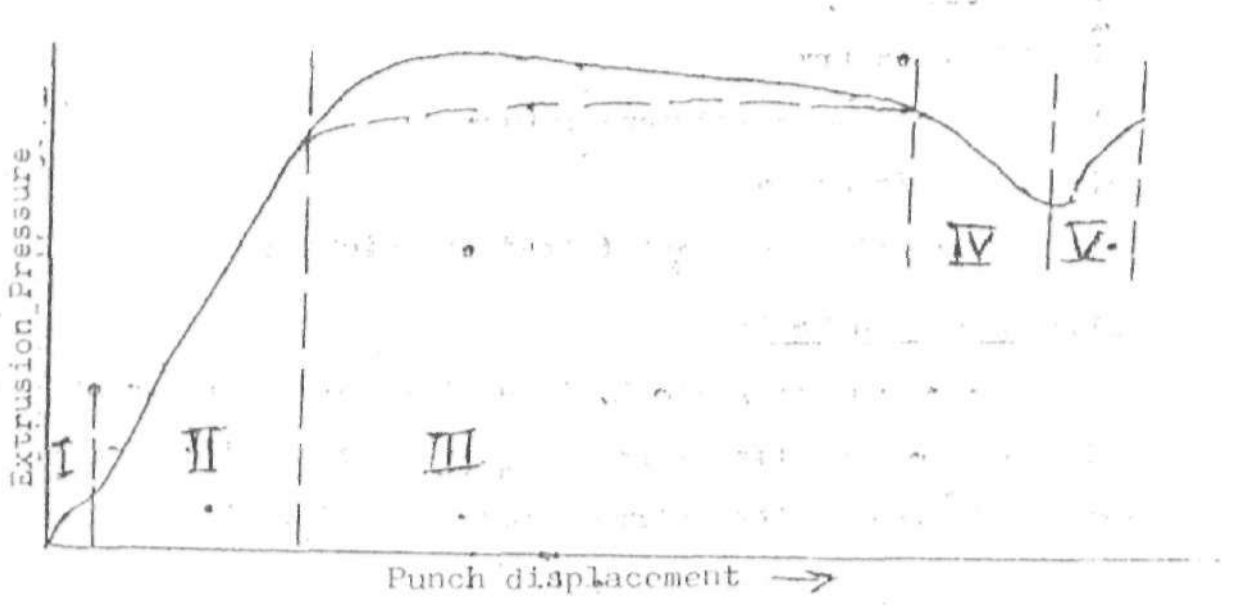


Fig.2.1 - Idealized characteristic curves for extrusion

———— Direct (foward) extrusion

— — — — Indirect (Backward) extrusion.

The incidence of the piping defect results in a more rapidly decreasing pressure during stage IV until a minimum value is obtained. At this stage, the punch is in contact with the thin disc of material remaining in the chamber and the extrusion pressure rises sharply throughout stage V with very little flow of material. Any departure from these idealized conditions of an actual extrusion will be reflected in the characteristics curve obtained.

Johnson (1956) recognises three stages only, defined as the coining phase, the steady state phase and the unsteady state phase with its origin at the coring point, that is the position at which piping begins. Although many workers use the maximum extrusion pressure as the basis for comparing data, Johnson prefers the value of pressure at which coring begins.

2.2 Main Variables in the Extrusion Process:

The effect of any single factor on the extrusion process is usually assessed from results of tests in which only that factor is varied. This assessment is usually based on a comparison of the basic punch load - punch travel curves and of the flow patterns before and after the factor is varied. It is tacitly assumed that the factors are mutually independent and are not complicated by metallurgical considerations. The principal variables which influence the force required to cause extrusion include:-

(a) Extrusion Ratio

(b) Die Geometry

(c) Working Speed and Temperature

(d) Slug Dimension

(e) Lubrication and the Coefficient of Friction

2.2.1 Extrusion Ratio:

The extrusion ratio R, is defined as the ratio of the original cross-sectional area A_o, divided by the cross-sectional area of the extruded material A_f, ($R = A_o/A_f$). Since volume of material remains constant, the extrusion ratio may also be calculated by increase in length. For example an extrusion ratio of 4 to 1 indicates that the length has increased by a factor of four. The metal being extruded has a large effect on the maximum ratio that is obtainable. Some typical approximate maximum extrusion ratios obtainable (ASM, 1973) are 40 for 1100 aluminum alloy, 5 for 1018 steel and 3.5 for type 305 stainless steel. Generally extrusion pressure increases with extrusion ratio. An examination of the flow pattern of some extruded metals by Watkins et al (1954), reveals different patterns for different reductions. It is found that in the extrusion of rod, increase in reduction results in greater flow of metal along the axis as compared with that at the periphery and there is less tendency to form dead-metal zones.

Due to the fact that an increase in extrusion ratio results in a corresponding increase in the amount of cold deformation, the effects of work-hardening normally will vary directly with extrusion ratio.

2.2.2 Die Geometry:

The angle of the die, the lead-in radius, the length of the land and the fillet radius at the entry corner between the die and the container are normally designed in such a manner as to improve the metal flow, to reduce the pressure or to minimize tool wear.

The dimensional accuracy and surface quality of the extruded product is dependent on tool design. Tool design requires a knowledge of the flow characteristics of the metal at the extrusion temperature, the thermal and mechanical stresses which have to be accommodated and the technique of producing balanced flow of metal into all parts of the die (Laue, 1955). Although flat dies with 90° half-die angle are used for most extrusion experiments, extrusion through wedge-shaped dies have shown that the extrusion pressure decreases with decreasing die angle (Johnson and Kudo, 1962). More uniform deformation of the metal results with small angle dies. For a metal which exhibits strain hardening, dead metal zones are observed when the die angle is large. In cold extrusion of eleven steels with a reduction of 65 per cent, Hauttmann, (1951) found that the maximum pressure required to extrude slugs through a die of 40°

conical entry was 30 per cent less than that for the sharp edged die.

In tests conducted by Watkins et al (1954), in which specimens of lead, Aluminium, Copper and Brass have been extruded at various reductions through dies having profiled entries of radii ranging from 1.27mm to 6.35mm and of cone angles ranging from 60° to 170°, examination of the punch load - punch travel diagrams has shown that the initial build up in extrusion pressure to the maximum value is much more gradual for radiused or conical entry dies than it is for the sharp - edged die. This is presumably due to the greater movement of metal required during the compacting stage. An examination of the flow patterns indicates that increasing the radius or decreasing the cone angle of a profiled entry die is particularly effective in suppressing the central piping defect or coring. The deformation zone becomes more and more localized near the die aperture the greater the radius and the smaller the cone angle.

2.2.3 Working Speed and Temperature:

The effect of working speed and the general temperature level of extruded material are usually combined. The strain-rate of material is directly proportional to the working speed and the billet temperature increases with speed. Thus the combined effect of the speed and temperature influences principally the yield stress of the material and

accordingly the extrusion pressure.

Speed and temperature also seriously interfere with the friction between the material and the tools. It is generally supposed that the friction coefficient does not vary with speed when using solid lubricants and that it decreases with increasing speed when low viscosity lubricants are used. Temperature may have positive or negative effects on the friction. For instance organic lubricants will either deteriorate by burning or improve through oxidation. In many cold extrusion tests, i.e in extrusion at temperatures below the recrystallization point of the material, the extrusion pressure is observed to decrease with decreasing speed, especially when the reduction in speed is high (Johnson and Kudo, 1962). For slow speed extrusions at room temperature, the process may be regarded as isothermal and the yield stress of the material and accordingly the extrusion pressure will depend on the extrusion speed and strain rate of the operation respectively. Friction coefficient does not alter significantly with speed. As the speed increases, the temperature rise caused by the plastic and frictional work increases and the yield stress of the material is lowered.

As pointed out earlier the effect of temperature is generally coupled with that of extrusion speed. In hot extrusions, the container and other tools are usually cooler than the billet, thus causing a cooling of the billet when the extrusion is carried out slowly. On the

other hand, the heat generated by the plastic working lowers the extrusion load towards the end of the process if hot extrusion takes place (Johnson and Kudo 1962).

Extrusion when heat conduction plays a conspicuous role results in non-uniformity of the yield stress throughout the billet which considerably complicates the flow behaviour of the material. Hirst and Ursell (1958), on calculating the mean temperature rise in a fast extruded rod, heat conduction being neglected, have suggested the use of an average yield stress value to the initial and extruded mean temperatures.

According to Dieter (1981), a tenfold increase in the speed of extrusion results in about a 50% increase in pressure. Johnson (1958), in the determination of how the extrusion load is altered with the speed of the punch in the extrusion of pure lead and tellurium lead alloy, found that extrusion load increases with speed. For a given increment in speed however, the effect on the load is more pronounced the slower the operation.

2.2.4 Slug Dimensions:

Most of the mild steel components produced by cold extrusion are relatively short, the starting billet usually having an initial length to diameter ratio equal to or less than unity (Pugh H.LL.D, 1966). However, there is requirement for the production of longer components and hence the need for more information on the effect of billet length.

Johnson (1958) observed that the maximum pressure required for the forward extrusion of rod decreases with decrease of billet length. This may be due in part to the relative movement between the billet and the chamber wall resulting in an increase in frictional losses with increasing billet length.

In the direct extrusion of copper lead slugs of different length - diameter ratios by Chang (1950), it was found that the maximum value of extrusion pressure was not developed until the slug length - diameter ratio was unity and for higher values appeared to be independent of slug length.

2.2.5 Lubrication and the Coefficient of Friction:

In order to check the theoretical solutions, the best possible surface finishes for the tools and the best lubricants are required. Every time an extrusion is carried out, it is necessary to lubricate the container, the die and the punch in some way to avoid seizure which would almost certainly occur without lubrication. Infact, it is unlikely that a hot extrusion could be made if the tools have not been lubricated. The lubricants in general use are graphitic ones and glass, the later being covered by the Ugine - Sejournet patent. Petroleum jelly, white lead in oil, molybdenum - disulphite, graphite in tallow, lanolin and wax have been used for room temperature tests with lead and aluminium.

In extrusion and related processes most of the

billet or slug surface is in contact with the tool, thus resulting in large frictional effects. It was pointed out by Johnson (1956) that none of the means of minimizing friction as mentioned above is entirely satisfactory. Thomsen and others (1954) found that extrusion pressure decreased about 10% with the conduction of tests step wise i.e by taking billet out of container after each small step and re-lubricating before continuing the test.

Despite theoretical assumptions that there is a constant frictional coefficient, a number of measurements reveal that it varies and depends greatly on the speed of sliding, contact area, pressure and on the whole history even for a given set of contiguous materials and lubricants (Bowden and Tabor, 1950).

The state of friction during extrusion and similar processes is more complex than in simple compression. At the very beginning of an operation, excess lubricant will be squeezed out and the remaining portions will be trapped between the tool and the surface of the material. The trapped lubricant will not be squeezed out because of the wide area of contact unless it is taken out by the material which moves out of the orifice. No lubricant, however, will be supplied or drawn in between the interfaces.

Owing to the complexity of the friction state in extrusion and the large variations of the friction coefficient from point to point and stage to stage, the

direct measurement of the friction coefficient on the surface of the deformation zone is especially desirable if it can be performed. Recent works towards achieving this goal are thus being reviewed.

2.3 Friction and Lubrication in the Cold Extrusion of Metals:

2.3.1 Friction Phenomena:

One of the important forces which must be considered in any metal working operation is that of friction between the tool and the work piece. Whenever there is relative motion between two bodies in contact there is a resistance to this motion. This resistance is called friction. The magnitude of the force (frictional force) is important in determining the overall power requirements. In addition, the force influences the structure and the properties of the final product as well as the life of the tools.

Friction may be assumed to either obey Coulomb's Law of friction or to be a constant proportional to the flow stress of the material. If friction is assumed to obey Coulomb's Law, then

$$\tau = \mu P \qquad 2.2$$

The tangential stress τ at any point is proportional to the pressure (P) between the die and the material. The coefficient of friction is taken as a constant for a given die and material under constant surface and temperature conditions.

If friction is assumed constant, then

$$\tau = m\frac{\sigma_o}{\sqrt{3}} \qquad 2.3$$

The shear factor m is taken as constant for a given die and material under constant surface and temperature conditions. For no friction condition, m is zero, and maximum possible friction is denoted by m = 1.

2.3.2 Measurement of Friction Coefficient:

As highlighted above it is assumed in practically all metalworking theory that the tangential stress τ at the surface of the workpiece is directly proportional to the normal stress P in the presence of a lubricant. From equation 2.2, a coefficient of friction which can thus he defined, is analogous to the familiar ratio of tangential and normal forces in elementary physics. The tangential stress τ is however, limited to a value equal to the shear yield stress, k of the metal itself. As the least value of the normal stress which can cause plastic flow is Y, the uniaxial yield stress, the maximum value of the coefficient of friction for full sticking condition is given by the ratio K/Y. These quantities are, of course related in accordance with the yield criterion.

Using Von Mises criterion.

$$2k = 1.155Y \qquad 2.4$$

$$Thus\ \mu max = k/y = 0.577 \qquad 2.5$$

The Tresca criterion gives

The condition of constant coefficient of friction is

usually known as slipping friction. The coefficient of friction may actually vary through a working pass as the lubrication deteriorates due to thinning of the film and extension of the surface. Experimental studies suggest, however that this is negligible for all well-lubricated operations.

There is at present no generally accepted method of measuring the values of the coefficient of friction for given surfaces and lubricants. Various factors can influence the result, and it is essential that test conditions such as surface geometry, chemical condition, lubricant film thickness, temperature, speed, environment and degree of deformation should match as closely as possible the actual conditions of the operation. This implies that the only strictly reliable friction data to use are those obtained from measurement during the operation considered. Special instrumentation to measure the average Coulomb coefficient of friction is described by Wistreich (1955) and Yang (1961). There, a special split die or a split die constrained by an instrumented load ring (Yang, 1961) is used. Yang (1961) describes measurement of friction in approximately plane-strain drawing. Whitton and Ford (1955) described experimental work on an instrumented rolling mill. The coefficient of friction for various materials and lubricants was evaluated through the measured separation force and roll torque.

The present investigation is based on Evans - Avitzur's experimental procedure (Evans and Avitzur, 1968) for the evaluation of friction coefficient for processes like wire drawing and rod extrusion through an open die. The procedure assumed friction either to obey Coulomb's law ($\tau = \mu P$) or to be constant proportional to the flow stress of the material.

In the test procedure, a wire of initial radius (R_o) is drawn through the conical portion of the die as depicted in the geometry of die and wire of figure 2.2. The cylindrical portion of the die causes friction losses, but it is required for dimensional accuracy.

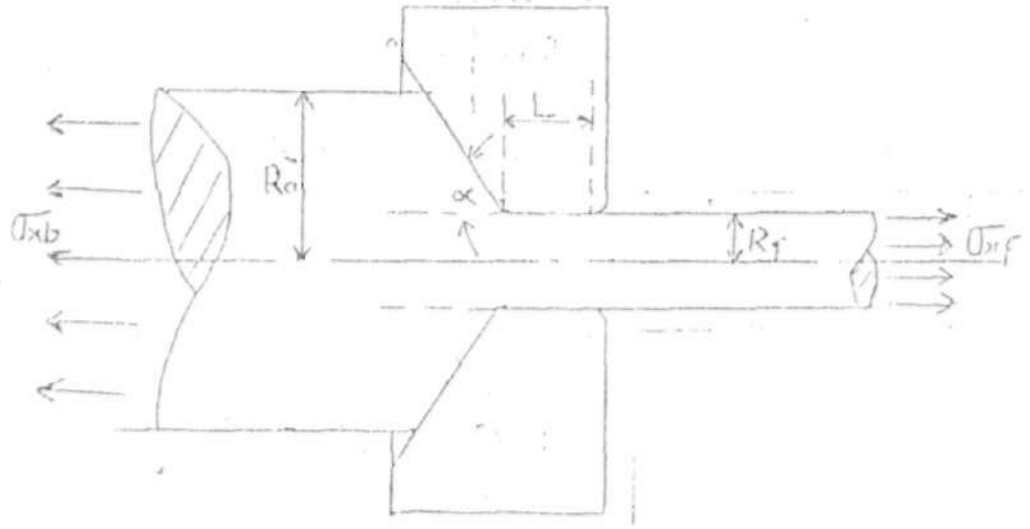


Figure 2.2 Die and Wire

As previously established (Wistreich, 1961, Avitzur 1964, 1965, Avitzur and Sortais, 1966), forces required during flow through conical converging dies are dependent on the cone angle. There always exists an optimal cone angle which requires the minimum force. With too small a cone angle (smaller than the optimal cone angle) the

drawing force is high because the length of contact between the wire and the die is high causing significantly high frictional losses. With too large a scone angle (larger than the optimal cone angle), the distortion becomes a predominant factor causing high forces.

Rased on energy method, the relative drawing stress for open die extrusion can be expressed as follows:-

$$\frac{\sigma_{xb}}{\sigma_o} = \frac{\sigma_{xf}}{\sigma_o} - 2f(\alpha)\ln\frac{R_o}{R_f} - \frac{2}{\sqrt{3}}\left[\frac{\alpha}{Sin^2\alpha} - Cot\alpha + m(Cot\alpha)\ln\frac{R_o}{R_f} + m\frac{L}{R_f}\right] \quad 2.7$$

When friction is assumed to obey Coulomb's law of friction, the relative extrusion stress for open die extrusion becomes (Avitzur, 1964):-

$$\frac{\sigma_{xb}}{\sigma_o} = \frac{\sigma_{xf}}{\sigma_o} - 2f(\alpha)\ln\frac{R_o}{R_f} - \frac{2}{\sqrt{3}}\left[\frac{\alpha}{Sin^2\alpha} - Cot\alpha\right]$$

$$- 2\mu\left[(Cot\alpha)\left[1 - \frac{\sigma_{xf}}{\sigma_o} + \ln\frac{R_o}{R_f}\right]\ln\frac{R_o}{R_f} + \left(1 - \frac{\sigma_{xf}}{\sigma_o}\right)\frac{L}{R_f}\right] \quad 2.8$$

The function $f(\alpha)$ for equations (2.7 and 2.8) is

$$f(\alpha) = \frac{1}{Sin^2\alpha}\left[1 - (Cos\alpha)\sqrt{1 - \frac{11}{12}Sin^2\alpha} + \frac{1}{\sqrt{11.12}}\ln\frac{1 + \sqrt{\frac{11}{12}}}{\sqrt{\frac{11}{12}}Cos\alpha + \sqrt{1 - \frac{11}{12}Sin^2\alpha}}\right] \quad 2.9$$

With the assumption of Coulomb's coefficient of friction, the friction value for open die extrusion is found from equation 2.8 as:

$$\mu=\frac{1}{2}\frac{\frac{\sigma_{xf}}{\sigma_o}+2f(\alpha)\ln\frac{R_o}{R_f}-\frac{2}{\sqrt{3}}\left[\frac{\alpha}{Sin^2\alpha}-Cot\alpha\right]-\frac{\sigma_{xb}}{\sigma_o}}{\left[(Cot\alpha)\left[1-\frac{\sigma_{xf}}{\sigma_o}+\ln\frac{R_o}{R_f}\right]\ln\frac{R_o}{R_f}+\left(1-\frac{\sigma_f}{\sigma_o}\right)\frac{L}{R_f}\right]} \qquad 2.10$$

Based on previous investigations into forward rod extrusion (Lange and Steck, 1966) a tapered die with 2α = 60° orifice angle was used.

2.4 Lubrication in the Cold Extrusion of Steel:

Every time an extrusion is made, it is necessary to lubricate the container, the die and the mandrel in some way to avoid seizure which would almost certainly occur without lubrication.

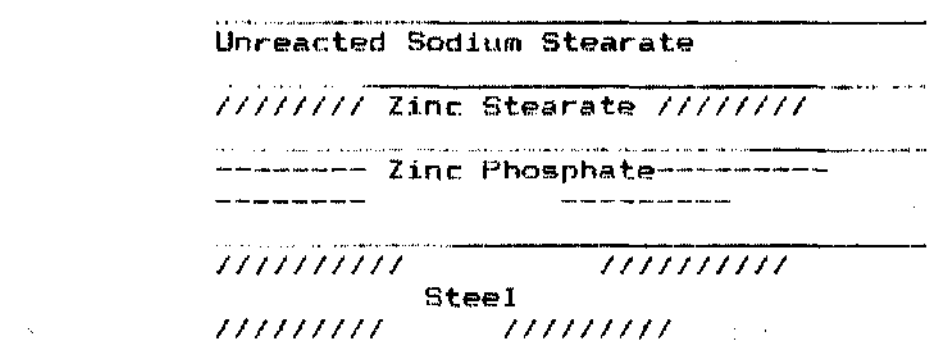
The cold extrusion of steel was not possible till 1934 when Singer patented the use of a zinc phosphate coating on the surface of the steel billet to act as a carrier for the metal-working lubricant. Today, despite its relatively high cost and other limitations, this method of lubrication is still a standard treatment in use. In the zinc phosphate - soap mode of lubrication, the zinc phosphate coating is usually applied by immersing the billet in a solution containing zinc phosphate, phosphoric acid, nitric acid, sodium or nickel nitrate, and distilled water at 80°C to 90°C. The bath usually contains chemicals known as accelerators which speed up the process by oxidizing to water the hydrogen bubbles which would otherwise form a film at the metal solution interface. The phosphated billet is lubricated by immersion in a sodium stearate base soap at 65°C for

about 4 minutes.

The nature of the reaction between the cleaned steel surface of the billet and the phosphating solution is very complex but as explained by James (1966), it is sufficient to state that a layer of crystals of predominantly tertiary zinc phosphate is produced, chemically bonded to the base metal. At the lubricant stage, a further reaction takes place:

$$Zn_3(PO_4)_2 + 6C_{17}H_{35}COO\,Na \rightarrow 3(C_{17}H_{35}COO)_2Zn + 2Na_3PO_4$$

This produces zinc stearate which is a very efficient extreme pressure lubricant (chemically bounded to the zinc phosphate coating). The complete lubricant film is infact a composite which is shown diagrammatically as,



The performance of the film is influenced not only by the manner in which it is applied to the surface of the billet but also by the way in which this surface is deformed by the constraining tools. By this approach better lubrication of rod and tube products was achieved by Mckenzie (1964), when billets were extruded through conical entry dies of 130° included angle or less. Blended radii at the entry to the cone, as well as the entry and exit of the throat of the die also improve the

performance of the lubricant.

Other lubricants that have been used in conjunction with zinc phosphated surfaces include crystalline solids such as graphite or molybdenum disulphide (MOS_2) in pastes, dispersions or powders (Mckenzie, 1967).

Mckenzie (1967) found that the extrusion pressures required for zinc phosphated billets lubricated with 'wet' MOS_2, were lower than those lubricated with dry MOS_2 or a tallow based soap lubricant. Pressures required with a sodium stearate soap were similar to those required with a tallow based soap.

2.4.1 Advantages and Limitations of the Zinc Phosphate - Lubricant System:

The Zinc phosphate - soap system is well established as the standard lubricant in the cold extrusion of steel. It is tenacious, has a low friction characteristic, does not allow pick-up on the tools, it is clean and free from smell, does not foul the operators' hands, handling equipment or tools, it does not decompose at the temperatures reached in cold extrusion and inhibits rusting of the component.

The main disadvantages are:- Large capital expenditure involved in the process, floor space requirements, and length of the process (making it unsuitable to instal in a production line or adapt to a progressive cold - forming sequence); other disadvantages are that, it is limited to cold forming steels of chromium content less than 5 percent. The phosphate film

must be removed if carburizing, brazing or welding are required. Finally, good knowledge of chemistry is needed by the operators to maintain the cleanliness and equilibrium of the baths.

2.4.2 Alternative Methods of Lubrication:

Due to the shortcomings of the zinc phosphate - lubricant system of lubrication, it has always been necessary to look for alternative methods of lubrication for the cold extrusion of steel. Other lubricant carriers, such as metallic (e.g. lead, Cadmium, zinc or copper) or chemical coatings (e.g. phosphates, oxalates, lime and borax) have seen limited applications. Lime and borax are generally limited to applications where the steel is very ductile and the reduction is low. Oxalate coatings are employed with alloy steels which are difficult to phosphate (Machu, 1965).

Hauttman (1951) found that steel billets provided with a zinc phosphate coating required extrusion pressure slightly higher than those provided with the more expensive metallic zinc coating but lower than those with copper coating. A cold aqueous solution of graphite is also in use. It is applied onto the work simply by immersing the cleaned billet in the solution. Although the resulting extrusion pressures are equal to or lower than those obtained with the standard lubrication,

the treatment is limited to the extrusion of shallow cans and low extrusion ratios because of lubrication breakdown (Anon, 1965).

The application of a lubricant to a rusted surface, a technique used by Schuster (1952) on tube drawing, gave reasonable results provided that the rust had not become abrasive. However, the results of these tests were no better than those with the same lubricant coated on a clean steel surface.

Abdul (1977) evaluated some 16 EP lubricants in relation to the conventional zinc phosphate - sodium stearate system under typical industrial cold extrusion of steel. To some of the lubricants, chlorine was added while to others combinations of chlorine, sulphur, phosphorous and fatty acids were added. He found that the conventional zinc phosphate - sodium stearate system of lubrication provided better lubricity than the lubricants containing only chlorine as an additive. The other lubricants which contained mainly other chemical additives such as sulphur, phosphorous and fatty acids showed better lubricating ability compared to the conventional phosphate - soap system.

2.4.3 Fatty Lubricants:

Appreciable amounts of fats or fatty acids and substances derived from them are used as lubricants either alone or often compounded with mineral oils.

Originally, vegetable and animal fats provided almost exclusively the means of lubrication (Kirschen Bauer, 1969). Comparatively recently with the development of the petroleum industry, mineral oils began to replace the fatty oils as lubricants. More recently however, fatty oils and their derivatives have again found limited applications, mainly because of their one outstanding property known as "oiliness". That is the ability of a lubricant to form a tenacious film on metal surfaces, which is particularly important where rubbing surfaces have small clearances from which the oil may be squeezed by excessive pressure as in extrusion.

The vegetable oils under investigation are fatty oils. Fatty oils consist mainly of fatty acids. They are compounds having long slender molecules with a straight chain of ten or more carbon atoms and a polar group at one end. The magnitude of their polarity is an important factor in their performance.

The fatty acids are attracted to the metal by strong adsorption forces. Actually the polar head is attracted by the metal. The result is the anchoring of the molecule with the polar end on the surface of the metal and the long chain sticking out. Due to Vander Waal forces, the molecules tend to align themselves parallel to each other in a multi-molecular fashion. At the same time the orienting field of the adsorbed layer induces the positioning of the clusters with their methyl groups stacking up on the methyl groups of the tails of the

adsorbed mono layer. As a result, they all line up straight up, normal to the metal surface. This is repeated many times depending on the strength of the orienting polar group, creating a multi storied construction of fatty acid molecules. These structures are hard to compress out but easy to shear at any layer. The sheared off friction layer however, does not stay away for too long. The strong orienting forces continue to act and they rebuild the thick layer as it was before. This allows the same surface to be ready for another shearing encounter.

The chemical reactivity of various surfaces with fatty acids under standard conditions was studied by Gregory (1954), Lauric acid was used and the metal surface heated up to 150°C with the acid in contact with it. The results showed that the metals examined fall into two distinct classes of which, (a) chemical attack is absent or very slight (e.g. Mg, Al, Ni, Cr) and (b) those for which chemical attack is marked (e.g Cu, Cd and Zn). A comparison of the chemical reactivity and lubricating properties showed a striking correlation. Those metals which are most readily attacked by the fatty acids are those which are most effectively lubricated.

Dacus, Coleman and Roess (1944) have done some work in measurement of the rate at which a lubricant film is worn away during sliding. Their result show that, with mono - layers of fatty acids, there is a marked increase in the "durability" of the lubricating film with

increasing chain length.

The chemical analysis of the vegetable oils that are being investigated in this project was carried out by Ajala (1981). The results of chemical composition, saponification value, percentage free acid value, iodine value and percentage phosphorous content of each of the oils are given in appendix, 2. The stability of an oil is determined by its percentage free acid value while the saponification value indicates the ease with 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 oils.

Generally the diverse qualities which must be evaluated in selecting a lubricant for use in the press - shop include (Wilson, 1966):-

(a) Ability to eliminate pick-up and scouring in the operation concerned.

(b) Promotion of the required surface finish.

(c) Ability to reduce friction and to promote formability.

(d) Ease of application: Cleanliness, and freedom from harmful or objectional effects on operators or equipment.

(e) Ease of removal: Freedom from staining and corrosive effects, freedom from a tendency to leave objectionable residues on the surfaces.

(f) Stability in storage

(g) Overall economy

In this project which is a part of a larger program to develop local metal working lubricants, some local vegetable oils namely, palm oil, groundnut oil, shea butter oil and soya bean oil were investigated as possible cold extrusion lubricants.

Examined parameters for evaluation of these local oils as extrusion lubricants included the friction coefficient between the billet and the die using each of the oils, the quality of the product (surface finish) and the hardness obtained on the extruded products.

To set a standard for comparison, the performance of each of the local oils as a cold extrusion lubricant (on the basis of the afore mentioned parameters) is being compared with that of the conventional zinc phosphate - sodium stearate lubrication system.

The Aladja ST60-2 steel was used as a result of its availability. It was also hoped that the Aladja ST60-2 steel would act as a severe test for the oils since it is not an extrusion quality of steel.

CHAPTER THREE

Experimental Equipment and Procedure

3.1 Equipment:

In general, it is not common to have a press available which is specifically designed for experimental cold extrusion of steel. Usually, therefore, the extrusion tools prepared are made to fit between the compression plates of a universal testing machine. The facilities of the machine are then used to measure punch load and travel (Molden, 1966).

For the present work, due to the non-availability of a cold extrusion press, a 500KN universal testing machine with a speed control which could be preset within the range 0 - 22 cm/min was employed in a manner similar to that suggested by Molden for carrying out the extrusion experiments. For the measurement of the distance travelled by the punch during the extrusion, a meter rule was used in conjunction with a pointer which was attached to one of the moving parts of the machine. Various loads required to extrude the steel slugs under various lubrication conditions were read on the machine gauge.

3.2 Tools:

The development of cold extrusion as an economically competitive production process is entirely dependent on the improvement of tooling. Whereas it was advances in lubrication i.e phosphate coating, that first made the

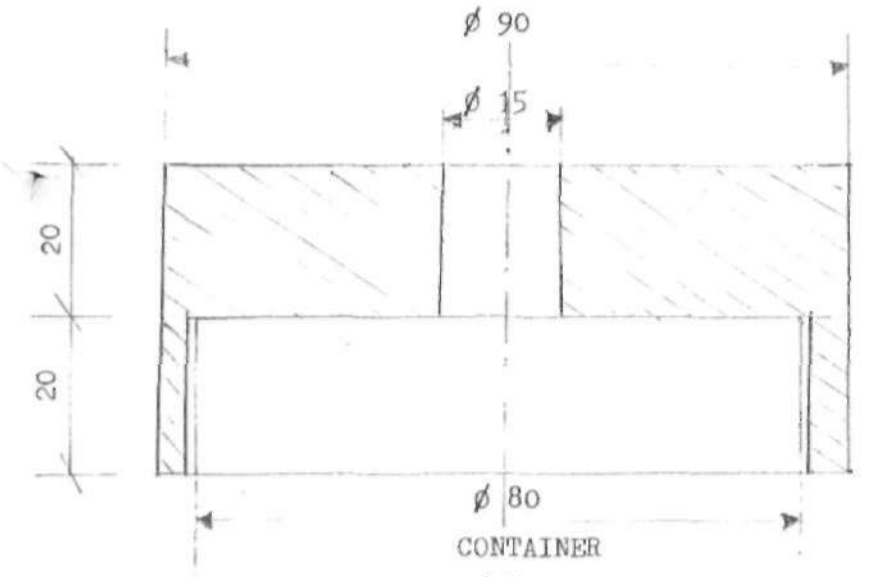
cold extrusion of steel possible, it is only when tools are made at low prices and with long lives that the process is economically viable.

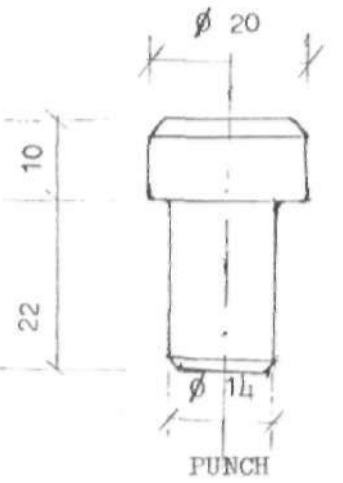
3.2.1 The Punch:

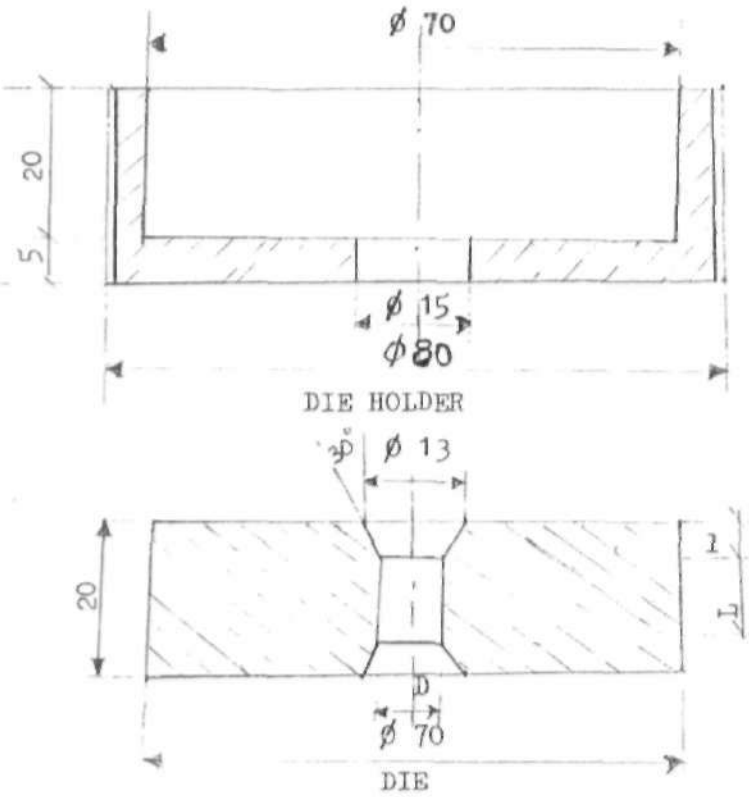
The main difficulty in punch design lies in assessing the nature and magnitude of the stresses to which the punch is subjected in service, and this is a problem to which there is yet no satisfactory solution. Since the stresses are dynamic, fatigue effects will arise and these in conjunction with the inherently "brittle" nature of tool steels, necessitate care in avoiding design features likely to give rise to stress concentrations.

Based on previous research effort (Spikes, 1966), there are three main metallurgical reasons for the failure of a punch, namely, excessive wear, fatigue and insufficient compressive strength. The AISI-M2 type of high speed steel which has extremely good wear resistance is the most commonly used materials for punches.

For the present work, because an appropriate tool steel was not available, the punches used were machined from a medium carbon steel bar. The design of the punches is as shown in Fig.3.1.







	D	L	l
1	12	17	1.5
2	11	15	2.5
3	10	14	3.0
4	9	12	4.0

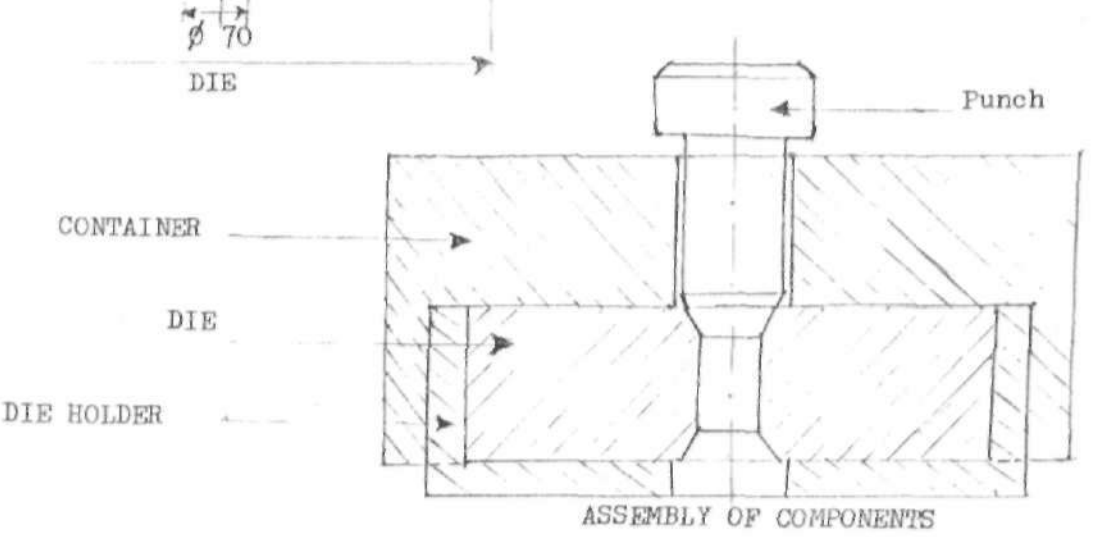


Fig. 3.1: Tools used in the extrusion process

The fabricated punches were carburized at 900°C for 12 hours and then tempered at 400°C.

3.2.2 Dies and Extrusion Container:

In the design of dies for forward or backward extrusions, somewhat similar problems are encountered to those for punches in respect of permissible tool stresses, failure, etc. The main difference however, is that for dies, high stresses of a tensile nature must be catered for. In the absence of any better guide, it is commonly assumed that the die must withstand a uniform hydrostatic internal pressure equal in magnitude to some percentage (usually between 70 percent and 100 percent) of the peak extrusion pressure.

The die gives rise to considerable problems particularly when it has a stepped bore. Failure from the step is usually by fatigue. The requirements for a die steel are therefore, high wear resistance combined with good fatigue strength. The steel should also be able to withstand the heat generated in service.

The steels normally employed in the construction of extrusion dies fall into three main groups (Spikes, 1966):-

(a) AISI-S1 This material has a high fatigue strength but would require carburizing to give reasonable resistance to wear. It has a reasonable resistance to tempering.

(b) AISI-D3 This is the conventional material for dies, having excellent resistance to wear. However, it is particularly prone to fatigue failure when the die is stepped. This has better resistance to tempering compared with S1 and a higher hot hardness.

(c) AISI-M2, M2 has a better wear resistance and fatigue strength than D3. It has excellent resistance to tempering and hot hardness, however, its initial cost is quite high.

Since the extrusion container is subjected to almost similar system of stresses as the die, similar materials are normally used for its construction.

For the present project, as a result of non availability of the appropriate tool steel, a medium carbon steel was again used in the fabrication of the dies and extrusion container. In all, four dies and a container schematically shown in Fig.3.1 were made. To increase their strength and wear resistance, the fabricated dies and extrusion container were subjected to a carburizing treatment.

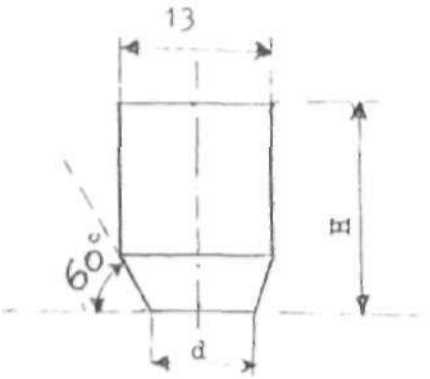
3.3 Materials and Procedure:

The billets to be extruded were machined from an Aladja St60-2 steel, the composition of which is given in table 3.1.

Table 3.1 Chemical Composition of the ST60-2 Steel Used in the Cold Extrusion:

C	Mn	Si	P	S
0.35 - 0.42	0.90 - 1.20	0.20 - 0.30	0.04 Max	0.04 Max

The billets were machined into the shape shown in Fig.3.2. A 60° chamfer was provided on the billet to allow for easy alignment in the die.



H (mm)	d (mm)
10	12 11 10 9
13	12
15	12
17	12

Fig.3.2. The Shape of billets used in the Extrusion Process.

The billets were all made of 13mm diameters, but were machined with various heights of 10mm, 13mm, 15mm and 17mm. In all 80 billets were machined for extrusion under the various experimental conditions.

3.3.1 Heat Treatment of Billets:

To ensure adequate metallurgical properties in the machined billets prior to extrusion, the billets were

annealed by heating to 900°C, soaked at this temperature for 45 minutes to allow for full austenitization, and finally furnace cooled to room temperature.

3.3.2 Phosphating:

The phosphating operation on the steel billets was carried out at EMCON Ltd, in Zaria. However, prior to the phosphating operation, the annealed billets were pickled in 18% hydrochloric acid for 10 minutes. This was followed by alternate cold water and hot water rinses. The hardness of the billets was then measured.

3.3.3 Lubricant Application:

The zinc phosphated steel billets for the standard lubrication condition were dipped in sodium stearate solution (42.5g/litre) at 65°C for four minutes and then allowed to dry off. Application of the various vegetable oils on the zinc phosphated steel billet surface was also by dipping at ambient temperature. Both the container and the die were lubricated with the appropriate oil under investigation using a brush. Punch head was also lubricated appropriately by immersion.

3.3.4 Extrusion Proper:

The lubricated billet was placed in the container in contact with the die and properly aligned with the die cavity. After aligning the punch with the billet, the load was applied on the punch to achieve extrusion of the

billet at the selected speed and ratio under each lubrication condition. The values of the load at intervals of 1.0mm of punch travel were noted. Before each extrusion operation, the tools were degreased to remove all traces of lubricant remaining from the previous test. For each of the extrusion ratios of 1.17, 1.40, 1.69 and 2.09, and for each lubrication condition, the extrusion was carried out at three different speeds of 2cm/min, 4cm/min and 6cm/min.

The surface finish of each of the extrudates was measured using a subtronic stylus probe. This was with the exception of those extruded at an extrusion ratio of 2.09 as the extruded lengths were too small to be traversed by the stylus.

Hardness measurements were taken across a diameter length on the extruded billets using a Vickers hardness testing machine.

3.3.5 Metallography:

To qualitatively study the effect of cold extrusion under the various lubrication conditions on the Aladja ST60-2 Steel, 15 of the extruded specimens were selected for metallographic examination.

The selected specimens were ground to obtain a flat surface of the area to be examined. The grinding of the specimens was carried out on a strip grinder using different grades of grinding paper.

Polishing of the specimens was then undertaken to remove from their surfaces the fine scratches introduced during the grinding operation and ultimately to produce a highly polished scratch free surface. The polishing was carried out on a polishing wheel which is fixed to rotate in a horizontal plane.

In order to make visible the many structural characteristics of a specimen, it is necessary to etch the specimen. Prior to etching, the specimens were washed thoroughly with water and allowed to dry. The specimens were then etched by swabbing the polished surfaces with cotton saturated with 3% Nital. The specimens were then washed in warm water to prevent the continued action of the etchant.

Using the adequate facilities provided by the Nigerian Metallurgical Development Centre, Jos, the Photomicrographs of the specimens were taken at various magnifications.

CHAPTER FOUR

RESULTS

The results of the cold extrusion of Aladja ST60-2 structural steel showing variation of punch load with punch displacement under the investigated local oils lubrication conditions at different extrusion ratios and extrusion speeds are represented in graphs. The surface finish of the extruded billets and cross-sectional hardness values of the extruded billets are also represented.

Figure 4.1 - 4.6 show the punch load - punch displacement curves for extrusions under various lubrication conditions for different extrusion ratios, extrusion speeds and initial billet lengths used in the investigations.

Table 4.1 shows the calculated values of friction coefficient (equation 2.10) for the various lubrication conditions at the different extrusion ratios, extrusion speeds and initial billet lengths used in the investigations. The values of maximum load obtained for the various extrusion conditions are shown as appendix 1.

Table 4.2 shows the surface finish of the billets extruded under various lubrication conditions for various extrusion ratios, extrusion speeds and initial billet lengths.

Table 4.3 shows the hardness measurement taken radially on billets extruded using a speed of 4cm/min under various lubrication conditions at the different extrusion ratios.

Plates 1 – 16 are photomicrographs of billets extruded under various lubrication conditions at various extrusion ratios using an extrusion speed of 4cm/min.

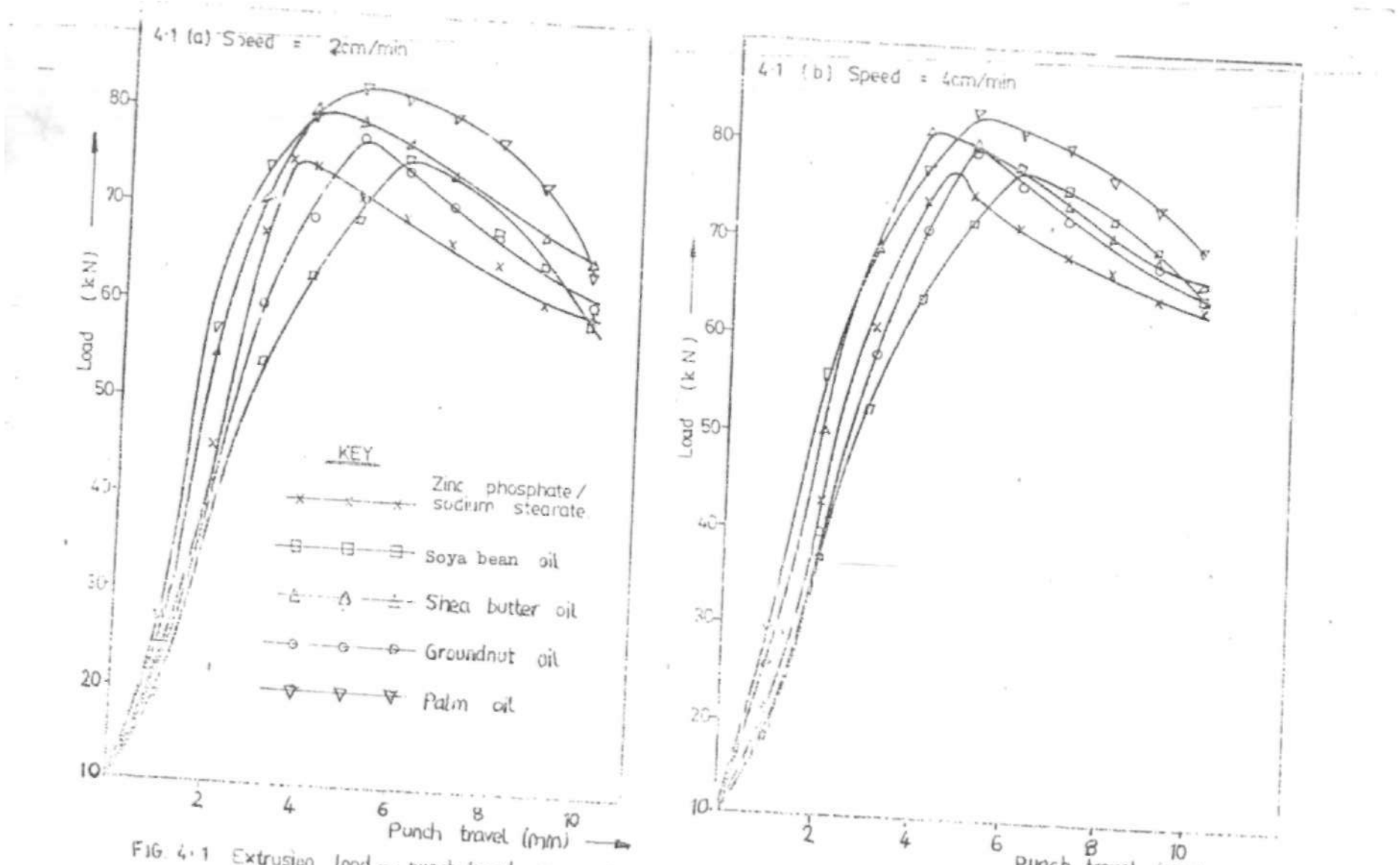


FIG. 4·1 Extrusion load — punch travel curves for an extrusion ratio of 1·17 with initial billet length 10mm under various lubrication conditions and at various extrusion speeds.

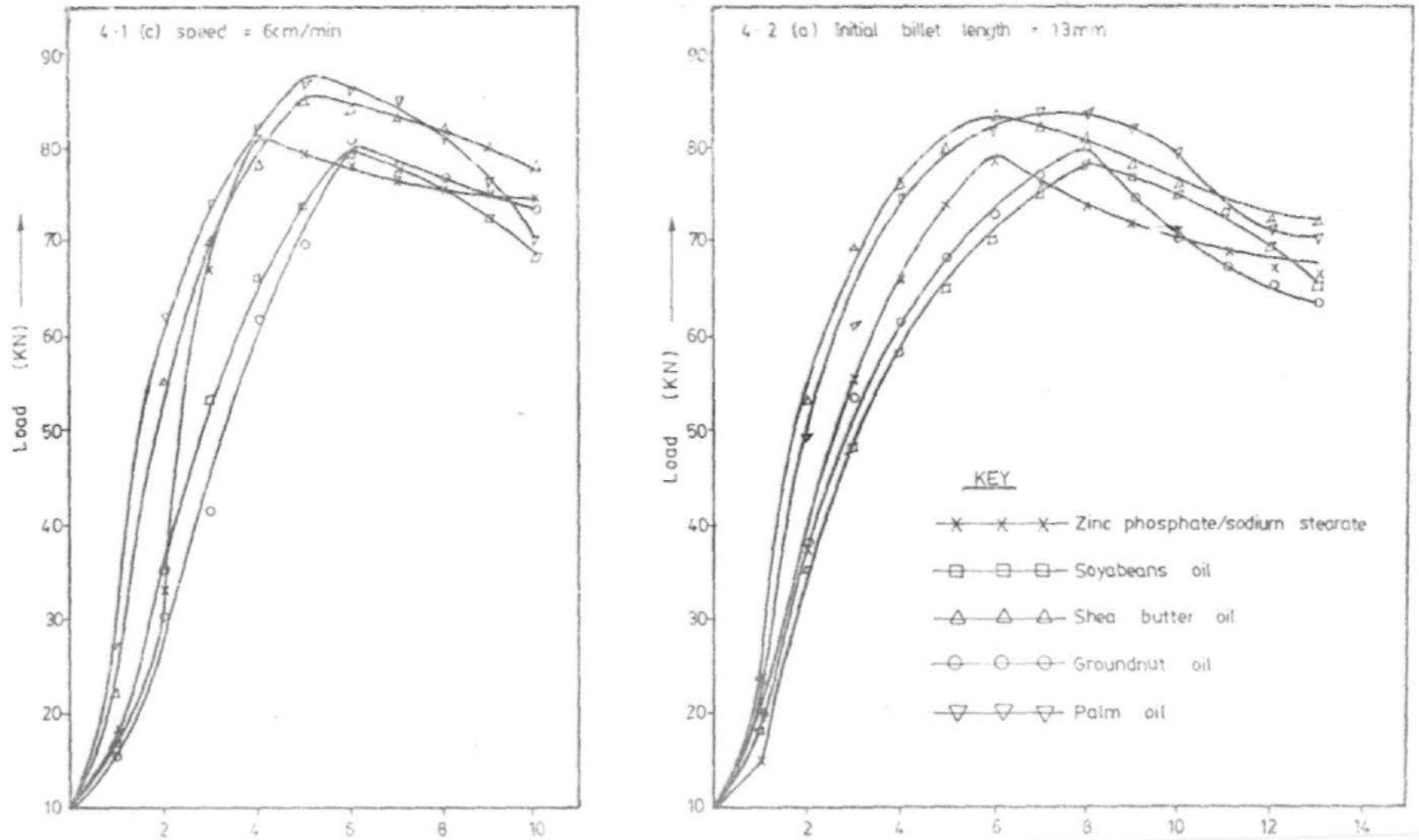
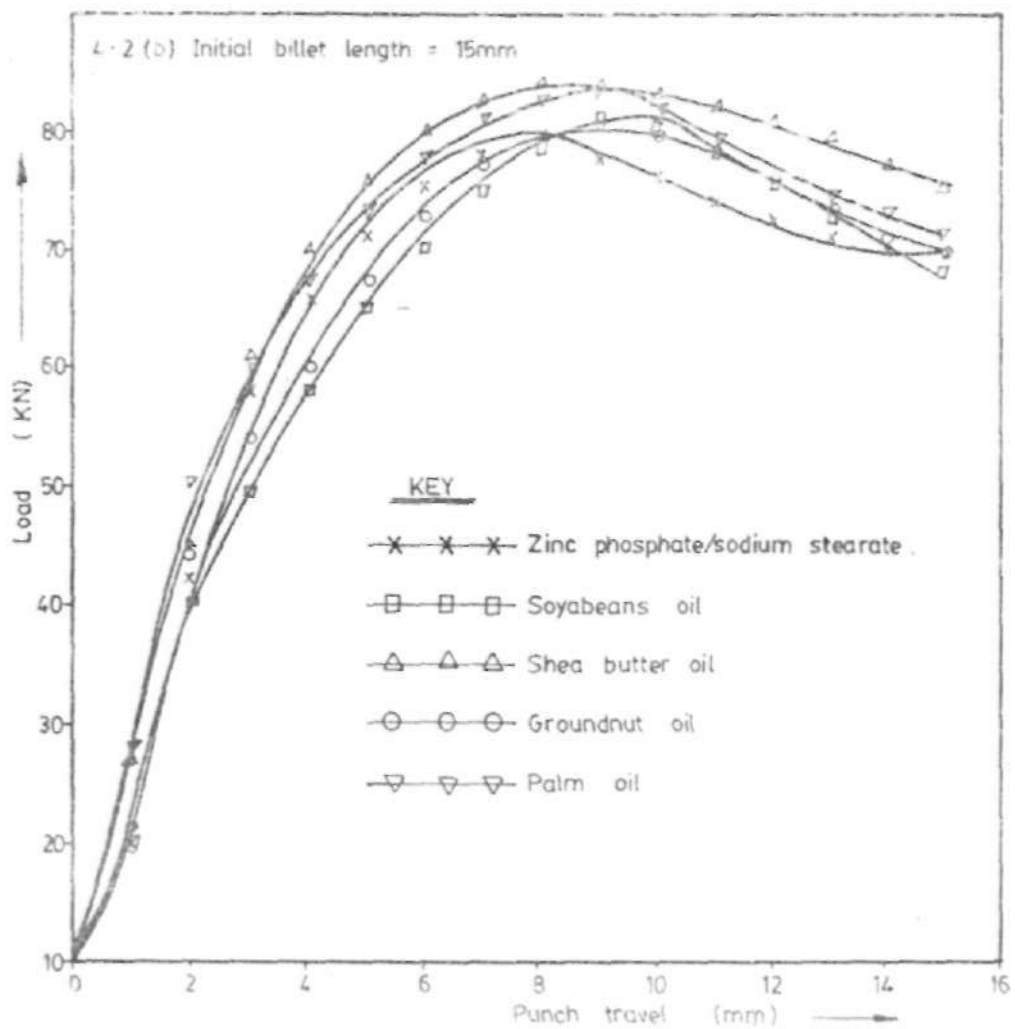
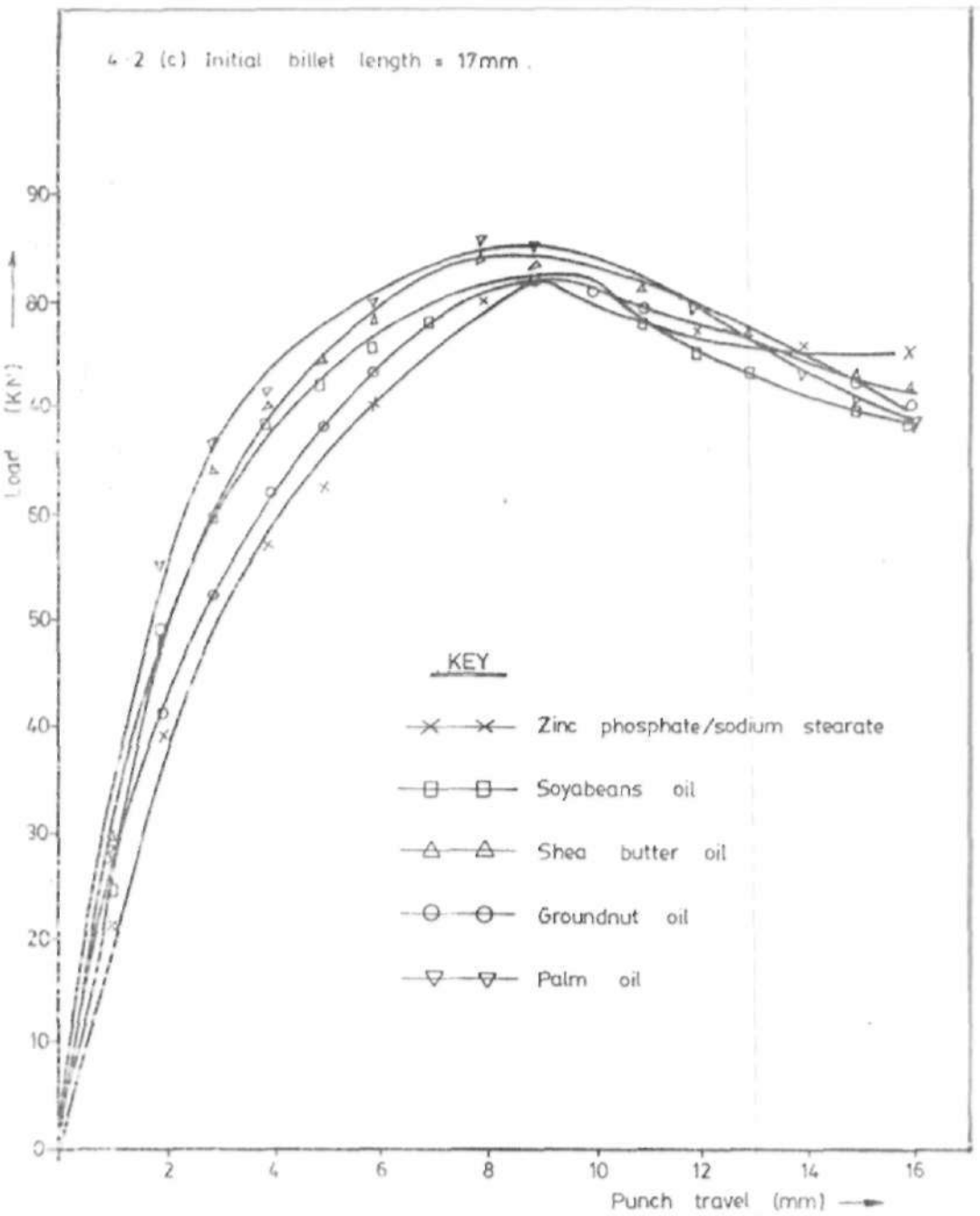
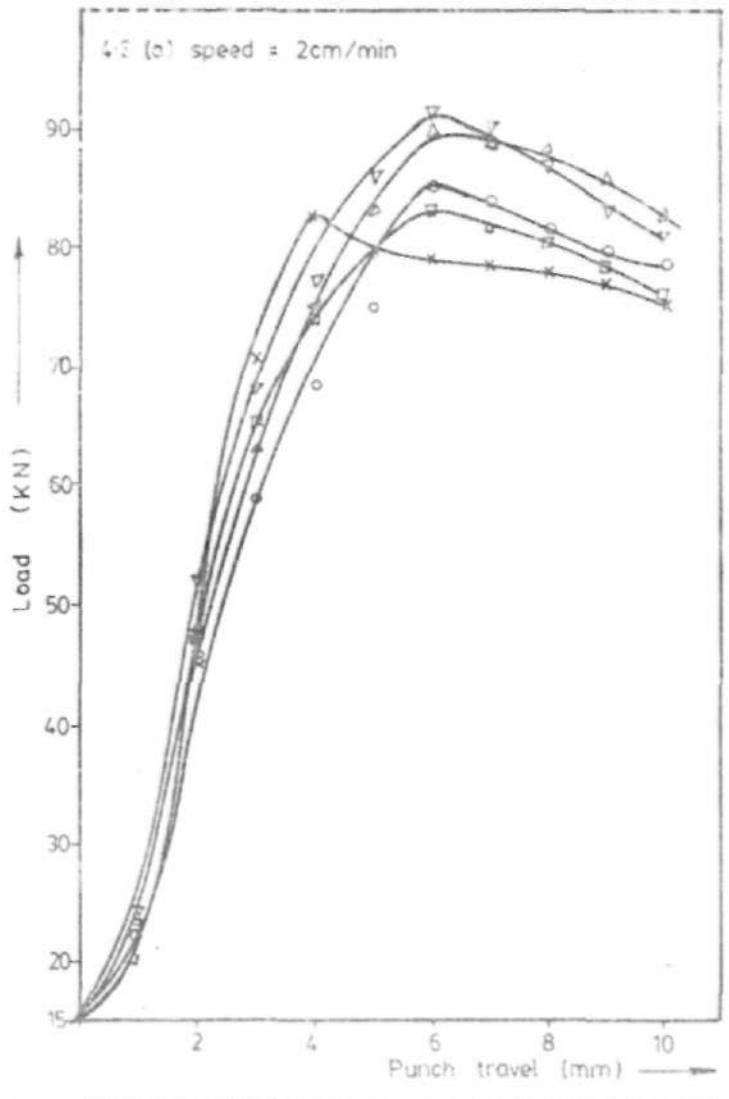


FIG. 4·2 Extrusion load — punch travel curves for an extrusion ratio of 1·17 extrusion speed of 4cm/min with billets of various initial lengths


4·2 (b) Initial billet length = 15mm
Load (KN)
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16
Punch travel (mm)
KEY
Zinc phosphate/sodium stearate
Soyabeans oil
Shea butter oil
Groundnut oil
Palm oil

4·2 (c) Initial billet length = 17mm.





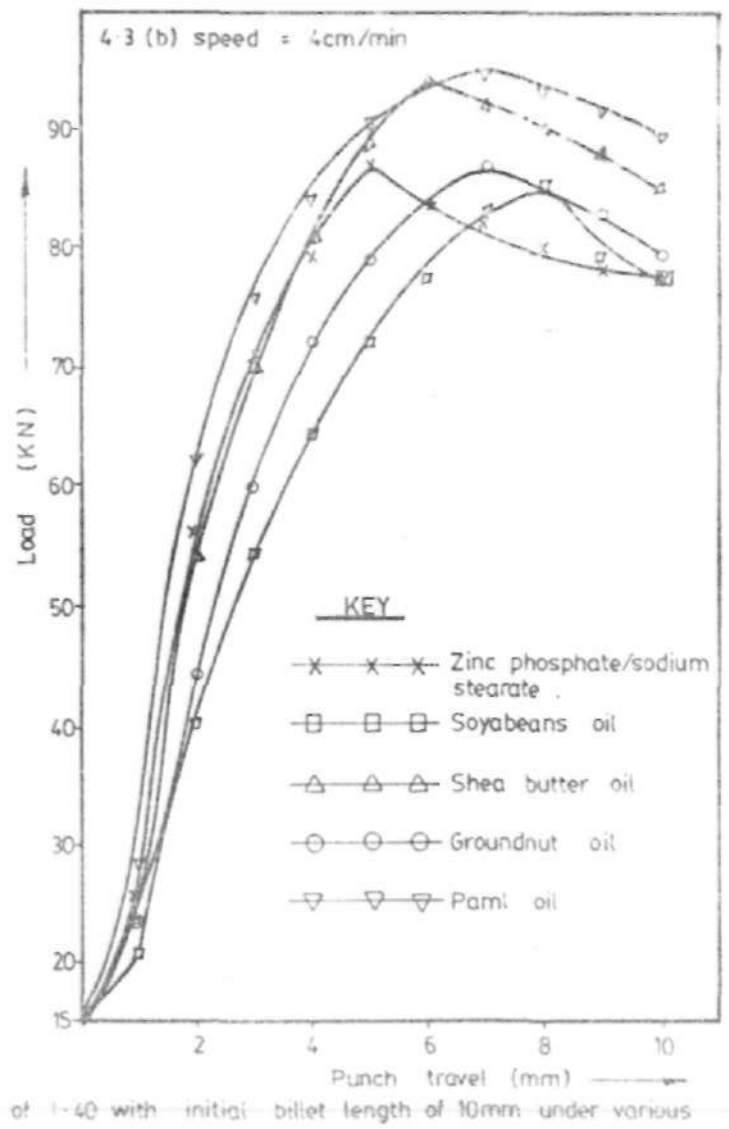


FIG. 4·3 Extrusion load — punch travel curves for an extrusion ratio of 1·40 with initial billet length of 10mm under various lubrication conditions and at various extrusion speeds.

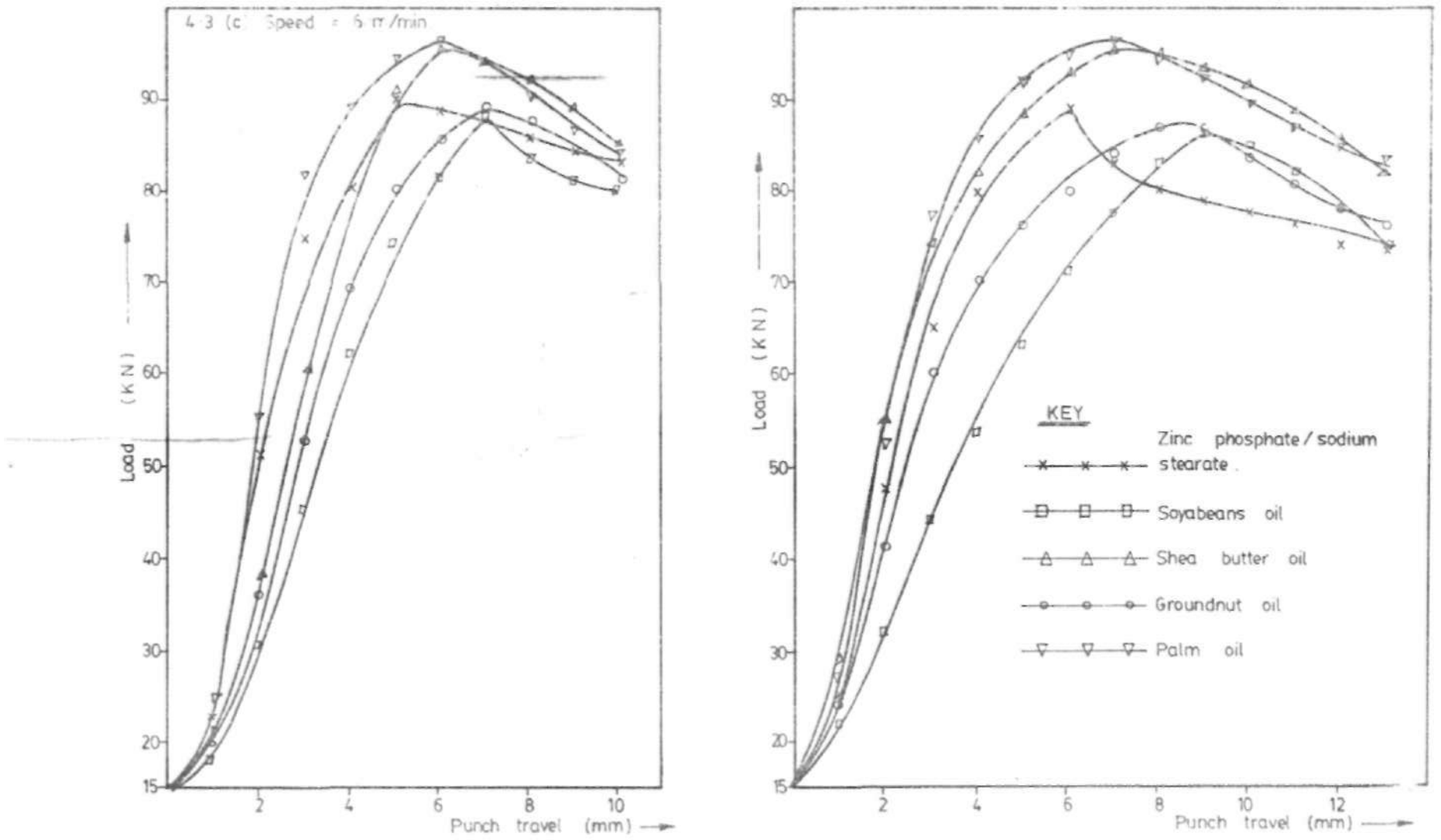


FIG. 4.4 Extrusion load — punch travel curves for an extrusion ratio of 1.40 with initial billet length of 13mm at an extrusion speed of 4cm/min under various lubrication conditions

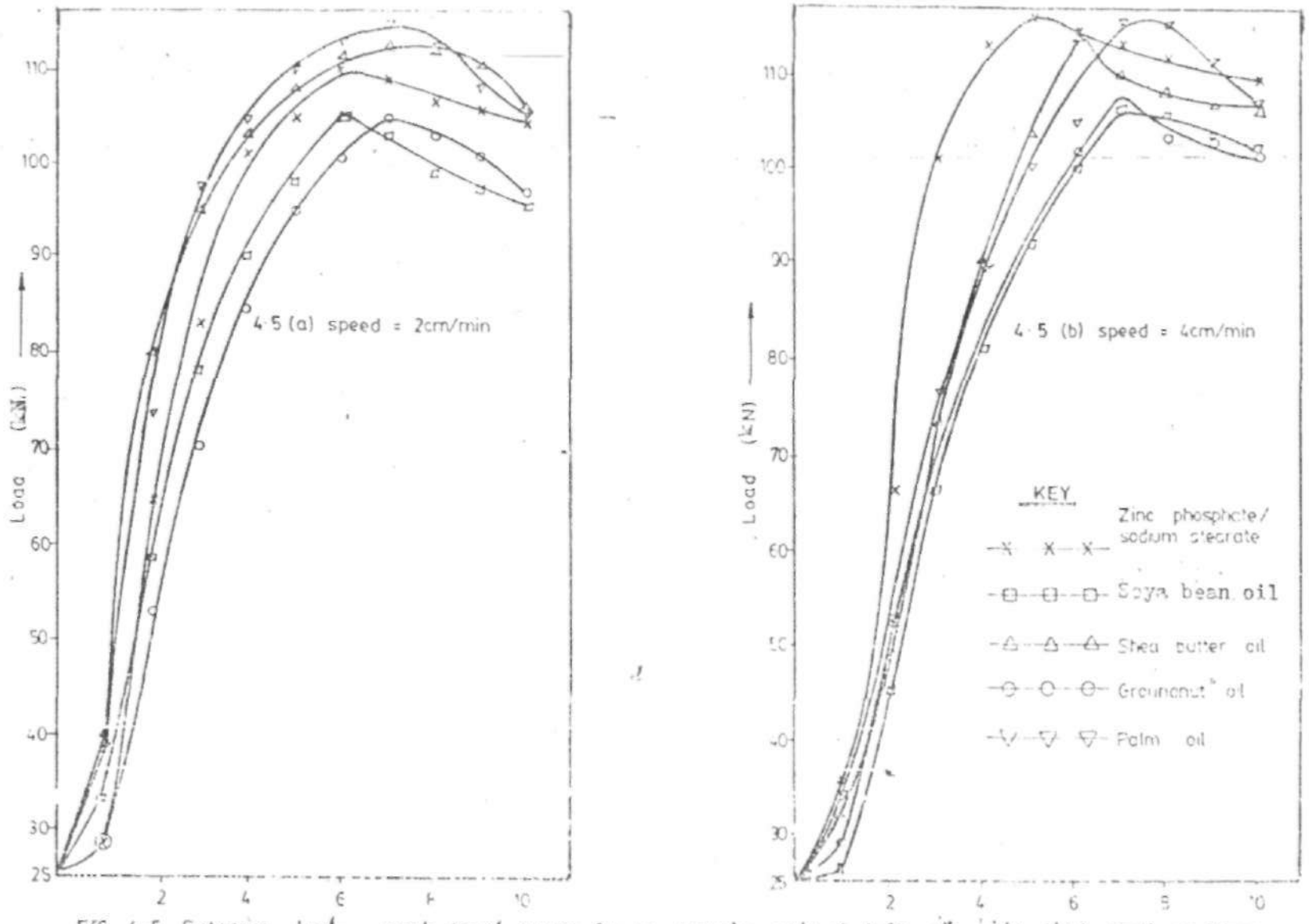
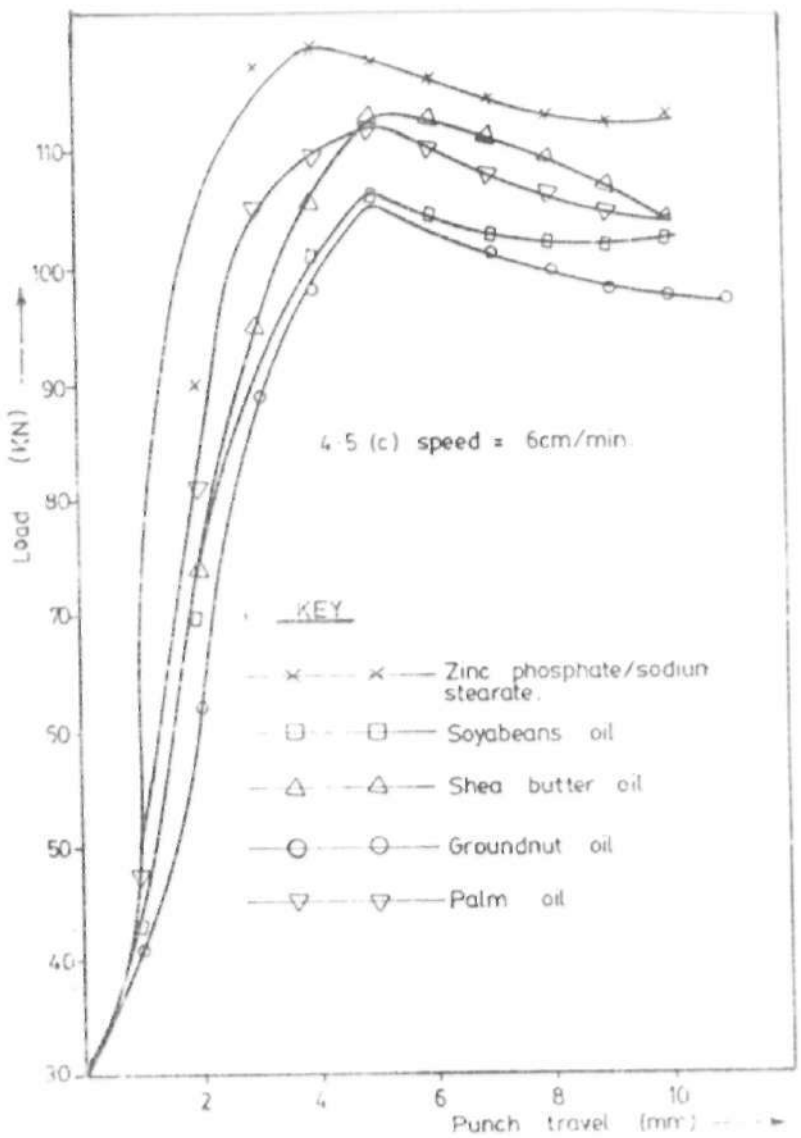
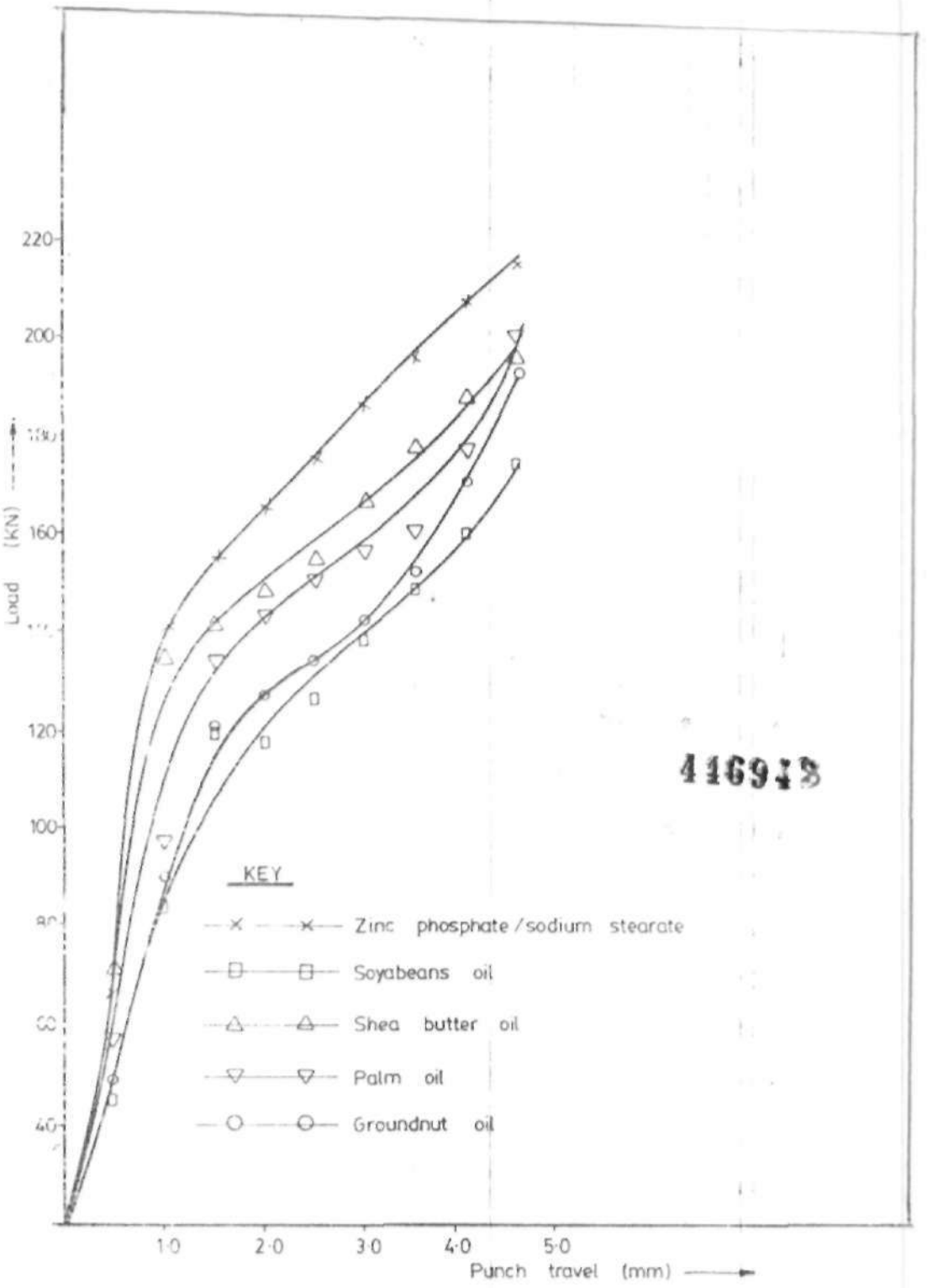


FIG. 4.5 Extrusion load — punch travel curves for an extrusion ratio of 1·69 with initial billet length of 10mm under various lubrication conditions and at various extrusion speeds.


4·5 (c) speed = 6cm/min.
Load (KN)
110
100
90
80
70
60
50
40
30
2
4
6
8
10
Punch travel (mm)
KEY
Zinc phosphate/sodium stearate.
Soyabeans oil
Shea butter oil
Groundnut oil
Palm oil



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FIG 4.6 (a) Extrustion Load – punch travel curves for an extrusion ratio of 2·09 at various speeds under various lubrication conditions. (a) Extrusion speed = 2cm/min (b) 4cm/min (c) 6cm/min.

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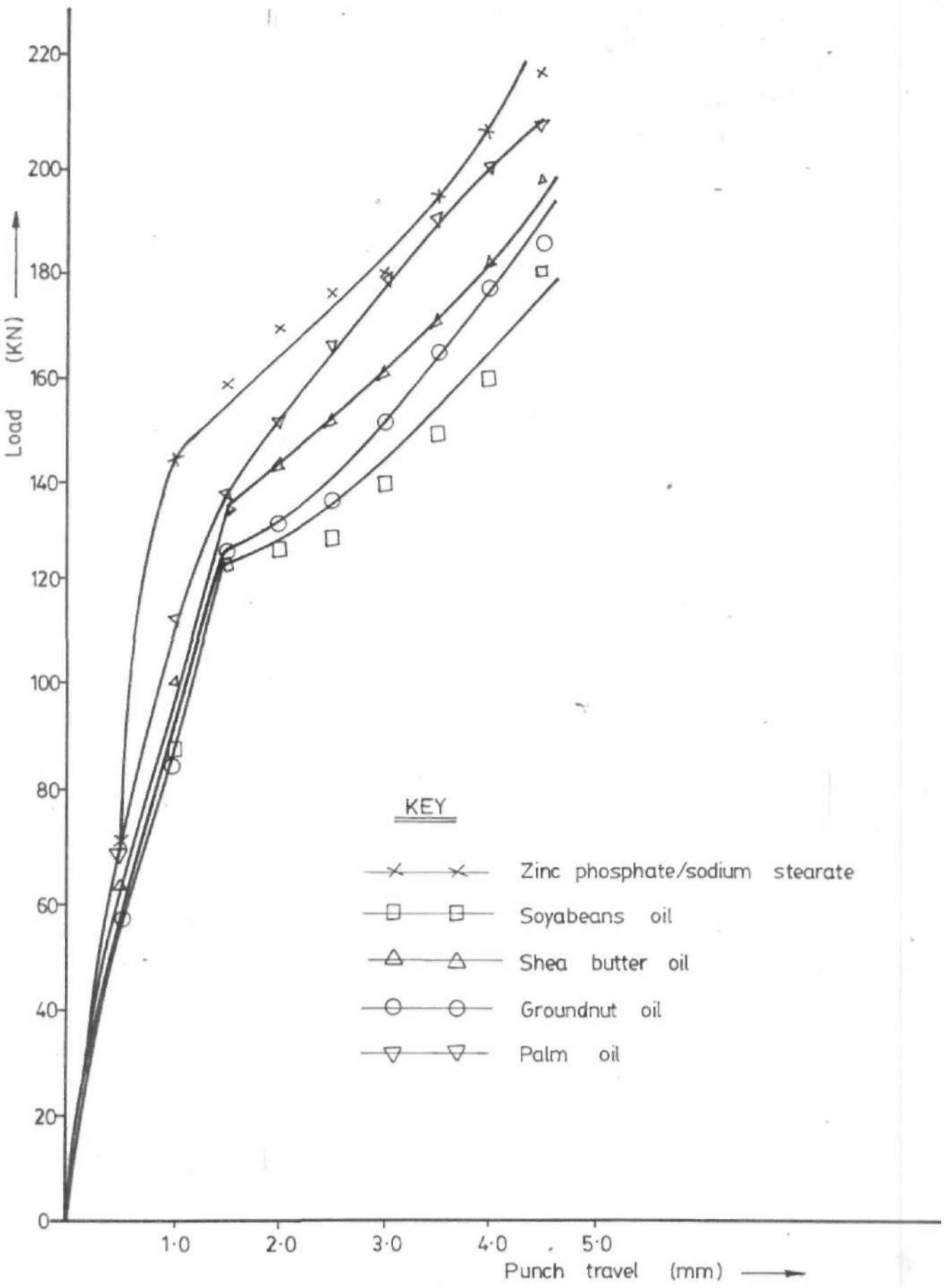

Load (KN)
220
200
180
160
140
120
100
80
60
40
20
0
1·0
2·0
3·0
4·0
5·0
Punch travel (mm)
KEY
Zinc phosphate/sodium stearate
Soyabeans oil
Shea butter oil
Groundnut oil
Palm oil

FIG. 4·6 (b)

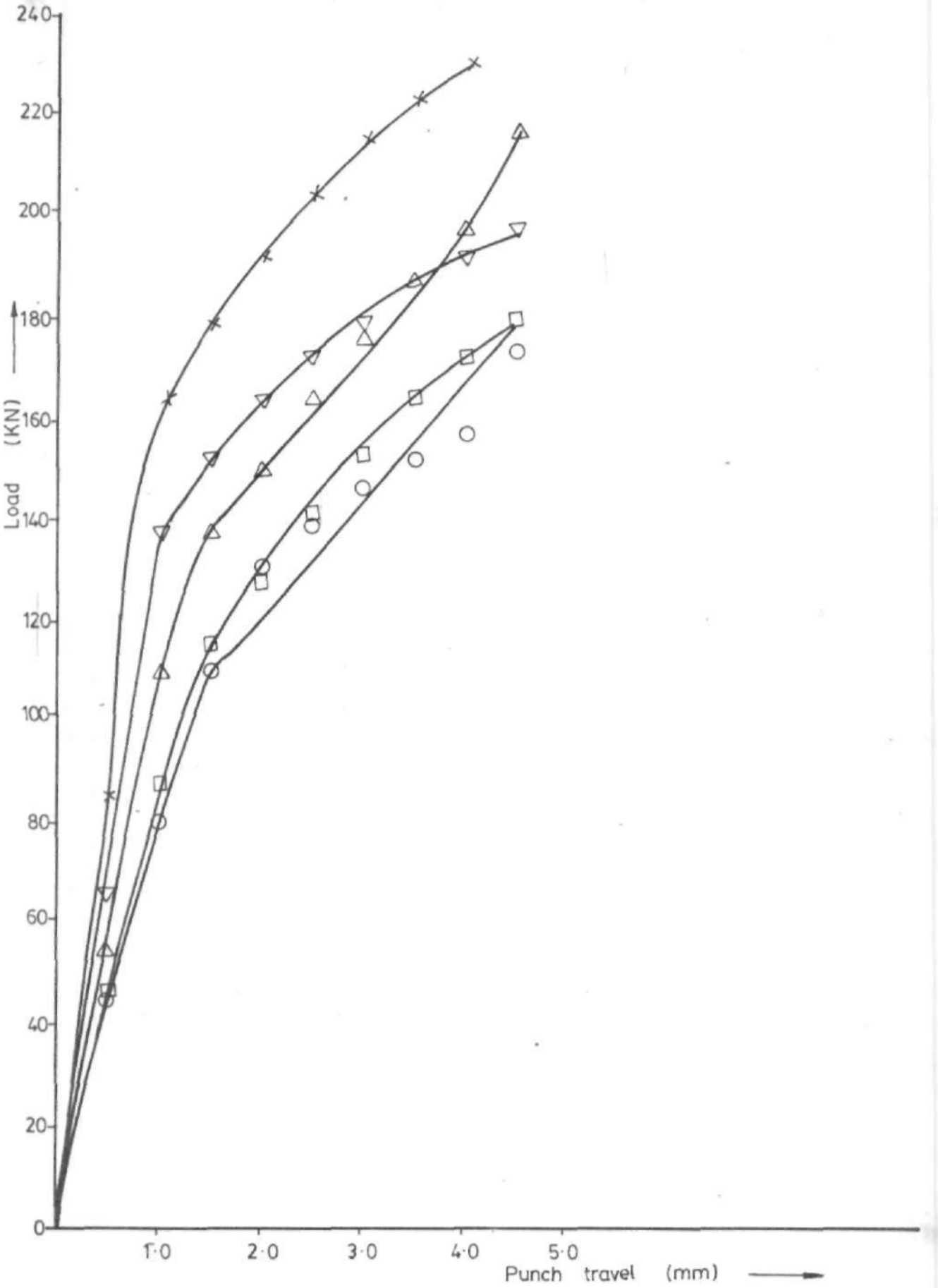

240
220
200
180
160
140
120
100
80
60
40
20
0
Load (KN)
1·0
2·0
3·0
4·0
5·0
Punch travel (mm)

FIG. 4·6 (c)

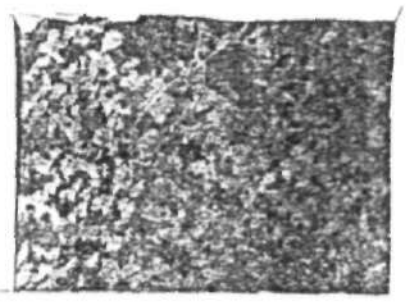


PLATE 1

AS - ANNEALED
ALADJA ST60-2 STEEL
BILLET

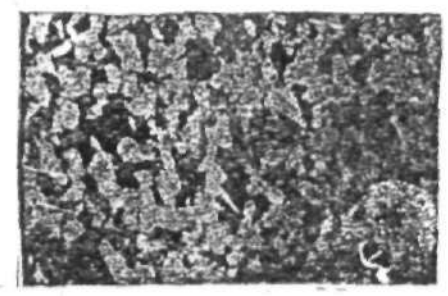


PLATE 2

ZINC PHOSPHATE/SODIUM
STEARATE LUBRICATION

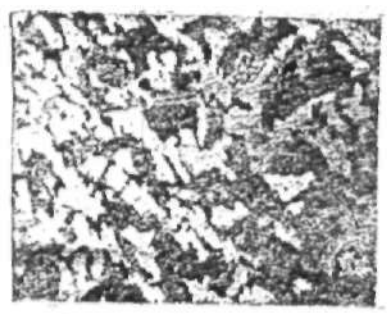


PLATE 3

C/NUT OIL LUBRICATION

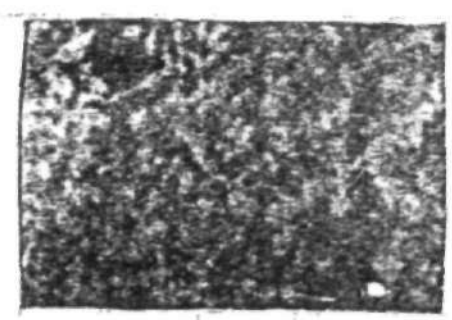


PLATE 4

SOYABEANS OIL LUBRICATION

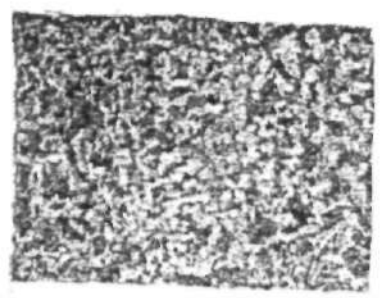


PLATE 5

PALM OIL LUBRICATION

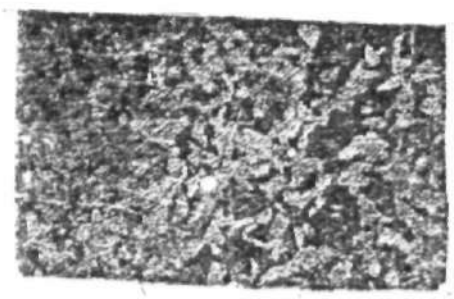


PLATE 6

SHEA BUTTER OIL LUBRICATION

PLATE 1 Micrograph of the as-annealed Aladja ST60 - 2 Structural Steel before Extrusion. The annealed structure consist of ferrite (light) and pearlite (dark), Nital etch, X500.

PLATE 2 - 6 Micrographs of Steel Billets Extruded at an Extraction ratio of 1.17 under various lubrication conditions, X500, etched in 3% Nital

Microstructure of all the specimens are essentially ferrite (white)

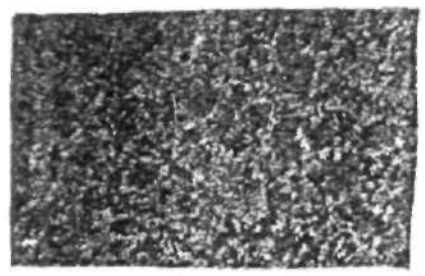


PLATE 7
C/NUT OIL LUBRICATION

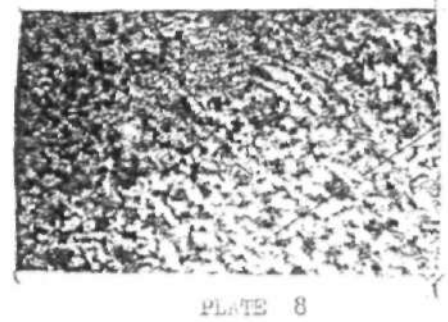


PLATE 8
SOYABEANS OIL LUBRICATION

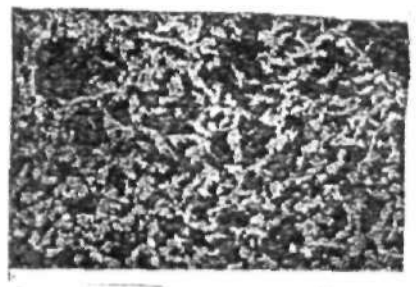


PLATE 9
PALM OIL LUBRICATION

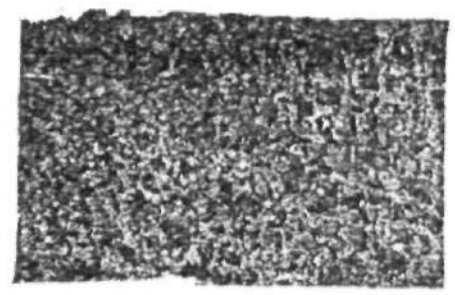


PLATE 10
SHEA BUTTER OIL

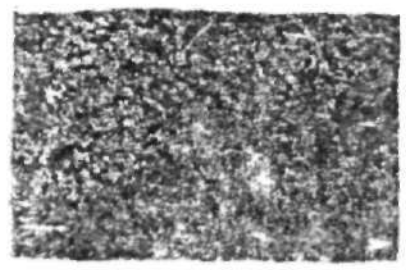


PLATE 11
ZINC PHOSPHATE/SODIUM
STEARATE LUBRICATION

PLATES 7 – 11: Micrographs of steel billets extruded at an extrusion ratio of 1.5 under various lubrication conditions, X100, etched in 2% Nital.
Microstructure of all the specimens consist essentially of ferrite (white) and pearlite (black), with varying amount and degree of fineness.



PLATE 12
C/NUT OIL LUBRICATION

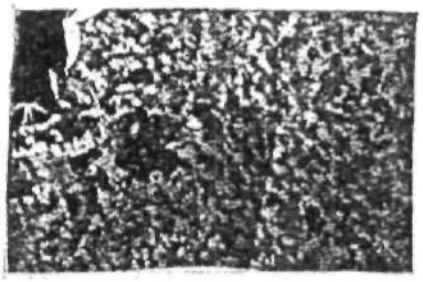


PLATE 13
SOYA-BEANS OIL LUBRICATION

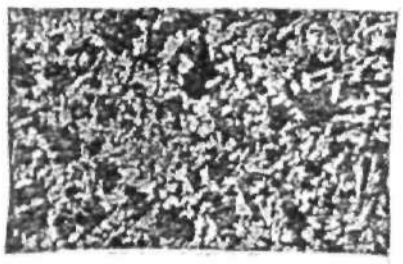


PLATE 14
PALM OIL LUBRICATION

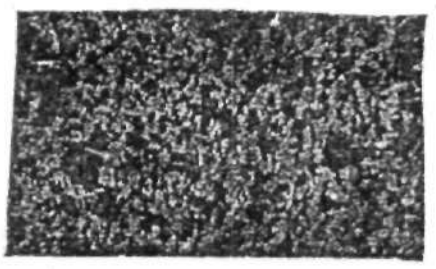


PLATE 15
SHEA BUTTER OIL LUBRICATION

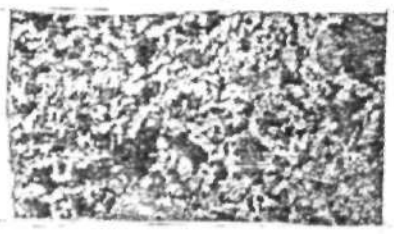


PLATE 16
ZINC PHOSPHATE/SODIUM
STEARATE LUBRICATION

PLATE 12 - 16: Micrographs of Steel Billets extruded at an Extrusion ratio of 1.69 under various Lubrication conditions, X500, etched in 3% Nital.

Microstructure of all the specimens consist essentially of ferrite (white) and pearlite (black) with varying amounts and degree of 'lines'.

Table 4.1 The Coefficient of Friction under Various Lubrication Conditions at Various Extrusion Ratios and Speeds

Table 4.1a Extrusion ratio of 1.17, initial billet length of 10mm at various speeds

Lubricants										
speed (cm/min)	zinc phosphate/sodium stearate		soya bean Oil		shea butter Oil		Groundnut Oil		Palm Oil	
	$\bar{\sigma}_{wb}$ (N/mm²)	μ	$\bar{\sigma}_{wb}$ (N/mm²)	μ	$\bar{\sigma}_{wb}$ (N/mm²)	μ	$\bar{\sigma}_{wb}$ (N/mm²)	μ	$\bar{\sigma}_{wb}$ (N/mm²)	μ
2.0	*565.0*	*0.170*	*586.8*	*0.172*	*606.5*	*0.190*	*583.9*	*0.179*	*621.6*	*0.197*
4.0	583.9	0.179	587.7	0.181	614.0	0.193	595.2	0.185	625.3	0.199
6.0	610.3	0.192	595.2	0.185	640.4	0.206	606.5	0.190	651.7	0.211

Table 4.1b Extrusion ratio of 1.40, initial billet length of 10 mm at various speeds

Lubricants										
speed (cm/min)	zinc phosphate/sodium stearate		soya bean Oil		shea butter Oil		Groundnut Oil		Palm Oil	
	$\bar{\sigma}_{wb}$ (N/mm²)	μ	$\bar{\sigma}_{wb}$ (N/mm²)	μ	$\bar{\sigma}_{wb}$ (N/mm²)	μ	$\bar{\sigma}_{wb}$ (N/mm²)	μ	$\bar{\sigma}_{wb}$ (N/mm²)	μ
2.0	*622.5*	*0.171*	*625.3*	*0.172*	*678.1*	*0.198*	*640.4*	*0.180*	*689.4*	*0.203*
4.0	655.5	0.187	644.2	0.181	708.2	0.212	655.5	0.187	712.0	0.214
6.0	678.1	663.0	0.191	721.4	0.219	670.5	0.195	670.5	723.3	0.220

Table 4.1c Extrusion ratio of 1.69, initial billet length of 10 mm at various speeds

speed (cm/min)	Lubricants									
	zinc phosphate/sodium stearate		soya bean Oil		shea butter Oil		Groundnut Oil		Pala Oil	
	$\bar{\sigma}_{xb}$ (N/mm²)	$\bar{\mu}$	$\bar{\sigma}_{xb}$ (N/mm²)	$\bar{\mu}$	$\bar{\sigma}_{xb}$ (N/mm²)	$\bar{\mu}$	$\bar{\sigma}_{xb}$ (N/mm²)	$\bar{\mu}$	$\bar{\sigma}_{xb}$ (N/mm²)	$\bar{\mu}$
2.0	*828.8*	*0.214*	*791.1*	*0.198*	*847.6*	*0.222*	*791.1*	*0.198*	*8.66.4*	*0.231*
4.0	*879.6*	*0.236*	*798.6*	*0.201*	*858.9*	*0.227*	*809.0*	*0.206*	*870.2*	*0.232*
6.0	*896.6*	*0.244*	*798.6*	*0.201*	*851.4*	*0.224*	*794.9*	*0.199*	*843.8*	*0.221*

Table 4.1 d Extrusion ratio of 1.17, speed of 4cm/min and various initial billet lengths

Initial billet length (mm)	Lubricants									
	zinc phosphate/sodium stearate		soya bean Oil		shea butter Oil		Groundnut Oil		Pala Oil	
	$\bar{\sigma}_{xb}$ (N/mm²)	$\bar{\mu}$	$\bar{\sigma}_{xb}$ (N/mm²)	$\bar{\mu}$	$\bar{\sigma}_{xb}$ (N/mm²)	$\bar{\mu}$	$\bar{\sigma}_{xb}$ (N/mm²)	$\bar{\mu}$	$\bar{\sigma}_{xb}$ (N/mm²)	$\bar{\mu}$
10	583.9	0.179	587.7	0.181	614.0	0.193	595.2	0.185	625.3	0.199
13	*591.4*	*0.179*	*591.4*	*0.183*	*629.1*	*0.201*	*602.7*	*0.188*	*631.0*	*0.201*
15	*602.7*	*0.188*	*614.0*	*0.193*	*634.8*	*0.203*	*610.3*	*0.192*	*632.9*	*0.202*
17	*617.8*	*0.195*	*617.8*	*0.195*	*632.9*	*0.202*	*621.6*	*0.197*	*640.4*	*0.206*

Table 4.2 Surface Finish of Billets Extruded under Various Lubrication Conditions at Various Reductions

			LUBRICANTS				
			Zinc Phosphate/ Sodium Stearate	Soya bean Oil	Shea butter Oil	Groundnut Oil	Palm Oil
Extrusion Ratio, R	Speed (cm/min)	Billet Length (mm)	Surface Finish (Microns)	Surface Finish (Microns)	Surface Finish (Microns)	Surface Finish (Microns)	Surface Finish (Microns)
1.17	2.0	10.0	0.056	0.063	0.194	0.120	0.256
1.17	4.0	10.0	0.115	0.125	0.223	0.165	0.269
1.17	6.0	10.0	0.213	0.163	0.325	0.189	0.394
1.17	4.0	13.0	0.144	0.145	0.288	0.175	0.298
1.17	4.0	15.0	0.176	0.220	0.310	0.215	0.306
1.17	4.0	17.0	0.233	0.231	0.305	0.256	0.328
1.40	2.0	10.0	0.060	0.069	0.275	0.123	0.313
1.40	4.0	10.0	0.169	0.133	0.413	0.168	0.420
1.40	6.0	10.0	0.269	0.206	0.450	0.225	0.469
1.40	4.0	13.0	0.231	0.169	0.444	0.210	0.475
1.69	2.0	10.0	0.419	0.263	0.481	0.258	0.503
1.69	4.0	10.0	0.520	0.294	0.494	0.318	0.513
1.69	6.0	10.0	0.525	0.289	0.488	0.281	0.475

Table 4.3 Hardness Distributions along the cross section of Billets Extruded Under Various Lubrication Conditions

		Hardness at various points on extrudates (DPN)			
Extrusion Ratio	Lubricants	0.75R	0.5R	0.25R	Centre
1.17	Zinc Phosphate/Sodium Stearate	188.8	186.0	183.5	182.2
	Soya bean oil	190.0	187.5	185.0	183.4
	Shea butter oil	211.6	208.7	205.0	203.1
	Groundnut oil	198.8	196.2	194.0	192.2
	Palm oil	220.0	219.0	215.0	214.6
1.40	Zinc Phosphate/Sodium Stearate	208.2	206.0	204.5	204.0
	Soya bean oil	195.0	193.2	192.0	191.4
	Shea butter oil	235.3	234.0	232.0	230.8
	Groundnut oil	207.4	206.0	202.5	202.0
	Palm oil	260.0	258.7	257.0	256.3
1.69	Zinc Phosphate/Sodium Stearate	294.0	292.8	292.0	291.1
	Soya bean oil	213.1	211.3	211.0	210.9
	Shea butter oil	303.3	302.3	300.0	300.0
	Groundnut oil	239.7	238.0	237.0	236.3
	Palm oil	315.0	314.5	312.0	312.0
2.09	Zinc Phosphate/Sodium Stearate	324.0	322.8	322.0	322.0
	Soya bean oil	357.0	254.8	254.0	253.2
	Shea butter oil	351.7	350.0	349.0	348.5
	Groundnut oil	276.0	274.4	274.0	273.5
	Palm oil	383.5	382.8	382.0	381.5

Hardness of unextruded billet = 101.3DPN
R = Radius of extruded billet.

CHAPTER FIVE

Discussion of Results, Conclusions and Recommendations:

Since the ability of a lubricant to perform satisfactorily under a given set of conditions is related to its physical and chemical characteristics, laboratory tests have been developed for measuring the chemical and physical properties in ways that permit expressing the degree to which a lubricant possesses a given property by a numerical value which enables different lubricants to be evaluated on a comparative basis.

In the on-going project the extrudability of steel produced in Nigeria, using certain vegetable oils as lubricants was investigated. The lubricants were assessed based on:

(a) The friction effect at different extrusion ratios, extrusion speeds and initial billet lengths.

(b) Surface finish of the extruded billets under each local oil lubrication condition.

(c) Hardness, taken radially on the billets extruded under each lubrication condition.

Metallographic examination of some of the extruded billets was also undertaken to qualitatively study some of the factors considered in the investigation.

To set a standard for comparison, the results obtained for the vegetable oils were compared with those obtained for the standard zinc phosphate/sodium stearate lubrication

system.

5.1 Extrusion Pressure Curves:

The basic data for a particular extrusion is obtained in the form of curves relating punch load or extrusion pressure with punch travel or displacement.

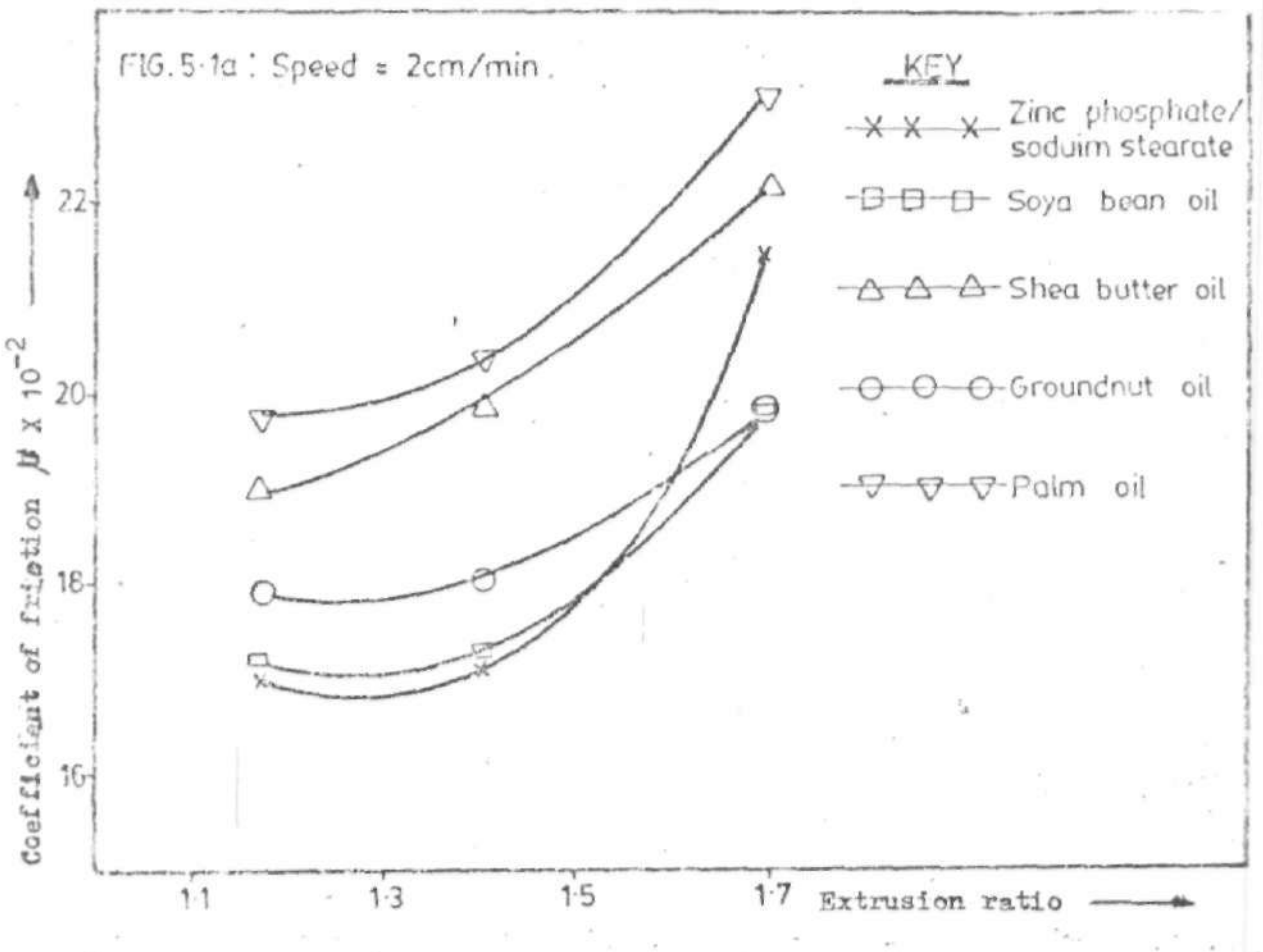
Curves of punch load against punch travel are shown in Figure 4.1 - 4.6. Figures 4.1 - 4.5 are similar to the characteristic extrusion pressure curve of Fig. 2.1, except the absence of stage V. Normally, for most practical extrusions, stage V is normally absent. According to Dieter (1981) it is uneconomical to develop enough pressure to force the billet completely through the die. In Fig. 4.6, only two of the stages can be identified for cases of extrusion ratio of 2.09. After stage II the slope of the curve changes but the load continues to rise with punch travel though more slowly. Two possible explanations could be given for this. Due to the great amount of reduction involved, the extrusion loads were quite high. As a result of the high loads there is the possibility of lubricant breakdown after the break through pressure was achieved, therefore instead of a progressive drop in load with punch travel, a continuous rise in load with punch travel is obtained. This reasoning is supported by the work of Morgan (1959) where similar curves were obtained. The shapes of the curves were attributed to a breakdown in the lubrication causing a steeply increasing load requirement.

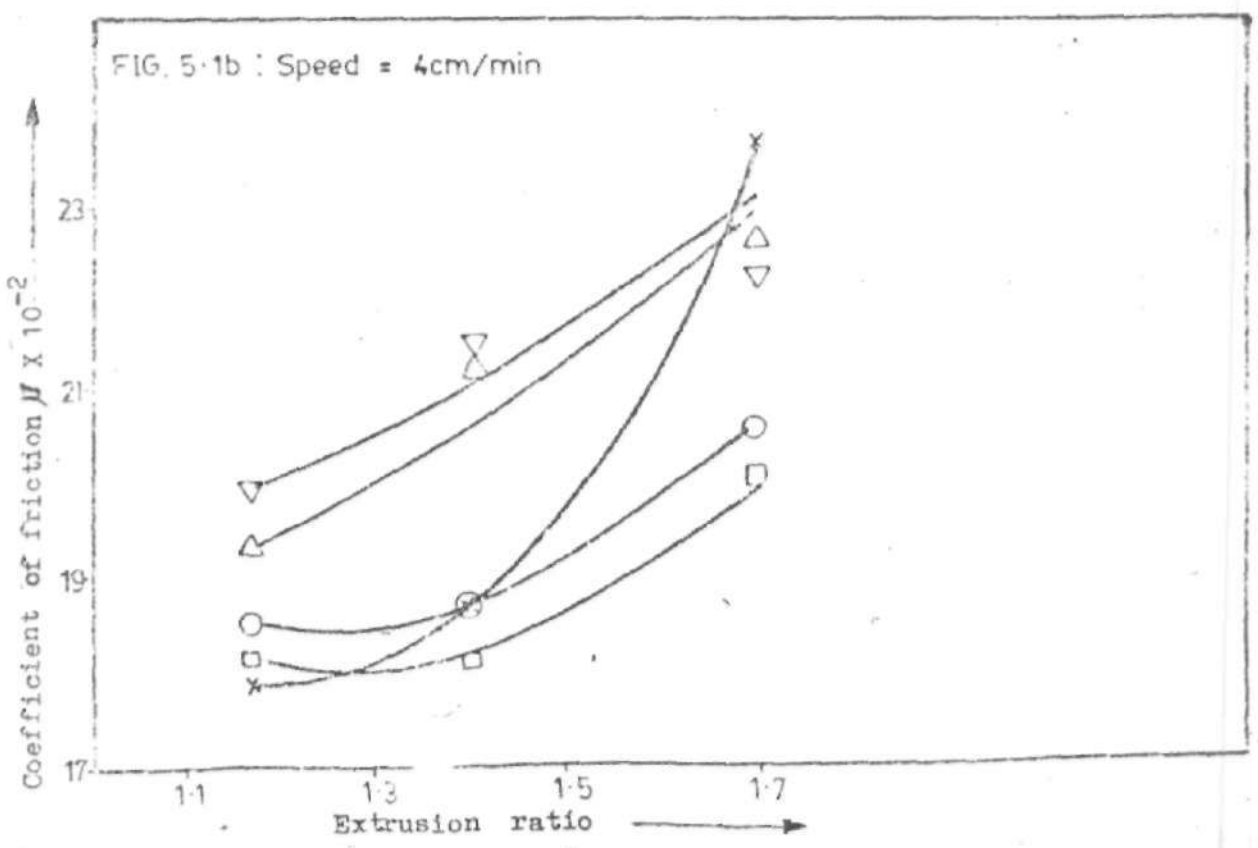
An additional reason for the type of curves obtained

could be punch deformation. At this extrusion ratio the punches started barrelling after a short distance of travel thereby completely filling up the container. Subsequently the punch itself was being deformed. The extrusion load observed therefore was that for extruding the billet as well as in deforming the punch and hence the continuous increase in load with punch travel.

5.2 Effect of Extrusion Ratio on the Friction Coefficient Under Various Lubrication Conditions:

From the friction coefficient values obtained under various lubrication conditions, the effect of extrusion ratio on the coefficient of friction at the extrusion speeds of 2cm/min, 4cm/min and 6cm/min are presented in Figures 5.1(a), (b) and (c) respectively. At the extrusion speed of 2cm/min (Fig. 5.1(a) and for an extrusion ratio of 1.17, the zinc phosphate/sodium stearate lubrication provided the lowest value of friction coefficient, Soya bean oil and groundnut oil gave a performance comparable with that of the zinc phosphate/sodium stearate lubrication. The remaining two oils, shea butter oil and palm oil, also gave favourable performance. The order of increasing friction coefficient is zinc phosphate/sodium stearate, Soya bean oil, groundnut oil, shea butter oil and palm oil. It can be seen that, generally, the coefficient of friction


FIG. 5·1a : Speed = 2cm/min.
KEY
Zinc phosphate/ soduim stearate
Soya bean oil
Shea butter oil
Groundnut oil
Palm oil
Coefficient of friction μ X 10⁻²
22
20
18
16
1·1
1·3
1·5
1·7
Extrusion ratio


FIG. 5·1b : Speed = 4cm/min
Coefficient of friction μ X 10⁻²
23
21
19
17
1·1
1·3
1·5
1·7
Extrusion ratio

increases continuously with extrusion ratio. It can be observed also that the rate of change in friction coefficient with extrusion ratio is greatest in the zinc phosphate sodium stearate mode of lubrication as compared with that of the vegetable oils lubrication. This is so much so that the zinc phosphate/sodium stearate lubrication which produced the lowest value of friction coefficient at the lowest reduction gave the highest value of friction coefficient at the highest reduction.

At the extrusion speed of 4cm/min the trend is similar to that of the speed of 2cm/min as shown in Fig. 5.1(b). At this speed, at an extrusion ratio of 1.40, the performance of soya bean oil as an extrusion lubricant is better than that of the standard lubricant. At R = 1.69, the performance of both soya bean oil and groundnut oil is better than the standard lubricant.

At an extrusion speed of 6cm/min [Fig. 5.1(c)], lower values of friction coefficient were obtained under soya bean oil and groundnut oil lubrication conditions at the lowest reduction of R = 1.17 when compared with the zinc phosphate/sodium stearate lubricant. The other vegetable oils also gave favourable performances. At an extrusion ratio of 1.69 all the vegetable oils performed better than the zinc phosphate/sodium stearate lubricant.

Generally, it is known that the rate of work hardening increases with deformation and hence frictional resistance to deformation should also increase in the same vein. Vegetable oils are boundary lubricants which function by

reacting with the metal surface to form a solid separating film. Their reactivity and hence lubricity increases with temperature up to their melting point (Abdul, 1977). Owing to the extensive deformation produced in cold extrusion, considerable internal heating of the metal results. The higher the reduction the greater the amount of heating. The increase in temperature of the metal with increased reduction enhanced the reactivity of the vegetable oils with the metal surface thereby increasing the lubrication efficiency. As reduction increased, two competing processes were developed - increasing work hardening with resultant increase in frictional resistance and increasing temperature that promotes boundary lubrication efficiency resulting in a reduction in frictional resistance. Whether frictional resistance increases or decreases with increase in reduction will depend on the interaction between these two effects. In cold extrusion the predominant effect is the high rate of work hardening hence frictional resistance should increase with increasing reduction. Under vegetable oil lubrication conditions, a reduction in frictional resistance is expected because of increased chemical reactivity that promotes lubricity. The less rapid increase in friction coefficient with increasing reduction observed under the vegetable oils lubrication conditions could therefore be attributed to their moderating effect as a result of enhanced lubricity with increasing reduction.

5.3 Effect of Extrusion Speed on Friction Coefficient Under Various Lubrication Conditions:

Figures 5.2(a) - (c) show the effect of extrusion speed on friction coefficient at various extrusion ratios. For the various lubrication conditions, the friction coefficient increases with increasing speed. The effect of extrusion speed on friction coefficient under the various lubrication conditions has been found to be similar to the effect of extrusion ratio.

The explanation for the observed effect of increased extrusion speed on friction coefficient is similar to that of increased reduction. As extrusion speed increases deformation resistance of the billet material increases. There is also an increase in the amount of heat generation in the metal with increasing extrusion speed. The scenario explained above is therefore applicable here.

The better performance of the vegetable oils at higher speeds and extrusion ratios as compared to that of zinc phosphate/sodium stearate lubricant could therefore be attributed to their increased reactivity under these conditions and consequently enhanced lubricating potentials of these oils.

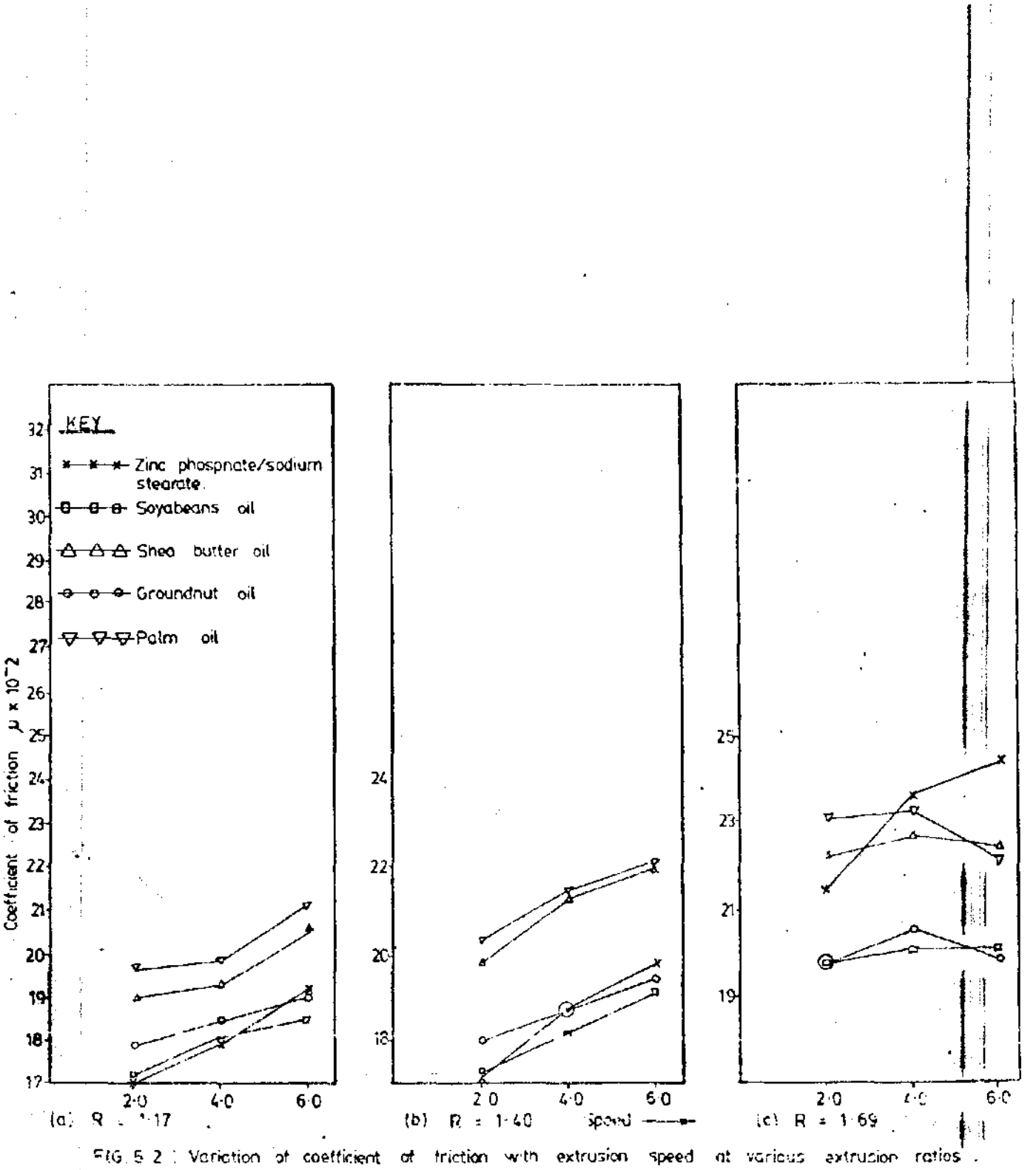


FIG. 5.2 : Variation of coefficient of friction with extrusion speed at various extrusion ratios.

5.4 The Effect of Initial Billet Length on the Coefficient of Friction:

Fig. 5.3 shows the effect of initial billet length on the coefficient of friction for an extrusion ratio of 1.17 and extrusion speed of 4cm/min under various lubrication conditions. As revealed in the figure, the coefficient of friction generally increases with increasing billet length for each of the lubrication conditions. This is in agreement with the observation of Lange et al (1966) that the maximum pressure required for the forward extrusion of rod increases with billet length. This may be due to the relative movement between the billet and container wall resulting in an increase in frictional losses with increasing billet length. The order of increasing lubricating properties for the oils ranges generally from palm oil, shea butter oil, groundnut oil, soya bean oil and zinc phosphate/sodium stearate. The figure (fig. 5.3) suggests that the relative performance of the oils is independent of the initial billet length.

5.5 Appraisal of Surface Finish of The Extruded Products under various Lubrication Conditions:

All products manufactured by plastic metal working are expected to conform to certain surface finish standards. Lubricants are among the most important factors affecting surface finish.

Table 4.2 gives the surface finish of billets extruded under various lubrication conditions at different extrusion

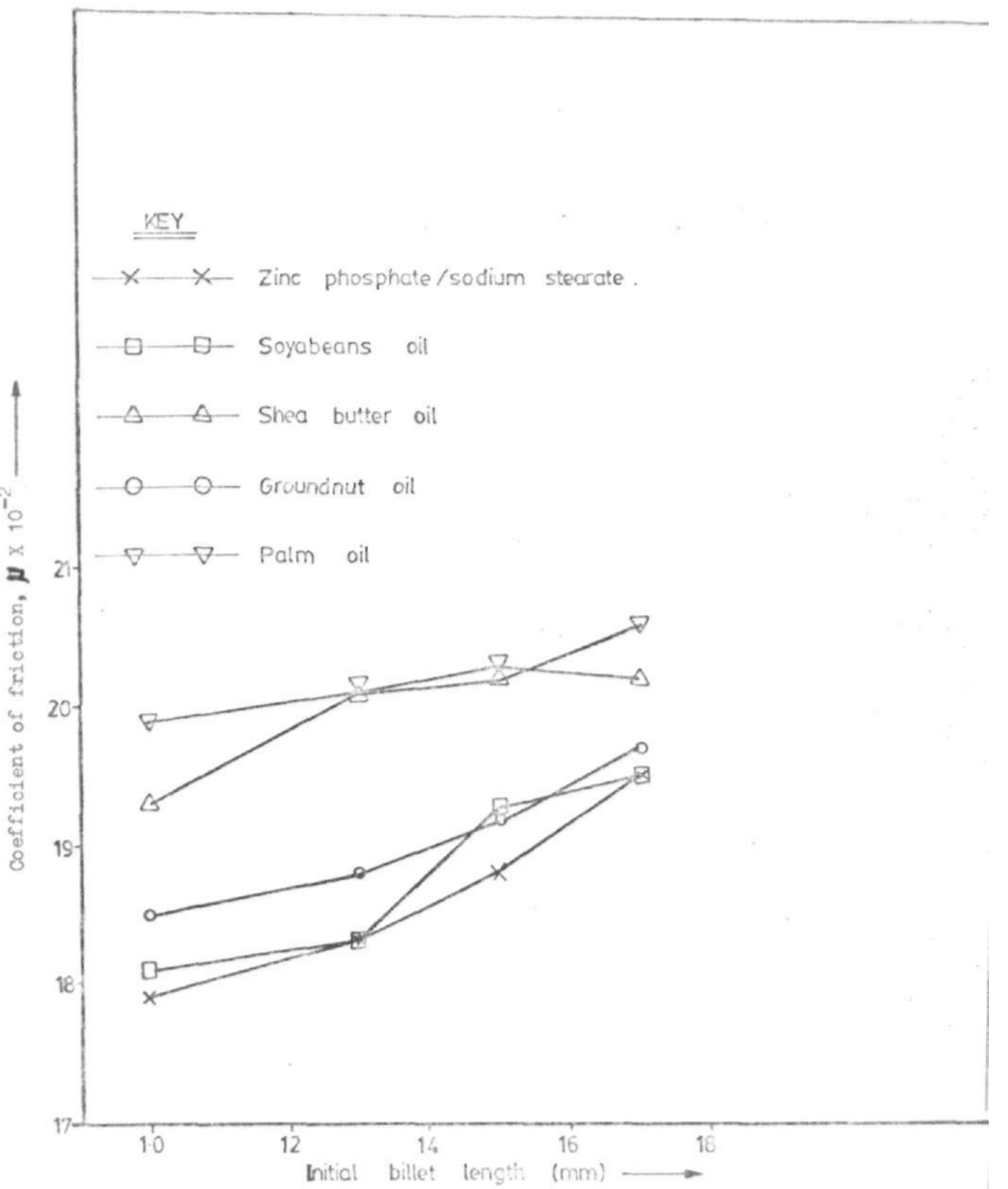


FIG. 5·3: Variation of coefficent of friction with initial billet length at an extrustion speed of 4cm/min.

ratios. Graphs showing the effect of extrusion ratio, extrusion speed,initial billet length, on surface finish under various lubrication conditions are shown in Figures 5.4, 5.5 and 5.6 respectively. The surface finish of an extruded product depends mainly on the frictional condition at the tool/work interface. The surface roughness of the extruded billets is therefore expected to change in the same direction with the friction coefficient. The coefficient of friction was earlier observed to increase with increasing extrusion ratio (Fig. 5.1). Surface roughness is therefore expected to increase with increasing extrusion ratio. This is what is obtained in (Fig. 5.4) where the surface roughness can be seen to increase with extrusion ratio under the various lubrication conditions. The relative performance of the oils in producing a smooth surface is of the same order as their corresponding friction coefficient as can be observed by comparing Fig. 5.1(b) and Fig. 5.4.

Fig. 5.6 shows that surface roughness increases with increasing initial billet length. This is consequent from the fact that as explained earlier, friction coefficient increases with initial billet length.

Figure 5.5 shows that surface roughness increases with increasing extrusion speed under various lubrication conditions. This could also be due to the fact that, (as shown in Figure 5.2) coefficient of friction increases with extrusion speed. The relative performance of the lubricants in reducing surface roughness corresponds to

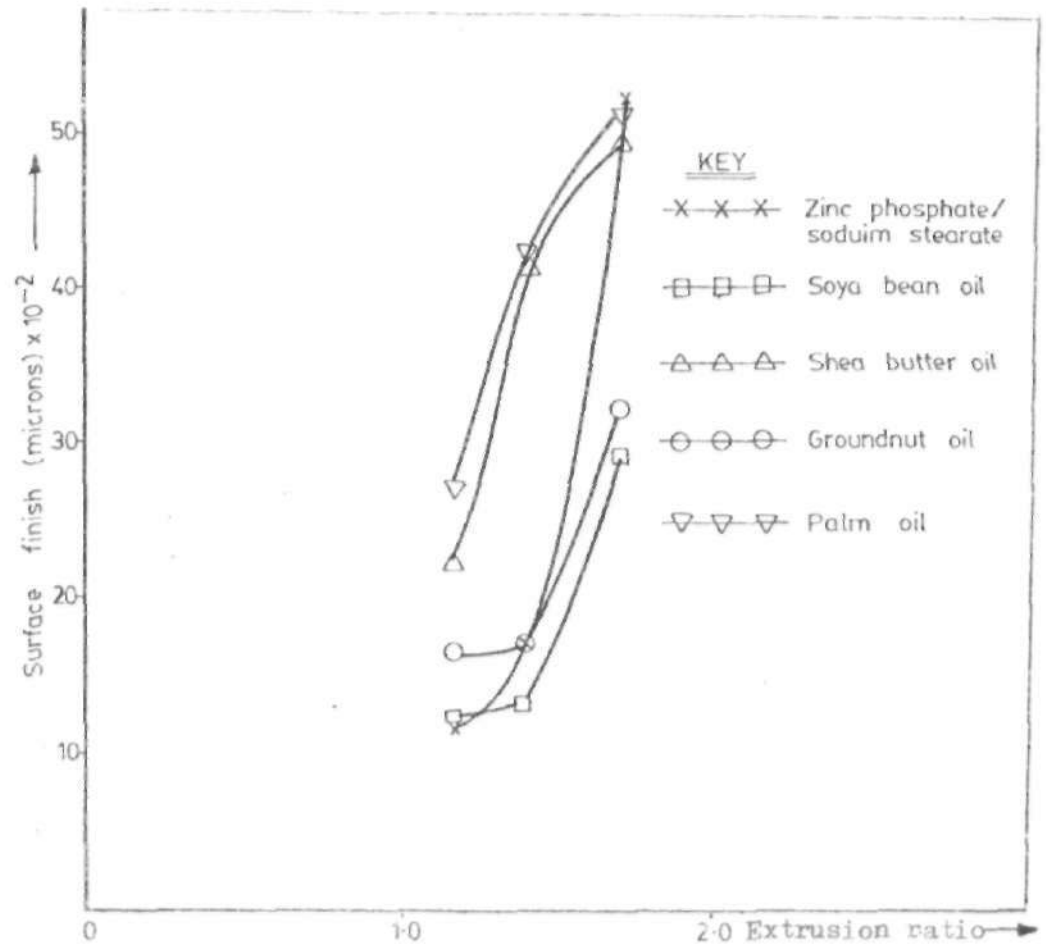


FIG. 5.4: Variation of surface finish with extrusion ratio at an extrusion speed of 4cm/min.

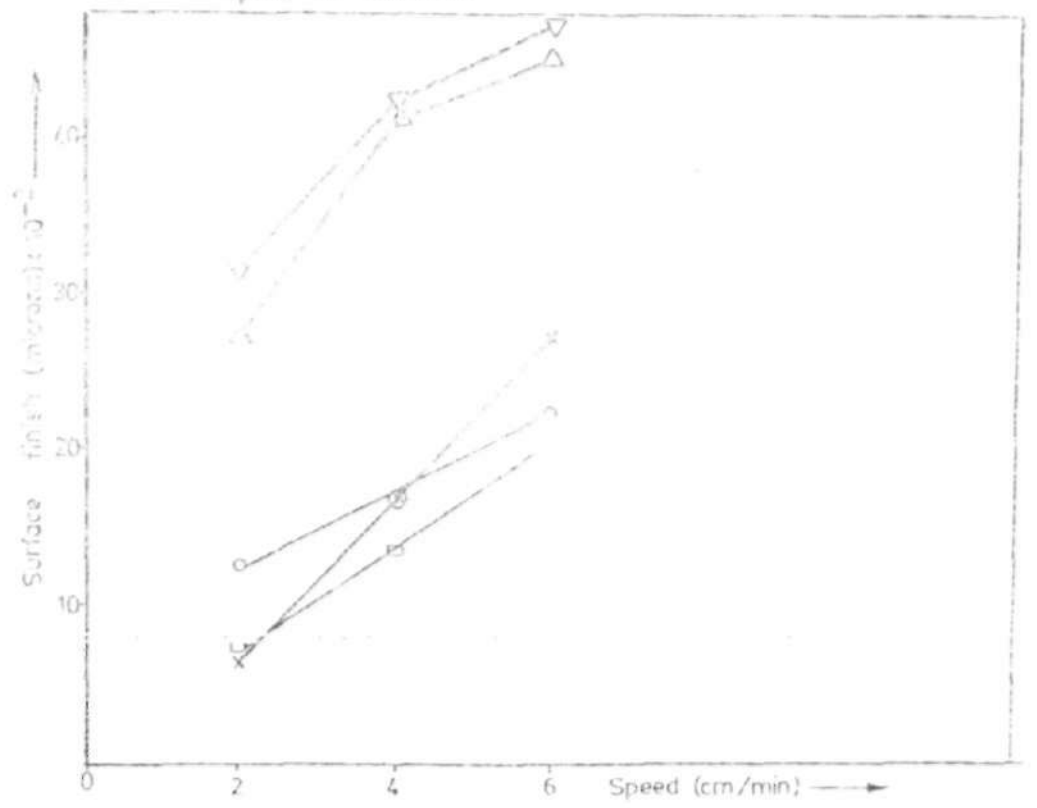


FIG. 5.5: Variation of surface finish with extrusion speed at an extrusion ratio of 1:1

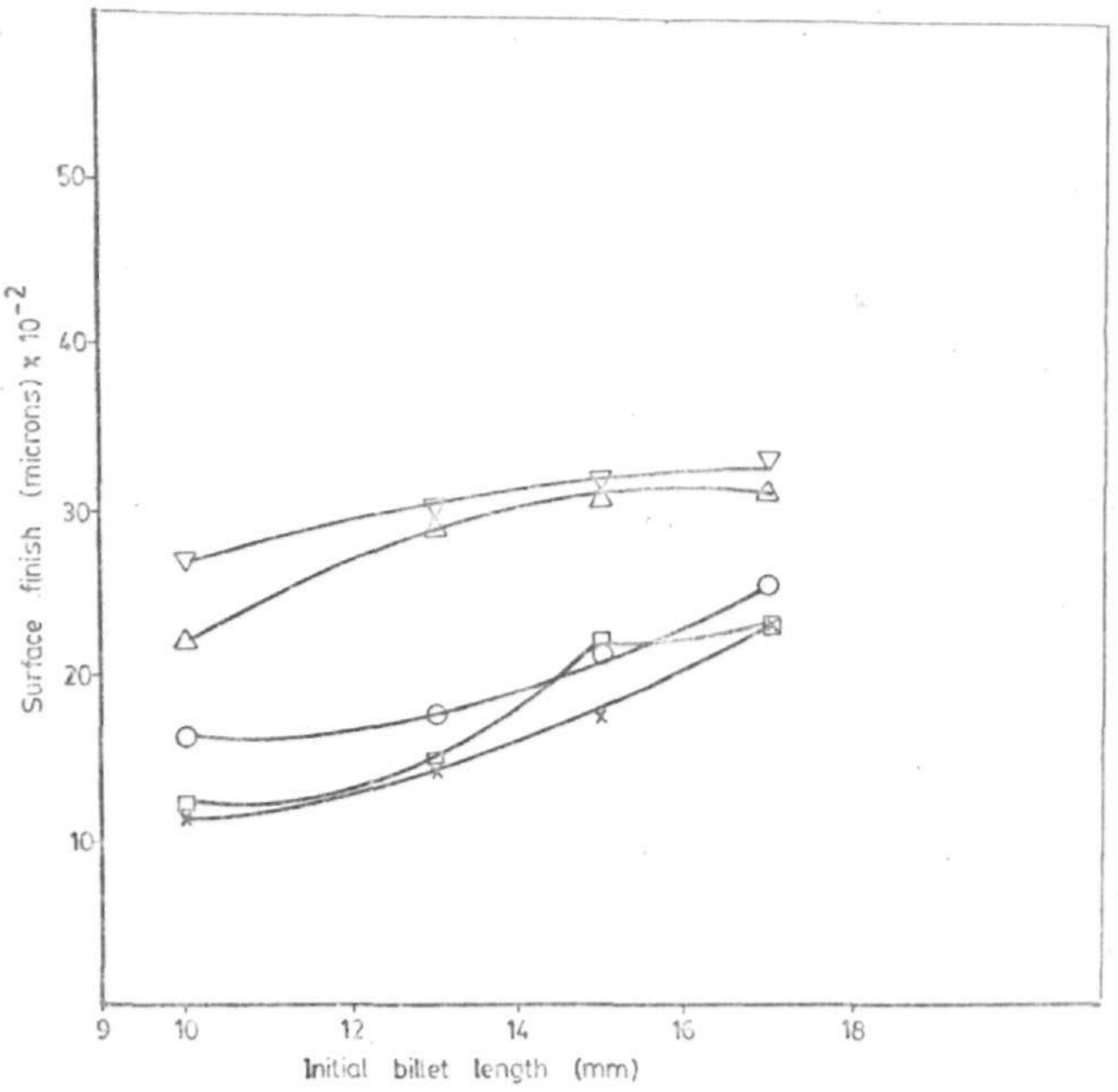


FIG. 5·6 : Variation of surface finish with initial billet length at an extrusion speed of 4cm/min, extrusion ratio of 1·17 .

their relative performance in reducing the friction coefficient as can be seen by comparing Figure 5.2(b) with Figure 5.6.

In terms of appearance, the billet extruded using the zinc phosphate/sodium stearate lubricant had the brightest surface. With the exception of palm oil, bright and shiny surfaces were produced under the various vegetable oils lubrication conditions. Palm oil produced a black stained surface and this was more pronounced at higher reductions and extrusion speeds. The stability of the vegetable oils relative to oxidation is indicated by their percentage free acid content. Palm oil has a percentage free acid content of 7 - 31% (appendix 2). The black stained surface on the extrudate while using palm oil as lubricant may be due to excessive oxidation which occurred. The oxidation should increase with temperature arising from increased speed and reduction.

5.6 Hardness Traverses in Billets Extruded under various Lubrication Conditions:

Table 4.3 shows the hardness values measured radially on selected cross-sectional planes of billets extruded under various lubrication conditions.

Curves of hardness values against radial distance from the centre of the extruded billets under various lubrication conditions and at different extrusion ratios are shown in Figure 5.7. The hardness can be seen to decrease on movement from the edge of the billet towards its centre. This may be due to the greater working of the billet at the outer surface which is in contact with the die. The hardness traverses of the extruded billets shown in figures 5.7(a) - (c) reveal the fact that hardness increases with extrusion ratio. This may by due to increase in deformation and hence in the rate of work hardening with increased extrusion ratio.

The variation in hardness from the outside to the centre of the billet is greater at lower reductions. As suggested by Pearson and Parkins (1961) this may be due to the fact that the centre receives only slight deformation at lower reductions.

Table 5.1 gives the variation of average hardness of the extruded billets with extrusion ratio for the various lubrication conditions while the graphical representation of the variation is given in fig. 5.8. As can be seen from the figure, hardness increases with extrusion ratio. The change is initially gradual becoming steeper as the extrusion ratio increases. The variation in hardness from

the least to the highest extrusion ratio is greatest for the zinc phosphate/sodium stearate lubrication

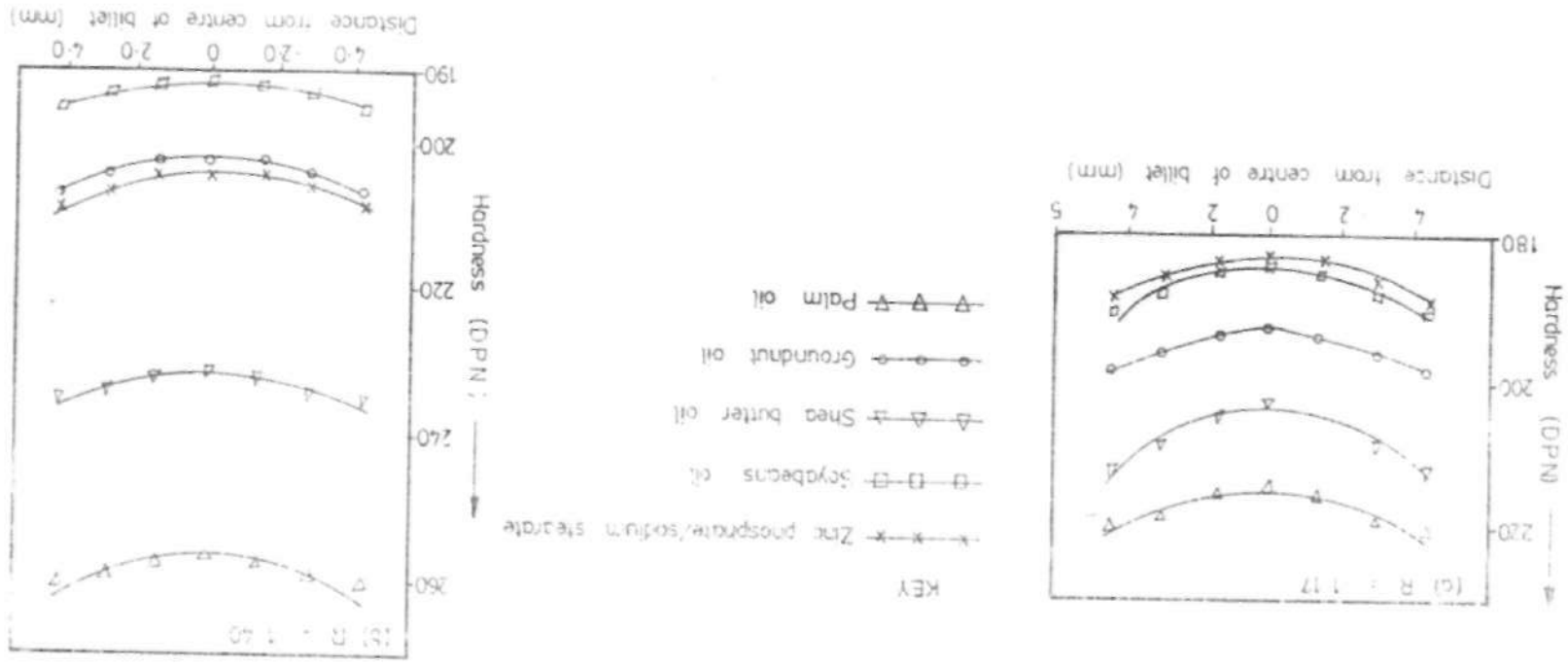


FIG 5.7 Curves of cross sectional hardness values of extruded billets against distance from the centre of the extruded billets for various lubrication conditions at various extrusion ratios

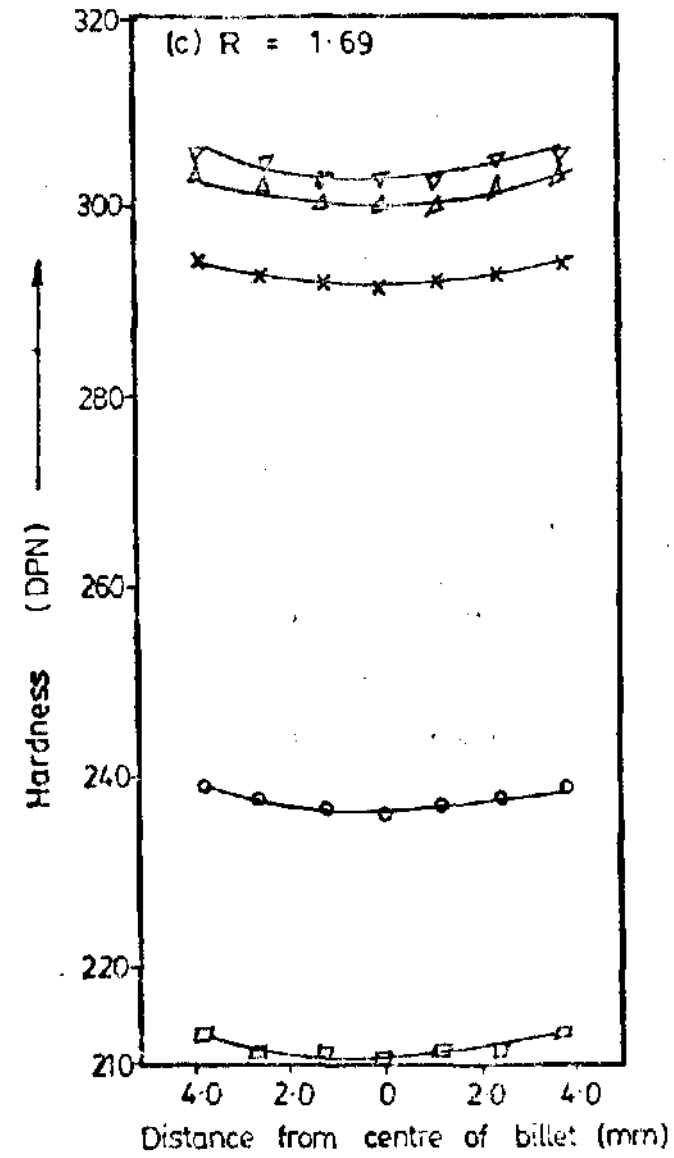

(c) R = 1·69
320
300
280
260
240
220
210
Hardness (DPN)
4·0
2·0
0
2·0
4·0
Distance from centre of billet (mm)

Table 5.1: Variation of hardness with extrusion ratio for the various lubrication conditions

Hardness (DPN)	Extrusion Ratio	Lubricants				
		Zinc Phosphate/ Sodium stearate	Soya bean Oil	Shea butter Oil	Groundnut Oil	Palm Oil
	1.17	185.0	186.5	207.0	185.0	217.0
	1.40	205.5	193.0	234.0	204.0	258.0
	1.69	292.5	211.5	301.5	238.0	314.0

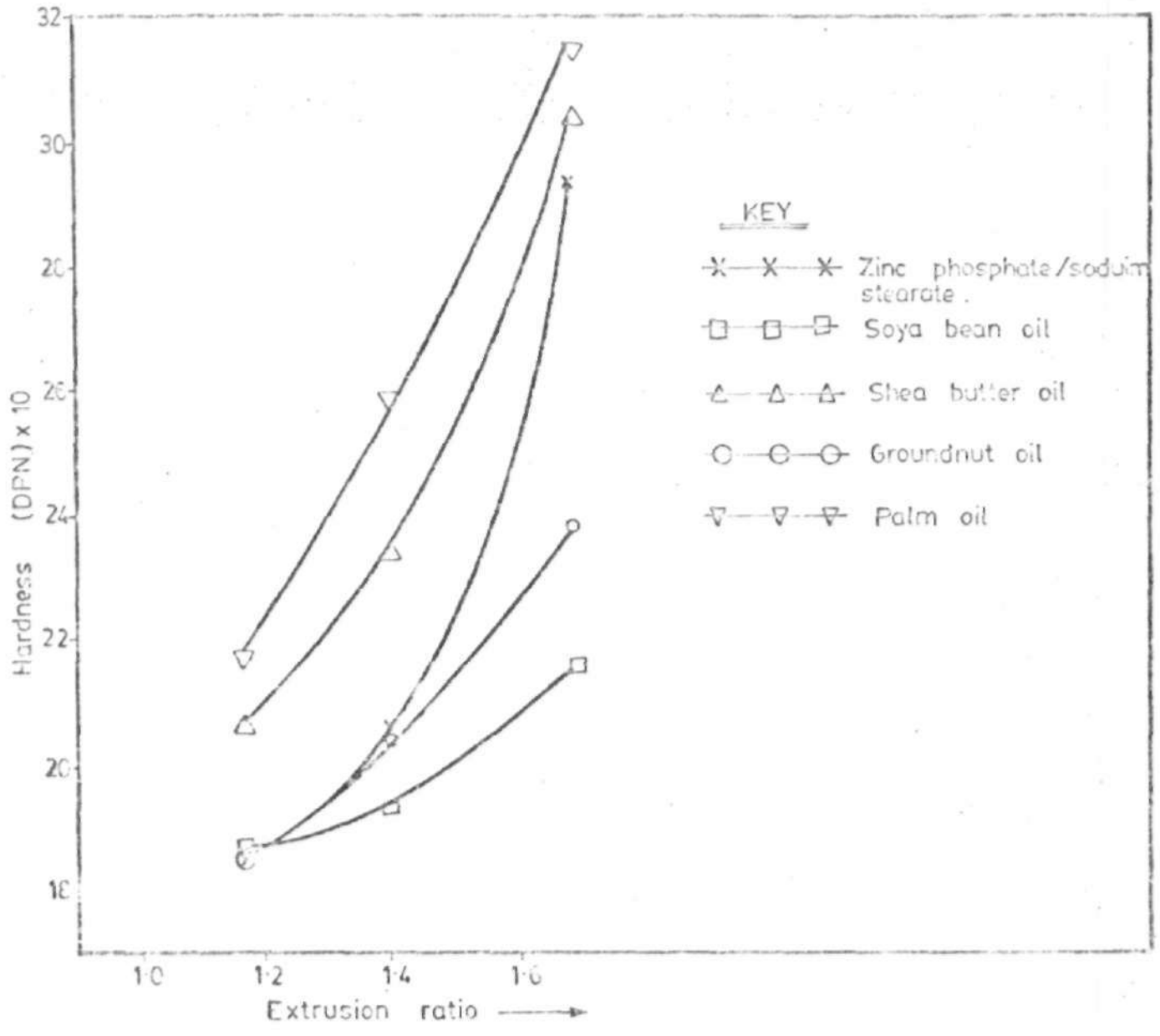


FIG. 5·8: Variation of hardness of extruded billets with extrusion ratio for t various lubrication conditions.

5.7 Metallographic Examination of Billets Extruded under various Lubrication Conditions:

The photomicrographs of the cross section of billets extruded under various lubrication conditions at various extrusion ratios at a speed of 4cm/min are shown in Plates 1 - 16.

From the composition of the Aladja ST60 - 2 Steel (Table 3.1) the room temperature structure consists mainly of ferrite and pearlite.

The ferrite shows up as white while the pearlite is dark. The hardness of the steel depends on the composition as well as grain size of the constituents. The greater the amount of pearlite, the harder the steel. The hardness of the steel is also greater the finer the grain size.

Under the same lubrication it can be observed that the grains are coarser at the lower reductions compared to those at the higher reductions. According to Pearson and Parkins (1961) areas having coarse grains in an extruded billet are those which have been subjected to lesser amount of working. The comparison of the hardness values with photomicrographs agrees with this observation. In addition according to Polukhin et al (1965), the coarsening of grains increases with rising temperature. The coarse grains at the lower reductions may be as a result of non uniform temperature rise and the possibility of the centre of the billets being left at a higher temperature after extrusion due to a faster rate of cooling on the outside.

5.8 Correlation of Physico-Chemical Properties of the oils with Lubricity:

The lubrication potential of the vegetable oils under investigation is governed by their ability to react with the work metal. This ability is governed by the various chemical and physical properties of the oils as underlined below.

5.8.1 Fatty Acid Content:

As previously established (Ajala, 1981) the saturated fatty acid content of the vegetable oils are myristic, palmitic, stearic, caprylic, capric, arachidic, beharic and lignoceric acids. With the presence of carboxylic groups these acids help in maintaining a strong molecular adherence of the vegetable oils to metal surfaces thereby minimizing friction and consequently encouraging good surface finish on the products. Furthermore, the unsaturated fatty acid contents of the oils are oleic and linoleic acids. These acids are themselves reactive in addition to the presence of carboxylic groups. They therefore contribute more to the adherence of the vegetable oils onto metal surfaces. The amount of the acids in the various oils is given in appendix 2. Groundnut oil, shea butter oil and palm oil with oleic acid composition of 62.0, 49.5 and 38.0 respectively gave lubrication performance in terms of reducing friction coefficient and improving surface finish in the same order as their oleic acid composition. However, soya bean oil with oleic acid

composition of 55.0 gave better performance than groundnut oil. This may be due to the fact that the overall unsaturation of soya bean oil as shown by the iodine values is greater than that of groundnut oil.

5.8.2 Iodine Value:

The iodine value of an oil is a measure of the degree of unsaturated fatty acids in an oil. It therefore indicates the degree of reactivity of the oils. Since the lubricating performance of the oils is based on their ability to react with the work metal, their performance as lubricants is expected to increase with increasing iodine value. Soya bean oil, groundnut oil, Shea butter oil and palm oil with iodine values of 120.0, 106.1, 65.0, 64.5 respectively, gave lubrication performance which is in the same order as their iodine values as shown by their ability in friction reduction and providing a good surface finish on the extruded billets. The hardness values obtained for the various oils increased in opposite direction to direction of increasing iodine value. This may be due to increased reactivity with increased iodine value. As suggested by Gbadamasi (1991), the products of the reaction hinder the effective extraction of heat from the billet during extrusion.

5.8.3 Phosphorous Content:

Phosphorous has over the years been used either singly

or in combination with other reactive elements such as sulphur and chlorine to improve the lubrication performance of oils. The phosphorous content of soya bean oil and shea butter oil is not available. However, groundnut oil and palm oil with phosphorous content of 0.067% and 0.048% respectively (appendix 2) gave lubrication performance in the same order as their phosphorous content in reducing friction coefficient and surface roughness.

5.8.4 Percentage Free Acid:

The stability of these oils relative to oxidation is indicated by their percentage free acid content. The free acid contains unsaturated hydrocarbons which are very reactive and on exposure to the atmosphere get oxidized. The vegetable oils were found to have high stability in storage.

5.8.5 Saponification Value:

The presence of lubricant residue on an extruded product contributes significantly to its appearance, future corrosion properties, and where additional operations like welding or heat treatment are to be carried out, it may constitute an impediment to the process. A good lubricant should therefore leave no residue on the products and where it does, it should be easily removable. The saponification value of an oil indicates the ease with which the oil can be degreased in an alkaline medium. The relatively low saponification values of the vegetable oils (appendix 2)

indicates that they can be easily degreased in an alkaline medium.

5.9 Summary and Conclusions:

The suitability of vegetable oils - palm oil, groundnut oil, soya bean oil and shea butter oil - as lubricants in the cold extrusion of steel has been investigated.

The assessment of the vegetable oils under investigation as cold extrusion lubricants was based on three parameters namely, the coefficient of friction, the surface finish of the extrudates and the cross sectional hardness values of the extruded billets. These values were compared with those obtained under the standard zinc phosphate/sodium stearate lubrication condition.

The performance of the vegetable oils in producing favourable friction condition as compared with the performance of the standard zinc phosphate/sodium stearate lubricant was found to be satisfactory. Infact at the higher reductions and extrusion speeds all the vegetable oils performed better than the zinc phosphate sodium stearate lubricant.

The performance of the vegetable oils in terms of the surface finish produced on the extruded billet was also impressive. All the vegetable oils performed favourably compared to the standard zinc phosphate/sodium stearate lubrication mode. At the higher extrusion ratios and extrusion speeds, soya bean oil and groundnut oil produced better surface finishes on the extruded billets compared

with the standard lubricant.

The hardness values obtained on the billets extruded using the vegetable oil as lubricants were similar to those for which the standard lubricant was used. At the higher extrusion ratio, billets lubricated with shea butter oil and palm oil gave higher hardness values compared with the standard lubricants while lower hardness values were obtained on those lubricated with soya bean oil and groundnut oil.

5.10 Recommendations for further Work:

In the light of the afore going teet results, the followings have been suggested for future work in the development of vegetable oils as lubricants for the cold extrusion of steel.

(a) Chemical reactions which take place between the work piece and the oil during extrusion should be investigated. This would enable the extraction of only those constituents that are actually necessary for the lubrication reaction and hence ensure optimal utilisation of the oils as lubricants.

(b) A test run, in the production of definite artirles under production conditions, should be carried out. It is only under these conditions that some very important extrusion parameters such as tool life and indeed actual cost of lubrication can be effectively measured.

(c) Since the vegetable oils are mostly edible oils it may

be necessary, as an interim measure, to blend them (vegetable oils) with mineral oils. However, this will be more effectively undertaken after recommendation under (a) must have been carried out.

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Appendix 1: The maximum extrusion load under the various lubrication conditions for various extrusion Parameters

1.a Extrusion ratio of 1.17 inital billet length of 10mm at various speeds.

Speed cm/min	Lubricants				
	Zinc phosphate/ sodium stearate	Soya bean Oil	Shea butter Oil	Groundnut Oil	Palm Oil
	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)
2.0	75.0	75.5	80.5	77.5	82.5
4.0	77.5	78.0	81.5	79.0	83.0
6.0	81.0	79.0	85.0	80.5	86.5

1.b Extrusion ratio of 1.40, initial billet length of 10mm at various speeds

Speed cm/min	Lubricants				
	Zinc phosphate/ sodium stearate	Soya bean Oil	Shea butter Oil	Groundnut Oil	Palm Oil
	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)
2.0	82.8	83.0	90.0	85.0	91.5
4.0	87.0	85.5	94.0	87.0	94.5
6.0	90.0	88.0	95.8	89.0	96.0

1. c Extrusion ratio of 1.69, initial billet length of 10 mm at various speeds.

Speed cm/min	Lubricants				
	Zinc phosphate/ sodium stearate	Soya bean Oil	Shea butter Oil	Groundnut Oil	Palm Oil
	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)
2.0	110.0	105.0	112.5	105.0	115.0
4.0	116.8	106.0	114.0	107.5	115.5
6.0	119.0	106.0	113.0	105.5	112.0

1.d Extrusion ratio pf 1.17, speed of 4cm/min and various initial billet lengths.

Speed cm/min	Lubricants				
	Zinc phosphate/ sodium stearate	Soya bean Oil	Shea butter Oil	Groundnut Oil	Palm Oil
	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)	Max. Load (kN)
10	77.5	78.0	81.5	79.0	83.0
13	78.5	78.5	83.5	80.0	83.8
15	80.0	81.5	84.3	81.0	84.0
17	82.0	82.0	84.0	82.5	85.0

APPENDIX 2: **Fatty Acid Composition of the Vegetable Oils under Investigation:**

Fatty Acids	Groundnut Oil	Pala Oil	Soya bean Oil	Shea butter Oil
Myristic	-	1.0	0.25	-
Stearic	4.5	4.0	4.0	35.5
Palmitic	7.5	48.0	9.0	7.0
Arachidic	3.0	-	-	-
Beharic	2.0	-	0.5	-
Lignoceric	2.0	-	-	-
Oleic	62.0	38.0	55.0	49.5
Linoleic	20.0	9.0	8.0	4.5

APPENDIX 3: **% Free acid, saponification values, Iodine values, and phosphorous content of the vegetable oils under investigation.**

Vegetable Oil	% Free Acid	Saponification Value	Iodine Value	% Phosphorous Content
Pala Oil	6.99 - 31.99	225.4 - 227.6	64.5	0.048
Groundnut Oil	0.11 - 0.24	223.0 - 230.2	106.1	0.067
Soya bean Oil	-	189.0 - 195.0	130.5	-
Shea butter Oil	14.21 - 52.36	178.0 - 196.0	65.0	-