THE EFFECT OF PUNCH PROFILE RADIUS ON PUNCH LOAD, EDG PULL-IN AND THICKNESS STRAINS IN DEEP DRAWING

BY

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A thesis submitted to the **Department of Mechanical** Engineering, **in** partial **fulfillment of** the requirements for **the** degree of Master of **Engineering** in Production Engineering.

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DEDICATION

This work is dedicated to

Cerie

for her support throughout the

duration of this work.

ACKNOWLEDGEMENT

My sincere gratitude goes to my Supervisors, Professor S. Y. Aku, and Dr. W. R. Rychwalski for their advise and helpful review throughout the preparation of this work.

I also wish to express my gratitude to the Staff of the Mechanical Engineering Workshop, who saw to the Manufacture of the tools and Mr. Sani, who was very helpful with the commissioning of the equipment.

Iheanyi Ofondu.

November, 1984.

LIST OF SYMBOLS

E	-	Young's Modulus
$\Delta\sigma$	-	Change in stress
$\Delta\varepsilon$	-	Change in strain
r'	-	Strain ratio
ε_t	-	Thickness strain, (ε_2)
ε_w	-	Width strain, (ε_3)
ε	-	Strain,
σ	-	Stress,
K	-	Strength co-efficient,
e_u	-	Uniform elongation,
n	-	Strain hardening exponent,
H	-	Clamping force,
σ_1	-	Radial drawing stress,
σ_2	-	Stress normal to blank,
σ_3	-	Circumferential stress,
	-	Co-efficient of friction,
t	-	Blank thickness,
r	-	Instantenous radius of an element in the flange of blank,
R	-	Initial radius of an element in the flange of blank,
r_o	-	Instantenous radius of rim of blank,
R_o	-	Initial radius of rim of blank,

t_m – Instantenous mean thickness of metal between the rim, radius r_o and any radius r,

t_o – Initial thickness of an element of radius r_o,

$\bar{\sigma}_o$ – Yield stress,

$\bar{\sigma}$ – Representative stress,

σ' – Drawing stress due to blank-holding friction,

B, C – Constants

$\bar{\varepsilon}$ – Representative strain

ε_1 – Radial strain

ε_2 – Thickness strain

ε_3 – Hoop strain

g.M.s – Galvanized mild steel

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A B S T R A C T

The need to produce sheet metal parts of various shapes and sizes, in large quantities, economically, has led to the study of the parameters that govern sheet metal forming processes in order to be able to predict the process and product properties. Deep drawing, involving the use of prosses to form sheet metal parts of shapes and sizes determined by the shape and size of the drawing punch and die, has come into increased use in industry, for the production of car bodies, aircraft parts, pots, pans, cups and so on.

In this work a study of the effect of the punch profile radius on the formability of sheet metal, with respect to the press load and thickness strains cups produced by deep drawing of circular blanks, was carried out. The thickness strain variation at progressive stages of the drawing operation, using five punches of varing profile radius, was investigated. Three metals, aluminium, brass and galvanized mild steel were used. The progression of edge pull-in of cup flange for the various punch radii was studied. One die of profile radius 15mm was used. Circular blanks of constant diameter for

each material were employed. Constant pressure blank holding was employed and no lubricants were used. Sheet metal thickness varied between metals.

A 400KN sheet - metal testing equipment was commissioned and used for this work. The equipment essentially a double - action hydraulic press, is supplied with a drawing punch and die, a pressure blank holder and an X-Y recorder. Four more punches and a die were designed but only the punches were produced.

The study showed that, the punch profile radius has little effect on the punch load. The plot of the thickness strains showed one neck. The necking was more pronounced and occured closer to the centre of the cup base, with the more generous punch profile radii. Thickening of the cup flange increased with depth of draw. Thinning at the base of the cups increased with the depth of draw. The more generous the punch profile radius, the more the thinning at the cup base. Tool material and finish was noted to have an effect on the thinning at the cup base Alluminium exhibited the least ability to draw.

Lubrication showed little improvement. Thicker blanks required larger punch loads and exhibited more thickness strains at the base of cups.

CHAPTER - 1

INTRODUCTION

1.1 General

The term 'deep drawing' applies to the process of deforming sheet metal characterized by the use of a punch and a die, with the sheet metal being drawn inwards and over the die profile by the advancing punch. The flange of the sheet metal not yet drawn in controlled and prevented from wrinkling by moderate pressure applied to its faces by a suitable blank holder. Dies can have any shape from simple circular form to the complicated shape required for a car body. The main variables of the deformation in deep drawing are the radius of the die profile, the radius of the punch profile, the blank material, the blank holding conditions the lubrication and the geometrical ratio of the blank size to the punch size.

The primary objective of studies into the mechanisms of deep drawing has been to make it possible to predict:

1. the press load required to perform a particular drawing operation;

2. The stresses and strains induced in the sheet metal during the operation;

3. The probability that metal of known mechanical properties will draw successfully.

1.1 Theory and Analysis of Deep Drawing

The simplest deep drawing operation is the production of a cylinderical cup from a flat circular blank of sheet metal. Figure (1.1) shows the process of deep-drawing of a circular blank. The blank is divided into three zones, X, Y and Z. The outer annular zone X consists of material in contact with the die. The inner annular zone Y is initially not in contact with either the punch or the die and the circular zone Z is in contact with the punch.

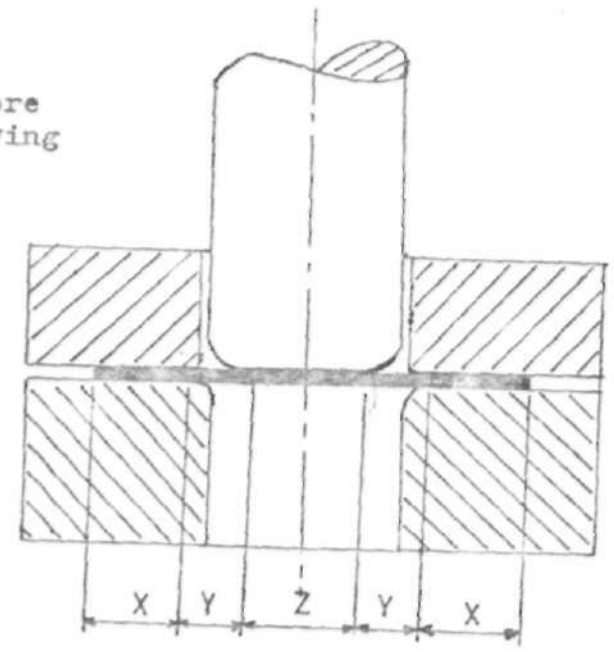
As drawing proceeds, the material in zone X is drawn inwards towards the die profile under an applied radial tensile stress, inducing a compressive hoop stress which causes an increase

in material thickness. This compressive hoop stress will cause the flange to wrinkle if no form of blank-holding is employed. As the material in zone X passes over the die profile, it is thinned by plastic bending under tensile stress. Finally, the inner parts of zone X are further thinned by tension between the die and the punch.

Zone Y partly undergoes bending and sliding over the die profile, stretching in tension between the die and punch, and bending and sliding over the punch profile.

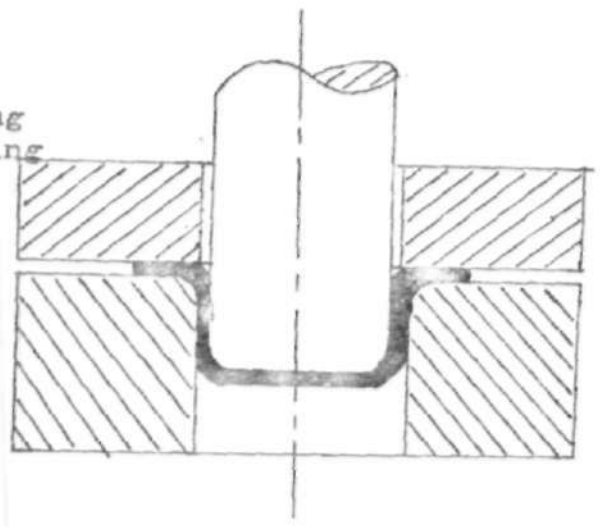
Zone Z is subjected to stretching and sliding over the punch head. The amount of stretching depending on the geometry of the punch head and the frictional conditions. Between the fibres associated with drawing over the die and with stretching over the punch, there is a narrow band in zone Y, which escape plastic bending over the die profile and stretching over the punch profile, and is thus subjected to predominantly simple tensile conditions throughout the drawing operation. This narrow band stretches and thins under

(a) Before Drawing



Zone X undergoes radial drawing between die and blank holder, bending and sliding over die profile, and stretching between punch and die.

(b) During Drawing



Zone Y undergoes bending and sliding over die profile, stretching between punch and die, and bending and sliding over punch profile radius.

Zone Z undergoes stretching a sliding over punch head, bend and sliding over punch radius.

Fig. 1.1: Deformation of blank under punch load.

tension to a lower extent than the fibres on either side of it and gives rise to a thicker band between two apparent necks. Figure (1.2) schematically highlights the two necks A and B. Fracture of the metal takes place at one of the necks, usually at the one nearest to the punch head, neck B in Figure (1.2), according to Johnson and Mellor (1962). The punch load at any phase of drawing is determined by the radial drawing regime, and it in-turn governs the strains in the stretch-forming region. If the blank is held rigidly at the die to prevent radial drawing, the process becomes one of pure stretch-forming.

1.2.2 Stresses and Strains in Deep Drawn Cups Pure Radial Drawing

For an isotropic material the principal stresses for plane radial drawing are the radial drawing stress σ_1, the stress σ_2, normal to the blank and the circumsferential stress σ_3. Considering an element in the flange, at current radius r, and with stresses acting as shown in Figure (1.3), it can be shown that the equation of radial equilibrium is:

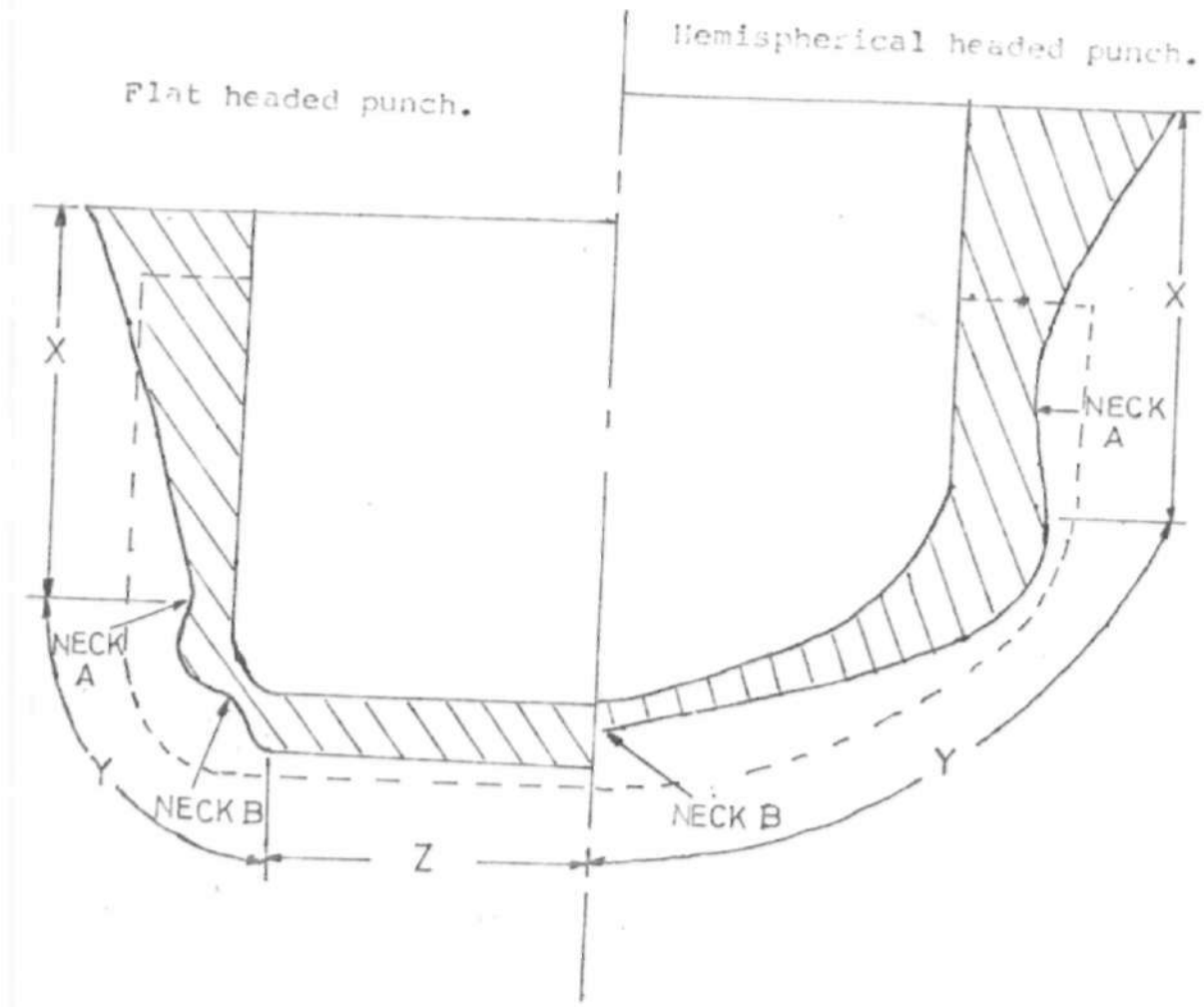


Fig. 1.2 **Schematic** representation of thickness variation **around the** punch profile.

$$\frac{d}{dr}(\sigma_1) + \frac{t}{r}(\sigma_1 - \sigma_3) - 2\mu\sigma_2 = 0$$

where μ is the co-efficient of friction, assumed constant across the flange. The physical conditions show that σ_1 will be tensile, σ_2 and σ_3 will be compressive. Since the blank thickens most at the rim, it will be assumed that all the blank-holding force is exerted at the rim and that elsewhere $\sigma_2 = 0$. Thus, considering frictional effects separately, the equilibrium equation becomes:

$$\frac{d}{dr}(t\sigma) = \frac{t}{r}(\sigma_3 - \sigma) \quad \text{------ (1.2)}$$

where σ is the portion of the drawing stress due only to frictionless radial drawing, i.e. $\mu = 0$.

The yield criterion may be written as:

$$\sigma - \sigma_3 = m\bar{\sigma} \quad \text{------ (1.3)}$$

where $\bar{\sigma}$ is the representative stress and m according to Johnson and Mellor (1962), has a value of 1.1 to give optimum agreement between the Tresca and Von Mises criteria of yielding.

$$d\sigma = -m\bar{\sigma}\frac{dr}{r} - \sigma\frac{dt}{t} \quad \text{------ (1.4)}$$

considering dt to be small at any moment, the equilibrium equation then becomes:

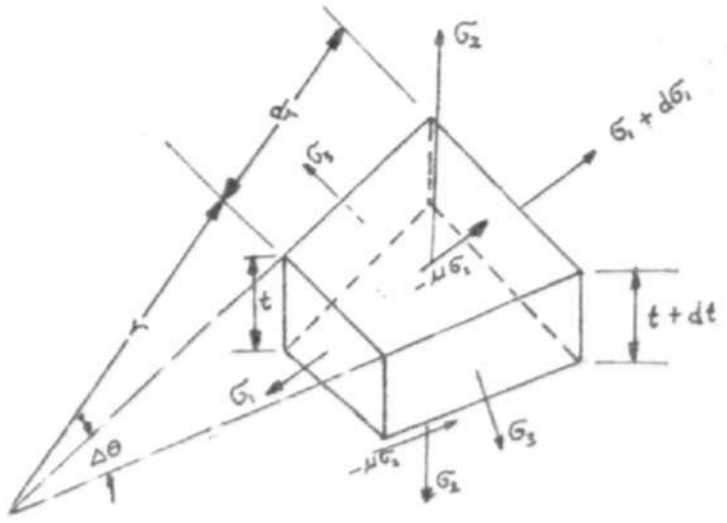


Fig 1.3 Stresses on element in flange

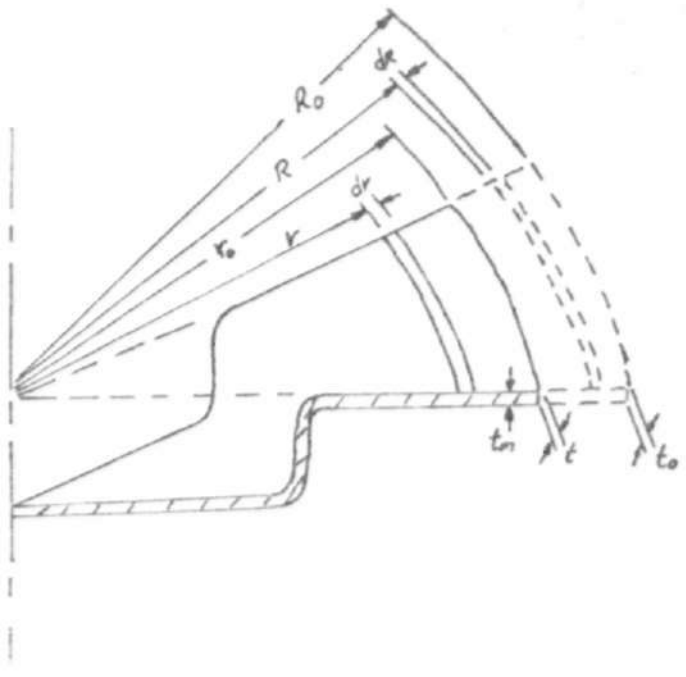


Fig 1.4 Section of a partially drawn cup

$$d\bar{\sigma} = -m\bar{\sigma}\frac{dr}{r} \quad \text{------ (1.5)}$$

Assuming that the strain-rate during radial drawing is constant and ignoring the effect of changing stress ratio, the current value of the representative stress:

$$\bar{\sigma} = \sqrt{\tfrac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]}$$

depends only up on the representative strain

$$\bar{\varepsilon} = \sqrt{\tfrac{2}{3}\left[(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2 + (\varepsilon_3 - \varepsilon_1)^2\right]}$$

Also, Hill (1950) has shown that $\bar{\varepsilon}$ is never more than about 3 per cent greater than the numerical value of the hoop strain, ε_3.

Introducing strain-hardening, a suitable empirical expression, according to Ford (1963) is Ludwik's power law:

$$\bar{\sigma} = \bar{\sigma}_o + B\bar{\varepsilon}^{\,n} \quad \text{------ (1.6)}$$

where $\bar{\sigma}_o$, B and n are constants. For practical purposes, therefore, it can be written as:

$$\bar{\sigma} = \bar{\sigma}_o + B\,(\ln R/r)^n \quad \text{------ (1.7)}$$

where $\ln R/r$ is the hoop strain, R being the initial radius and r the current radius to a particle.

From Figure (1.4), if tm represents the current mean thickness of the metal between the rim and the element under consideration, The condition of incompressibility gives, equating the volume of metal before and during radial drawing;

$$\pi (R_o^2 - R^2)\ t_o = \pi(r_o^2 - r^2)\ tm$$

where t_o is the original thickness of the blank. This may be written in the form

$$(\frac{R}{r})^2\ (\frac{t_o}{t_m}) - 1 = (R_o^2\ \frac{t_o}{t_m} - r^2{}_o)\ \frac{1}{r^2} = \frac{C}{r^2} \quad \text{say.}$$

Hence, the hoop strain $_3$ is

$$\text{In}\ \frac{R}{r} = \tfrac{1}{2}\ \text{In}\left\{\frac{t_m}{t_o}\ (1 + \frac{C}{r^2})\right\} \text{ ------ (1.8)}$$

substituting in equating (1.7)

$$\bar{\sigma} = \bar{\sigma}_o + B\left[\tfrac{1}{2}\ \text{In}\left\{\frac{t_m}{t_o}\ (1 + \frac{C}{r^2})\right\}\right]^n$$

If this is substituted in the equation of equilibrium (1.5)

$$d\sigma = -m\bar{\sigma}_o\ \frac{dr}{r} - mB\left[\tfrac{1}{2}\ \text{In}\left\{\frac{t_m}{t_o}\ (1 + \frac{C}{r^2})\right\}\right]^n \frac{dr}{r}$$

and integrating, the portion of the drawing stress, at current radius r, due to radial drawing alone is;

$$\sigma = -m\bar{\sigma}_o \ln\left(\frac{r}{r_o}\right) - mB \int_{r_o}^{r} \tfrac{1}{2} \ln\left[\frac{t_m}{t_o}\left(1 + \frac{c}{r^2}\right)\right]^n \frac{dr}{r} \quad \text{------ (1.9),}$$

where r_o is the current radius of the rim of the blank. If H is the total blank - holding force, the portion of the drawing stress, σ^1, due to blank-holding friction, can be shown to be $\sigma_1^1 = \frac{4H}{\pi r_o t}$ ------ (1.10)

where μ is the co-efficient of friction, assumed constant and equal for both sides of the blank. The total radial drawing stress is then

$$\sigma_1 = \sigma + \sigma_1^1 \quad \text{------ (1.11)}$$

Once the stresses are known, the strains can be obtained from the Levy-Mises relationship taking σ_2 to be zero.

$$\text{Thus} \quad \frac{dt}{t} = -\left[\frac{\sigma + \sigma_3}{2\bar{\sigma} - \sigma}\right] \frac{dr}{r}$$

and substituting $\sigma_3 = \sigma - m\bar{\sigma}$ from the yield criterion

$$\frac{dt}{t} = -\left(2 + \frac{3m\bar{\sigma}}{\sigma - 2m\bar{\sigma}}\right) \frac{dr}{r} \quad \text{------ (1.12)}$$

The thickness changes of any particular element of metal of initial radius R is got by substituting the values of σ and $\bar{\sigma}$ in equation

(1.12) and integrating. The relation between r and r_o is derived from the equation of incompressibility

$$(r_o^2 - r^2)\frac{t_m}{t_o} = (R_o^2 - R^2) = \text{constant} = C, \text{ say.}$$

$$\text{Thus;} \quad r = (r_o^2 - C.\frac{t_o}{t_m})^{\frac{1}{2}}$$

where t_m is the current mean thickness of metal between the rim, radius r_o, and any radius r.

The final thickness strains in the walls of the drawn cup will be less than this due to the bending and unbending over the die.

1.3 Relevant Previous Work

A number of investigation into deep drawing of cylindrical cups from circular blanks have been carried out in the past. The main points arising from these investigations are summarised.

1.3.1 Blank-holding

Blank holding is employed to prevent wrinkling of the cup flange during radial drawing, but with minimum of interference with free drawing. Two types are commonly used, clearance blank-holding and pressure blank-

holding. With clearance blank-holding an initial clearance of 5 percent was found by Jones (1951) to be sufficient for the required purpose. With pressure blank-holding, the minimum force required to prevent wrinkling is found and it has been shown by Johnson and Mellor (1962) that increasing this force has little effect on the maximum punch load or on the final thickness in the base and profile radius of the cups, but the cup walls were thinner with the higher loads. Thomas (1970) recommended a blank-holding pressure of not more than 75 percent above that required to suppress wrinkling.

1.3.2 Drawing Ratio

The drawing ratio has been defined as the ratio of the blank diameter to the punch diameter. It has been noted by Woo (1969) that for any given drawing condition, the maximum punch load increases almost linearly with the blank diameter over the whole of the useful range. Also, if the blank diameter is approximately twice the punch diameter (i.e., drawing ratio of 2), the punch load, under favourable lubrication and holding conditions, becomes equal to the strength of the cup near the bottom at its weakest section.

1.3.3 Die Profile Radius

Provided that the radius does not fall below ten times the blank thickness, the die profile radius has been found to have little significance in the maximum punch load. The sharper the die profile radius, the greater is the maximum punch load, because of the increased process work due to plastic bending under tension. Decreasing the die profile radius below a value ten times the blank thickness lowers the limiting drawing ratio. Increasing the die profile radius above ten times the blank thickness causes negligible improvement in drawability, while a greater tendency towards wrinkling is apparent on the drawn cups. This being due to the early removal of the guiding influence of the blank-holder.

1.3.4 Punch Profile Radius

For any given drawing conditions, Johnson and Mellor (1962) found that the more generous the punch profile radius, the more gradual is the rise of the punch load and the longer the punch travel, but the maximum punch load is almost unaffected. The provision of a generous profile radius gives rise to general thinning

and the danger of fracture, near the centre of the cup base. A sharp punch profile radius leads to severe plastic bending and the danger of an early fracture.

Chung and Swift (1951) carried out a series of tests covering a range of punch profile radii with a drawing ratio of 2. From the measured thickness strains, two distinct zones of necking were recorded one at the lower end of the cup wall near its junction with the punch profile radius and the other at some slightly smaller radius. The location and severity of the profile neck closest to the cup centre was noted to change systematically with the punch form. The greatest thinning occuring with the hemispherical punch. The final strains with walls of the cups were scarcely affected by the punch profile radius.

1.3.5 Radial Clearance

Radial clearance is defined as the difference between the punch diameter and the die throat diameter. In cases where an irregular punch is in use, radial clearance refers to the space between the punch and the die on any one side.

Sometimes clearance simply refers to the allowance provided for the thickening of the blank during a drawing operation and could be positive, when an allowance is made for thickening or negative when ironning is intended. Radial clearance may affect the drawing process by controlling the freedom of the walls either to thicken, or to taper and pucker. According to Sachs (1951) insufficient radial clearance or negative clearance causes an increase in the operating power and a reduction in tool life due to the wear associated with ironing. Excessive clearance results in cups with conical shapes and wrinkles. Sachs (1951) established through experiments that radial clearance of at least +36 percent of material thickness was necessary when ironing is not desirable, when working with aluminum blanks. Johnson and Mellor (1962) recommended clearance of +40 percent of blank thickness when working with most common metals.

1.3.6 Material

Some Mechanical properties as determined from tensile tests and the surface conditions of the sheet metal are known to influence the drawing operation. The maximum punch load has

been found to be related to the ultimate tensile strength of a material under test. The formability of a material as discussed in section 5, depends to some extent on the mechanical properties of the material. Johnson and Mellor (1962) established through experiments that the thickness strains in the base and profile radius of the drawn cups differed between different materials, under similar working conditions.

1.3.7 Lubrication

It was demonstrated by Loxly and Freeman (1954) that lubrication has a marked effect on the maximum size of blank that can be drawn successfully. Lloyd (1966) and Fogg (1967) gave the optimum conditions as those which for a given blank size, give the smallest radial pull-back force and also restrict the straining in the region over the punch profile radius. This means lubrication between blank and die face and none between blank and punch. In some cases, due to the surface conditions of the material; lubrication may not have a marked effect on the drawing process. The speed of drawing has been reported by Fogg (1967), to affect the effectiveness of some lubricants. This occures mostly with light

oils where higher speeds make for better drawability.

1.4 Sheet Metal Properties

An understanding of the mechanism of deep drawing is enhanced by the knowledge of some sheet metal properties and the common failures associated with forming sheet metal.

1.4.1 Mechanical Properties

1.4.11 Strength

The strength characteristics of a metal is determined from tensile tests. It is known that a metal can withstand a certain amount of load without undergoing any significant permanent deformation. Some permanent deformation occurs after the elastic limit is exceeded. Mild steel often exhibits a definite and sudden yielding at load, known as the yield point. The yield stress is defined as the load at the point divided by the original cross-sectional area of the specimen.

Most metals and alloys do not show a definite and pronounced yielding exhibited by mild steel. The change from purely elastic to elastic-plastic deformation is gradual in these metals and in

such cases, a proof stress instead a yield stress is adopted. A proof stress is defined as the stress which will cause a permanent extension equal to a specified percentage of the original gauge length. The ultimate tensile stress or tensile strength in tension is the maximum strength observed under a tensile load and is determined by dividing the maximun load sustained during the test by the original cross sectional area of the specimen.

1.4.12 Stiffness

Stiffness is considered to be an indication of resistance to deformation below the elastic limit. It is represented by the slope of the initial straight line portion of the stress-strain curve.

The Young's Modulus or Modulus of Elasticity (E) is a measure of stiffness and is given by the expression;

$$E = \frac{d\sigma}{d\varepsilon},$$

which for the case of straight line/linear materials is;

$$E = \frac{d\sigma}{d\varepsilon} = \frac{\Delta\sigma}{\Delta\varepsilon}$$

1.4.13 Ductility

The ability of metals to undergo deformation in tension once the elastic limit has been exceeded is known as ductility. A metal with good ductility exhibits appreciable elongation under tension before fracture occurs.

Metals with good ductility form well.

1.4.14 Toughness

A metal that combines high elastic limit with good ductility is tough. Graphically toughness is indicated by the area under the stress-strain curve up to the point of rapture. Toughness is an indication of the ability of a metal to absorb relatively large quantities of energy.

Tough metals make for good forming but require large forming loads.

1.4.15 Hardness

Hardness is considered to be the resistance of metal to indentation and is therefore, closely associated with stiffness and elastic limit of a metal. Brinell, Rockwell and Vickers scales are mainly in use.

1.4.2 Anisotropy

Anisotropy or directionality refer to the phenomenon of differing strength properties in different directions. Anisotropy fluctuates during processing in regard to its magnitude and specific nature. The development of 'ears' in deep-drawn cups exhibit the presence of anisotropy. In cold-worked metals anisotropy increases steadily with increasing strain hardening, and can not be avoided. However, annealed sheet metals possess minimum anisotropy. This is common with copper and aluminum. The presence of anisotropy is unavoidable in low-carbon steel, possibly due to the continuous hot-rolling and cold-rolling practice common for this metal.

The presence of ears in drawn parts increases the trimming scrap. Also sheets with pronounced directionality are liable to crack during the drawing process.

1.4.3 Work Hardening

The ability of metals to become stronger and harder when loaded above the elastic limit is termed work hardening. As the metal

undergoes permanent deformation, it work-hardens until its strength eventually balances the load and deformation ceases. If the load is increased slightly, additional permanent deformation and work hardening occur until the load is again balanced. This process goes on until rapture eventually occurs. Work hardening increases the resistance to plastic deformation and the tensile strength of a metal.

1.4.4 Common Failures in Sheet-Metal Forming

Extensive experimental investigation and plant research by Chung and Swift (1951) and Sachs (1951) et al have revealed that the failure of a sheet metal part on forming is usually by one of the following:

i. Fracturing;
ii. necking under tension stresses;
iii. buckling under compression stresses;
iv. drawing failures.

1.4.41 Fracturing

When the length of a metal fibre is increased beyond a certain limit, fracture occurs. In most instances fracturing is caused by the presence of tensile stresses.

The strain at which fracture occurs, termed 'ductility', depends on the method by which it is obtained. Fracturing is considered the most common type of failure. However, it has been observed that in a number type of parts, cracking occurs at strains which are far below the ductility of the material. In such instances, excessive thinning occured before the crack appeared. Such local reduction in thickness according to Sach's (1951) is known to be similar to the necking observed on tensile testing of ductile materials.

1.4.42 Necking

The phenomenon of necking determines the forming limit, or stretching ability, for a number of part types, namely, curved sections, parts with stretch flanges and deep-recessed parts. In such parts according to Swift (1954) failure results from the tensile stresses acting in certain locations and stretching the metal beyond its forming limit.

1.4.43 Buckling

If a compressive stress acts in a slender sheet's plane it will cause the part to buckle

rather than contract. In this case, geometrical features of the formed part, and details of the forming procedure determine the tendency to buckle to a greater extent than the metal properties. Buckling phenomena either limit the forming of parts with shrink flanges or demand that special measures be used to prevent or control the buckling or wrinkling of such parts. Buckling according to Sachs (1951) could be troublesome in the forming of curved sections, of shallow-recessed parts, and of deep-recessed parts. The forming of these parts being considerably influenced by the necessity of avoiding buckling in various locations which are subjected to compressive stresses.

1.4.44 Drawing Failure

A drawing failure is unique and different from other failure types in that the over-all change in shape rather than the straining of certain locations is the limiting factor. This could be explained by the fact that the forming forces must be transported through sections of the part from their sources, namely, the punch to the plastically deforming areas. If the desired change in shape involves too large a

volume of metal, the strength of the metal connecting the power source and the deformed area may be insufficient, and failure will occure at the weakest point of this connecting link. The relation of this drawing failure to any particular metal property is obscure but Sachs (1951) noted that certain operational conditions, particularly the surfaces of the metal and tools, the shape of the punch and die profiles and the size of the blanks, are influencing factors in drawing.

1.5 Formability

Formability has been defined by Pope and Berry (1973) as the ability of a material to withstand a drawing or other forming operation without failure. Mechanical properties of a metal as determined from tensile and hardness tests, play a significant role in formability of a metal but their knowledge is not sufficient to predict the performance of the metal during a particular forming operation. Thus, special forming tests are used to confirm the conclusions drawn from the tensile parameters.

Swift (1954) has shown that tensile failures generally do not occur within the drawing zone. Owing to the character of the applied stress system and that failures in co compression by flange wrinkling can usually be suppressed by the use of an adequate clamping system. Thus, the ability of a metal to sustain stretching and/or bending under tension without failure generally determines its formability. Stretching and bending over the punch profile leads to thinning (necking) of the material. This necking phenomenon, according to Johnson and Mellor (1962), determines the forming limit or stretching ability of the material and that generally failure takes place as a result of tensile stresses acting in some locations and stretching the metal beyond its forming limit. Another failure associated with thinning is that of bending over the punch profile. Sachs (1951) noted that there is a minimum radius over which a metal can be bent without fracture depending on the ductility of the metal. When the bend radius is such that the strains on the outer or tensile surface is greater than the

ductility, the metal will fail. Another criterion used to determine the formability of a material is the limiting drawing ratio, defined as the ratio of the maximum diameter of blank that can be deep drawn successfully to the diameter of the punch diameter. This forming limit is termed drawability. The values for drawability vary with materials and conditions of draw.

Forming Limit diagrams (FLD) were developed by Keeler and Godwin (1971) for drawing quality grades of low carbon steels and have since been applied to the other materials. Forming limit Diagrams refer to the stretching performance of sheet metal during a forming operation. According to Wilson and Acselrad (1979). Forming Limit Diagrams specify the way in which the limiting value of the maximum surface strain (ε_1) varies with the magnitude of the minimum surface strain (ε_2) in a range of stretching operations which are characterised by differing values of the applied strain ratio ($\varepsilon_2/\varepsilon_1$). Forming limit Diagrams have been used increasingly in recent times to discribe

the formability of sheet metals. However, Blom (1980), has shown that Forming Limit Diagram is not exhaustive in describing the formability of a material as small differences in composition or processing of the material do not change the Forming Limit Diagram. Sheet metal formability is thus a complex property which cannot be characterised by a single parameter. However, by studying the two extremes, deep-drawability and stretchability separately, it is possible to describe them by simple parameters and stimulate them by well-known forming tests.

1.5.1 Deep-drawability

Deep drawing implies simultaneous tensile and compressive strains. The drawability is improved by reduced thickness straining (thinning) and thus by increased width straining. The strain ratio (r) is defined as the ratio between the width strain (ε_w) and the thickness strain (ε_t) and is given by:

$$r = \frac{\varepsilon_w}{\varepsilon_t}$$

Strain ratio (r) is related to plastic anisotropy and is usually measured on sheet

specimens which are orientated at 0^{o}, at 45^{o} and at 90^{o} to the rolling direction, designated, r_{o}, r_{45} and r_{90} respectively. r is got from the average given by r $= \frac{1}{4} (r_{o} + 2\, r_{45} + r_{90})$.

1.5.2 Stretchability

Stretch forming is defined as biaxial tensile straining. Hence a sheet material with good stretch ability must distribute strains evenly to delay the local thinning leading to fracture. High and uniform elongation; and high strain-hardening rate are thus the important properties for stretch forming.

CHAPTER - 2

E Q U I P M E N T S

The main equipment used for this work, a 400kN sheet metal testing machine is supplied with one drawing punch of 5mm profile radius and one die of 15mm profile radius. To test the influence of the punch and die radii, several punches of various profile raddi and a die of profile raddi less than 15mm were designed.

2.1 Punch And Die Production

Four punches of profile raddi 3mm, 10mm, 15mm, and 18mm were made. The punches are of the same length and diameter as the original punch but the profile radii are altered. The production drawing for the punches is shown in drawing number 1a.

In the machining of the punch radii, correct tools with the required radii were not available, hence the radii of the punches were approximated. This was done by adjusting the position of the tool post with respect to the work piece (the punch), thus placing the cutting tool at various angular positions to the work piece and enabling cuts to be made

at angular positions. Radius gauges were used to check the radius of a profile at various stages of the cutting till the correct radius was obtained. The punches were made from mild steel as no tool steel was available.

2.1.2 Case Hardening

The punches made of mild steel could not be heat-treated directly and had to be carburized. Carburizing entails the enrichment of the outer layer of the mild steel to a high carbon steel by heating the material in a carbon rich medium.

The punches were packed in a steel box together with charcoal granules as the carbon rich material. The punches were packed such that the charcoal granules covered each of them on all sides for a thickness of not less than 10mm. The box was then covered and heated in a furnace for nine hours at a temperature of 950°C, during which carbon infused into the surface of the punches. The punches were then quenched in water and tempered at a temperature of 200°C. This entailed

reheating the punches to 200°C for 15 minutes and then allowing them to cool in air. This tempering treatment relieves the thermal stresses and toughers the core. After the heat treatment, an average surface hardness of about 450HV_{30} on the Vickers pyramid tester was recorded, compared with the original hardness of about 160HV_{30}.

After the case hardening treatment, a final polishing of the punches was carried out using emery cloth. Plate 1 shows the punches after production.

Die Production

The die profile radius of the original die of the drawing equipment is rather large at 15mm considering that blanks of thickness 1mm to 1.5mm were to be used in the experiment. Thus to avoid wrinkling a die of profile radius 10mm was designed. Details of the die which is essentially the same shape and dimensions as the original die, are shown in drawing number (1b). However die could not be produced due to unavailable steel plate of the dimensions required for the production.

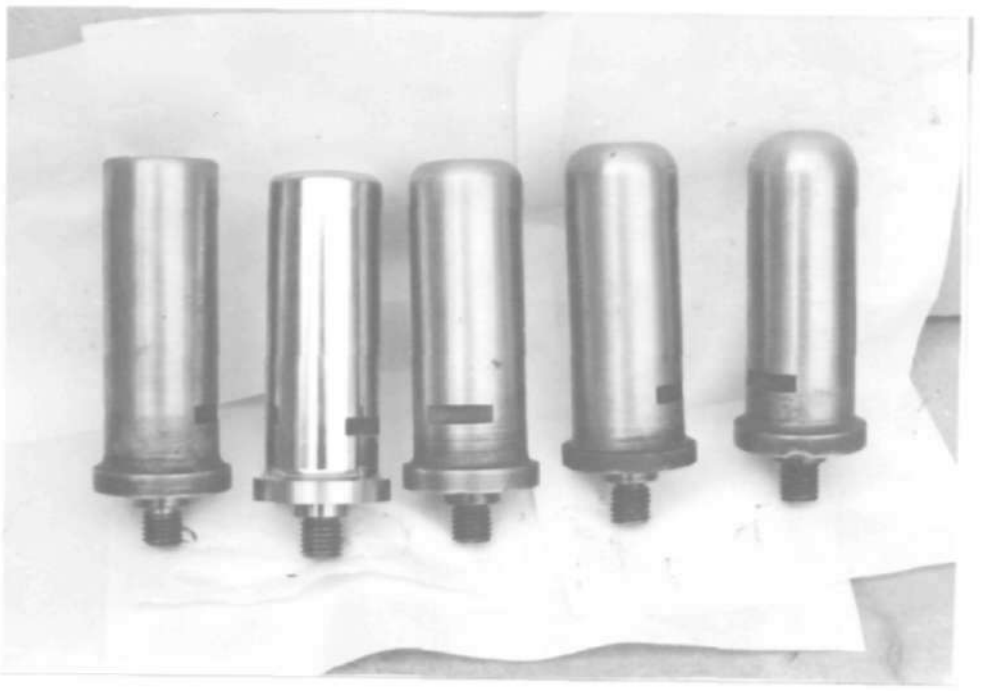


Plate-I: Drawing punches after production.
(Original punch 2nd from left)

2.2 Main Equipment

2.2.1 Description of the Main Equipment

The main equipment used for this work, a 400kN Universal Sheet Metal Testing Machine, is simply a hydraulic press with electronic equipment to measure load and displacement in a pressing operation. The main function of the press is to deform material and this is effected by the main ram to which the pump is attached. The drawing punch is screwed onto the main ram. Clamping of the sheet metal specimen is effected by the clamping ram to which the clamping plate is attached. The primary clamping and secondary clamping delivering loads of 0 -- 30 N and 0 - 100 N respectively. Figure (2.1) shows the hydraulic circuit for the main press and clamping systems.

The speed of the main ram is variable and is adjusted by means of the speed control valve located next to the push button station as shown in plate II. The movement of the rams is controlled from the push button station. Clamping loads are controlled by

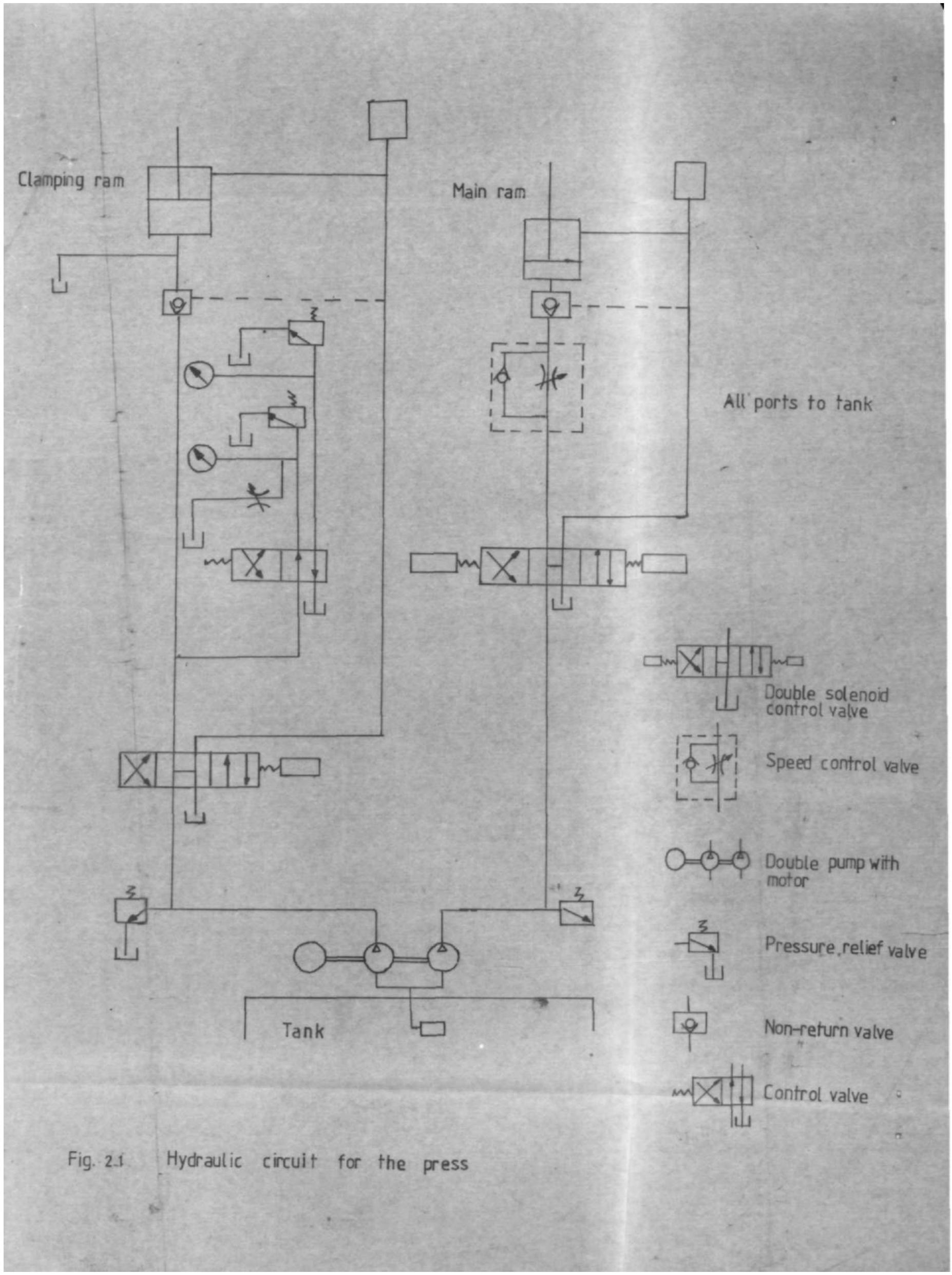


Fig. 2.1 Hydraulic circuit for the press

the clamping pressure controls located on the right hand side of the machine as in Plate II and the loads are given on the associated pressure gauges. The speed of the clamping ram is fixed.

The two rams are supplied by the same double vane pump which is driven by a 7.5H.P., electric motor, as shown in Figure (2.1).

The press unit consists of a fabricated steel cylinder with two hydraulic cylinders and rams, a screwed bayonet locking ring, a hinged die holder which mates with the locking ring, and a centring unit with centring fingers for accurately centering circular test pieces. Figure (2.2) shows the press unit in part. The central column of the press is located between the main ram and the punch and is accurately guided in a ball bush set. The central column includes strain gauge load cells used to record the drawing loads. The movement of the punch is measured with a linear potentiometer, attached to the central column. The outputs from the

load cell and linear potentiometer are fed to the X-Y recorder. Load is recorded on the X-axis and displacement on the Y-axis of the recorder.

2.2.12 Commissioning the Machine

The machine which had been installed but not been used for a long time had to be commissioned. The procedure for commissioning as specified in the operators manual was adhered to.

2.2.1.21 Running the Press:

Before the press was run; the oil level in the oil tank was checked and topped up. The electrical circuits were checked to ensure good continuity. The equipment was cleaned of dirt and rust. Having established that the machine was in good order, the motor was started by pressing the appropriate push button. Initially turbulent flow of the hydraulic oil was observed in the transparent hoses which would have required bleeding of the system if it had persisted. The turbulence stopped after a few minutes of operation and oil was seen flowing freely in

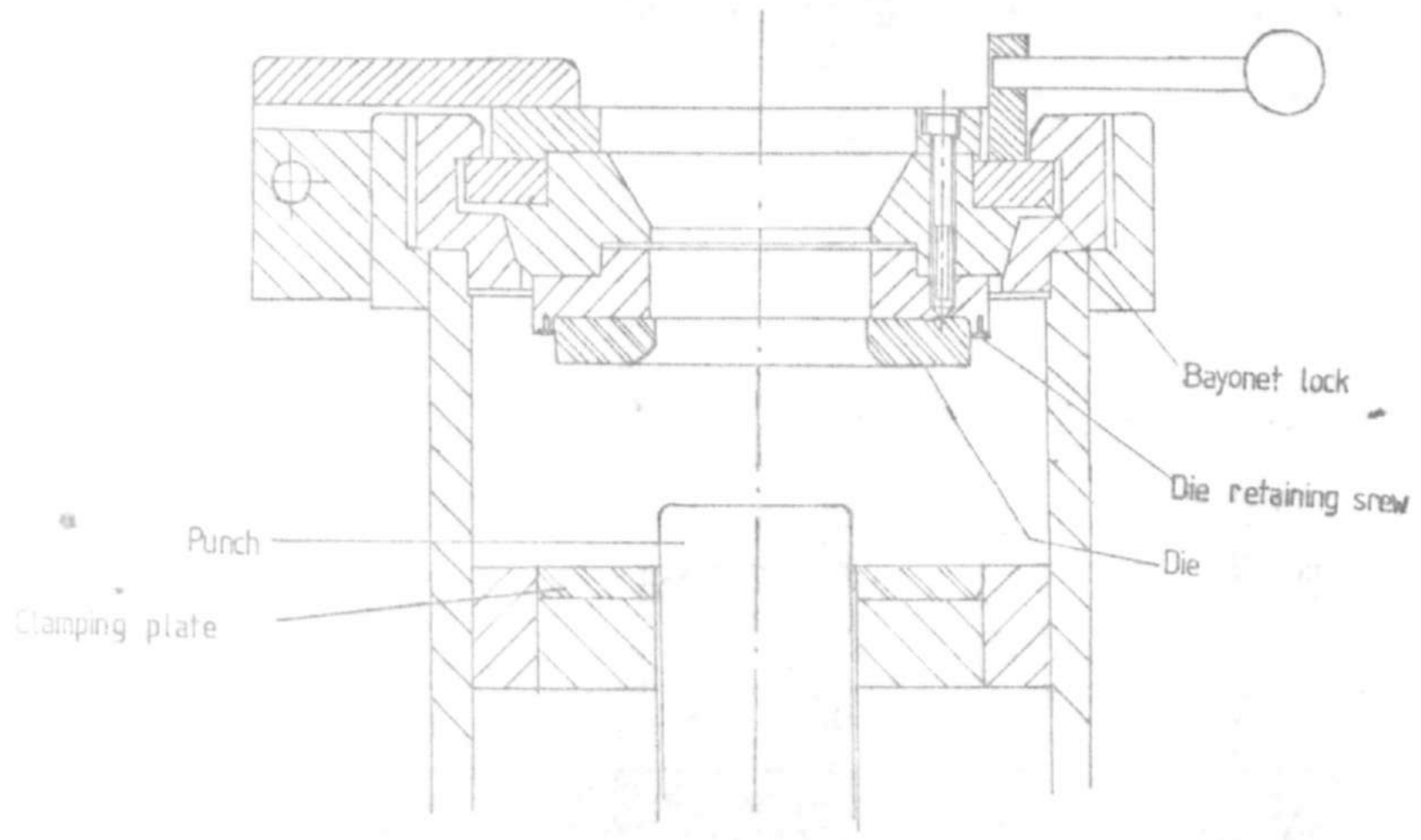


Fig. 2.2 The press unit

the transparent hoses. With the speed control valve set at maximum speed, the press was run up and down a number of times until it was functioning smoothly. The same procedure was adopted for the clamping ram, with the pressure control valves turned to the open positions. The ram was run up and down a few times until it ran smoothly. With the main and clamping rams running smoothly the press unit was ready to be used.

22.13 The X-Y Recorder

The X-Y recorder records the drawing load and the movement of the punch independently on cartesian co-ordinates. The load signals are given by a strain gauge load cell and the movements by a linear potentiometer. The load recorded on the X-axis (the horizontal) of the recorder, and the displacement of Y-axis (the vertical).

The recorder has two operational modes of scale, the 'variant' (var) and the 'caliberated' (cal.) modes. With variant mode in operation, the sensitivity of the recorder adjusted by the

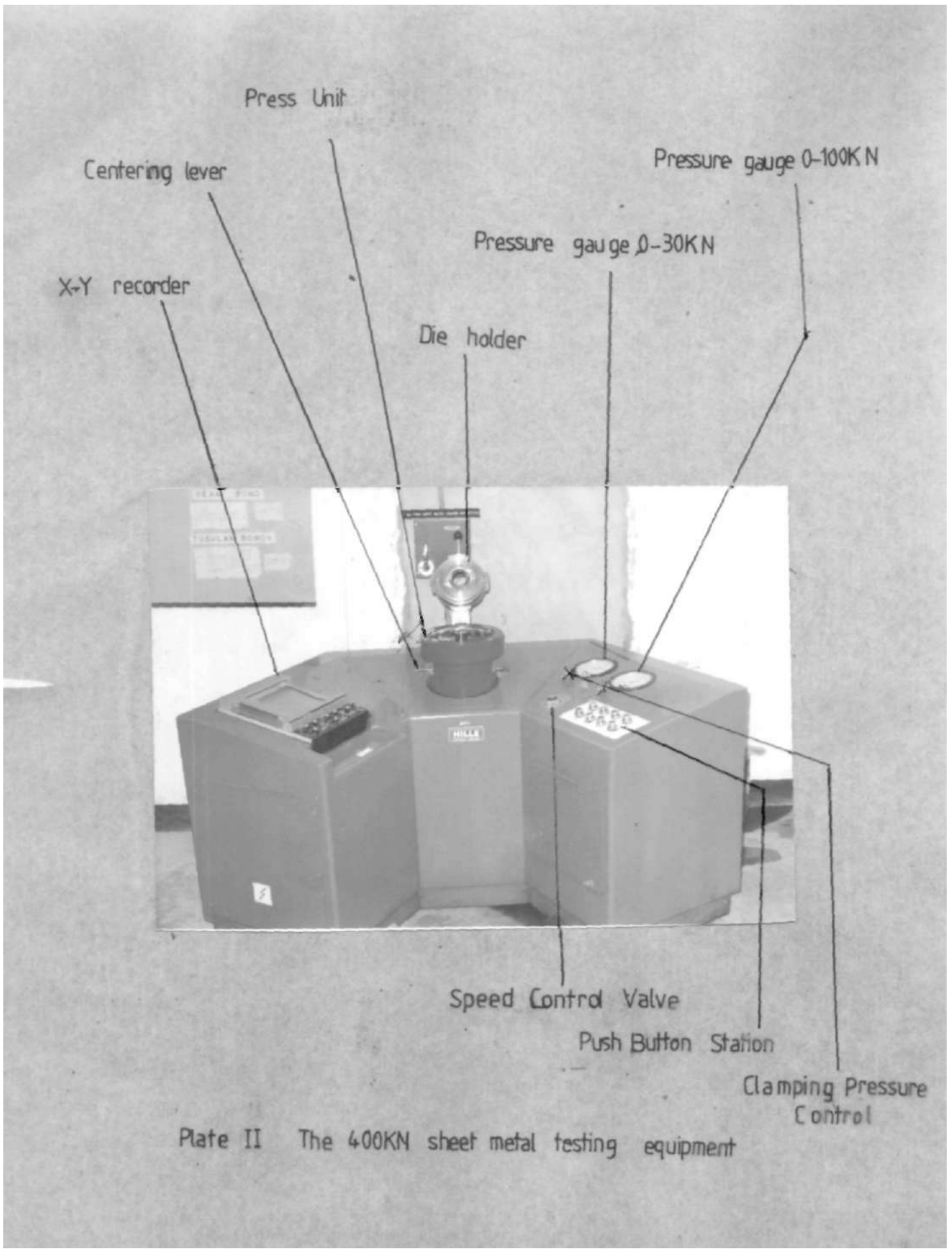


Plate II The 400KN sheet metal testing equipment

operator while the calibrated mode has a fixed sensitivity set by the manufacturer.

22.14 Commissioning the X-Y-Recorder

The X-Y recorder had been installed on the equipment but has been out of use for a long time. It was noticed that some control cables in the unit, had been gnawed off by rats and the three-way togle switch for the pen broken. Some of the demamaged wires were replaced and others repaired by taping up the exposed parts. A check on the circuits was carried out with a multitester aided by the circuits diagrams supplied in the operation manual, to ensure that the repairs were properly done. Efforts to secure a three-way togle switch for the pen failed, hence the broken switch was replaced with a two-way switch. Only the 'down' and 'off' positions were connected leaving off the remote position which is not necessary for the proper operation of the pen movement.

To eliminate jittery movement on the Y-axis, the position foodback potentiometer mounted underneath the Y-axis gantry cover

X-axis, the sensitivity control switch was set to 2.5MV/cm position, the load selection switch was set at the 10 tonne position. With the calibration push button held in, the position of the pen gantry was adjusted by rotating the range control until the calibrated signal read full scale deflection on the machine. The load scale of the recorder at this stage, was then set to read correctly on any of the six scales selected. The load scale selection switch was left at 10 tonne of the trial run.

On the displacement axis (Y-axis), the sensitivity control was set to the 10MV/cm position. With the calibration push button held in, the sensitivity was adjusted by rotating the X-axis range control to give a pen deflection of 25mm on the graph paper. At this position, a punch movement of 1mm will register 1mm on the graph paper. With the range control left at this position, other scales could be got by selecting positions on the sensitivity control. However, to get the pen to make a deflection of 25mm on the graph paper, proved on

impossible task. Apprently some damage has been done to the circuit which was not detected. Drawing test pieces showed discrepancies in the plots obtained. Thus, the variant mode of operation was discarded and the Cal mode adopted after trial runs confirmed that the Cal mode was in order.

With the Cal mode of operation the sensitivity switch for the load axis (X-axis) was set at 2.5MV/cm and for the displacement axis (Y-axis) it was set at 10MV/cm. The load selection switch was set at 10 tonnes. Trial runs on the equipment, using identical test blanks gave consistent results. The Cal mode of operation was therefore, adopted throughout the experiment.

2.3 Other Equipment

2.3.1 Tensometer

The tensometer shown in Plate III was used to determine the tensile properties of sheet metals used in this work. Specimens to be tested on the tensometer were made to 100mm length and 12mm wide. Each specimen

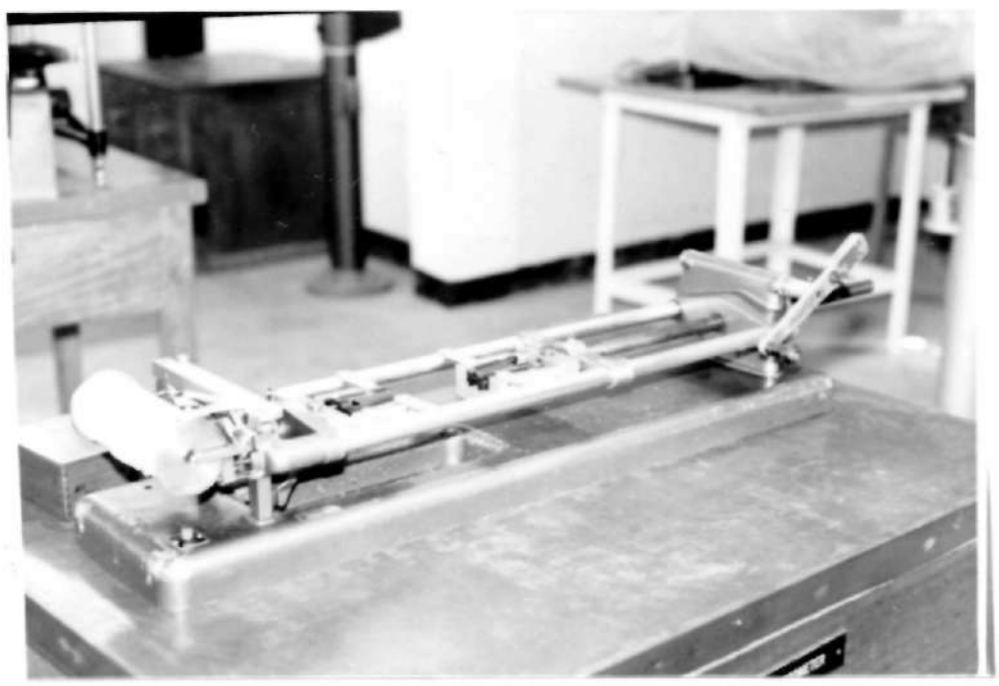


Plate-III: The tensometer

was introduced into the jaws of the tensometer such that the gauge length came to 50mm. Before the specimens were tested, a rigid piece of metal was first tested in order to establish the extension of the members of the tensometers. Load/extension graphs were ploted on the machine for the specimens and corrections due to deformation of frame were introduced. Three specimen **were** tested for each material at a strain rate of approximately 2×10^{-1}/second. The stress-strain relations obtained from the test are shown in Figure (4.1) in page 59.

2.3.2 Micrometer Screw Gauge With Attachment

The mictometer screw gauge shown in Plate IV was used to measure the thickness of the cup base and wall. In order to measure thickness at a point, a brass conical attachment was designed and produced.

Thus, the micrometer with the attachment was in Plate IV is able to measure thickness at a point.

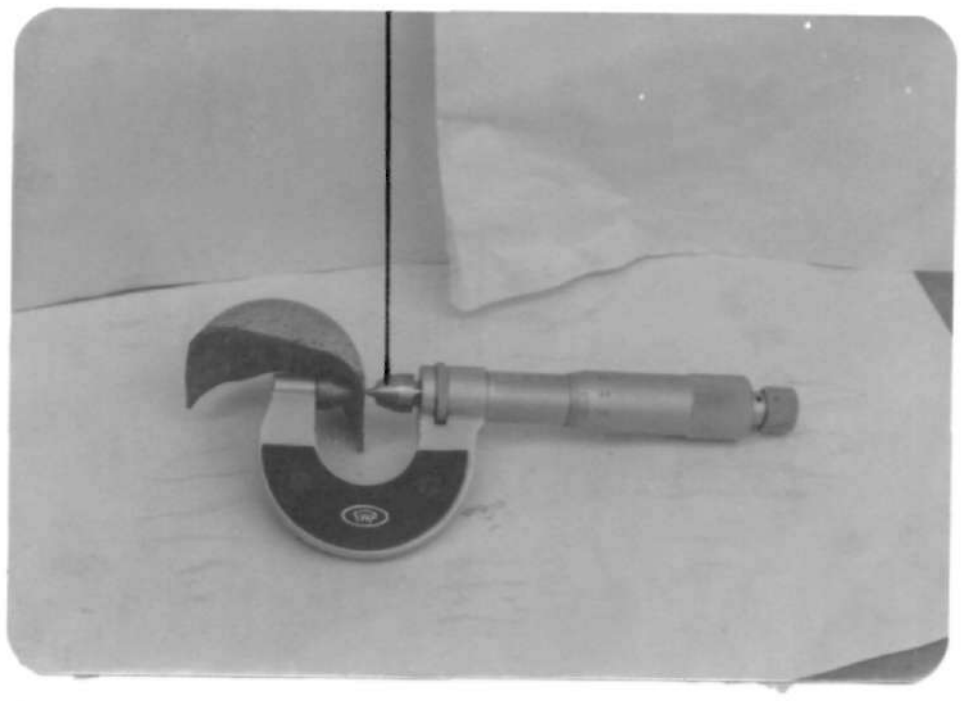


Plate-IV: The micrometer screw gauge with attachment

2.3.3 Pyramid Hardness Tester

The pyramid hardness tester in Plate V was used to determine the hardness of the case hardened punches after production. Tests were carried out on three spots of each punch, at a load of 30Kg and the average value obtained for each punch. For all four punches the mean hardness was found to be about 450HV.

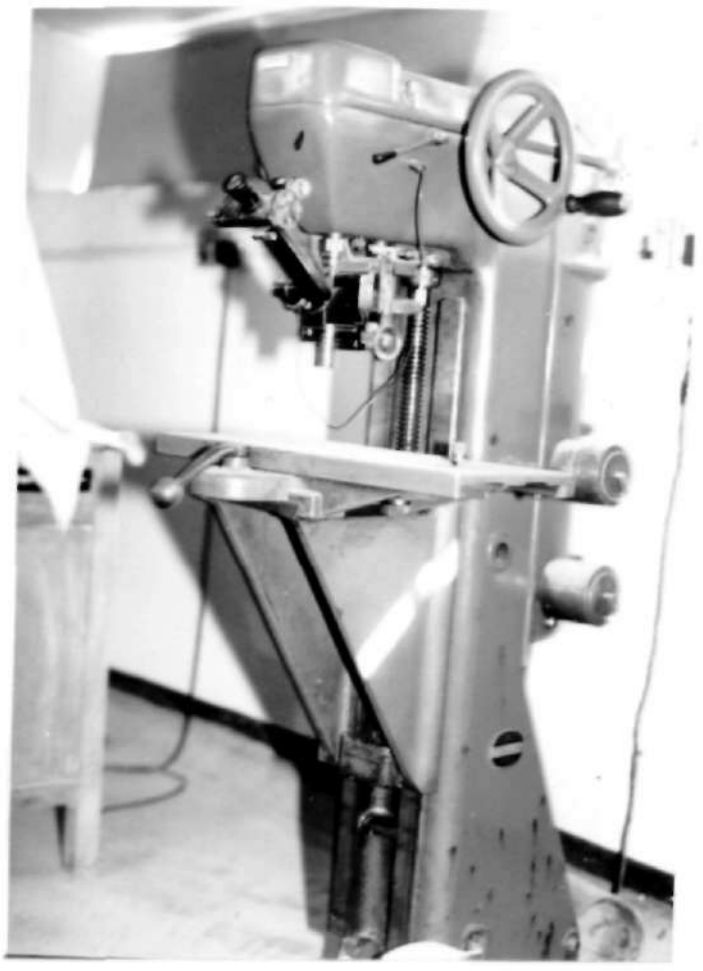


Plate-V: The pyramid hardness testing machine

CHAPTER-3

EXPERIMENTAL PROCEDURE

3.1 Blank Preparation

Before cutting a blank for the drawing operation, it is important to know how large the blank must be in order to produce the required results. From the discussions in Chapter 1 and 2, a drawing ratio of 2 was assumed to be ideal for the purpose intended in this work. However, due to the larger die profile radius of 15mm, which may cause early wrinkling of the flange material as it leaves the influence of the blank holder, a blank diameter of 106mm was adopted. A uniform blank diameter for all three materials, brass aluminum and galvenized mild steel, was intended when making the choice but aluminum was found to fracture at the profile radius before a full cup could be drawn. Hence, blanks of 100mm diameter were adopted for aluminum.

To prepare the blanks required for the drawing operation, the sheet metal was cut

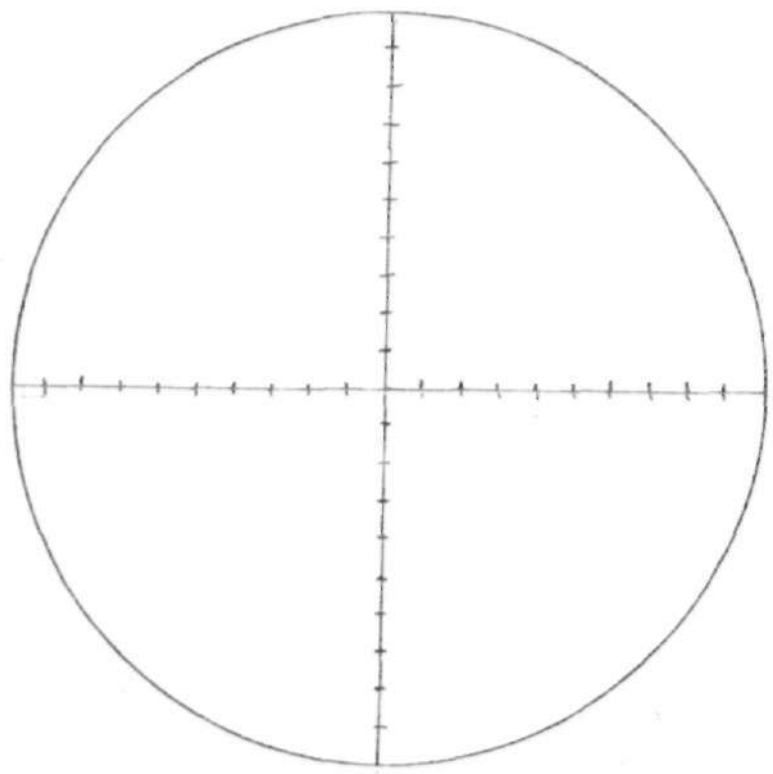


Fig. 3.1:
Schamatic representation of specimen blanks showing marks.

into 120mm squares using a shearing machine. Circles of diameters equal to the required blank diameter, were inscribed on the sheet metal squares, and marked out as shown in Figure 3.1. Circular blanks of size a little larger than the inscribed circles were then cut out of the square blanks using a hand guillotine or a tin snip. The circular blanks were then carefully ground to size with a grinding stone in order to remove the work-hardened edge of the blanks. Burrs at the blank edges were removed with a hand file. The blanks thickness was measured and recorded. Specimen numbers were then inscribed on each blank and it was introduced into the drawing equipment as required. Care was taken to grind the blanks as close as possible to the inscribed circles and the burrs carefully removed to avoid erroneous readings at the edge of the drawn cups. However, some error arising from the grinding of the blanks to circules and the deburring of the blanks was inevitable. Plate VI shows prepared specimen blanks of galvanized mild steel, brass, and aluminum ready for testing.

3.2 Positioning the Specimen

To position the specimen in the drawing equipment, the bayonet locking ring was unlocked and the die holder lifted, to make asses to the clamping plate possible from above. With the required punch screwed on to the main ram, the punch and clamping plate were lowered to their bottom position. The specimen blank to be tested was placed on the clamping plate and centred by the centering fingers. The centering fingers were returned to their rest position after centering the blank, in order to avoid their being damaged during the drawing operation. The die holder was lowered and locked in place. The clamping plate with the blank was raised until it touched the die face then the punch was raised to a position where it just touches the blank. A sheet of graph paper was placed on the X-Y recorder, the power supply to the recorder was switched on and the graph paper positioned in place by the help of markers. The required scale was selected on the selection switches.

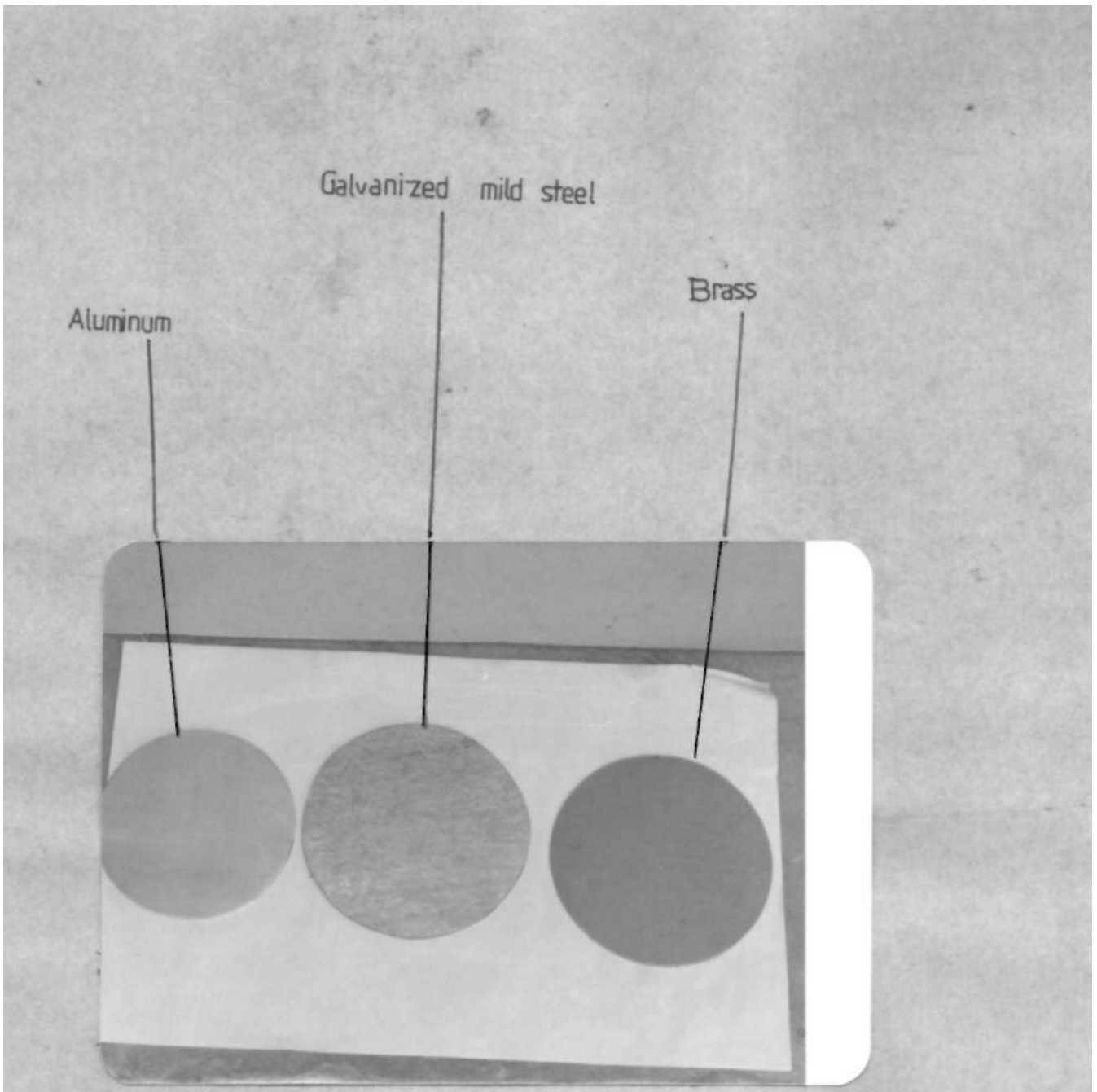


Plate VI Specmen blank ready for use

3.3 Running the Drawing Operation

With the set-up ready for the drawing operation, the required clamping force for the specimen blank was applied through the clamping plate and the clamping force adjusted from the primary pressure control gauge. Since the clamping force required all through the experiment was less than 30kN only the primary clamping pressure gauge was used. The punch speed was then set at the speed control valve (Plate II) and the drawing operation commenced with the actuation of a push button. Another push button stops the punch movement and yet another sends it down, thus making it possible to draw to any depth required. The punch load against punch travel or cup depth curve was recorded on the graph paper as the operation proceeds.

Partial cups of various depths were produced. For galvanised mild steel and brass, partial cups of depths 10mm, 20mm and 29mm were drawn while for aluminum partial cups of depths 10mm, 20mm and 27mm were drawn. Full drawn cups were also produced for each metal type.

Each of the five punches were used in turn, to produce partial cups from the different metals. Partial cups deeper than 29mm for galvanised mild steel and brass, and 27mm for aluminum developed wrinkles.

The flange diameters of the partial cups were measured with a steel rule and recorded. The percentage edge pull-in was determined from the deference between the initial blank diameter and the final flange diameter divided by the initial blank diameter.

The cups were then cut longitudinal into two halfs along a marked diameter as in Plate VII using a band saw. The thickness variation along the cup was measured on the marks, using the micrometer screw gauge with a conical attachment as in Plate IV. From the recorded data got from such measurements graphs of percentage thickness strains were plotted against the initial diameter of elements on the blank.

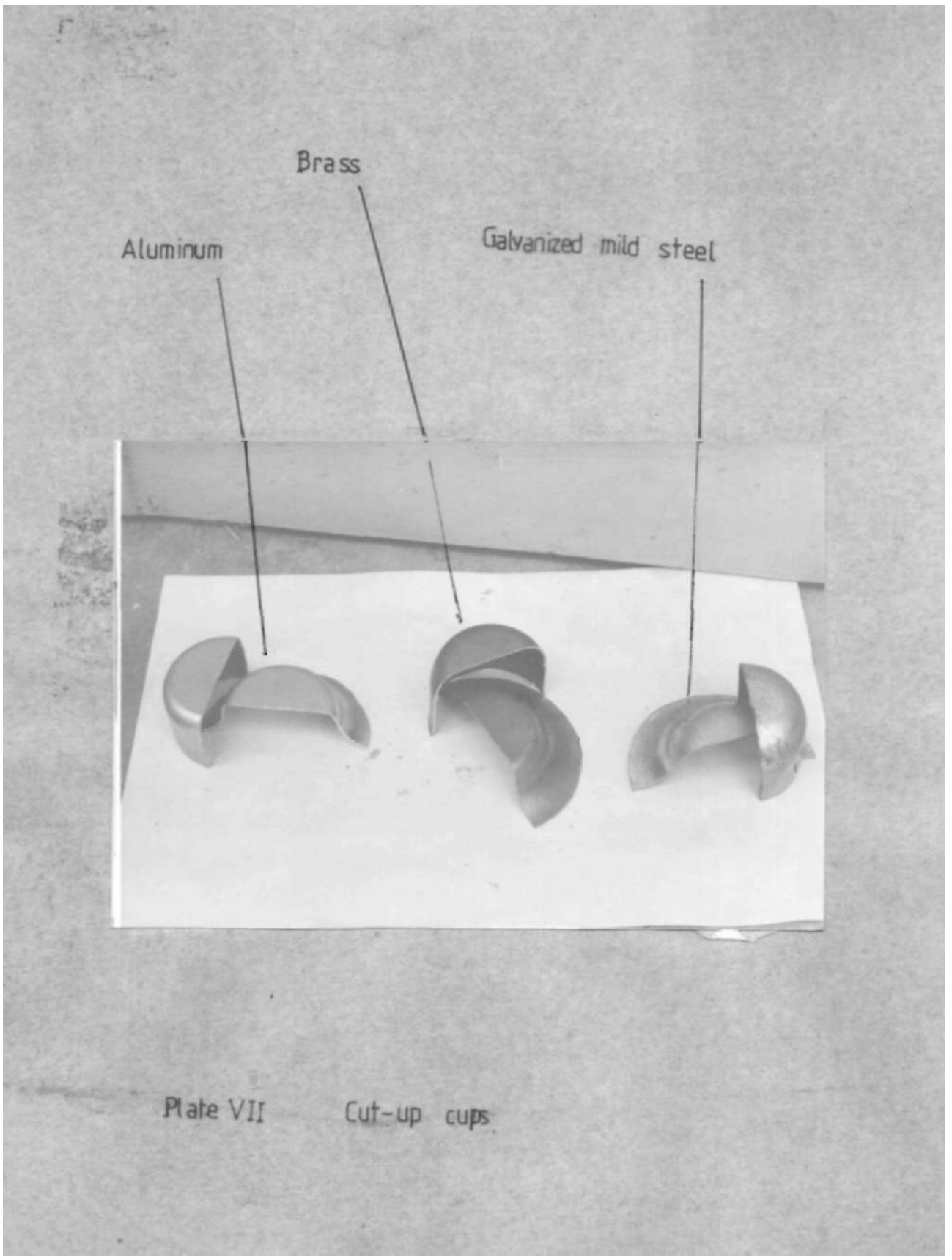


Plate VII Cut-up cups

CHAPTER - 4

4.1 Drawing Parameters

A drawing speed of 20mm/sec. was used in all drawing operations. This is below the maximum speed of 35mm/sec. recommended by Hawtin (1969). A clamping pressure of 1.26N/mm^2 of blank contact area was adopted as it was found to be the minimum pressure required to suppress wrinkling in brass and galvanised mild steel. Aluminum required very little clamping pressure. A blank size of 106mm diameter was used for galvanised mild steel and brass, while aluminum blank size was 100mm in diameter. Lubrication of the blanks, showed little effect on the punch load and as such the experiments were conducted without lubricants. Table 1 shows the effect of an oil S.A.E 40, on the maximum punch load for the three materials used with a punch profile radius of 5mm. Both sides of the blanks were lubricated.

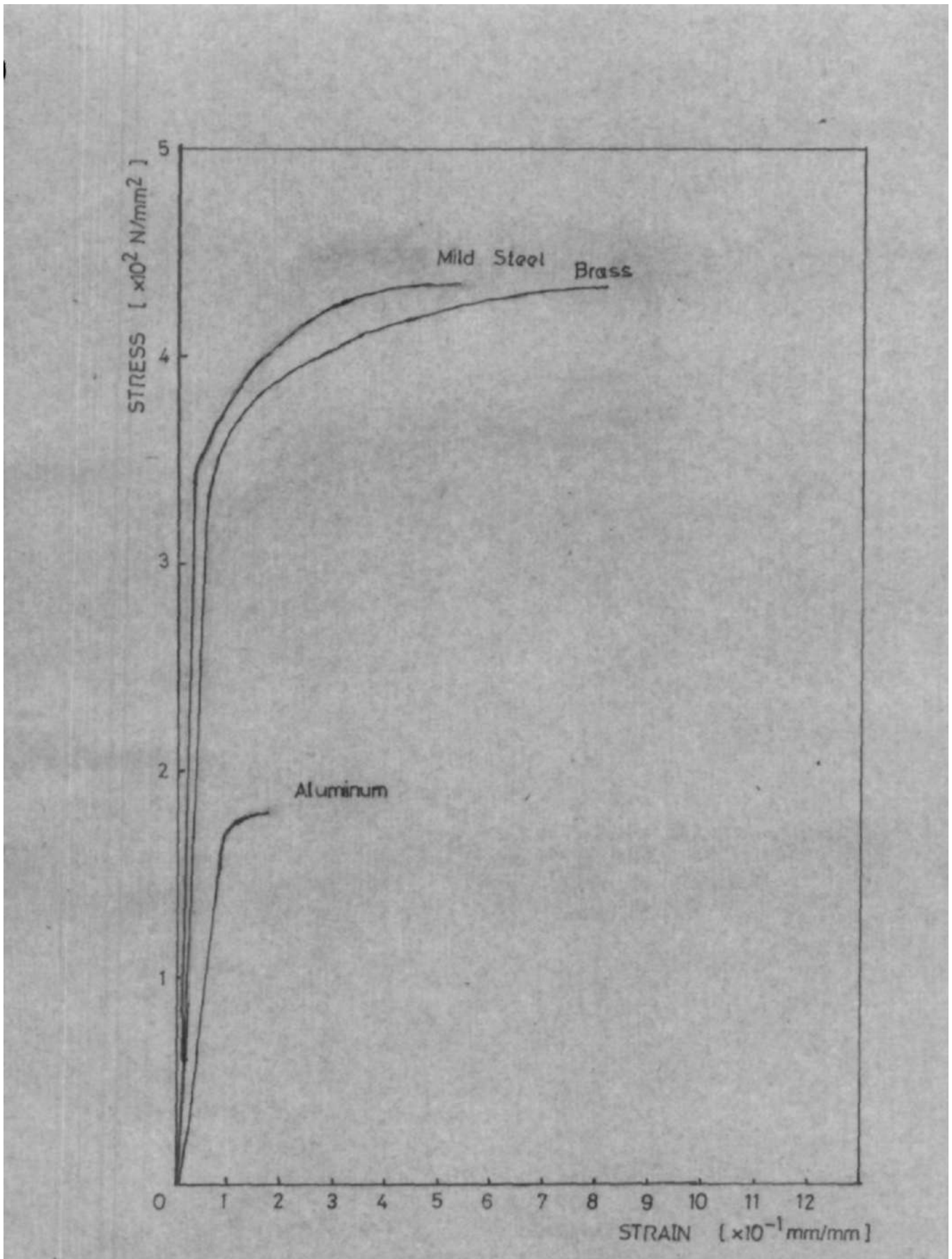


Fig 4.1 Stress -Strain relation of sheet metals

Table 1: Effect of Lubrication on Maximum Punch Load

Material	Blank Thickness	Blank Size	Maximum Punch Load With Lubricant	Maximum Punch Load Without Lubricant
Galvanized Mild Steel	1.2mm	106mm	55KN	56KN
Brass	1mm	106mm	47.5KN	48KN
Aluminum	1.5mm	100mm	20KN	20KN

4.2 Wrinkling of Cups

Wrinkling of cups occured with clamping pressures below 1.2N/mm^2 and at cup depths of over 30mm for brass and galvanized mild steel. Some wrinkling appeared at depth beyond 27mm for aluminium cups. Plate VIII shows partial cups with wrinkles.

4.3 Earing of Cup Flanges

Earing refers to the non-uniform edge pull-in of cup flanges due to the varying strength qualities of the sheet metal in different directions. Earing was noticed on brass and galvanized mild steel cups. Aluminum exhibited very little earing. For all the three materials, it was observed that the

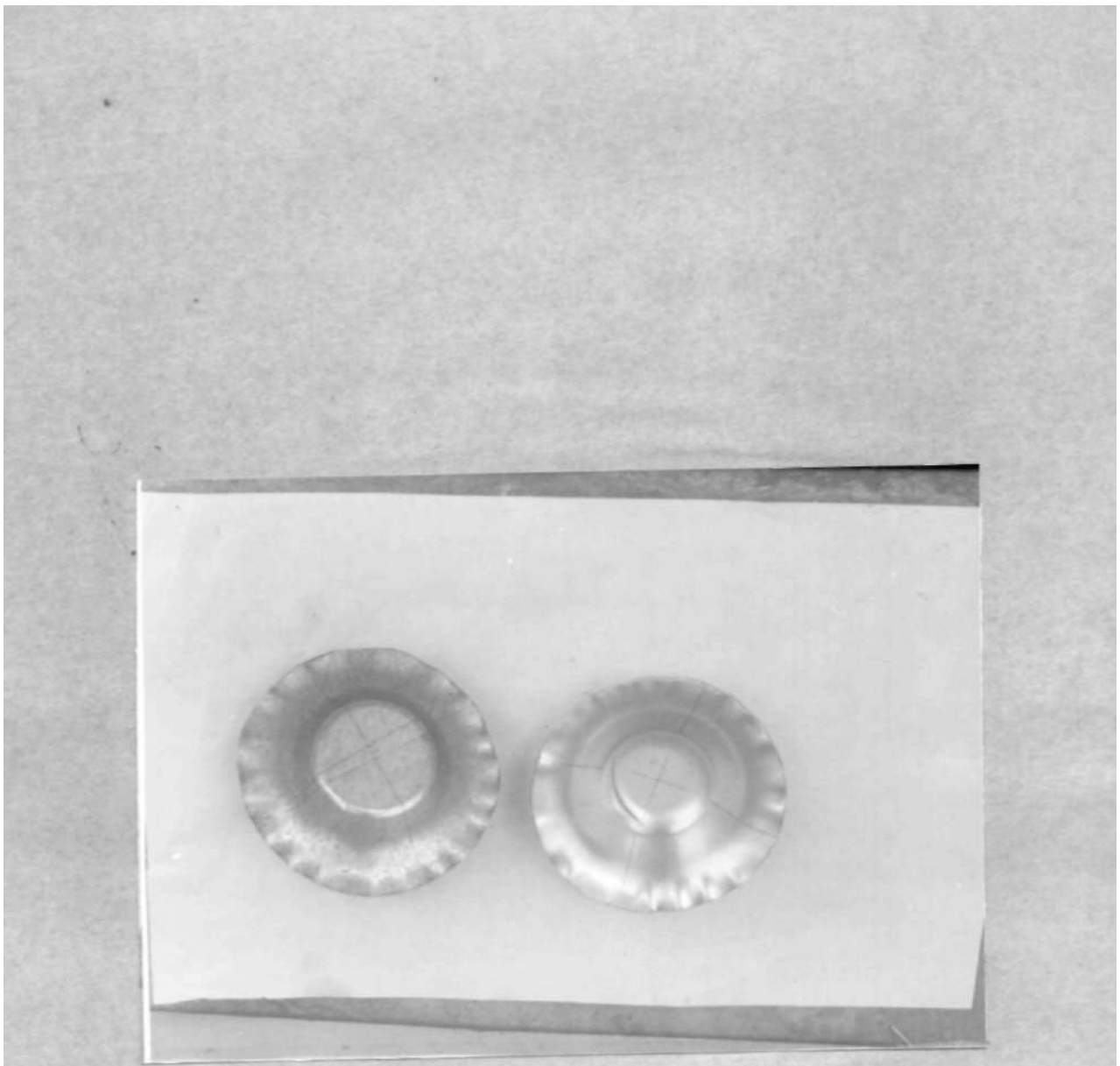


Plate VIII Cups with wrinkled flange

the smaller the punch profile radius the more pronounced the ears. Four ears were generally observed on cup flanges uneven and multiple earing was observed on the full drawn cups due to the wrinkling at the cup edges as in Plate X.

4.4 Stress-Strain Characteristic Curves

The stress-strain characteristic curves for brass, galvanized mild steel and aluminum presented in Figure (2.1), were produced from tensile test on sheet metal specimen of 12mm wide and 50mm gauge length. The specimens were cut out from sheet blanks with a hand gullotine and filed to size. The curves reveal that brass and galvanized mild steel work-hardened and strained more than aluminum. Galvanized mild steel exhibited a higher yield and tensile stresses than brass and aluminum. Aluminum shows from the curves to have the least tensile and yield stress. The speed of testing was about 0.5mm/sec.

4.5 Effect of Punch Profile on the Punch Load Versus Punch Travel Curves

The relations between punch load and punch travel for the various punch profiles,

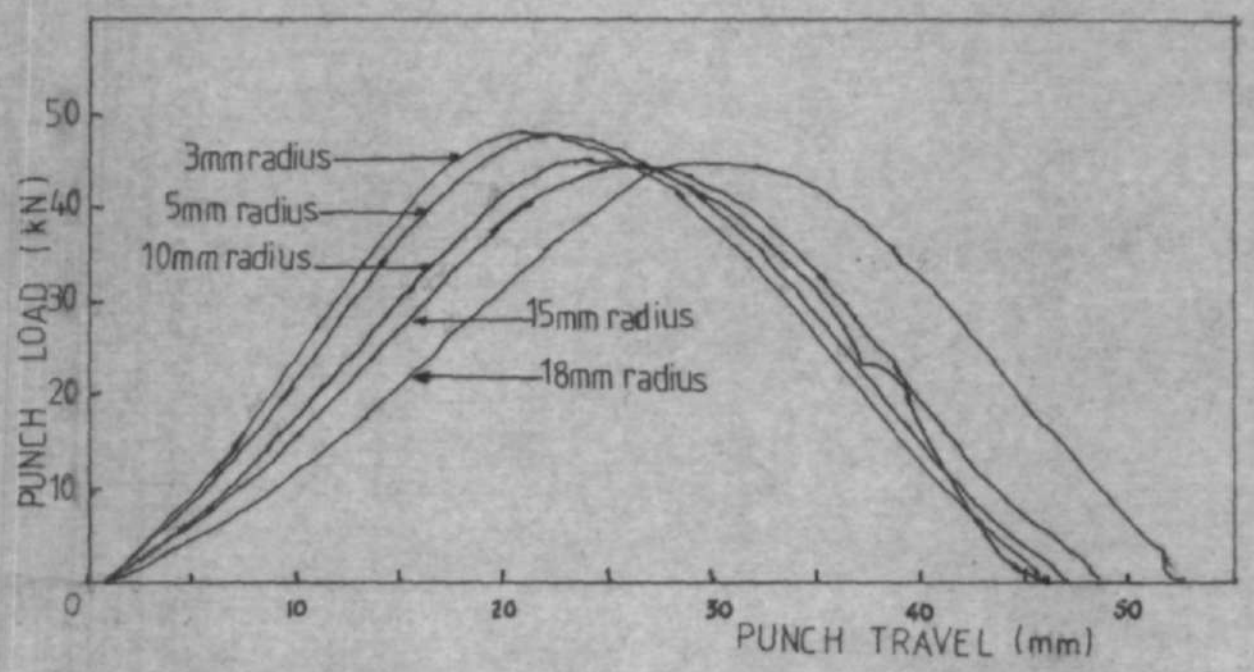


Fig.4.2 Effect of punch profile radius on punch load travel for Brass

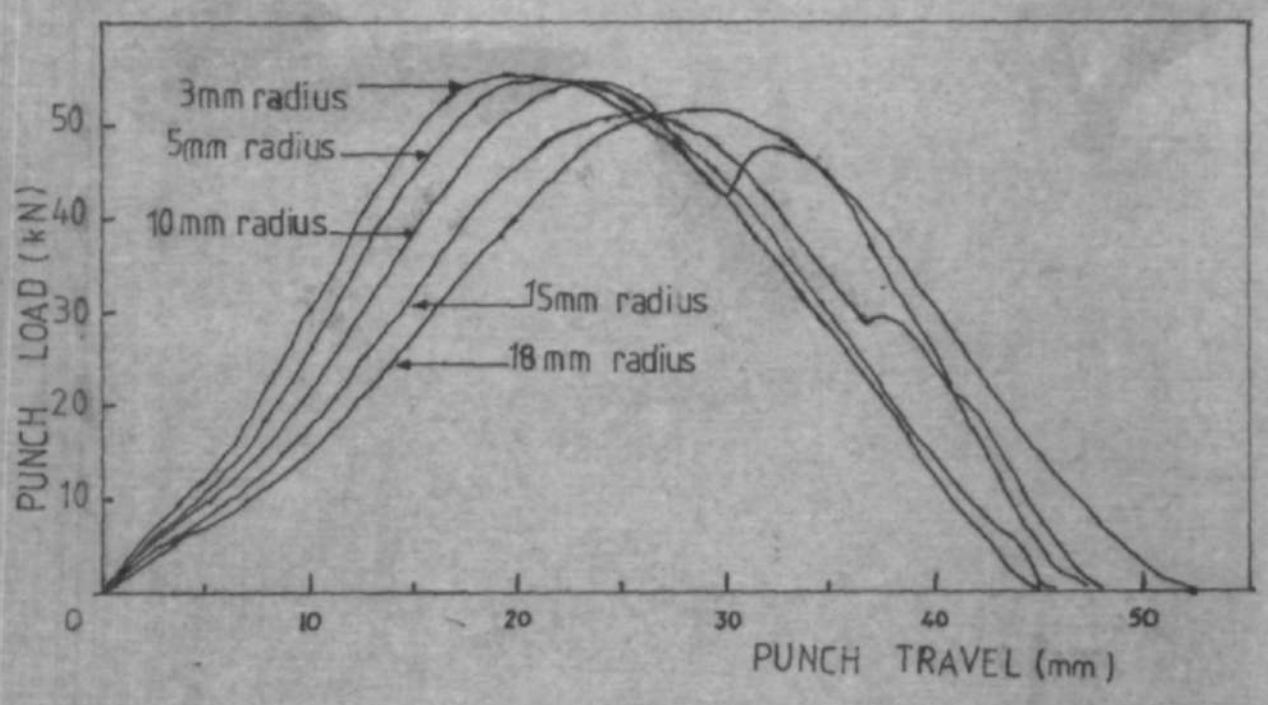


Fig 4.3 Effect of punch profile radius on punch load travel for gMS (1.2mm)

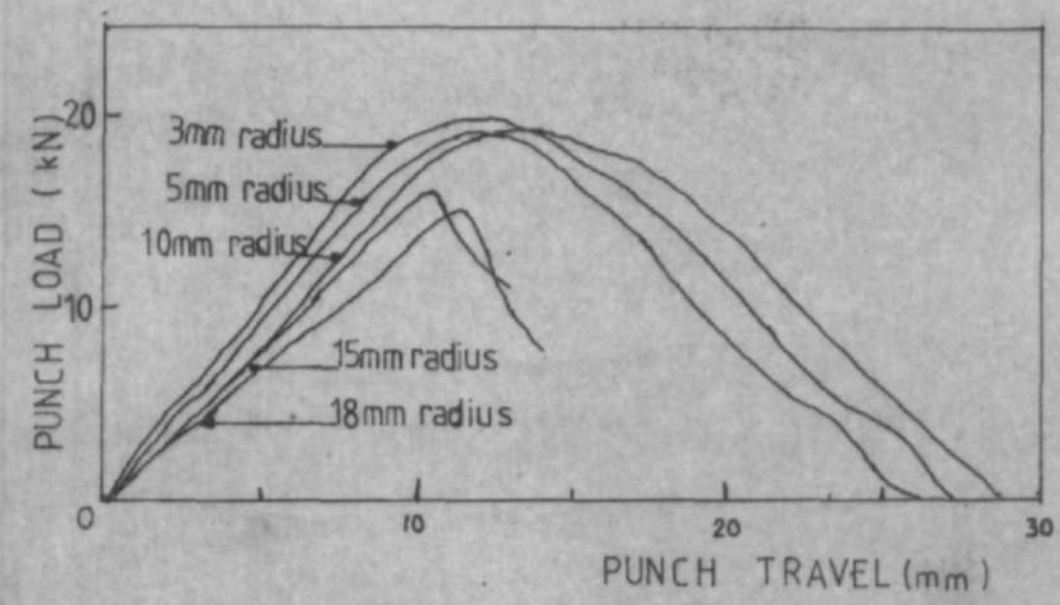


Fig4.4 Effect of punch profile radius on punch load-travel for Aluminum

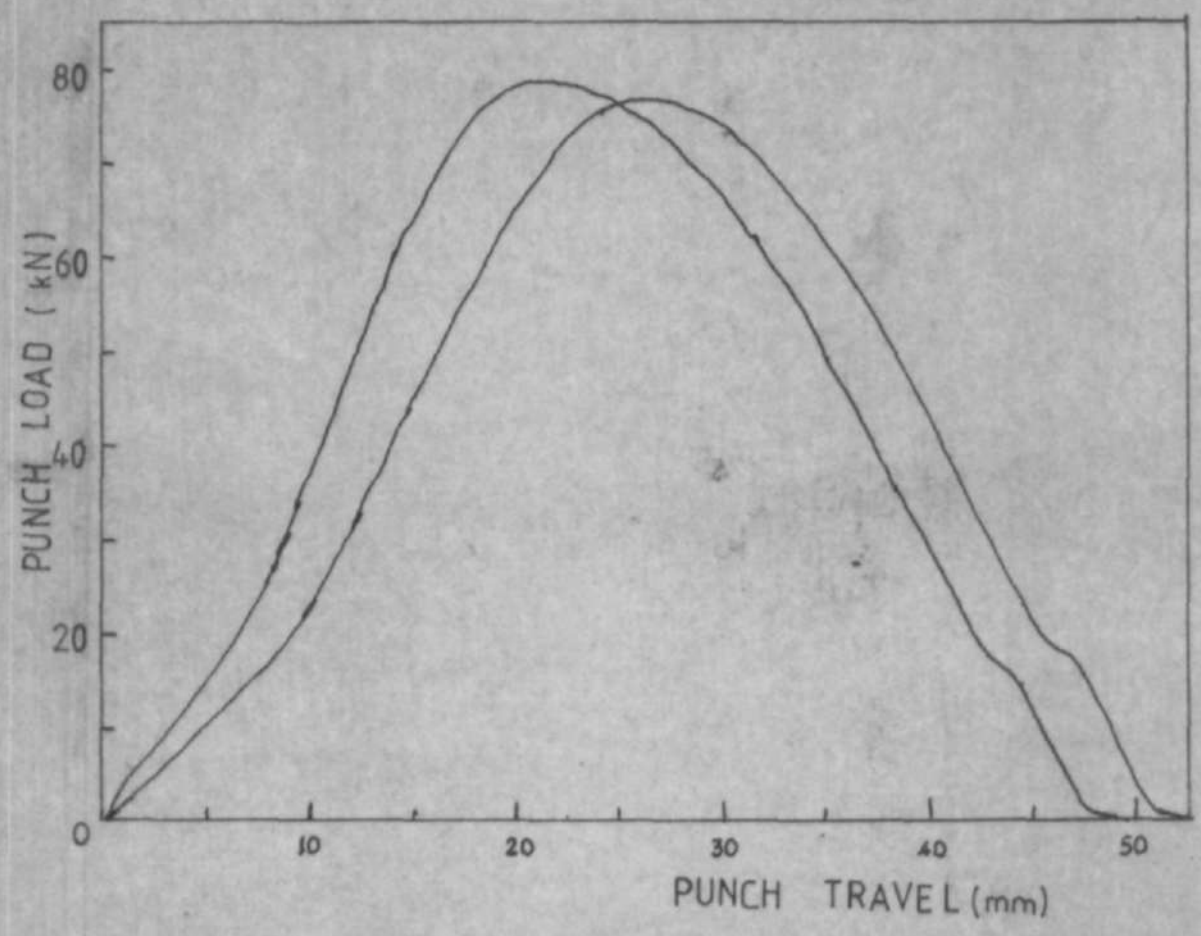


Fig. 4.5 Effect of punch profile radius on punch load-travel for 1.5mm thick galvanized mild steel

for the three materials are presented in figures (4.1), (4.2) and (4.3). The more generous the punch profile radius, the more gradual is the rise of the punch load and the longer is the punch travel. The maximum punch load almost unaffected by the punch profile radius. Smooth curves were obtained for all profiles and materials but for a few cases in the curves in Figure (4.2). The differences in these curves may be attributed to ironing of wrinkles arising from improper entering of the material due to improper centralisation of the blank. Figure (4.3) for aluminum shows some dis discontinuity in the curves for 15mm and 18mm radii. The cups fractured at these profile radii before they were fully drawn. Smaller blank sizes of 98mm and 96mm diameter were used before successful draws were recorded for the 15mm and 18mm profile radii respectively. A corresponding decrease in maximum punch load to 19KN for the 15mm radii punch (i.e. 98mm diameter blank) and 17KN for the 18mm radius punch (i.e. 96mm diameter blank) was recorded.

The Figure (4.4) shows the punch load versus punch travel curves obtained for

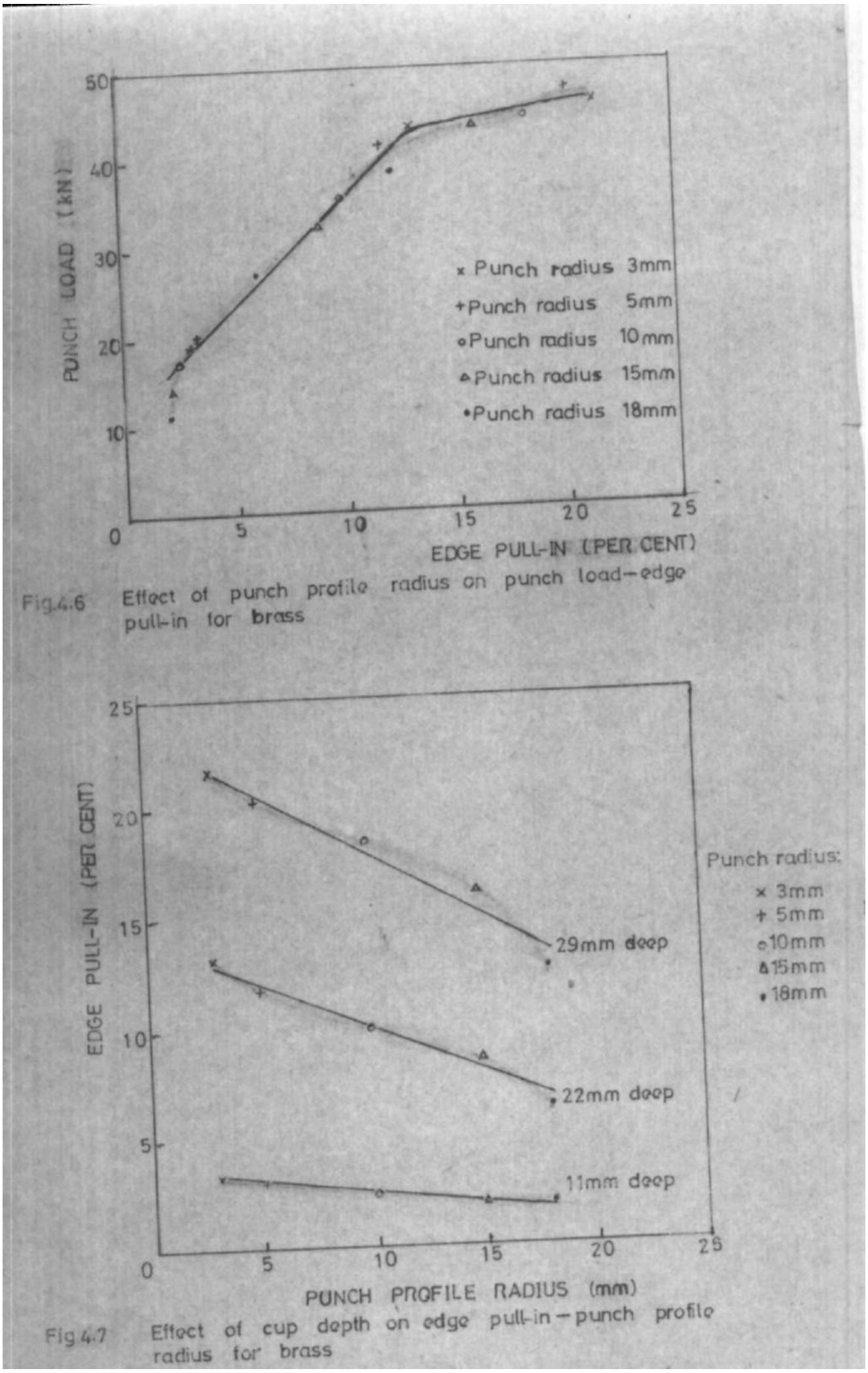


Fig.4.6 Effect of punch profile radius on punch load–edge pull-in for brass

Fig 4.7 Effect of cup depth on edge pull-in – punch profile radius for brass

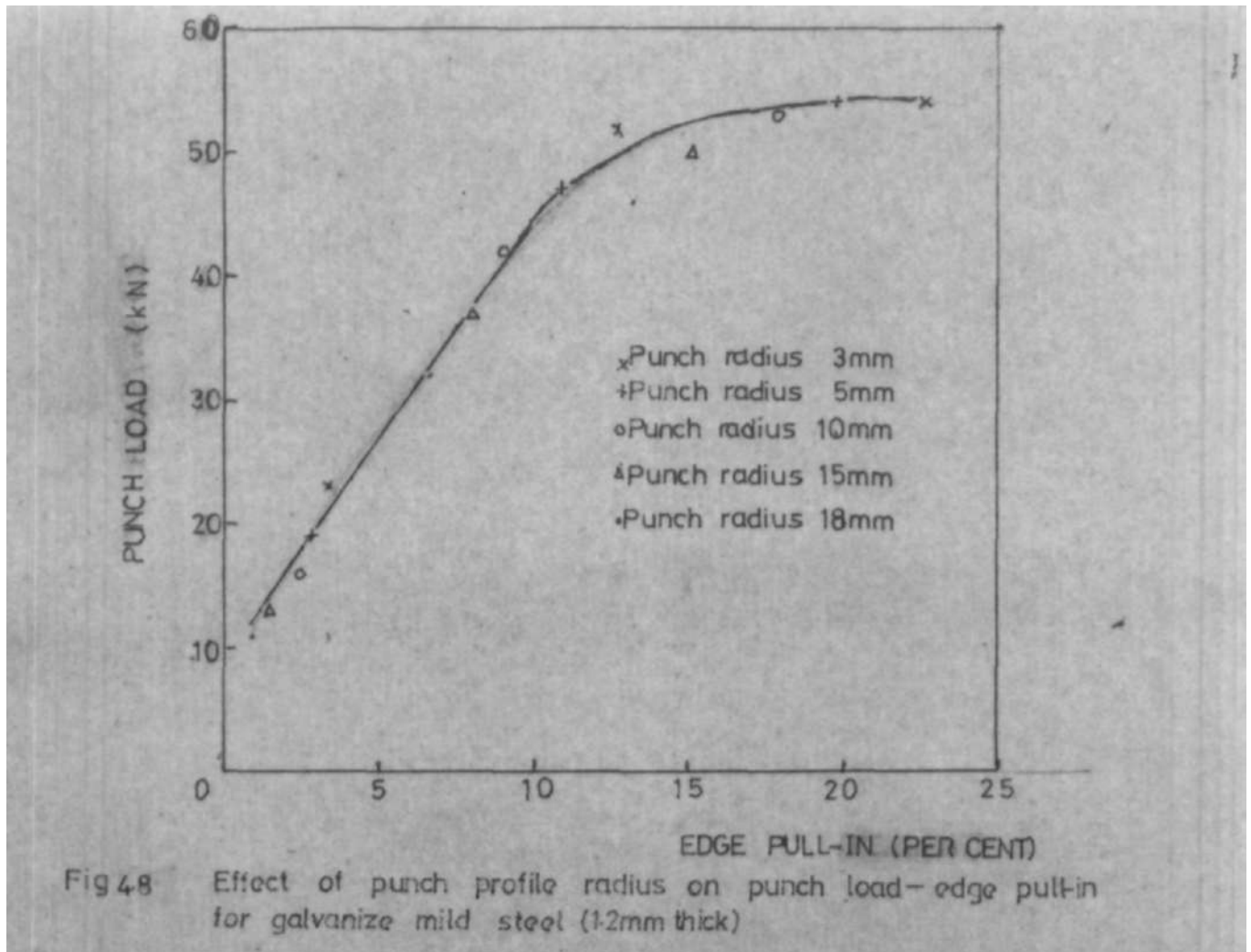


Fig 4.8 Effect of punch profile radius on punch load – edge pull-in for galvanize mild steel (1·2mm thick)

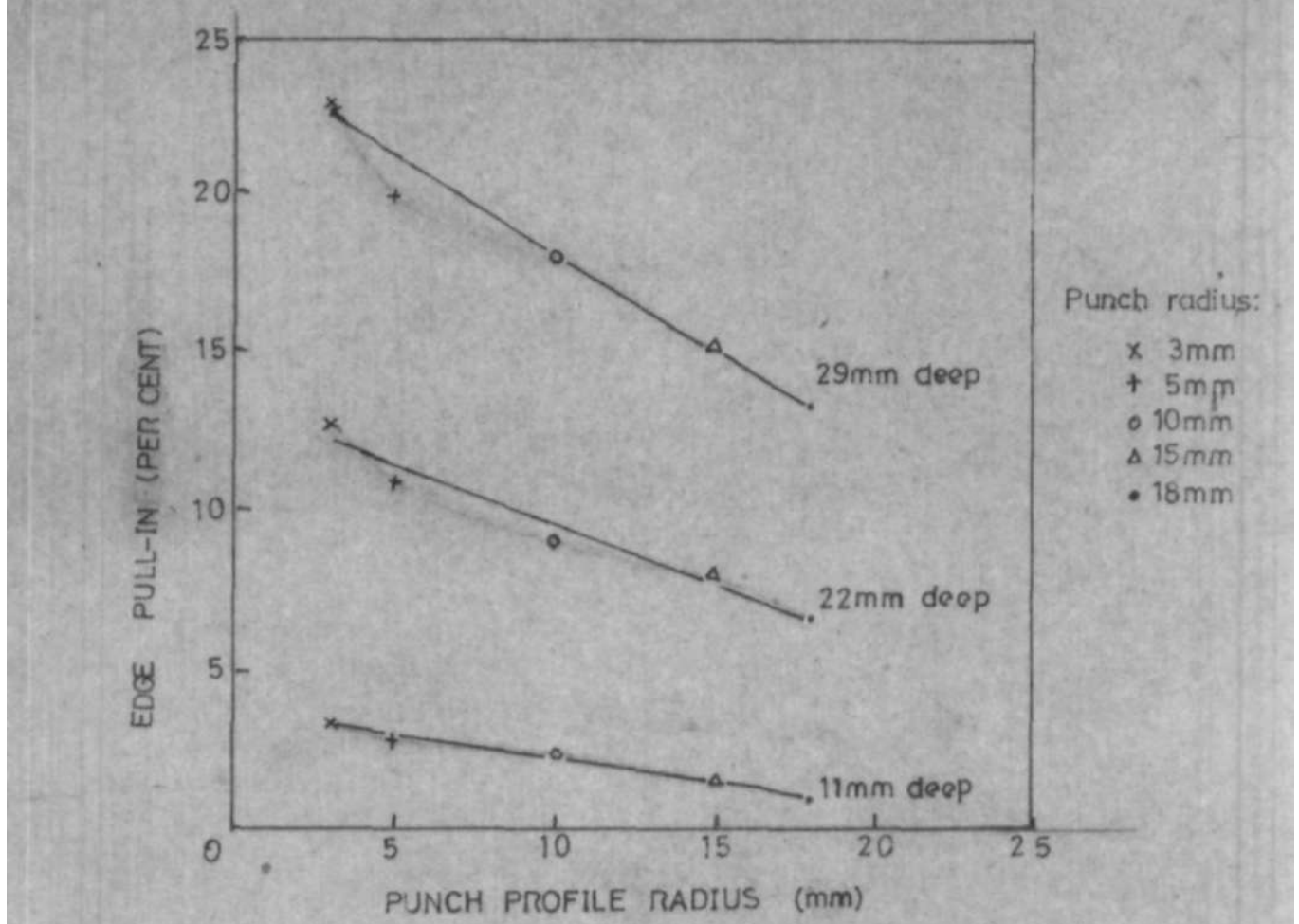


Fig 4.9 Effect of cup depth on edge pull-in – punch profile radius for galvanized mild steel (1·2mm thick)

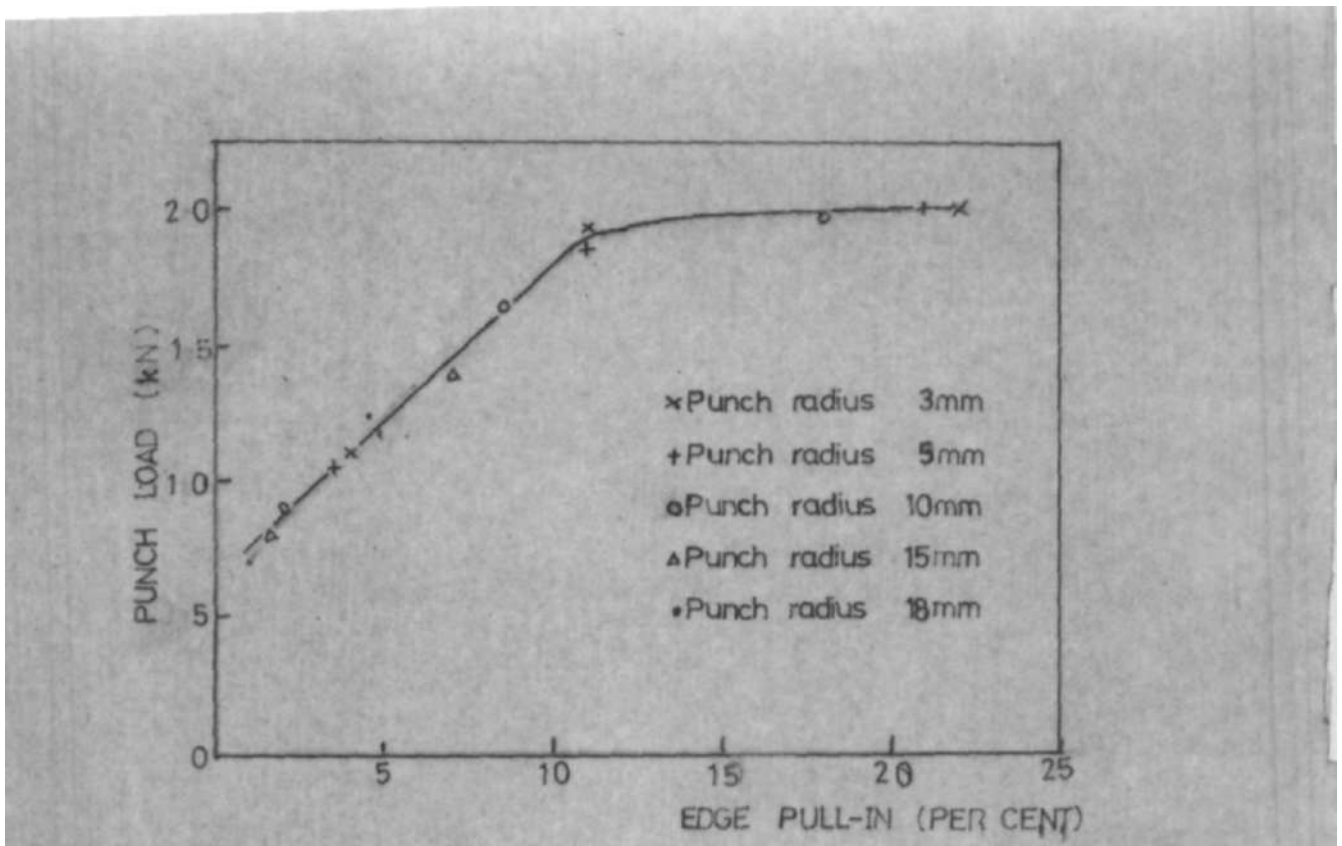


Fig4.10 Effect of punch profile radius on punch load—edge pull-in for aluminum.

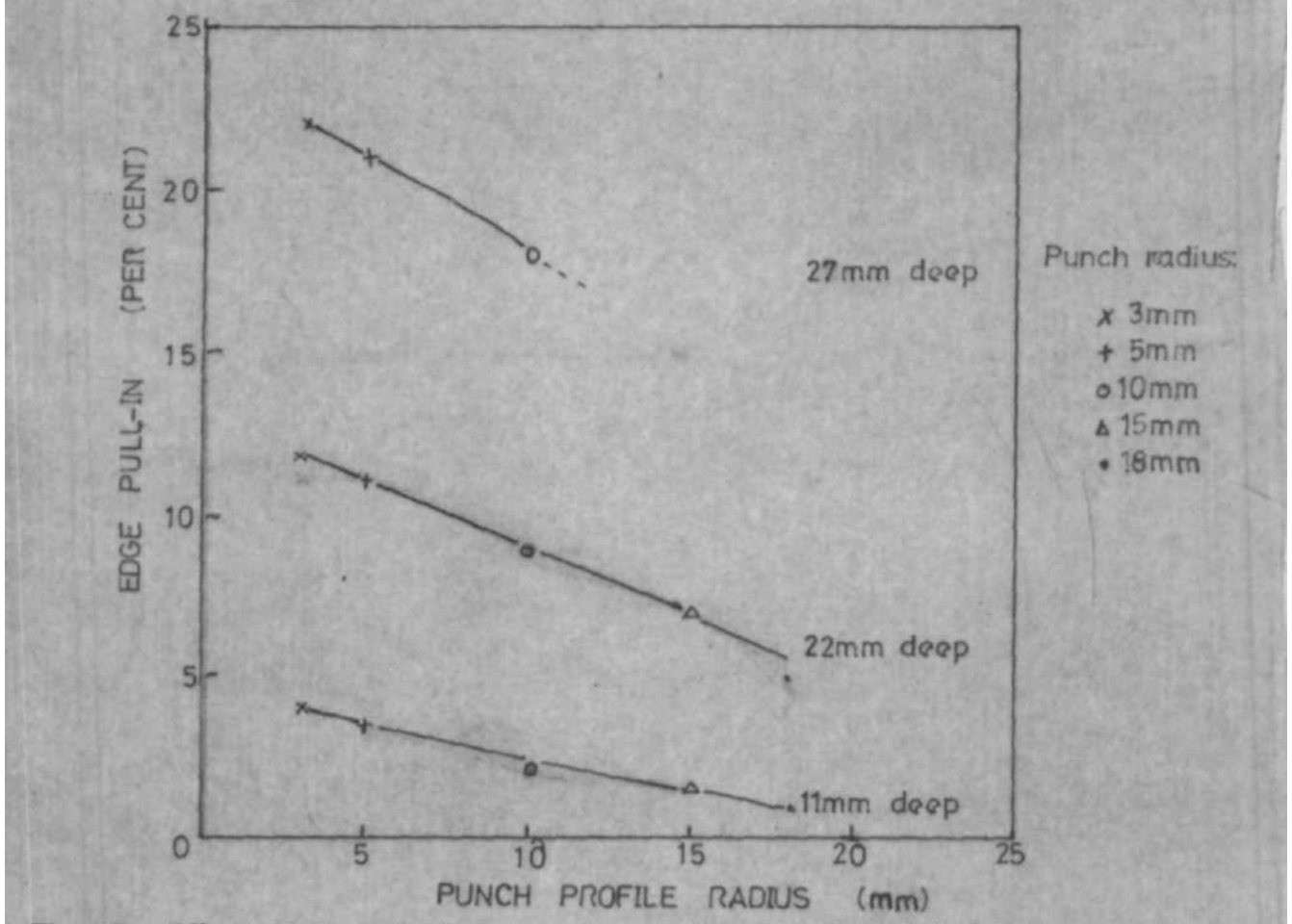


Fig4.11 Effect of cup depth on edge pull-in—punch profile radius for aluminum.

galvanized mild steel of thickness 1.5mm, using punch radius 8mm and 15mm. Higher punch loads and longer punch travels than 1.2mm thick blank of same material is noted from the curves.

4.6 Relation Between Edge Pull-in and Punch Load/ Punch Profile Radius

The graphs of the variation of punch load with edge pull-in for the various punch profiles are shown in figures (4.5), (4.7) and (4.9), for brass, galvanized mild steel and aluminum respectively. All three curves show a direct relation between the edge pull-in and the punch load, irrespective of the punch profile radius.

Figures (4.6), (4.8) and (4.10) show the variation of the edge pull-in with punch profile at various stages of the drawing operation. The edge pull-in decreases with increased punch radius at each stage, and as the drawing operation progresses, the slope of the curves increases.

4.7 Punch Profile Effect on the Progression of Thickness Strains

Figures (4.11) to (4.22) show the thickness strains variation at four depths of draw for

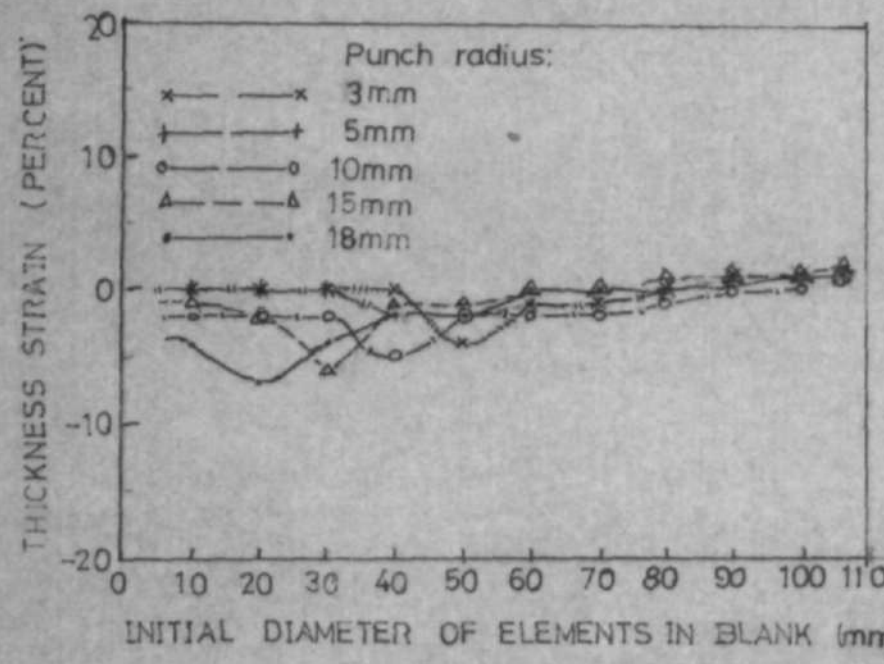


Fig4.12 Effect of punch profile on thickness strain for 10mm deep brass partial cups.

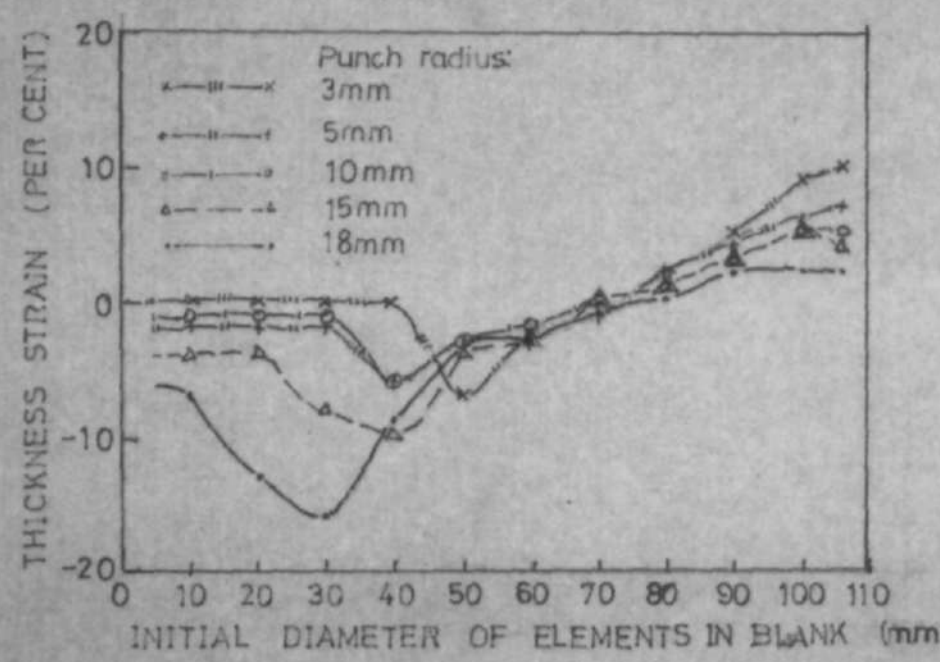


Fig4.13 Effect of punch profile on thickness strain for 20mm deep brass partial cups.

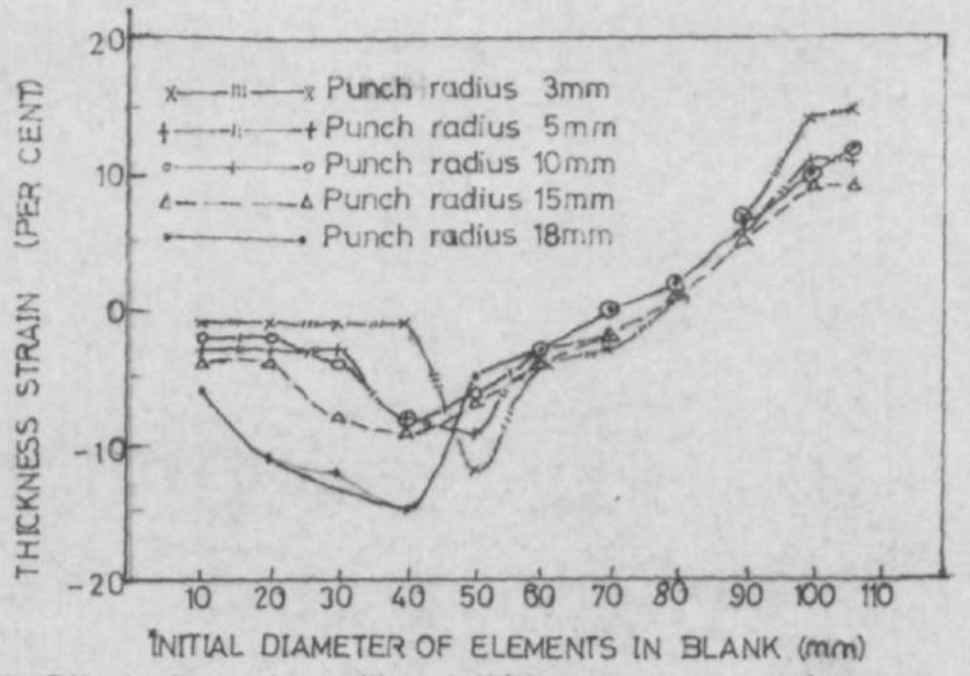


Fig4.14 Effect of punch profile on thickness strain for 29mm deep brass partial cups

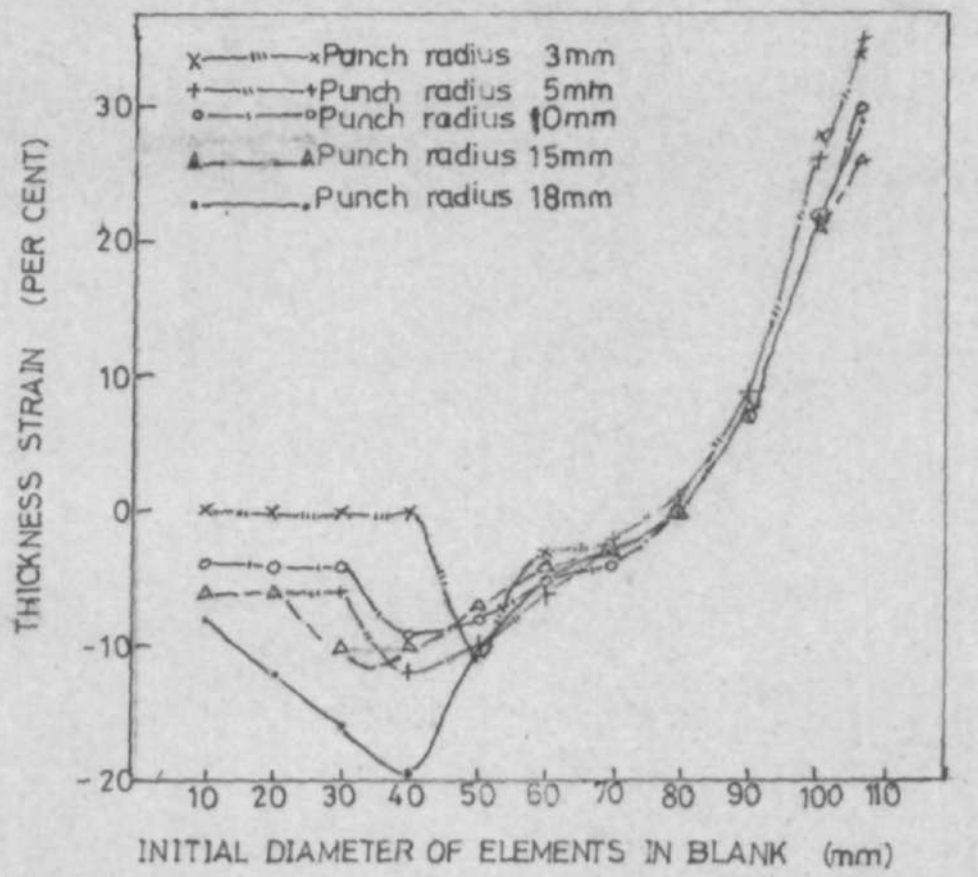


Fig4.15 Effect of punch profile on thickness strain for brass cups

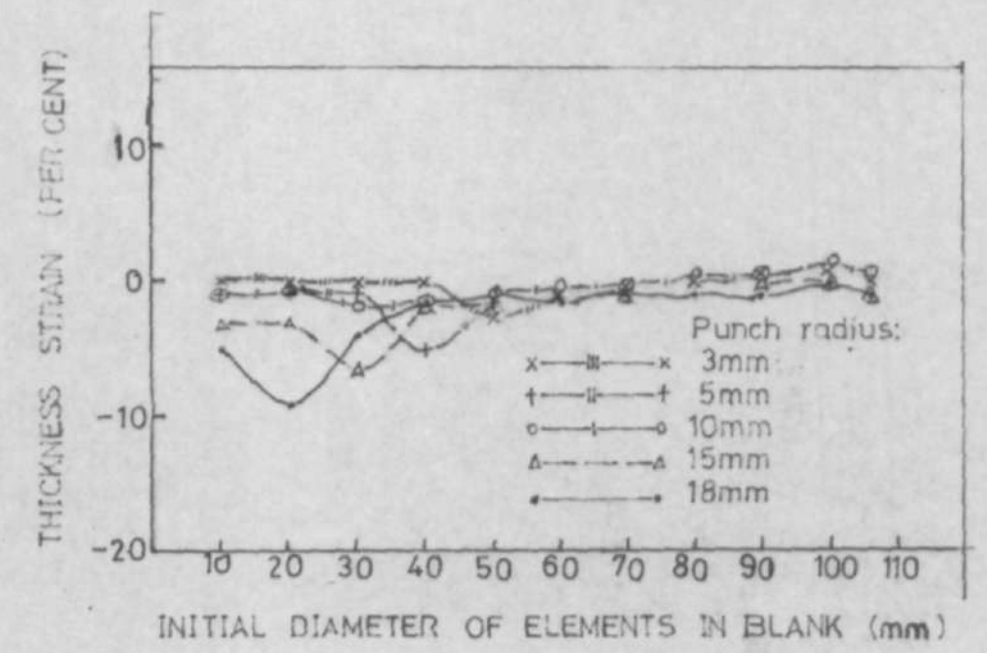


Fig4.16 Effect of punch profile on thickness strain for 10mm deep,[1·2mm thick] gMS.

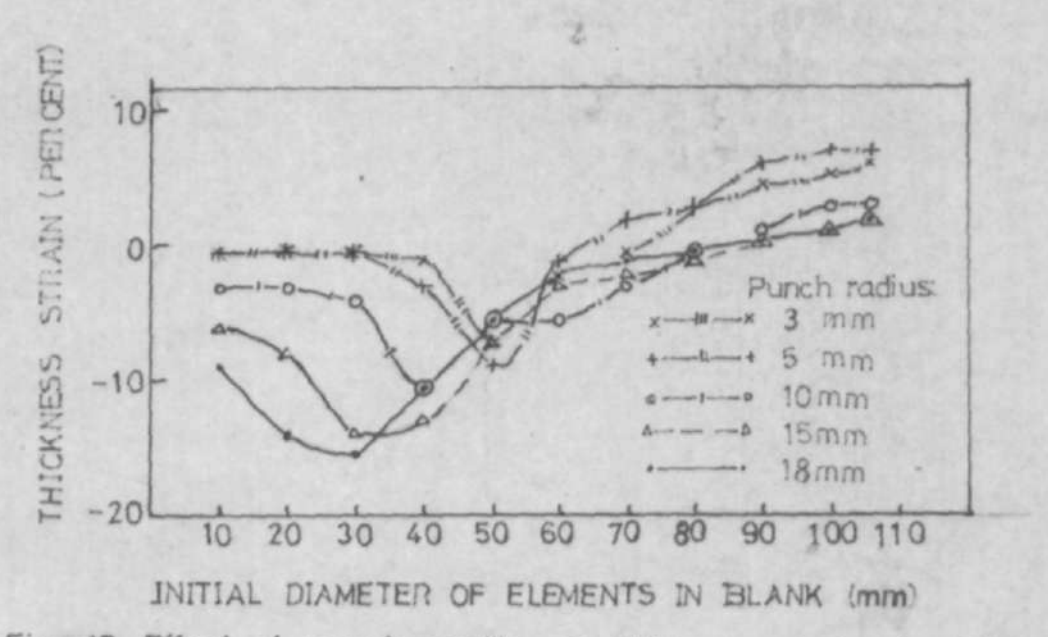


Fig.4.17 Effect of punch profile on thickness strain for 20mm deep[1·2mm thick] gMS.

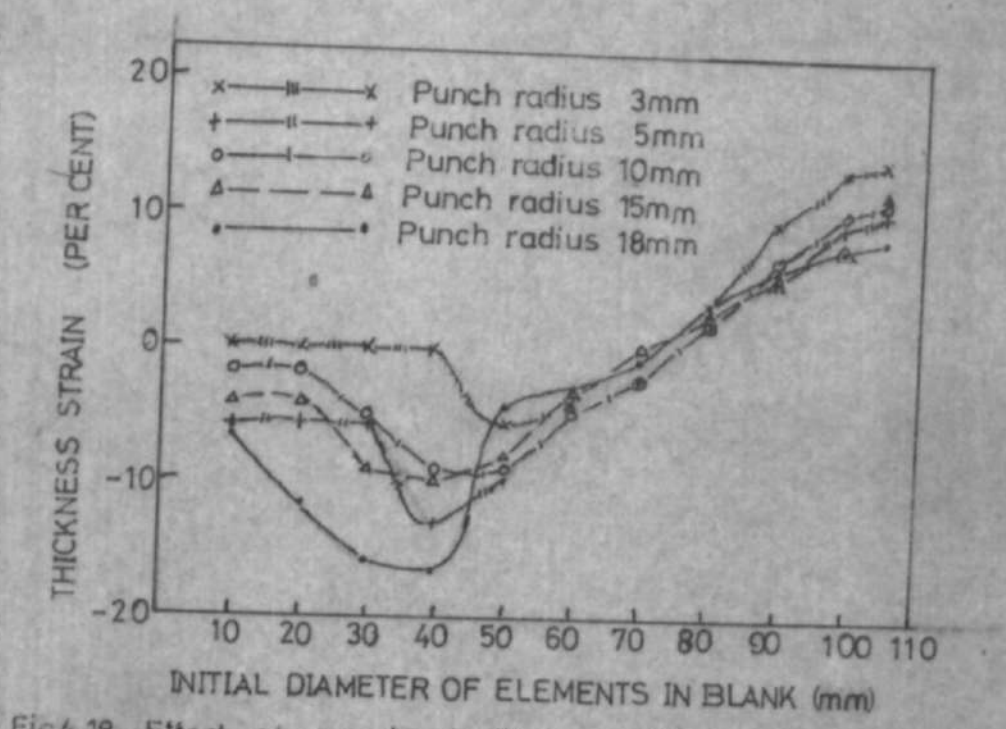


Fig 4.18 Effect of punch profile on thickness strain for 29mm deep, (1·2mm thick) gMS partial cups.

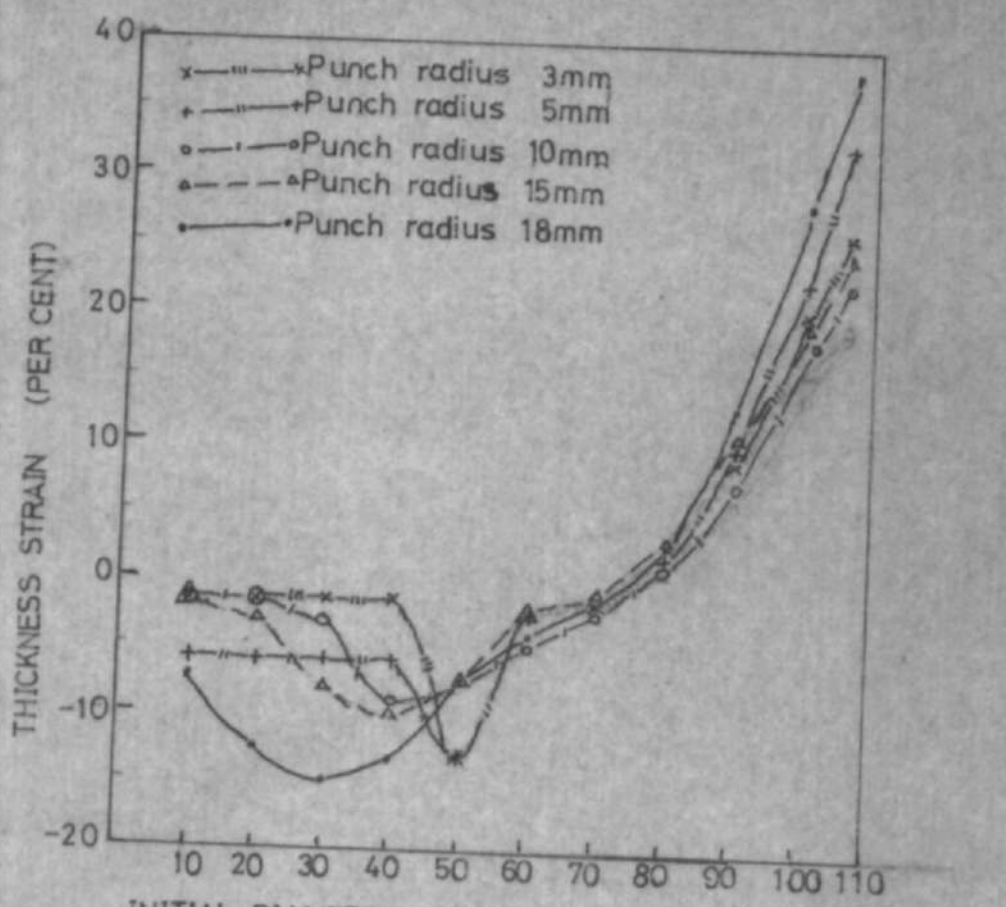


Fig 4.19 Effect of punch profile on thickness strain for (1·2mm thick) gMS cups.

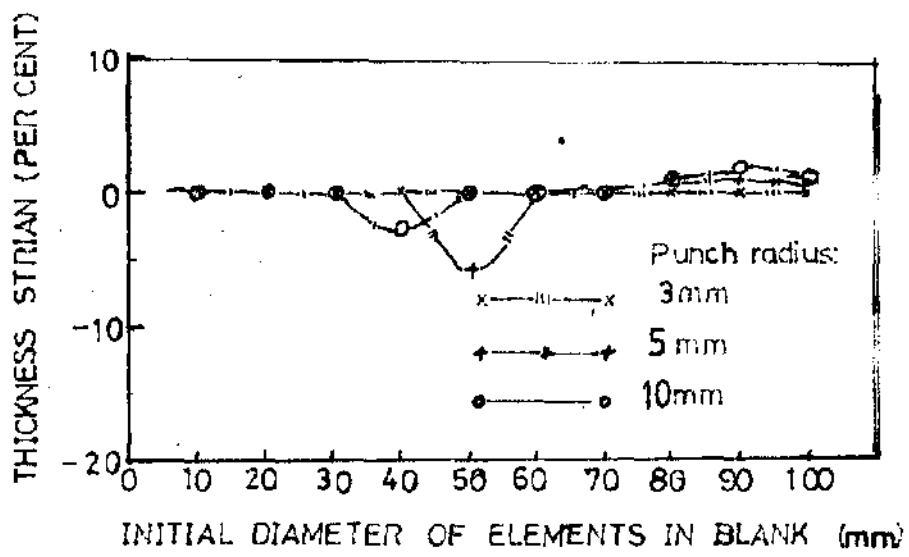


Fig4.20a Effect of punch profile on thickness strain for 10mm deep Aluminum partial cups

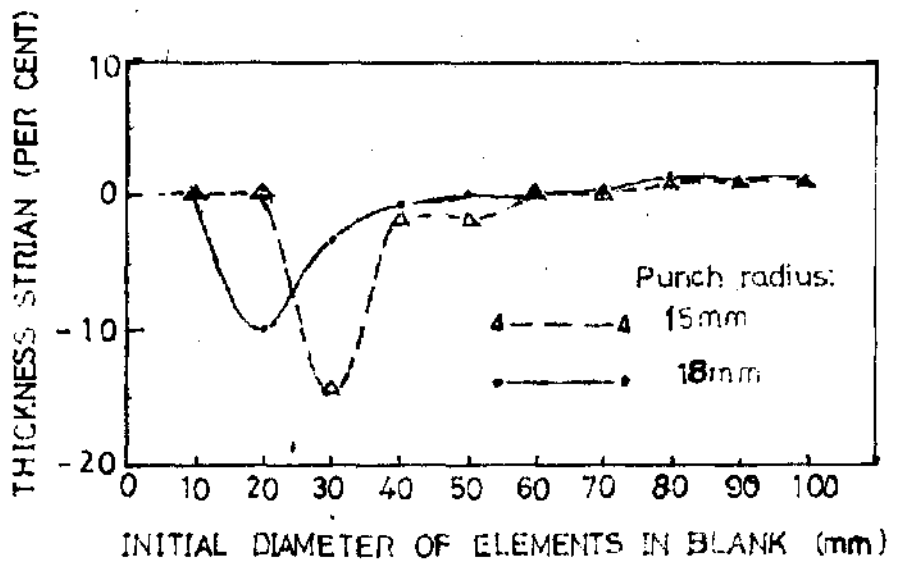


Fig.4.20b Effect of punch profile on thickness strain for 10mm deep Aluminum partial cups

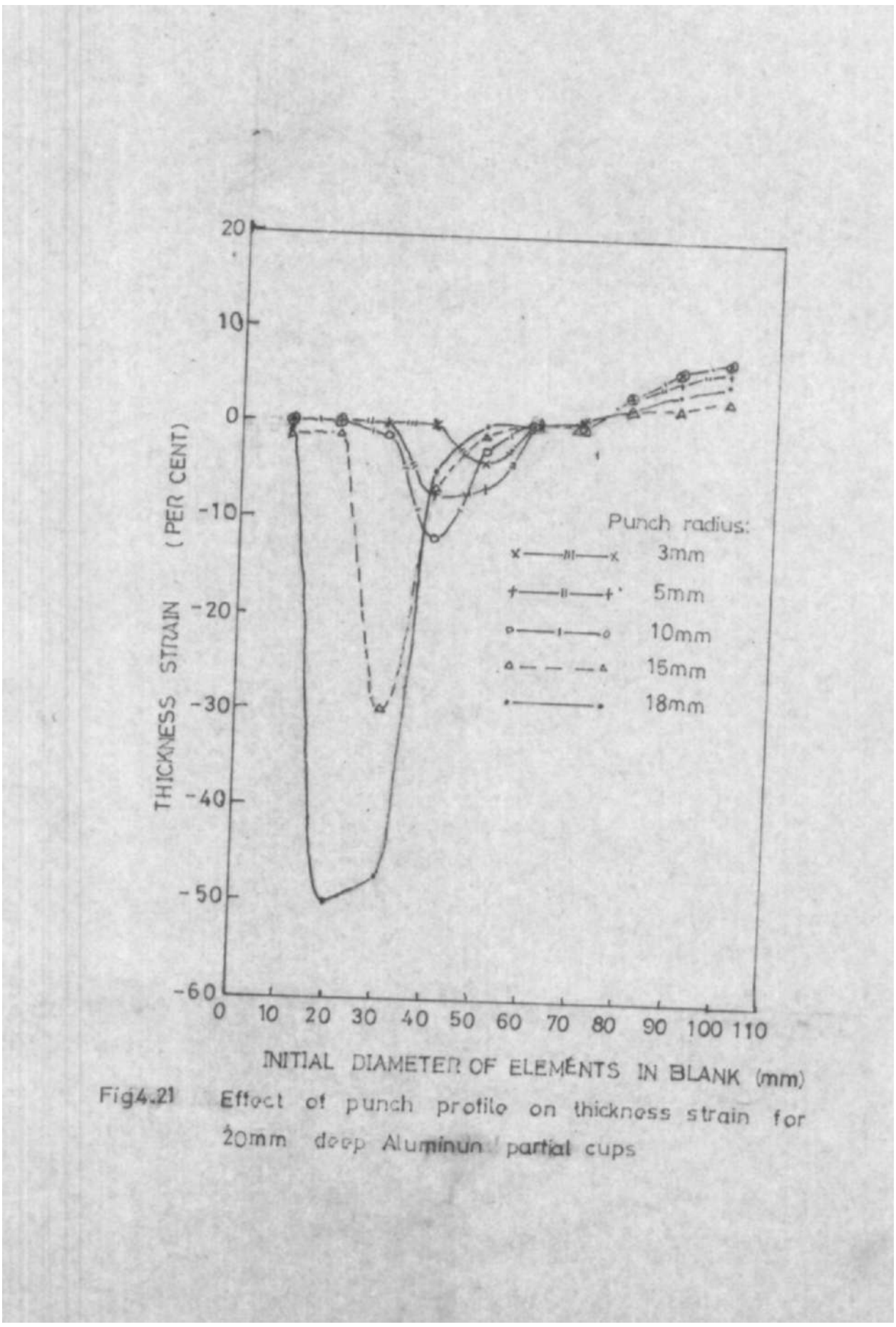


Fig4.21 Effect of punch profile on thickness strain for 20mm deep Aluminun partial cups

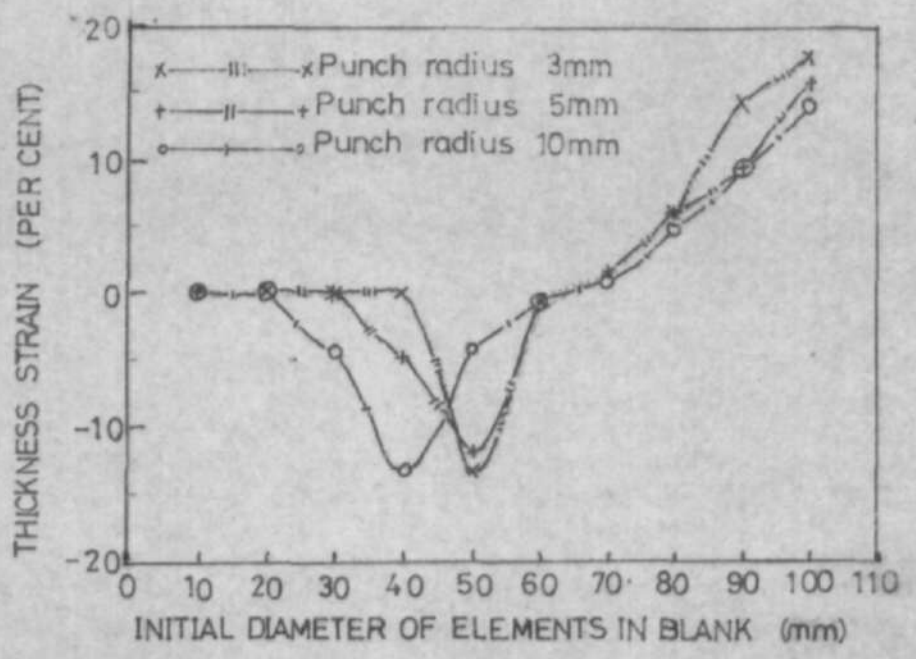


Fig4.22 Effect of punch profile on thickness strain for 27mm deep Aluminum partial cups

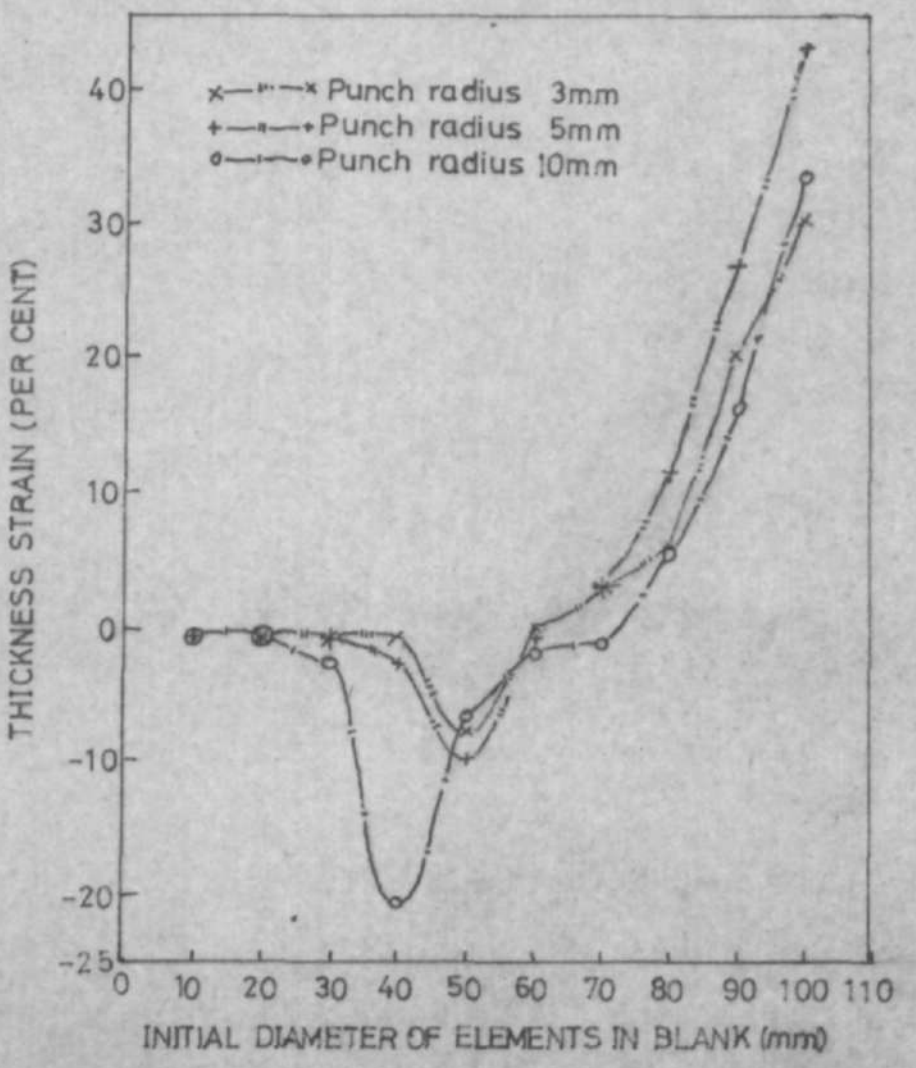


Fig.4.23 Effect of punch profile on thickness strain for Aluminum cups

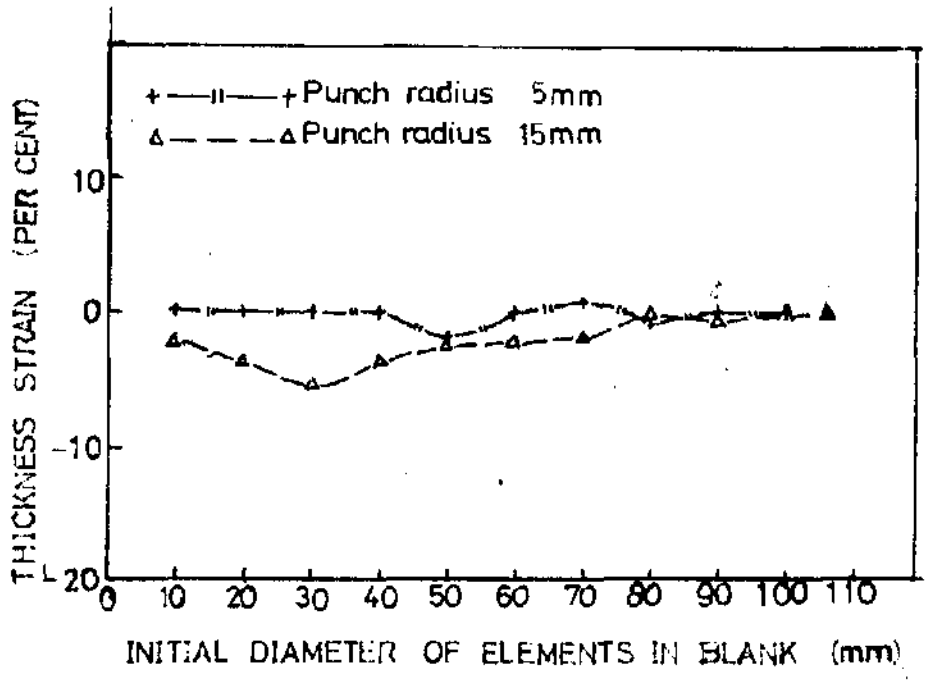


Fig.4.24 Effect of punch profile on thickness strain for 10mm deep [1·5mm thick] gMS.

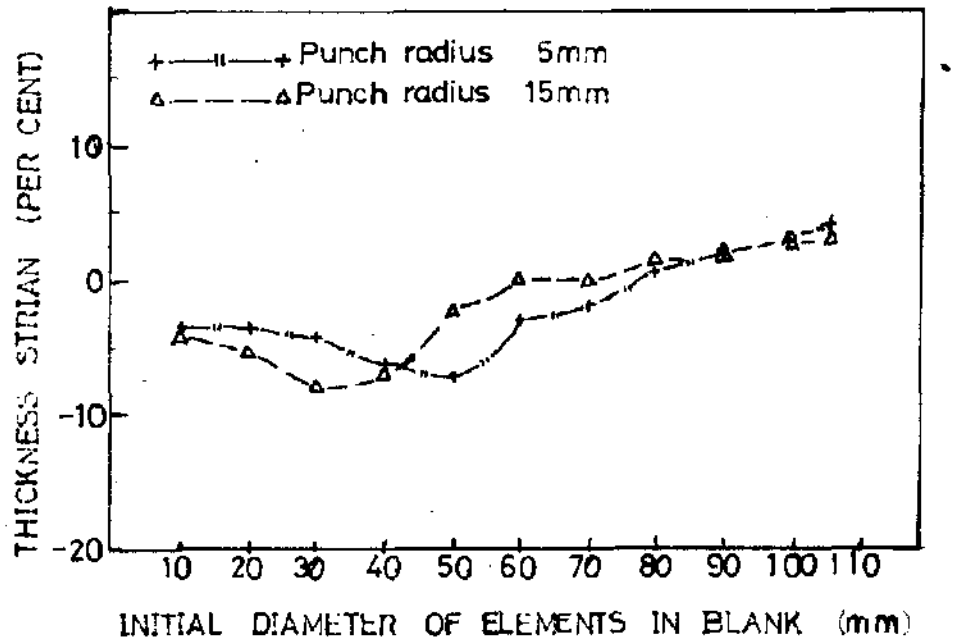


Fig. 4.25 Effect of punch profile on thickness strain for 19mm deep, [1·5mm thick] gMS.

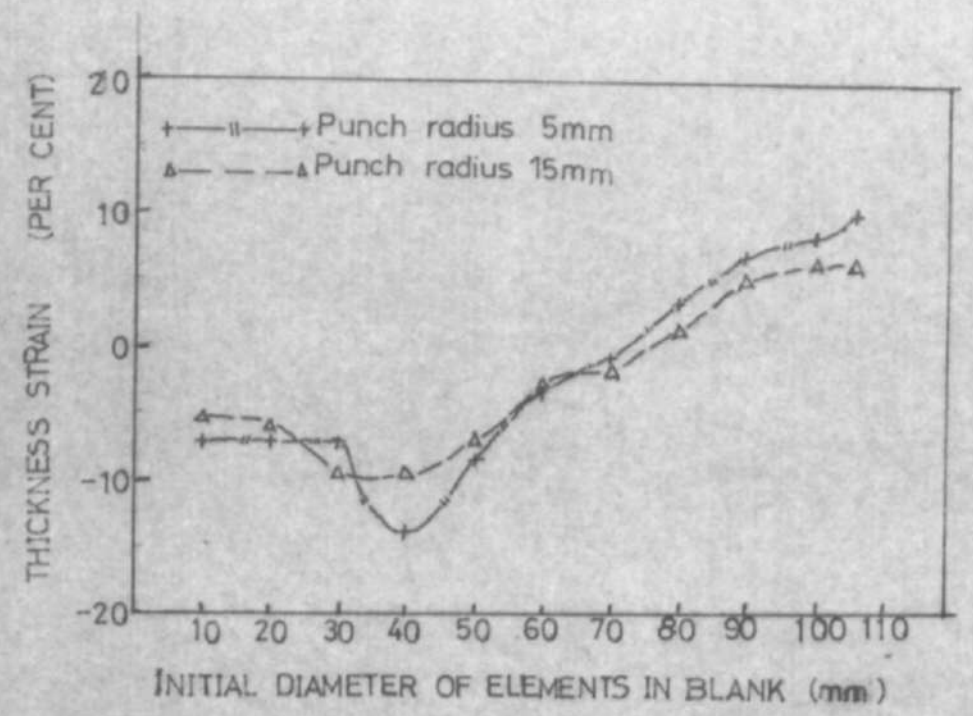


Fig4.26 Effect of punch profile on thickness strain for 29mm deep [1·5mm thick] gMS partial cups.

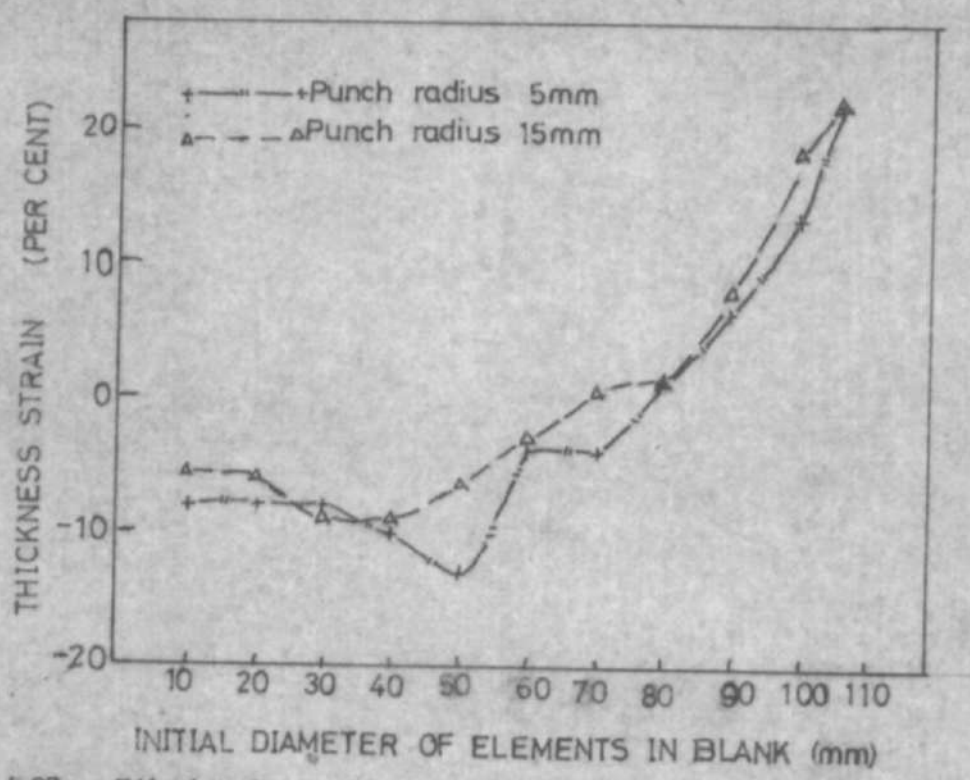


Fig4.27 Effect of punch profile on thickness strain for [1·5mm thick] gMS cups.

brass, galvanized mild steel (gMS), and aluminum. One neck only is apparent from the curves. The more generous the punch profile radius the closer is the neck to the centre of the cup. The first two stages of draw shown in Figures (4.11), and (4.12) for brass, (4.15) and (4.16) for galvanized mild steel, and (4.18) and (4.20) for aluminium, highlight this fact. At the initial stages of the drawing operation, necking was more pronounced with punches of larger profile radii. At a cup depth of 20mm, necking became more pronounced with the smaller punch profile radii of 3mm and 5mm, as shown in Figures (4.14), (4.19) and (4.21). Excessive necking is noticed with aluminum partial cups at a depth of 20mm and for the profile radii 15mm and 18mm. As much as 50 percent thinning is recorded for the 18mm radius neck. At a depth of 27mm, the 18mm and 15mm radius cups have failed by fracturing at the necks.

Thinning at the base of the cups increased as the draw depth increased. The more generous the punch profile, the more the thinning at the cup base. However, for punch of profile radius 5mm, made of polished stainless steel thinning

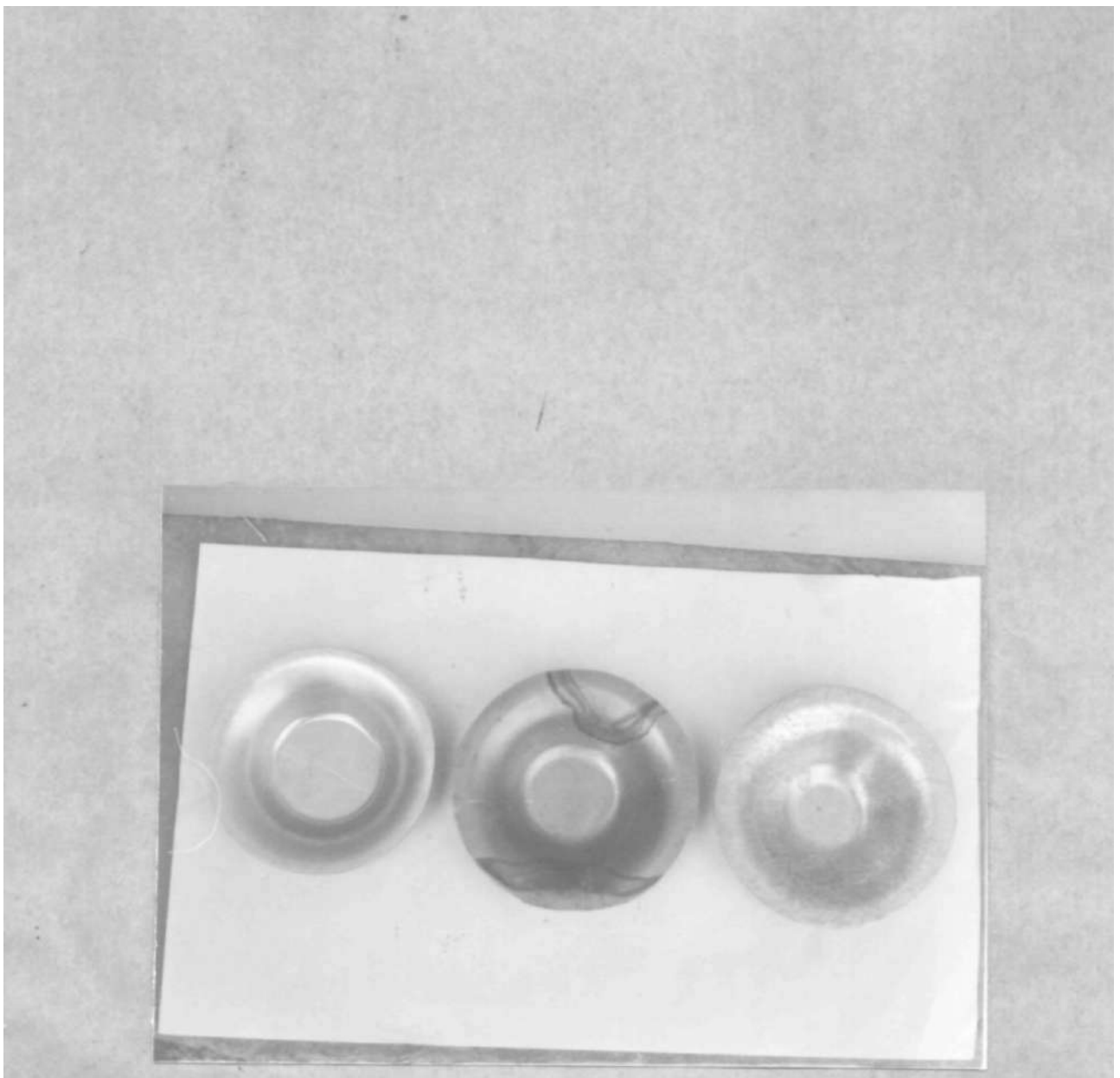


Plate IX Partially drawn cups

was more pronounced than, for the 45mm radius punch, as in Figure (4.14) and (4.18). Aluminum did not thin at the base for all radii and depths - Figures (4.19) to (4.22).

Thickening of the cup flanges are virtually absent up till a depth of 27mm for aluminum, and 29mm for brass and galvanized mild steel. Pronounced thickening can be seen to have occured on the upper half of the fully drawn cup's walls. Generally, the thickening of the cup walls are independent of the punch profile radius but for some discrepancies in the galvanized mild steel and aluminum cups.

With a 1.5mm thick blank of galvanized mild steel, second neck is noted in Figure (4.25). Also, thinning at the base of the cups increased slightly with the 5mm radius punch as shown in Figures (4.23), (4.24), (4.25) and (4.26).

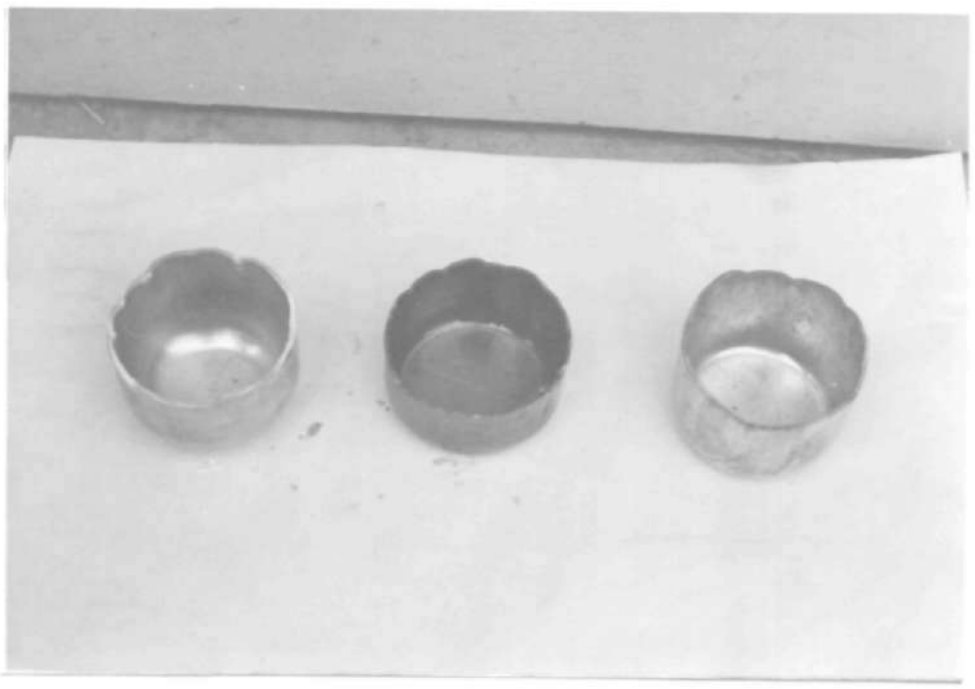


Plate-X: Fully drawn cups

CHAPTER - 5

DISCUSSION AND CONCLUSIONS

The wrinkling of the cups could be attributed to the large die profile radius leading to the early removal of the influence of the clamping plate from the cup flange. Also, the rather large clearance of about 150 percent of blank thickness as was the case with the brass specimen, could contribute to the wrinkling at the top of the cups.

Cups produced with punches of generous radii were deeper than those produced with smaller profile radii, due to the pronounced stretching of the cups at the base and profile radius for cups of large profile radius and as such more material was available to be radially drawn. Cups drawn by punches of smaller radii did not stretch much and thus shallower cups only could be produced.

The earing of the cup flanges points to the anisotropy in the materials, with galvanized mild steel exhibiting higher degree of anisotropy.

5.12 Punch Load Versus Punch Travel Curves

The relation between punch load and punch travel shows smooth curves with the load rising to a maximum and then falling to zero as the punch advances to form a cup. The punch profile radius has little effect on the maximum punch load. However, the less generous the punch profile, the earlier the maximum load is attained.

The differences noted on curves in Figure (4.2) for galvanized mild steel could be attributed to the ironing of wrinkles caused by the large die profile radius or the poor conditions.

5.13 Edge Pull-in Versus Punch Load/Punch Profile Radii

The amount of edge pull-in for each material increased with the punch load in a linear manner irrespective of the punch profile, up to about the maximum punch load. The smaller the punch profile radius the earlier the maximum punch load is attained and the less the amount of edge pull-in at which the maximum punch load is attained. This may be attributed to the

small amount of stretching at the profile and cup base of cups drawn with the smaller profile radius, thus allowing the material to draw in more and attain to maximum load earlier than the large profiled punches.

5.14 Thickness Strains

The absence of the second neck in the profile of the drawn cups could be due to the accuracy of the measuring device. Moreover, measurements were not made at very close intervals and as such, the second neck may have been omitted. The measuring device was not adequate for a very close measurement.

The deviations in the cup wall thickness strains for various punch profiles may be due to the wrinkling at the top of the cup wall and accuracy of the measuring device. The pronounced thinning at the base of the brass and galvanized mild steel cups with the 5mm radiused punch may be due to the punch material and surface conditions. Hawtin (1969) reported a possible tool material effect on the thickness strains at the base of drawn cups. The frictional conditions which differ between

materials may also contribute to this, since the highly polished tool steel used in the 5mm radiused punch, reduces friction and allows for better flow of the material thus making the cup to thin at the base. Aluminum with a higher coefficient of friction, did not show this thinning tendency as shown in Figure(4.23).

Tinning of the cup walls was absent due to the low clamping loads used.

5.2 Conclusions

1. The maximum available depth of the drawn cup is determined by the punch profile, the larger the profile radius, the deeper the cup.

2. The punch profile radius was found to have little effect on the value of the maximum punch load but a generous curvature delayed the point at which this maximum occurred.

3. The punch profile has little influence on the thickness of the cup walls but is the primary factor in determining the changes of thickness in and around the base of the cup.

4. The drawability of aluminum is dependent on the punch profile radius; with all other factors remaining the same.

5. The amount of edge pull-in at any depth is dependent on the punch profile radius; the edge pull-in increasing as the punch profile radius decreases.

6. Thicker blanks of same material require greater punch load.

7. The smaller the blank diameter, the less the punch load.

8. High tensile strength and ductility in materials made for better drawability but high punch loads are required.

9. The energy requirements for a drawing operation is virtually independent of the punch profile but is determined by the tensile properties of the material.

10. One neck only was observed on the thickness strain curves. The more generous the punch profile radius, the closer is the neck to the centre of the cup.

11. The experimental results obtained from this work correlate closely with results reported by earlier workers on deep drawing of sheet metals. Where discrepancies occurred, they were mostly due to the experimental conditions and errors in measurement.

12. The 400KN sheet metal testing machine was successfully commissioned and put to use.

5.3 Recommendations

1. With better blank preparation materials, investigations into the effect of drawing ratio on punch load and thickness strains could be carried out.

2. The effect of the die profile radius on punch load and thickness strains could be studied where more dies with varying profile radii are produced.

3. The ironing effect on punch load and thickness strains could be investigated, with reduced radial clearance.

4. The lubricity of various lubricants can be investigated by determining their effect on the drawability of the metal.

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