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NALYSIS OF CLOSED DIE COLD FORGING FOR SPUR GEAR USING THREE DIMENSIONAL SLAB TECHNIQUE

Ali A A A Alkhamees

Public Authority of Applied Education and Training, Construction Training Institute, Mechanical Works Division

ABSTRACT

The present study is concerned with upset forging of arbitrarily-shaped prismatic blocks which is characterized by three-dimensional deformation. From the proposed velocity field, the upper-bound load and deformed configuration are determined by minimizing the total power consumption with respect to some chosen parameters; such as the proposed method of analysis in this work can be used for prediction of forging load and deformation in upset forging of arbitrarily-shaped prismatic blocks. Closed-die forging of toothed disk is investigated using the slab method technique The tooth regions are approximated by prismatic rectangular sections. The velocity field comprising three-unit deformation regions is used. A constant frictional stress between work-piece and forging die is assumed. The average punch pressure normalized by the flow stress of the billet material is determined theoretically and compared with the present experimental results The experimental work is carried out on a commercial pure Aluminum (Al 1100) at room temperature The forging process is carried out using one die geometry without using any additional blocker dies. The theoretical predictions of forging pressures and deformation configurations are in good agreement with the experimental results. The experimental work proves that the analysis is good within approximately 36% of error according to many parameters.

Keywords: Closed Die forging; cold forming; Three Dimentional Slab method; Spur Gear

II. INTRODUCTION

Forging is the process of deforming a metal in order to shape a product into a given desired configuration. The prediction of metal flow or geometric change at the free surface of a workpiece is very important. The main factors affecting metal flow are friction, strength of the metal being formed, and the geometry of the tools and the workpiece.

Procedures for the analysis of cylindrical upsetting have been developed by various theoretical methods such as the slip-line method, the upper bound method, and the finite element method ... etc. It is, however, only recently that the upset forging of non circular blocks have been analyzed.

With the use of closed-die forging, complex shapes and heavy reductions can be made within closer dimensional tolerances which are usually feasible with open dies. Closed-die forging is adaptable to high- volume production improved structure, and good mechanical properties and surface finish. In closed-the forging a material must satisfy two basic requirements:

a. The material strength (or flow stress) must be low so that die pressures are kept within the capabilities of practical die materials and constructions.
b. The capability of the material to deform without failure (its forgeability) must allow the desired amount of deformation for a given material.

Both the flow stress and the forgeability are influenced by the metallurgical characteristics of the billet material and the forging parameters such as temperature, strain, strain rate and stress.

In the most practical closed-die forging operations, the temperature of the workpiece material is higher than that of the dies Material flow and die filling are largely determined by the resistance and the ability of the forging material to flow, I e. flow stress and forgeability Flow stress represents the resistance of a material to plastic deformation while forge ability is the ability of a material to deform without failure regardless of the magnitude of load and stress required for deformation.

Friction generally influences metal flow, pressure distribution, load, and energy requirements in closed-die forging since there is a considerable effect of friction on forgeability. Therefore, the friction problem must be treated carefully by using the appropriate lubricant.

Precision forged gears are made from billets have almost the exact volume of the material required for the final size of the gears. No allowance is made for flash formation. The development of precision forging gear processes has been an area of increasing activity in recent years. The analysis of corner filling characteristics in precision forging considering the effect of difference in work piece geometry and lubrication showed that the velocity field which leads to the best load prediction is not that which most closely describes changes of geometry in a billet. Kim et al [4] proposed some appropriate velocity fields for the upsetting analysis of three dimensional forging of arbitrarily-shaped prismatic blocks. The analysis showed a good agreement of forging load with their experimental results. Forging processes for heavy ingots by finite element method had been analyzed by Sun [5] who proposed the optimum geometrical parameters for the forging process. Large deformation behavior of Aluminum and low carbon steel short cylinders loaded axially in simple compression without using any lubricant was examined by Gupta and Shah [6]. Their results revealed that the profile of a deforming specimen can be approximated by an arc of a circle only after the onset of folding.

Forging of spur gear forms and closed die forging of gear-like elements using the upper bound technique have been analyzed [7,8]. In their analysis the assumption of no axial velocity in the tooth region imposes severe limitations on the validity of the analysis.

In the present work, the upper bound technique and slab method have been used to analyze the closed-die forging of a toothed part. Numerical calculations have been done to study the effect of process and material variables on forging load estimation. To determine the validity of the present analysis, an experimental program is carried out on commercially pure aluminum (Al 1100) billet to forge a toothed part having 12 teeth.

III. RELATED WORKS

The technology developed includes two steps in the forging process. Well-shaped products are forged successfully using a lower forging pressure than that of conventional forging. The accuracy of the forged spur gear obtained by the new precision forging technology is set nearly equal to that of a cut spur gear of the fourth and the fifth classes in the Korean industrial standard. [J.C Choia 1999]. Forging spur gear forms in completely closed cavity dies is investigated by means of an upper bound analysis. A velocity field comprising three unit deformation regions is proposed. The tooth regions are approximated by prismatic rectangular sections. The effects of root diameter, number of teeth and workpiece/die interface friction, on flow and forging pressures, are determined.

Forging pressure without friction is independent of root diameter but increases with the number of teeth. In the presence of friction forging pressure increases with reducing root diameter. [N.A. Abdul 1986]. The filling of corners in flashless forging of cylindrical shapes is considered. Experiments with commercially pure aluminum were carried out at room temperature and the effects of different workpiece geometries and lubrication on corner filling were observed. Three different upper bound solutions are applied to predict tool loads and metal flow. The extent of agreement between each of these and experimental results depends on billet geometry and boundary conditions. It is demonstrated that the velocity field which leads to the best load prediction is not that which most closely describes changes of geometry in a billet. [A.O.A. Ibhadode 1988].

A new technique to form spur gear from hollow billet was proposed, that is performing divided flow region and then final forging by the relief hole. At the same time 3D-FEM simulation of the whole process is performed using DEFORM-3D TM software. The results show that this new technique has many advantages over the conventional one, and gives a theory foundation for practical industry production. [XIA Shi-sheng, 2003].

The manufacture of bevel and cylindrical spur gears by the means of applying hot or cold bulk forming processes is a quite widespread production method due to its well-known basic advantages, such as material and time cost reduction and the increased strength of the teeth. However, the associated process planning and tool design are more complicated compared with those of other conventional forging or rolling technologies. [B.I Tomov 1999]. Insufficient corner filling is one of the main disadvantages of conventional cold closed-die forging of spur gears. To guarantee the dimension accuracy of spur gears, how to improve the filling condition is very important. Because the die shape is one of the most important factors in forming, three design schemes with different die shape are researched. A corresponding experiment is done, which is mainly utilized for supporting and validating the numerical simulation and theoretical investigation. [Chengliang Hua 2007]. Using the present model, various effects of forming parameter such as the friction factor, reduction, number of teeth, etc. upon the non-dimensional forging pressure, forging force and barreling of the spur gear forms and spline were analyzed systematically and the results compared with those of other researcher's analytical and experimental work. [Hung-Hsiou Hsu 2002]. The application of tool design expertise in conjunction with the virtual prototyping modeling techniques made possible the development of a tool system for performing the experiments. The experimental work is mainly utilized for supporting and validating the theoretical investigation but a later stage can be further developed in order to put the proposed forging concept on an industrial basis. [M.L Alvesa 2001]. The forging of spur gears has been investigated by means of upper-bound analysis. A kinematically admissible velocity field for the forging of spur gears has been newly proposed; especially, a neutral surface has been introduced into the forging of gears by using hollow billets with a flat punch. The half pitch of the gear has been divided into seven deformation regions. By using the kinematically admissible velocity field, the power requirements and suitable conditions for the forging of spur gears were successfully calculated by a numerical method. [Jongung Choia, 2000].

IV. METHODOLOGIES/THEORETICAL SETUP

Slab Method Analysis

A circular punch is used for forging a cylindrical billet placed in a die which has spaces for teeth on its periphery. The punch compresses the billet axially and as a consequence the material flow outward into the teeth spaces in the radial directions. In the initial stage of the forging process it is assumed that the billet closely fits the die which has a diameter equal to the dedendum diameter and that the reduction in height allows the material to flow in the teeth cavities. The deformation pattern of the material is considered as axisymmetric forging process for a billet which has a diameter equal to the root diameter of the toothed disk. The tooth formation is considered to take place as plane strain forging process. Integration for plane strain forging of teeth and axisymmetric forging of billet gives the complete solution of spur gear forging problem.

The cylindrical and Cartesian coordinate systems are used to carry out the analysis. The cylindrical coordinate (r, θ, z) is located at mid.-point of the billet while the Cartesian coordinate (x, y, z) is located at the point of junction of tooth with the billet as shown in Fig.(l).

The analysis proceeds as follows:
Consider first the equilibrium of forces in the x-direction:

$$\sigma_x wh - 2\mu\sigma_y wdx - 2\mu\sigma_z hdx - (\sigma_x + d\sigma_x) wh = 0$$

For plane strain condition :-

$$\frac{d\sigma}{dx} + 2\mu(\sigma_{y/h} + \sigma_{z/w}) = 0 \qquad (1)$$

$$\varepsilon_z = 0 \ , \ \sigma_z = \frac{\sigma_x + \sigma_y}{2} \qquad (2)$$

Substituting in E_q. (1)

$$\frac{d\sigma_x}{dx} + 2\mu(\sigma_{y/h} + (\sigma_x + \sigma_y)/2w) = 0$$

$$\frac{d\sigma_x}{dx} + \mu\frac{\sigma_x}{w} + \sigma_y\left(\frac{2\mu}{h} + \frac{\mu}{w}\right) = 0 \qquad (3)$$

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\left[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2\right]^{1/2}$$

$$= \frac{1}{\sqrt{2}}\left[\sigma_x^2 - 2\sigma_x\sigma_y + \sigma_y^2 + \sigma_y^2 - 2\sigma_y\sigma_z + \sigma_z^2 - 2\sigma_x\sigma_z + \sigma_x^2\right]^{1/2}$$

$$= \frac{\sqrt{7}}{\sqrt{2}}\left[\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - (\sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_x\sigma_z\right]^{1/2}$$

$$= \left[\sigma_x^2 + \sigma_y^2 + \left(\frac{\sigma_x + \sigma_y}{2}\right)^2 - \left(\sigma_x\sigma_y + \sigma_y\frac{(\sigma_x + \sigma_y)}{2} + \sigma_x\frac{(\sigma_x + \sigma_y)}{2}\right)\right]^{1/2}$$

$$= \left[\sigma_x^2 + \sigma_y^2 + \frac{\sigma_x^2}{4} + \frac{\sigma_x^2}{4} + \frac{\sigma_x\sigma_y}{2} - \sigma_x\sigma_y - \frac{\sigma_x\sigma_y}{2} - \frac{\sigma_y^2}{2} - \frac{\sigma_x^2}{2} - \frac{\sigma_x\sigma_y}{2}\right]^{1/2}$$

$$= \left[\frac{3}{4}\sigma_x^2 + \frac{3}{4}\sigma_y^2 - \frac{3}{2}\sigma_x\sigma_y\right]^{1/2}$$

$$= \frac{\sqrt{3}}{2}(\sigma_x^2 + \sigma_y^2 - 2\sigma_x\sigma_y)^{1/2}$$

$$= \frac{\sqrt{3}}{2}\left[(\sigma_x - \sigma_y)^2\right]^{1/2} \qquad (4)$$

Substituting E_q. (4) Into E_q. (3)

$$\frac{d\sigma_x}{dx} + \frac{\mu\sigma_x}{w} + (\sigma_x - \frac{2\bar{\sigma}}{\sqrt{3}})(\frac{2\mu}{2} + \frac{\mu}{w}) = 0$$

$$\frac{d\sigma_x}{dx} + \frac{\mu\sigma_x}{w} + \frac{2\sigma_x\mu}{h} + \frac{\sigma_x\mu}{w} - \frac{4\bar{\sigma}\mu}{\sqrt{3}h} - \frac{2\bar{\sigma}\mu}{}$$

Consider $\bar{\sigma}$ *is not function of x, then,*

$$\frac{d\sigma_x}{dx} + C_1\,\sigma_x = C_2 \qquad (5)$$

Where the constants C_1 and C_2 are:

$$C_1 = 2\mu(\frac{1}{w} + \frac{1}{h})$$

$$C_2 = (\frac{4\mu}{\sqrt{3}\,h} + \frac{2\mu}{\sqrt{3}\,w})\,\bar{\sigma}$$

The solution of the differential equation 5 is:

$$\sigma x = \frac{C_2}{C_1} + De^{-C_1 x}$$

Where D is a constant can be determined from the boundary conditions as follows:

$$\alpha \quad x = \ell \Rightarrow \sigma_x = 0$$

Therefore

$$D = (\frac{C_2}{C_1})e^{c_1\ell} \qquad (7)$$

Sub. Eq. (7) into (6)

$$\sigma x = \frac{C_2}{C_1} + (\frac{-C_2}{C_1}\ e\ c1\ell)$$

$$= \frac{C_2}{C_1} - \frac{C_2}{C_1}\ e^{c_1(\ell - x)}$$

$$\sigma x = \frac{C_2}{C_1}\left[1 - e^{C_1(\ell - x)}\right] \qquad (8)$$

From Eq. 8 and Eq. 4

$$\frac{2\bar{\sigma}}{\sqrt{3}} + \sigma y = (\frac{C_2}{C_1})\left[1 - e^{C_1(\ell - x)}\right]$$

$$\sigma y = (\frac{C_2}{C_1})\left[1 - e^{C_1(\ell - x)}\right] - \frac{2\bar{\sigma}}{\sqrt{3}}$$

$$\sigma y = \frac{\frac{2\mu}{\sqrt{3}}\ \bar{\sigma}\ (\frac{2}{h} + \frac{1}{w})}{2\mu\ (\frac{1}{w} + \frac{1}{h})}\left[1 - e^{c_1(\ell - x)}\right] - \frac{2\bar{\sigma}}{\sqrt{3}}$$

$$\sigma y = \frac{2}{\sqrt{3}}\ \bar{\sigma}\left[\frac{(\frac{1}{h} + \frac{1}{2w})}{(\frac{1}{h} + \frac{1}{w})}\left[1 - e^{c_1(\ell - x)}\right] - 1\right]$$

$$C = \frac{\frac{1}{h} + \frac{1}{2w}}{\frac{1}{h} + \frac{1}{w}}$$

$$\sigma y = \frac{2}{\sqrt{3}}\ \bar{\sigma}\left[C(1 - e^{c_1(\ell - x)}) - 1\right] \qquad (9)$$

The load required to forge the teeth at any stage of deformation can be obtained by equating the external load to the internal resistance,

$$Load = L_{tooth} = P_{av.} (w\ell)N \qquad (10)$$

$$L_{tooth} = N \int_o^{\ell} \sigma y \quad wdx$$

$$L_{tooth} = N \frac{2}{\sqrt{3}} \bar{\sigma} w \int_o^{\ell} \left[C(1 - e^{c_1(\ell - x)})\right] dx$$

$$= N \frac{2}{\sqrt{3}} \bar{\sigma} w \int_o^{\ell} \left[C(1 - e^{c_1(\ell - x)})\right] dx$$

$$= N \frac{2}{\sqrt{3}} \left[\ell(C-1)\right]$$

$$- C \int_o^{\ell} e^{c_1(\ell - x)} \, dx = - C \int_o^{\ell} (e^{c_1(\ell - x)} - e^{-c_1 x}) dx$$

$$= -C e^{c_1 \ell} \int_o^{\ell} e^{-c_1 x} \, dx$$

$$= -C \, e^{c_1 \ell} \left[\frac{-1}{C_1} (e^{-c_1 \ell} - e^0)\right]$$

Where N: number of teeth.

$$= -C \, e^{c_1 \ell} \left[e^{-c_1 \ell} - 1)\right]$$

$$= \frac{C}{C_1} \left[1 - e^{c_1 \ell}\right]$$

$$\therefore \quad L_{tooth} = \frac{Nw\bar{\sigma}2}{\sqrt{3}} \left[\ell(c-1) + c \, \frac{1}{c_1} - \frac{e^{c_1 \ell}}{}) \right]$$

From Eq. (10)

$$P_{av}. \quad \ell = \frac{L_{tooth}}{wN}$$

$$\therefore \quad \mathbf{P_{av}} \; \ell = \frac{2}{\sqrt{3}} \bar{\sigma} \left[\ell(c-1) + \frac{C}{C_1} \; (1 - e^{c_1 \ell})\right]$$

$$(\frac{P_{av.}}{\bar{\sigma}})_{tooth} = \frac{2}{\sqrt{3}} \left[(C-1) + \frac{C}{C_1 \ell} \; (1 - e^{c_1 \ell}\right] \qquad (11)$$

Equation (11) gives the normalized average pressure required to forge the material in the tooth region.
Take constant volume concept

$$\pi \; w_2^2 \, h_o = \pi \; r_2^2 \; h + Nw\ell h$$

$$\pi \; r_2^2 \, h_o = h(\; r_2^2 + Nw\ell)$$

$$\pi r_2^2 h_o = h(\pi r_2^2 + N\beta\beta_2 \ell) \qquad \beta = \frac{2\pi}{2N}$$

$$\pi r_2^2 h_o = h(\pi r_2^2 + N\frac{\pi}{N} r_2 \ell) \qquad w = \beta r_2$$

$$\pi r_2^2 h_o = \pi r_2 h(r_2 + \ell) \qquad w = \frac{\pi}{N} r_2$$

$$r_2 h_o = h(r_2 + \ell)$$

$$r_2 (h_o - h) = h\ell$$

$$\ell = r_2 \left(\frac{h_o}{h} - 1\right)$$

The tooth length at any time during the forging process

$$\ell = r_3 - r_2$$

$$r_3 = r_2 \left[(\frac{h_o}{h} - 1) \right] + 1$$

For the axisymmetric part of the gear which bounded by the circle r_2 the force equilibrium in the r direction gives: -

$$\frac{d\sigma r}{dr} + \frac{2\mu}{h} \sigma r = \frac{2\mu}{h} \bar{\sigma} \qquad (12)$$

The solution of this inhomogeneous linear diff. Eq. of the first order is:

$$\sigma_r = e^{\frac{-2\mu r}{h}} \left[\bar{\sigma} e^{\frac{2\mu r}{h}} + Q \right] \qquad (13)$$

Where Q is constant can be determined from the boundary conditions;

$$(\sigma_r) r = r_2 = (\sigma_x) x = 0$$

$$\frac{C_2}{C_1}\left[1 - e^{c_1 \ell}\right] = e^{\frac{-2\mu r_2}{h}} \left[\bar{\sigma} e^{\frac{2\mu r_2}{h}} + Q \right]$$

$$\frac{C_2}{C_1}\left[1 - e^{c_1 \ell}\right] = \bar{\sigma} e^{-2\mu r_2/h} e^{2\mu r_2/h} + e^{-2\mu r_2/h} Q$$

$$Q = \frac{\frac{C_2}{C_1}\left[1 - e^{c_1 \ell}\right]}{e^{-2\mu r_2/h}} - \frac{\bar{\sigma} e^{-2\mu r_2/h} e^{3\mu r_2/h}}{e^{-2\mu r_2/h}}$$

$$Q = e^{\frac{2\mu r_2}{h}} \left[\frac{C_2}{C_1}\left[1 - e^{c_1 \ell}\right] - \bar{\sigma} \right]$$

Let $D_1 = \dfrac{2\mu\, r_2}{h}$

$$\therefore\ Q = e^{D_1}\left[\frac{C_2}{C_1}\ (1-e^{c_1\ell}) - \bar{\sigma}\right] \qquad (14)$$ From Eq. (13) and Eq. (14)

$$\sigma_r = e^{-2\mu\mu_2/h}\left\{\bar{\sigma}\ e^{2\mu\mu_2/h} + e^{D_1}\left(\frac{C_2}{C_1}(1-e^{c_1\ell}) - \bar{\sigma}\right)^2\right\} \qquad (15)$$ Using the axisymmetric condition

$\sigma_r = \sigma_\theta$ is von - miscs yielding criterion load to;

$$\sigma_z = \sigma_r - \bar{\sigma} \qquad \textit{these} \qquad (16)$$ From Eq. (15) Eq. (16)

$$\sigma_z = \bar{\sigma} + e^{(D_1 - D_2 r)}\left[\frac{C_2}{C_1}(1-e^{c_1\ell}) - \bar{\sigma}\right] - \bar{\sigma}$$

$$\sigma_z = e^{(D_1 - D_2 r)}\left[\frac{C_2}{C_1}(1-e^{c_1\ell}) - \bar{\sigma}\right] \qquad (17)$$

Where;

$$D_2 = \frac{2\mu}{h}$$

The forging load for axisymmetric part of the year is obtained as follows

$$L_{ax.} = \int_o^{r_2} 2\pi r\, dr \sigma_z$$

$$= P_{av.}\ \pi r_2^2$$

$$\therefore \text{Load})_{axi} = \int_o^{r_2} 2\pi\, e^{(D_1 - D_2 r)}\left[\frac{C_2}{C_1}(1-e^{c_1\ell}) - \bar{\sigma}\right] r\, dr$$

$$= 2\pi\left[\frac{C_2}{C_1}(1-e^{c_1\ell}) - \bar{\sigma}\right]\int_o^{r_2} e^{(D_1 - D_2 r)}\ r dr$$

$$\therefore L_{axi} = 2\pi\left[\frac{C_2}{C_1}(1-e^{c_1\ell}) - \bar{\sigma}\right] e^{D_1}\{e^{-D_2 r_2}(\frac{r_2}{D_2} + \frac{1}{D_2})\} + \frac{1}{D_2^2}$$

$$P_{ar.}\ \pi r_2^2 = 2\pi\left[\frac{C_2}{C_1}(1-e^{c_1\ell}) - \bar{\sigma}\right]\left[e^{D_1}\{e^{-D_2 r_2}(\frac{r_2}{D_2} + \frac{1}{D_2^2})\} + \frac{1}{D_2^2}\right]$$

$$\frac{C_2}{C_1} = \frac{2\,\bar{\sigma}\, 2\mu}{\sqrt{3}\ 2\mu}\ \frac{(\frac{1}{h} + \frac{1}{2w})}{(\frac{1}{h} + \frac{1}{w})} = \frac{2}{\sqrt{3}}\bar{\sigma}\, C$$

$$P_{av.}\ r_2^2 = 2\left[\frac{2}{\sqrt{3}}\bar{\sigma}\, C(1 - e^{c_1\ell}) - \bar{\sigma}\right].I e^{D_1}$$

$$\int_o^{r_2} e^{(D_1 - D_2 r)}\ rdr = e^{D_1}\int_o^{r_2} e^{-D_2 r}\ rdr$$

$$= e^{D_1}\left[-r\frac{e^{-D_2 r}}{D_2} - \int \frac{-e^{-D_2 r}}{D_2}\,dr \right]_o^{r_2}$$

$$= \frac{-e^{D_1}}{D_2}\left[r\,e^{-D_2 r} + e^{-D_2 r/D_2} \right]_o^{r_2}$$

$$= e^{D_1}\left[\frac{r_2 e^{-D_2 r_2}}{D_2} + \left(\frac{-e^{-D_2 r2}}{D_2} - \frac{1}{D_2^2} \right) \right]$$

$$= eD^1\left[\{e^{-D_2 r_2}\left(\frac{r_2}{D_2} + \frac{1}{D_2^2}\right)\} + \frac{1}{D_2^2} \right]$$

Where;

$$I = \left\{\left[-e - D_2 r_2 \left(\frac{r_2}{D_2} + \frac{1}{D_2^2}\right]\right]\right\}$$

$$\left(\frac{P_{av.}}{\bar{\sigma}}\right)axi = \frac{2}{r_2^2}\left[\frac{2}{\sqrt{3}}C(1-e^{c_f \ell}) - 1\right]e^{D_1}.I \qquad (18)$$

Eq. (18) gives the normalized average pressure required to forge the material in the axi-symmetric part of the gear.

By using Eq. (18) Eq. (11)

$$\left(\frac{P_{av.}}{\bar{\sigma}}\right)_{total} = \left(\frac{P_{av.}}{\bar{\sigma}}\right)_{axi.} + \left(\frac{P_{av.}}{\bar{\sigma}}\right)_{tooth} \qquad (19)$$

* Modification of the analysis with the angle θ :-

θ = 11.5° See Fig. ( )

$$\sigma_x\, wh - 2\mu\, \sigma_y\, wdx - 2\mu\, \sigma_z\, \cos\theta\, hdx - (\sigma_x + d\sigma_x)\, wh = 0$$

For plane strain condition

$$\frac{d\sigma_x}{d_x} + 2\mu\left(\frac{\sigma_y}{h} + \frac{\sigma_z \cos\theta}{w}\right) = 0 \qquad (20)$$

$$\sigma_z = \frac{\sigma_x + \sigma_y}{2} \qquad (21)$$

Sub. In Eq. (20)

$$\frac{d\sigma_x}{dx} + 2\mu\left(\frac{\sigma_y}{h} + \frac{(\sigma_x + \sigma_y)\cos\theta}{2w}\right) = 0$$

Sub. In Eq. (23) in Eq. (22)

$$\frac{d\sigma_x}{dx} + \frac{\mu\sigma_x \cos\theta}{w} + \sigma_y\left(\frac{2\mu}{h} + \frac{\mu\cos\theta}{w}\right) = 0 \qquad (22)$$

$$\bar{\sigma} = \frac{\sqrt{3}}{2}(\sigma_x - \sigma_y) \Rightarrow \sigma_y = \sigma_x - \frac{2\bar{\sigma}}{\sqrt{3}} \qquad (23)$$

$$\frac{d\,\sigma_x}{dx} + \frac{\mu\,\sigma_w\,\cos\theta}{w} + (\sigma_x - \frac{2\,\bar{\sigma}}{\sqrt{3}})\,(\frac{2\mu}{h} + \frac{\mu\cos\theta}{w}) = 0$$

$$\frac{d\,\sigma_x}{dx} + \frac{\mu\,\sigma_x\,\cos\theta}{w} + \frac{2\sigma_x\,\mu}{h} + \frac{\sigma_x\,\mu\cos\theta}{w} - \frac{4\mu\,\bar{\sigma}}{\sqrt{3}\,h} - \frac{2\mu\cos\theta\,\bar{\sigma}}{\sqrt{3}\,w}$$

$$\frac{d\,\sigma_x}{dx} + 2\mu\mu_x\,(\frac{1}{h} + \frac{\cos\theta}{w}) = \bar{\sigma}\,(\frac{4\mu}{\sqrt{3}\,h} + \frac{2\mu\cos\theta}{\sqrt{3}\,h})$$

Consider $\bar{\sigma}$ is not function of x, then; $\frac{d\,\sigma_x}{dx} + \beta_1\,\sigma_x = \beta_2$ (24)

Where the constants β_1 and β_2 are:

$$\beta 1 = 2\mu\,(\frac{1}{h} + \frac{\cos\theta}{w})$$

$$\beta_2 = \bar{\sigma}\,(\frac{4\mu}{\sqrt{3}\,h} + \frac{2\mu\cos\theta}{\sqrt{3}\,w})$$

Solution of this differential equation is :

$$\sigma_x = \frac{\beta_2}{\beta_1} + M\,e^{-\beta_1 x} \qquad (25)$$

$$M = -\frac{\beta_z}{\beta_1} + e^{\beta_1 \ell}$$

$$\sigma x = \frac{\beta_2}{\beta_1} - \frac{\beta_2}{\beta_1}\,e^{\beta_1(\ell - x)} \qquad (26)$$

From Eq. (23)

$$\frac{2\,\bar{\sigma}}{\sqrt{3}} + \sigma_y = \frac{\beta_2}{\beta_1}\left[(1 - e^{\beta_1(\ell - x)})\right]$$

$$\therefore \sigma_y + \frac{\left(\frac{1}{h} + \frac{\cos\theta}{2w}\right)}{\left(\frac{1}{h} + \frac{\cos\theta}{w}\right)}\,\frac{2\bar{\sigma}}{\sqrt{3}}\,(1 - e^{\beta_1(\ell - x)}) - \frac{2\bar{\sigma}}{\sqrt{3}}$$

$$\sigma_y = \frac{2}{\sqrt{3}}\,\bar{\sigma}\,\left[\beta(1 - e^{\beta_1(\ell - x)}) - 1\right] \qquad (27)$$

where; $\beta = \left[\frac{\frac{1}{h} + \frac{\cos\theta}{2w}}{\frac{1}{h} + \frac{\cos\theta}{w}}\right]$

$$\text{Load} = P_{av.}\; w\ell N \qquad (28)$$

$$L_{tooth} = N\int_o^{\ell} \sigma_y\; wdx$$

$$= N \frac{2}{\sqrt{3}} \bar{\sigma} \; w \int_o^{\ell} \left[\beta (1 - e^{\beta_1 (L-x)}) - 1 \right] dx$$

$$\frac{2N \; w\bar{\sigma}}{\sqrt{3}} \left[\ell(\beta - 1) - \beta \int_o^{\ell} e^{\beta_1 (L-x)} dx \right.$$

$$\frac{2N \; w\bar{\sigma}}{\sqrt{3}} \left[\ell(\beta - 1) - \beta \left(\frac{1}{\beta_1} - \frac{e^{\beta_1 \ell}}{\beta_1} \right] \right.$$

From Eq. (28)

$$P_{av.} \; \ell = \frac{2}{\sqrt{3}} \bar{\sigma} \left[\ell(\beta - 1) + \frac{\beta}{\beta_1 \ell} (1 - e^{\beta_1 \ell}) \right]$$

$$\left(\frac{P_{av.}}{\bar{\sigma}} \right)_{tooth} = \frac{2}{\sqrt{3}} \left[(\beta - 1) + \frac{\beta}{\beta_1 \ell} (1 - \ell^{\beta_1 \ell}) \right] \quad (29)$$

According to the previous analysis with the change in variables (C_1 , C) to the new variables (β, β_1) we can find the axisymmetric portion:

$$\left(\frac{P_{av.}}{\bar{\sigma}} \right)_{axi.} = \frac{2}{r_2^2} \left[\frac{2}{\sqrt{3}} \beta (1 - e^{\beta_1 \ell}) - 1 \right] e^{D_1} I$$

* For the constant volume: -

$$\pi \; r_2^2 \; h_o = r_2^2 \; h + (Nw \; \ell h + N \; (\frac{\sin \theta}{\sin (90 - \theta}) \; h)$$

$$\pi \; r_2^2 \; h_o = \pi r_2^2 \; h + \pi \; r_2 \; \ell h + N \ell h \; (\frac{\sin \theta}{\sin (90 - \theta})$$

Where; $w = \beta \; r_2^2$, $\beta = \frac{\pi}{N}$

$$\pi \; r_2^2 \; (h_o - h) = \ell (\pi \; r_2 \; h + Nh \; \frac{\text{Sin } \theta}{\text{Sing } (90 - \theta)}$$

$$\ell = \frac{\pi \; r_2^2 \; (h_o - h)}{\pi \; r_2 h + Nh \; (\frac{\text{Sin } \theta}{\text{Sin} (90 - \theta)}}$$

Tooth behavior and state of Stresses

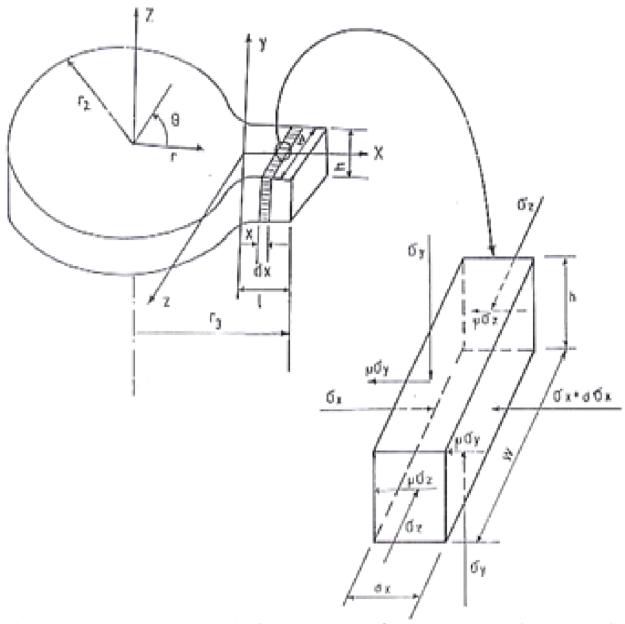


Fig. 1 the coordinate systems and the state of stress on the tooth of the gear.

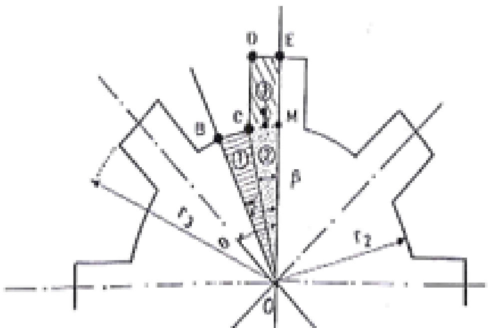


Fig. 2 the three deformation regions forming one deformation unit

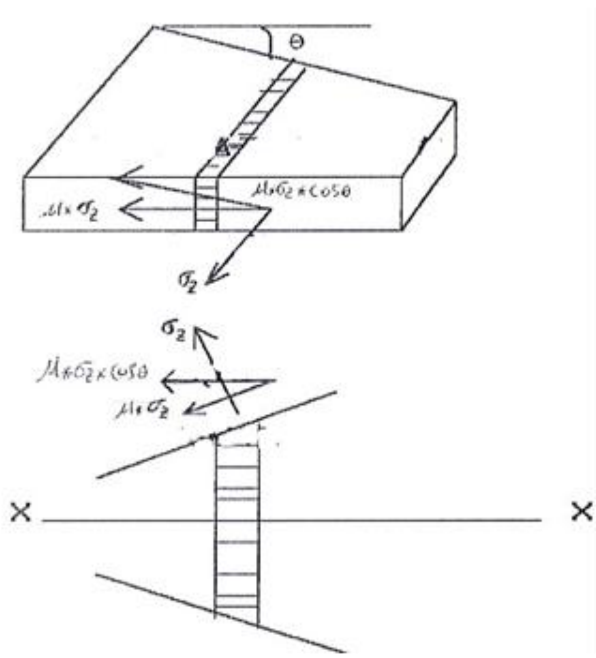
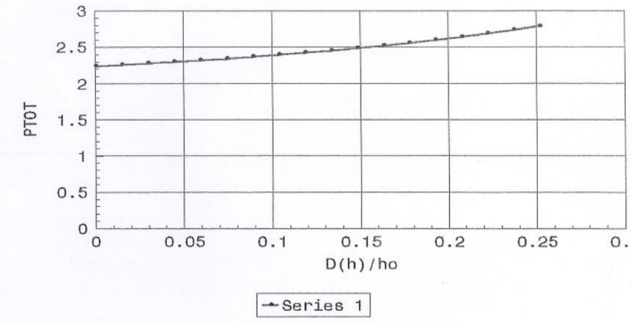


Fig. 3: Modification of the angle θ on the teeth.

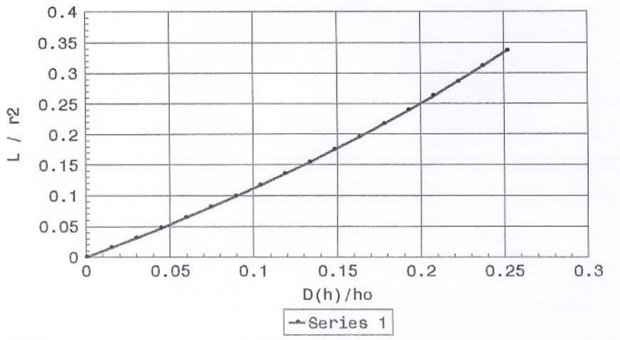
COMPUTER PROGRAM RESULTS WHERE THE EFFECT OF ANGLE ΘIS NOT CONCIDERED

FIG.# (4)
FIRST RUN



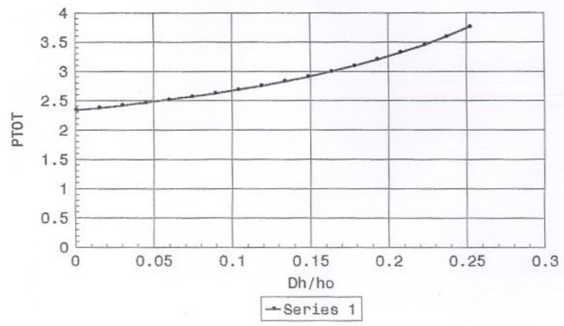
BEFORE MODIFICATION (N=12 , MU=0.1)

FIG.#(5)
FIRST RUN



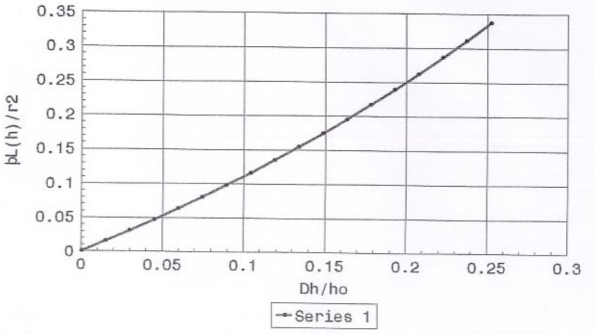
BEFORE MODIFICATION (N=12 , MU=0.1)

Fig. #(6)
Second run



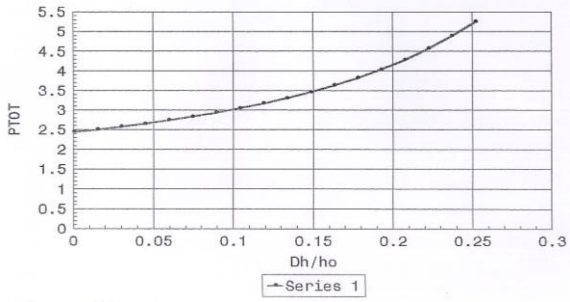
Before modification (N=12 , MU=0.2)

Fig. # (7)
Second run



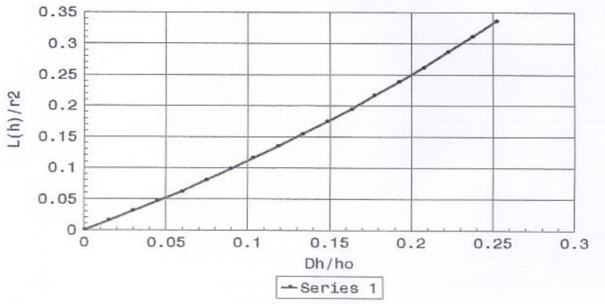
Before modification (N=12 , MU=0.2)

Fig.#(8)
Third Run



Before modification (N=12 , MU=0.3)

Fig.#(9)
Third Run



Before modification (N=12 , MU=0.3)

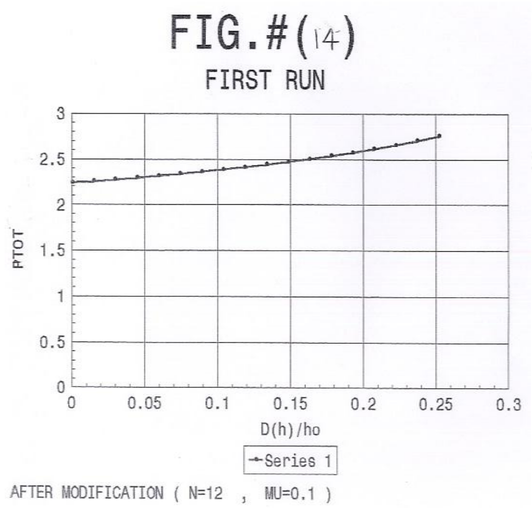


FIG.#(14)
FIRST RUN
PTOT
D(h)/ho
Series 1
AFTER MODIFICATION (N=12 , MU=0.1)

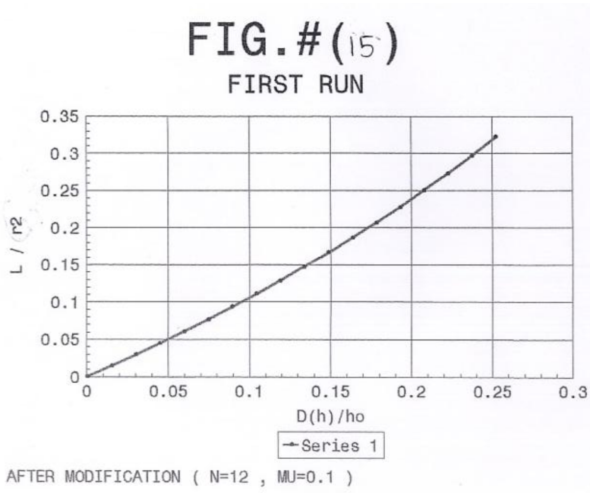


FIG.#(15)
FIRST RUN
L / r2
D(h)/ho
Series 1
AFTER MODIFICATION (N=12 , MU=0.1)

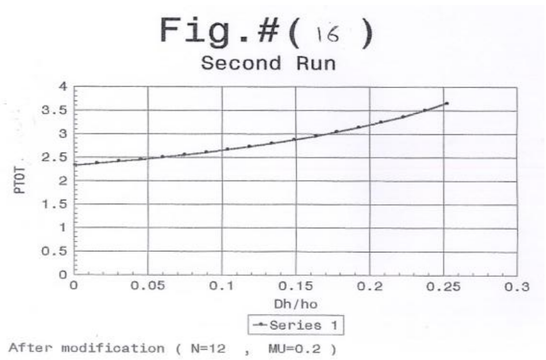


Fig.#(16)
Second Run
PTOT
Dh/ho
Series 1
After modification (N=12 , MU=0.2)

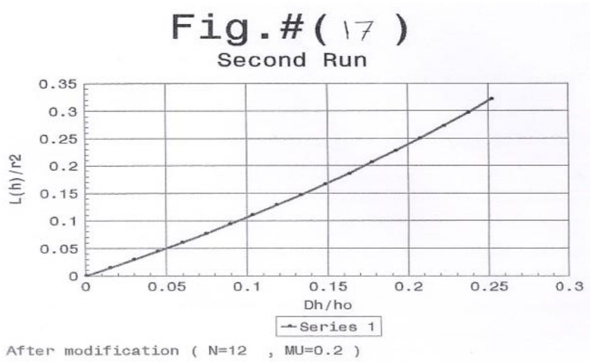


Fig.#(17)
Second Run
L(h)/r2
Dh/ho
Series 1
After modification (N=12 , MU=0.2)

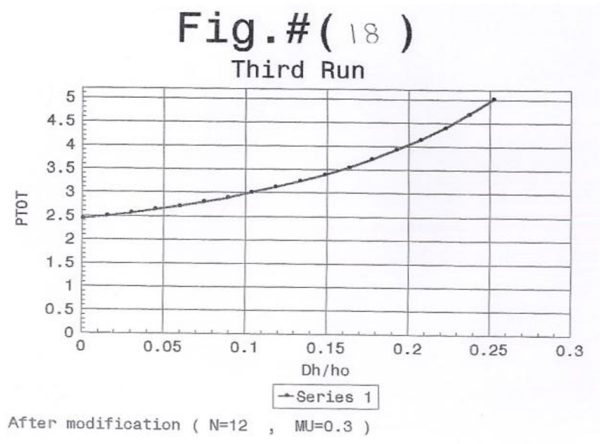


Fig.#(18)
Third Run
PTOT
Dh/ho
Series 1
After modification (N=12 , MU=0.3)

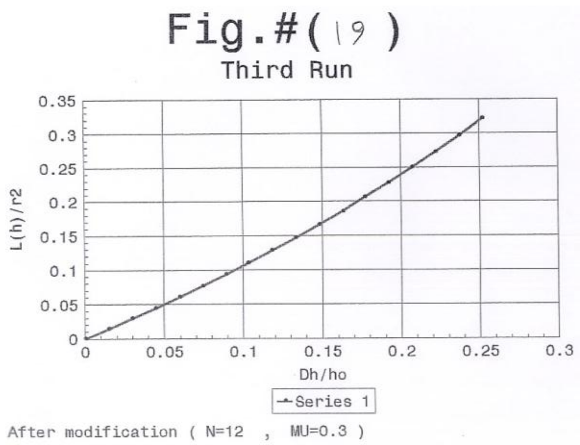


Fig.#(19)
Third Run
L(h)/r2
Dh/ho
Series 1
After modification (N=12 , MU=0.3)

I. EXPERIMENTAL RESULTS AND DISCUSSION

The forming die set, punch and die, have been designed and manufactured at the workshop of the Mechanical Engineering Department, Kuwait University.

Details of the die parts and the billet are hown in attached catalogue.

- **For the experimental work:**

Di = SQR (Do ^2*ho/hi)
Epsilon-bar = -In(hi/ho) = 2*In(Di/Do)
Segma-bar = [Li(PI/4)*Di^2
Where;
Di: Calculated diameter.
Do: Initial diameter.
Li: Applied load.
hi: Final height
ho: Initial height.
Epsilon-bar: $\bar{\varepsilon}$
Sigma-bar : $\bar{\sigma}$

“PTOT” is (Pav./ $\bar{\sigma}$)

**** Measurement of (Dh):***

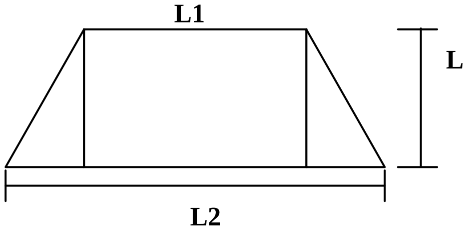


Fig.10 measurement of Dh

h * (L1 + L2)/2*L*N = (Dh) * P1 *r2 ^ 2
h * (L1 + L2)/2*L*N = (ho – h) * P1 * r2 ^ 2
L1 = 3 mm
L2 = 5 mm
L = 5 mm
h = 10 mm
10 * (3+5)/2*5*12 = (ho – 10) * P1 (16)^ 2
Solving this equation you get:
ho = 2.9841 mm

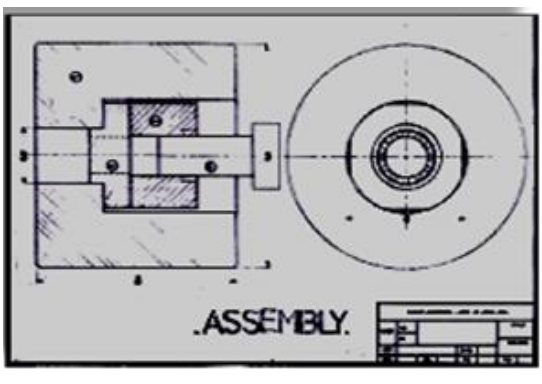


Fig.11 Test Assembly

CNC Works

Die part done by the CNC ET-Trak plus which is programming, operating & care manual. It acts like an advanced digital readout in manual machine operation, it acts like a CNC when programmed to do complex contouring, and it acts with the best qualities of each, when your job is best done by transitioning back and forth between manual and contouring CNC operations with the powerful DO ONE routines.

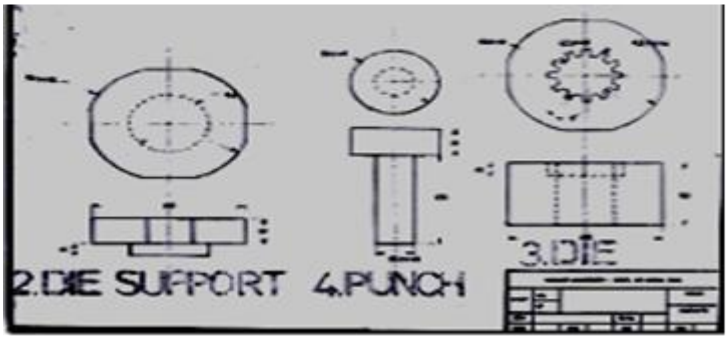
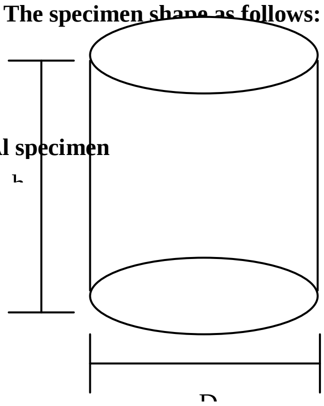


Fig.12 Sample of gear used in test

Compression test

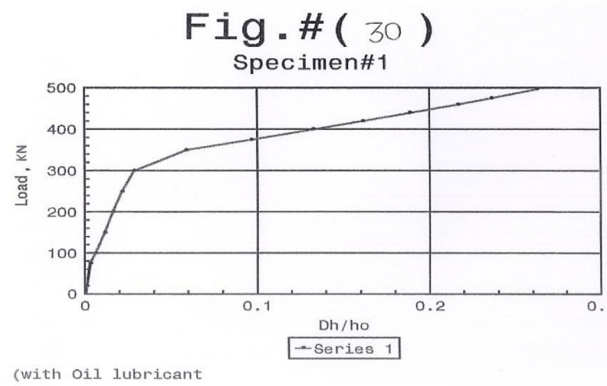
Al. Billet with hardness of 63 RB
(Before heat treatment)
**** With different type of lubricant.***
*** There is small deflection in the plates:**
In the small plate = 0.4 mm
In the big plate = 0.34 mm
*** The hardness of the Aluminum material:**
= 63 RB
*** The specimen shape as follows:**



ho = 13.56 mm
av. Do = 32.08 mm

Point #	Load (KN)	Displ. (mm)	D) exp (mm)	Di (mm)	Epsilon- bar	Sigma- bar
1	75	.038	32.1	32.125	.0028063	92.531
2	100	.082	32.17	32.177	.006066	122.976
3	150	.155	32.2	32.265	.011496	183.458
4	200	.219	32.2	32.34	.016282	243.478
5	250	.292	32.2	32.43	.021769	302.66
6	300	.386	32.2	32.546	.02888	360.61
7	350	.797	32.65	33.066	.060574	407.582
8	375	1.308	33.15	33.749	.1014	419.2
9	400	1.793	33.85	34.437	.1418	429.456
10	420	2.183	34.3	35.023	.1755	435.97
11	440	2.554	34.85	35.61	.2087	441.79
12	460	2.938	35.4	36.246	.2442	445.84
13	475	3.202	35.65	36.705	.2694	448.904
14	497.2	3.56	36.34	37.356	.3045	453.65

hf = 10.6 mm
Df = 36.34 mm
* There is small reduction in the height after reload.



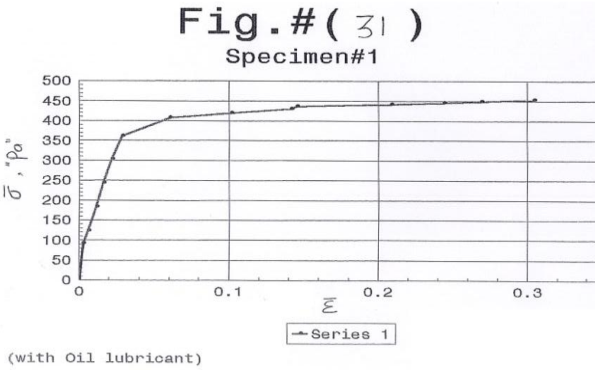


Fig.13 Specimen # 1

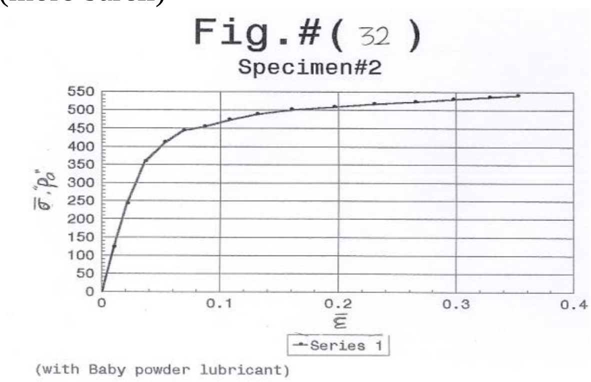
Specimen # 2

av. **ho = 13.48 mm**

Do = 32.09 mm

Point #	Load (KN)	Displ. (mm)	D) exp (mm)	Di (mm)	Epsilon-bar	Sigma-bar
1	**100**	**.137**	**32.2**	**32.252**	**.01021**	**122.404**
2	**200**	**.309**	**32.2**	**32.462**	**.02318**	**241.651**
3	**300**	**.483**	**32.2**	**32.675**	**.03648**	**357.766**
4	**350**	**.696**	**32.4**	**32.944**	**.05301**	**410.606**
5	**375**	**.896**	**32.6**	**33.203**	**.06878**	**433.098**
6	**400**	**1.113**	**32.6**	**33.491**	**.08617**	**454.06**
7	**425**	**1.375**	**33.2**	**33.85**	**.107**	**472.26**
8	**450**	**1.665**	**33.6**	**34.26**	**.131**	**488.143**
9	**475**	**2.001**	**34.05**	**34.754**	**.16**	**500.719**
10	**500**	**2.406**	**34.65**	**35.379**	**.196**	**508.614**
11	**525**	**2.779**	**35.0**	**35.986**	**.23**	**516.181**
12	**550**	**3.143**	**35.6**	**36.61**	**.265**	**522.484**
13	**575**	**3.463**	**36.1**	**37.194**	**.297**	**529.215**
14	**600**	**3.779**	**36.55**	**37.781**	**.328**	**535.197**
15	**620.2**	**4**	**36.59**	**38.215**	**.352**	**540.547**

hf = 10.89 mm
Df = 36.34 mm
* There is small reduction in the height after reload.
(more barell)



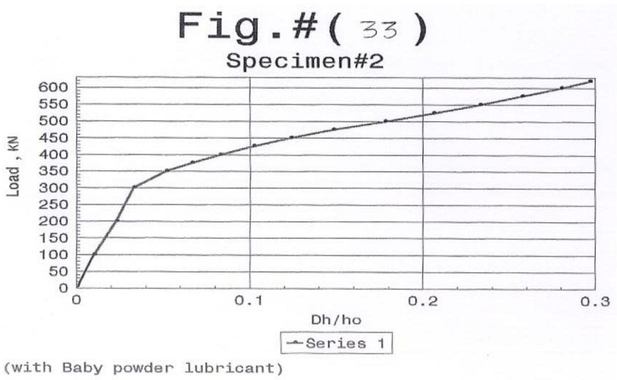


Fig.14 Specimen # 2

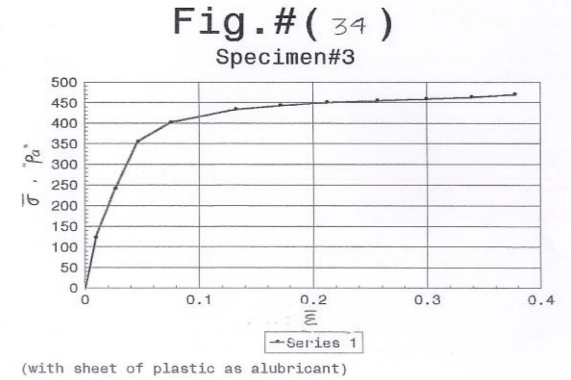
Specimen # 3

Lubricant : Sheet of plastic av. ho = 13.62 mm

Do = 32.102 mm
hf = 10.25 mm
Df = 35.66 mm

Point #	Load (Li) (KN)	Displ. (mm)	D) exp (mm)	Di (mm)	Epsilon-bar	Sigma-bar
1	100	.131	32.15	35.244	.009765	122.465
2	200	.351	32.15	32.511	.02638	240.246
3	300	.612	32.2	32.837	.04646	354.246
4	350	.973	32.65	33.305	.07491	401.753
5	400	1.681	32.8	34.283	.132	433.324
6	425	2.125	34.45	34.942	.171	443.204
7	450	2.581	34.9	35.66	.212	4503567
8	475	3.052	35.65	36.451	.256	455.2
9	500	3.487	36.35	37.23	.299	459.3
10	525	3.876	37	37.97	.33	463.65
11	552.7	4.236	37.55	38.696	.377	469.97

* There is small reduction in the height after reload.



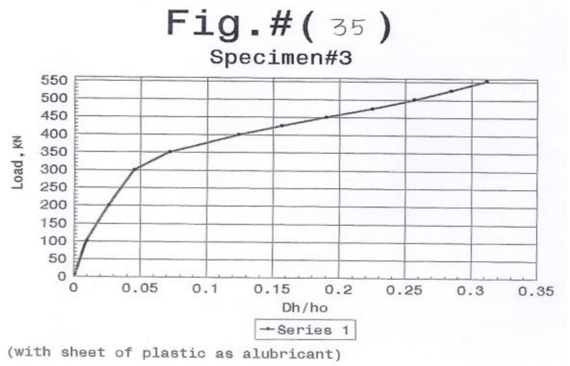


Fig.15 Specimen # 3

Forging process

Al. Billet with hardness of 29 RB
(After heat treatment)
*** With oil lubricant.**
Specimen # 1

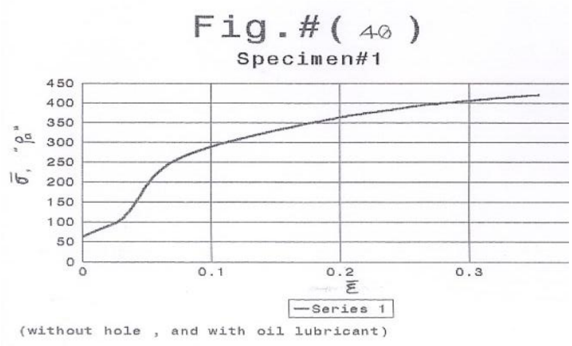
(without hole)

av. ho = 13.46 mm
Do = 31.912 mm

Lubricant : Oil

Point #	Load (Li) (KN)	Displ. (mm)	Di (mm)	Epsilon-bar	Sigma-bar (Pa)
1	50	0	31.912	0	62.51
2	60	.108	32.04	.008056	74.41
3	70	.217	32.17	.1625	86.12
4	80	.343	32.33	.02581	97.45
5	90	.414	32.41	.03124	109.09
6	100	.469	32.47	.03469	120.76
7	110	.499	32.52	.03777	132.43
8	130	.561	32.59	.04257	155.84
9	140	.690	32.63	.04482	167.42
10	150	.618	32.67	.04700	178.93
11	160	.649	32.71	.04942	190.40
12	170	.686	32.76	.05231	201.68
13	180	.720	32.80	.05497	213.03
14	190	.765	32.86	.05851	224.04
15	200	.817	32.93	.06261	234.83
16	210	.874	33.00	.06713	245.53
17	220	.943	33.09	.07263	255.82
18	230	1.024	33.20	.07912	265.68
19	240	1.118	33.33	.08671	275.07

20	**250**	**1.219**	**33.46**	**.09493**	**284.31**



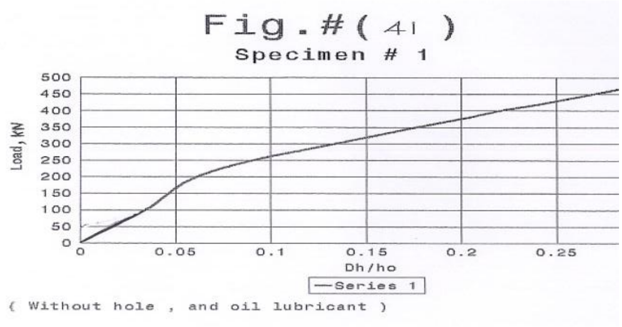


Fig.16 Specimen # 1

Specimen # 2

(With 5 mm hole in the middle of the billet)

Lubricant : Oil

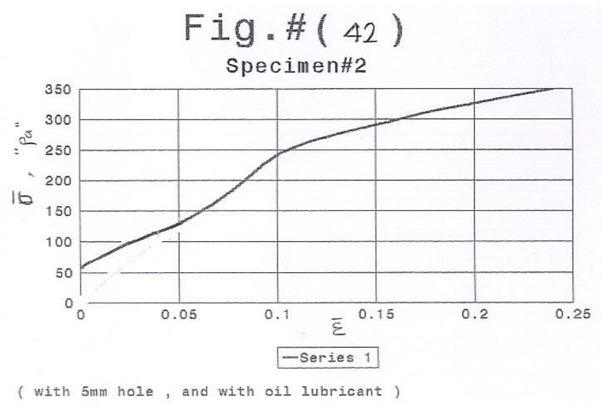
av. ho = 13.745 mm

Do = 32.09 mm

Lubricant : Oil

	Load (Li) (KN)	Displ. (mm)	Di (mm)	Epsilon-bar	Sigma-bar (Pa)
1	**46.9**	**0**	**32.09**	**0**	**57.99**
2	**50**	**.008**	**32.10**	**.0005822**	**61.78**
3	**75**	**.268**	**32.41**	**.01969**	**90.91**
4	**100**	**.571**	**32.78**	**.04243**	**118.49**
5	**120**	**.754**	**33.01**	**.0564**	**140.22**
6	**140**	**.897**	**33.19**	**.0675**	**161.82**
7	**160**	**1.017**	**33.35**	**.07687**	**183.20**
8	**180**	**1.118**	**33.45**	**.084837**	**204.46**
9	**200**	**1.214**	**33.61**	**.0924695**	**225.40**
10	**220**	**1.332**	**33.76**	**.10193**	**245.76**
11	**240**	**1.512**	**34.01**	**.116537**	**264.20**
12	**260**	**1.750**	**34.35**	**.136185**	**280.56**
13	**280**	**1.994**	**34.71**	**.156736**	**295.94**
14	**300**	**2.229**	**35.01**	**.17694**	**311.63**
15	**320**	**2.462**	**35.42**	**.197377**	**321.76**
16	**340**	**2.701**	**35.8**	**.21878**	**337.77**
17	**360**	**2.934**	**36.2**	**.24011**	**349.78**

Max. load = 520 KN



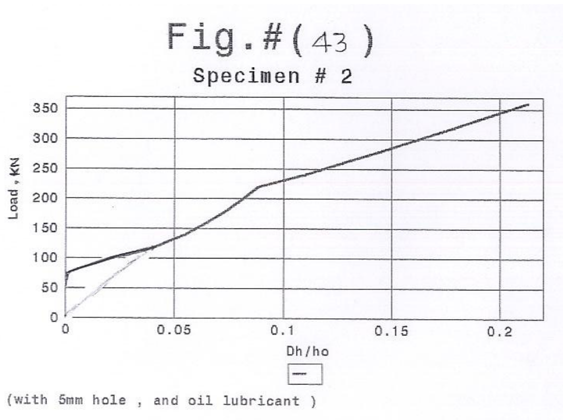


Fig.17 Specimen # 2

Specimen # 3

(With 10 mm hole in the middle of the billet)

Lubricant : Oil

av. ho = 13. 5 mm

Do = 31.94 mm

Pont #	Load (Li) (KN)	Displ. (mm)	Di (mm)	Epsilon-bar	Sigma-bar (Pa)
1	48.3	0	31.94	0	60.282
2	60	.028	31.97	.002076	74.74
3	80	.213	32.19	.0159	98.30
4	100	.523	32.58	.0395	119.95
5	120	.778	32.90	.059356	141.15
6	140	.960	33.14	.073766	162.3
7	160	1.113	33.34	.08604	183.3
8	180	1.220	33.49	.094799	204.34
9	200	1.341	33.65	.1046	224.89
10	220	1.485	33.82	.1143	244.90
11	240	1.616	34.04	.12749	263.72
12	260	1.843	34.37	.14678	280.24
13	280	2.083	34.73	.16758	295.60
14	300	2.338	35.13	.19017	309.51
15	320	2.568	35.49	.21099	323.48
16	340	2.788	35.85	.2313	336.83
17	360	3.003	36.22	.2516	349.4
18	380	3.226	36.61	.27307	360.99
19	400	3.431	36.98	.29323	372.42
20	420	3.616	37.33	.31177	383.74

Max. load = 506 KN

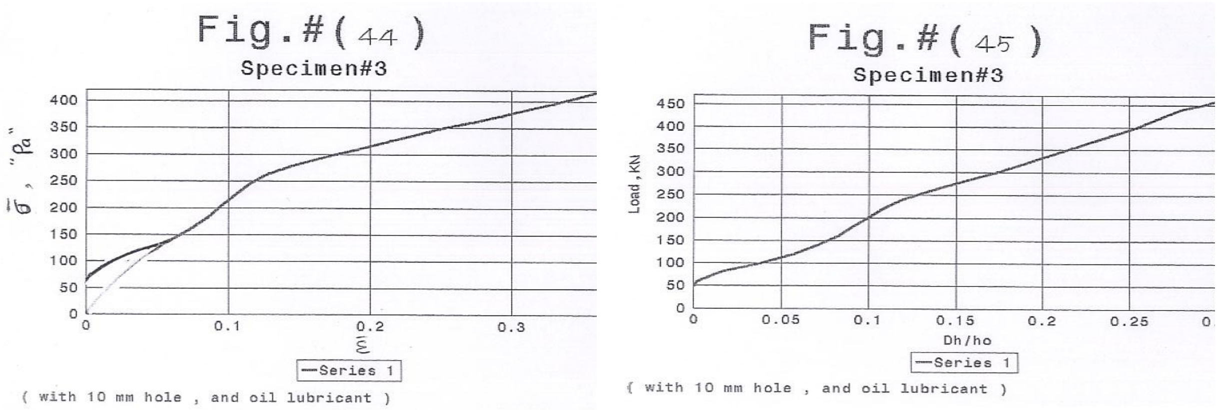


Fig.18 Specimen # 3

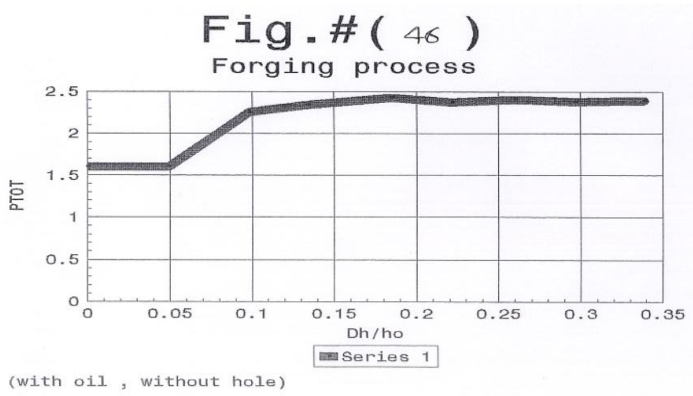


Fig.19 Forging process

II. DISCUSSION

- In the theoretical graphs the progressive increase of tooth length is plotted against the reduction in billet, tooth length is increase with the increase of reduction in billet height for all runs and values.
- The numerical values of the relative average punch pressure (Pay.! a) are determined for 12 teethes with root diameter of 32 mm by using slab method. The results are obtained by the slab method shown in Figures 4 to 22. These results are obtained for three values of coefficient of friction t such as (.1, .2 and .3) and three values of number of teeth N such as (12, 20 and 30). It is clearly shown that the relative average punch pressure (Pay. / $\bar{\sigma}$) is increasing in an exponential form. as the reduction in height of the billet increases.
- As the reduction in height increase the load needed is increase. Lubricants affect the compression test, where the value of $\bar{\sigma}$ is decrease when we add lubricant and we get red of barreling in the billet. The load decrease after heat treatment on the billet where the hardness of the material is decrease.
- As the effective strain increase the effective stress increase.
- Flow stress of the material was known by the compression test, with and without lubricant, before and after heat treatment.
- Finally a. comparison between the experimental and the theoretical shown from Fig.(6) and Fig.(46) . It is possible to see from the results shown that the slab method underestimate the values of (Pay. / $\bar{\sigma}$) for small values of reduction in height while it gives nearly closed values values for high values of reduction in height, which is seen it is good agreement within approximately 36% of error which is not to high.

III. CONCLUSION

A kinematically admissible velocity field taking into account the sidewise spread as well as the bulging along thickness has been proposed for upset forging of arbitrarily shaped prismatic blocks. The flexibility of the proposed method has been demonstrated by analyzing upset forging of clover-shaped and rounded rectangular blocks. For different experimental conditions in lubrication and billet shape, there is a good agreement between the theoretical forging load and the experimental load for Aluminum. The theoretical prediction of the deformed configuration is to some extent in good agreement with the experimental measurement except for high friction. The velocity field proposed in the present investigation can be used for the prediction of forging load and deformation in upset forging of arbitrarily shaped prismatic blocks.

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Appendix: A

COMPUTER PROGRAM SETUP

The following computer program has been prepared to solve the previous equations in order to calculate (pav./σ) which is denoted by PTOT throughout the program. Five computer runs have been performed according to the date accompanying each run.

```
REM  " THIS PROGRAM IS TO CALCULATE (Pav. / SEGMA)
REM             OF A GEAR WITH THE VARIETY OF H "
REM
REM " (pav. / SEGMA) tot  =  (Pav./SEGMA) tooth + (Pav./SEGMA) axi "
REM
REM " SEGMA = SEGMA - BAR "

DIM Dh (500), PTOT (500), L (500)
GLS
PRINT " A COMPUTER PROGRAM"
PRINT " DONE BY  : ALI AL-KHAMIS"
PRINT : ============================"
PRINT " "

INPUT " ENTER THE NO. OF TEETH N" ; N
INPUT " ENTER THE VALUE OF INNER RADIUS OF BILLET (r2)   IN  m"; r2
INPUT " ENTER COEFFICIENT OF FRICTION: ; MU
INPUT " ENTER THE VALUE OF INTIAL HEIGHT (ho)  IN m" ; ho
```

```
PRINT " THE VALUE OF N = " ; N
PRINT " THE VALUE OF r2 = " ; r2
PRINT " THE VALUE OF MU = " ; MU
PRINT " THE VALUE OF ho = " ; ho
Z = 0
PRINT "          h                    PT                          Paxi          "
PRINT "        --------            --------------                ----------------
FOR h  =  13.5 TO 10 STEP -.2
Z = Z + 1
W = (3.141592654 # / N)   *   Rw
A = (1 / w)  +  (1 / h)
B = (1 / h)   +  (1 / (2 * w) )
C = B  /  A
C1  =  2  *  MU  * A
IZ)  = r2   *  ((ho  /  h)  - 1)
I1 = 1 - EXP (c1  *  L (Z))
PT2  = c  /  (c1  *  L(Z))
PT3  =  c - 1
        = 1.1547  *  (PT3  +  (PT2  *  PT1))
D1  = (2  *  MU  * r2)  /  H
D2  = (2  *  MU)  /  h
L  =  (r2 / D2)   +  (1 / D2 ^ 2)
L2  =  -1 * EXP (-D2  *  r2)
L3  =  1 / D2 ^  2
      =  (L2  *  L1)  +  L3
PA1  =EXP (D1)  *  I
PA2  =  EXP (D1)   *  I
PA2  =  1.1547  *  c   *  (1 - EXP  (cl  *  L (z)))
PA3  =  2 / r2 ^  2
 Axi   =  PA3  *  (PA2  -  1)  *  PA1
PTOT(Z)  =  ABS (Paxi  +  PT)
Dh (z)  =  ho - h
PRINT  h;  "                              "' PT; "                             "; Paxi
NEXT h
PRINT "    PTOT                          D (h)                        L(h)"
PRINT " -----------------------------------------------------------------------"
    QA  =   1  TO Z
PRINT   PTOT (QA), Dh (QA),  L(QA)
NEXT  QA
SCREEN 9
WINDOW (—15, —15)—(25, 25)                               '40=50
LINE (—15, —15)—(30, 30), 0, BF
LNE (—15, —15)—(30, 30), 12, B
LINE (—15, 0)—(30, 0), 2
LINE (0, —15)—(0, 30), 2
LOCATE 2, 13: PRINT "Pav./SEGMA-BAR"
LOCATE 17, 73 PRINT "Dh/ho"
LOCATE 16, 28 PRINT "(0,0)"
LOCATE 22, 18: PRINT "FIFTH RUN"""
LINE (5, 0)—(5, 1), 8
LINE (10, 0)—(10, 1), 8
LINE (15, 0)—(15, 1), 8
LINE (20, 0)—(20, 1), 8
LOCATE 15, 38 PRINT " 005"
LOCATE 15, 48 PRINT " 01"
LOCATE 15, 58 PRINT " 015"
LOCATE 15, 68: PRINT ".02"
LINE (0, 5)—(1, 5), 3
LINE (0, 10)—(1, 10), 3
```

```
LINE (0, 15)—(1, 15), 3
LINE (0, 20)—(1, 20), 3
LOCATE 10, 25 PRINT "2"
LOCATE 7, 25: PRINT "3"
LOCATE 13, 25 PRINT "3"
LOCATE 4, 25: PRINT "4"
FOR P = 1 TO Z
IF PTOT(P) > 999 THEN
( )TO 1
ELSE
LINE (Dh(P) / ho * 15, PTOT(P) * 5)—(Dh(P + 1) / ho * 15, PTOT(P + 1) * 5), 6
END IF
NEXT P
A$ = INPUT$(1)
= INPUT$(1)
CLS
LINE (—15, —15)—(105, 40), 0, BF
LINE (—15, —15)—(105, 40), 4, B
LINE (—10, 0)—(85, 0), 8
LINE (0, —10)—(0, 85), 8
LOCATE 2, 25 PRINT " L/r2"
LOCATE 17, 73: PRINT "Dh/ho"
LOCATE 22, 18: PRINT "FIFTH RUN"
LINE (0, 5)—(1, 5), 3
LINE (0, 10)—(1, 10), 3
LINE (0, 15)—(1, 15), 3
LINE (0, 20)—(1, 20), 3
LOCATE 15, 38: PRINT ".005"
LOCATE 15, 48: PRINT ".01"
LOCATE 15, 58: PRINT ".015"
LOCATE 15, 68: PRINT ".02"
LOOCATE 10, 25: PRINT ".032"
LOCATE 7, 25: PRINT ".048"
LOCATE 13, 25: PRINT ".016"
LOCATE 4, 25: PRINT ".064"

LINE (5, 0)—(5, 1), 8
LINE (10, 0)—(10, 1), 8
LINE (15, 0)—(15, 1), 8
LINE (20, 0)—(20, 1), 8
FOR R = 1 TO Z
  PTOT(R) > 9000 THEN
(    )TO 2
ELSE
LINE (Dh(R) / ho * 60, L(R) / r2 * 60)—(Dh(R + 1) / ho * 60, L(R + 1) / r2 * 60:
 6
END IF
NEXT R
= INPUT$(1)
2A$ = INPUT$(1)
LOCATE 10, 32: PRINT " THE END"
LOCATE 19, 25: PRINT "****************************"
LOCATE 20, 27: PRINT "**** ALI AL-KHAMIS
LOCATE 21, 25: PRINT "****************************"
A$ = INPUT$(1)
```

Appendix: B

Computer program: With the effect of the angle θ on the teeth

```
REM " THIS PROGRAM IS TO CALCULATE (Pav./SEGMA)
REM OF A GEAR WITH THE VARIETY OF h "
REM
```

```
REM “ (Pav./SEGMA)tot = (Pav./SEGMA)tooth + (Pav./SEGMA) axi "
REM
REM “ SEGMA = SEGMA-BAR

DIM Dh(500), PTOT(500), L(500)
CLS
LPRINT “ A COMPUTER PROGRAM”
LPRINT “ DONE BY ALI AL-KHAMIS”
LPRINT " "
LPRINT " ========================"
LPRINT "  "

INPUT “ENTER THE NO. OF TEETH N”; N
INPUT “ENTER THE VALUE OF INNER RADIUS OF BILLET (r2)      IN m”; r2 INPUT “ENTER
COEFFICIENT OF FRICTION”; MU
INPUT “ENTER THE VALUE OF INTIAL HEIGHT (ho) IN rn”; ho

LPRINT “THE VALUE OF N = “; N
LPRINT “THE VALUE OF r2 = “; r2
LPRINT “THE VALUE OF MU = “; MU
LPRINT “THE VALUE OF ho “; ho
z = 0
LPRINT “                          h                                        PT                        Paxi  "  "
PRINT “                        -------                              --------------                -------------
FOR h = 13.5 TO 10 STEP -.2
Z  =  Z + 1
  = (3.141592654 # / N)  *  r2
A = (.9799247 # / W) + (1 / h)
B = (1 / h) + (.9799247# / (2  *  W))
C = B / A t.i = 2 * MU * A
C1  =  2  *  MU  *  A
F = 3.14159265# * r2   ^   2 * (ho — h)
M = 3.14159265# * r2 * h
K  = .2034523# * N * h
L(Z) = F / (M + X)
PT1 = 1 - EXP(c1 * L(Z))
PT2 = c / (c1 * L(Z))
PT3 = c - 1
PT = 1.1547 * (PT3 + (PT2 * PT1))
1  = (2 * MU * r2) / h
2  = (2 * MU) / h
L1 = (r2 / D2) + (1 / D2 ^ 2)
L2 = —1 * EXP(—D2 * r2)
L3= 1 / D2 ^  2
I = (L2 * L1) + L3
PA1 = EXP(Di) *
PA2 = 1.1547 * c * (i — EXP(c1 * L(Z)))
PA3 = 2 / r2 ^  2
Paxi = PA3 * (PA2 - i) * PAl
PTOT(Z) = ABS(Paxi + PT)
Ph(Z) = ho - h
LPRINT h;                                            “ ; PT ;                                              “ ; Paxi
NEXT h
LPRINT  "   PTOT                                 D(h) / ho                             l (h) / r2"
LPRINT  "  --------------------------------------------------------------------------------"
FOR QA  = 1 TO Z
LPRINT PTOT (QA), Dh (QA) / ho,   L(QA)  / r2
NEXT QA
```