# SIMULATION OF COLD FLAT ROLLING USING FINITE ELEMENTS MODELING

**Asaad K. Sayhood** **Dr. Mujtaba A. Almudhaffar** **Dr. A. kaream F. Hasan**
Univ. Of Basrah Tech. Coll./ Basrah Univ. Of Basrah

## ABSTRACT

This research makes a two-dimensional model for cold flat rolling process using ANSYS program The Contact pair are used between the contact surfaces using the boundary condition of Surface to Surface Contact . The process of symmetric rolling is tested for two types of materials (aluminum and mild steel) . The rolling force for (1%) to(25%) reduction of a slab of dimensions of (200*10)mm using (Avitzur) theoretical equations and ANSYS, The radius of the rolls for aluminum are (75)mm and that for mild steel are (300) mm.

The numerical results were compared with (Avitzur) theoretical equations . The comparison shows that the values of forces calculated using (Avitzur) theoretical equations are accurate enough up to (5%) reduction, and the numerical results proved its accuracy up to (25%)reduction.

The study shows that forces increases as a results of increasing the rolling metal area at entry rate. The angle of the neutral point was also studied in this work and it is found that it decreases with the increasing of reductions rate , due to an increase in the cohesion area on the sliding one within rolling process while the theoretical results failed to calculate the angle of the neutral point correctly.

# نمذجة عملية الدرفلة على البارد باستخدام تقنيات العناصر المحددة

اسعد كاظم صيهود
جامعة البصرة

د مجتبى عبدالواحد المظفر
الكلية التقنية البصرة

د عبدالكريم فليح حسن
كلية الهندسة جامعة البصرة

في هذا البحث تم بناء نموذج ثاني البعد لعملية الدرفلة على البارد باستخدام الحقيبة البرنامجية (ANSYS) وتم استخدام زوج الاتصال(contact pair) بين السطوح المتلامسة للدرفيل والمدرفل باستخدام شروط حدية لمنطقة التشكيل . جربت عملية الدرفلة المتماثلة على معدنين هما الحديد المطاوع والألمنيوم. حسبت قوة الدرفلة لنسب تخصر من (1%) إلى (25%) لعينة أبعادها 200mmطول و 10mmسمك باستخدام معادلة (AVITZUR) النظرية وباستخدام برنامج (ANSYS). نصف قطر الدرفيل لمعدن الالمنيومmm75 وللحديد المطاوعmm300.

بينت الدراسة إن المعادلات النظرية المتوفرة تصلح لحدود (%5) تخصر في حين إن الطرق العددية أثبتت دقتها ل(%25) تخصر.

وجدت الدراسة إن قوة الدرفلة تزداد نتيجة لزيادة مساحة المعدن المدرفل عند المدخل.

زاوية نقطة التعادل تمت دراستها في هذا البحث أيضا ووجد إنها تقل عند زيادة نسبة التخصر بسبب زيادة منطقة التلاصق أثناء عملية الدرفلة بينما فشلت المعادلات النظرية في احتساب زاوية نقطه التعادل.

## Introduction

Due to increasing competition in industry, there is an ever-increasing demand on the manufacturer to be more flexible, more responsive and competitive with energy saving efficiency. The competition is strong, and complex products are required at higher quality for the same cost and margins. Optimal rolling system designs can play a significant role in dealing with those challenges[1]. Scientific approaches in favor of traditional approaches is increasingly adopting and several algorithm are emerging as alternative solutions to deal with the complex search space properties of the real world process problems[2].

In rolling process whereby the work piece is a longitudinal prism, is placed between two opposite direction rollers to drag the work piece along the force to reduce the cross section , the rolls transfer energy to the strip through the friction between the two bodies . Under regular rolling condition the strip moves slower than the roll at the entrance and faster at the exit, with a neutral point in between at which the speeds are equal. The angle of no slip is small in strip rolling because the roll radius is larger than the thickness. The pressure is normal to the surface of the rolls. The friction force between the surfaces in contact with the rolls is increasing up to the end of the entrance side of the neutral point, and points toward the exit .while on the exit side of the neutral point, the friction force points towards the entrance side and it decreasing.[3].

The friction between the roll and the metal surface is of great importance in rolling. Not only because the frictional force pull the metal into the rolls, but also because it affect the magnitude and distribution of the roll pressure . The larger the frictional forces the greater must be the rolling load and the more steeply the pressure builds up toward a maximum value at the neutral point. The roll pressure distribution is commonly called Siebel's theory and known as "The theory of friction hill". It concluded that the pressure distribution along the area of contact is non-uniform and rising to a maximum value at a position which approximate the neutral point. The peak pressure and the average pressure increase as the coefficient of friction increases and decreases with the application of front and back tension .

The main variables which control the rolling process are : (1) The roll diameter,(2) the deformation resistance of the metal,(3) the friction between the rolls and the metal ,and(4) the presence of front tension and back tension.

Increasing the diameter of the rolls increases the rolling load for any reduction and frictional conditions because the contact area will be greater for a large roll diameter . The flow stress for cold rolling does not depend on the strain rate or roll speed.

## Deformation in Rolling Process

The deformation produced by rolling can be considered as a two-dimensional .To a good approximation in sheet rolling , the reduction in thickness is transferred into an increase in length with little increase in the width . Thus, there is good justification for the use of a plane-strain model in the mathematical analysis of rolling, while the lateral spread is usually of little importance in a rolling sheet and strip.

The amount of lateral spread depends on such factors as the diameter and condition of the rolls, the flow properties of the metal , and the amount of reduction. In comparison with other metal-working processes the deformation produced by rolling is relatively uniform. However, studies with grid networks have shown that the surface layers are not only compressed but also sheared.[5] While the greatest shear strain occurs at the outside fibers when a bar is always rolled in one direction, when the direction of rolling is reversed after each pass the maximum shear stress occurs near the center of the thickness.

## Cold Rolling Theory

The basic linear first order differential equation for rolling is :

$$\frac{dF}{d\alpha} = 2 \cdot R \cdot P_r \cdot (\sin\alpha \pm \mu \cdot \cos\alpha) \quad (1)$$

Where: $\frac{dF}{d\alpha}$ = variation of the force during the contact angle .

R=roll radius. $P_r$=Radial pressure. $\mu$=coefficient of friction.

Various rolling theories resorted to mathematical approximations in solving equation (1) according to the nature of these approximations.

Von Karman,[7] in his theory assumed that the normal pressure approximation equals the vertical stress . The form of Von Karman's equation is :

$$\frac{d(Pt)}{d\alpha} = 2 \cdot R \cdot P_r \cdot (\sin\alpha \pm \mu \cdot \cos\alpha) \quad (2)$$

Where: $\frac{d(Pt)}{d\alpha}$ = variation of the roll pressure multiplying by the thickness of the strip during the contact angle.

This equation cannot be directly integrated so that Trinks,[6] made a graphical solutions for the variables assuming a constant yield stress along the arc of contact. Tselikov derived roll force formula,[6] based on the assumption that the angle of contact is small and the neutral angle is equal to half angle of contact. So that Tselikov had reduced Von Karman equation to a from which can be easily integrated. He gave a series of diagrams showing the effect of the coefficient of friction, roll diameter and reduction on the pressure distribution along the arc of contact.

Ekelund formula has been derived [6,8] mainly for calculation of roll force in hot rolling. This formula has been simplified by Bland and Ford,[8] so as it can be used for calculation of the load in cold rolling. The new form of Ekelund formula is:

$$F = B \cdot \sigma_m \cdot \sqrt{R \cdot (t_o - t_f)} \times \left[ 1 + \frac{1.6 \cdot \mu \cdot \sqrt{R \cdot (t_o - t_f)} - 1.2 \times (t_o - t_f)}{(t_o + t_f)} \right]$$

........................(3)

Where $\sigma_m$ =mean yield stress, t= thickness, o for entry and f for exit

The influence of roll peripheral speed was not taken into account in Ekelund formula. Also this formula did not take into account the influence of front and back tension which was studied by Hessenberg and Sims[9,10]. Hessenberg and Sims showed that :

$$F = \left[ \frac{1 - \left( \sigma_{xb} \times (1 - \frac{\alpha_n}{\alpha}) + \sigma_{xf} \times (\frac{\alpha_n}{\alpha}) \right)}{\sigma_m} \right]$$

......................(4)

Where $\sigma_{xb}, \sigma_{xf}$ = back and front tensions.

, $\sigma_m$ =mean yield stress

$\alpha_n$ =neutral angle( Hessenberg and Sims assumed that $\alpha_n = \frac{\alpha}{2}$ )

Some theories have additional simplified assumptions. All of these assumptions aims to simplify the solving of equation(1).But unfortunately some of these assumptions leads to a sacrifice in accuracy of estimation of roll force and torque and average pressure[3].

The torque in rolling can be estimated by assuming that the roll separating force F acts in the middle of the arc of contact, [4,17] and

$T = 0.4\,F\,L$ For cold rolling

$T = 0.5\,F\,L$ For hot rolling

## FEM Generation of Cold Rolling process model

Many researchers(C. Liu, et al .1985,[12]. Fei-chin Jan and Oladipo Onioede Jr.,2000,[13]. Antonio Zavaliangos et al,2003,[14]. Luis Gerardo,2004,[15].Albert Sedlmaier,2005,[16]) uses different software packages to simulate elastic-plastic finite-element method for plane strain deformation of strip rolling . This work uses the finite element software ANSYS version 10.0 based on the following assumptions:

1- The arc of contact is circular, no elastic deformation of the rolls.

2- The coefficient of friction is constant at all points on the arc of contact.

3-There is no lateral spread, so that rolling can be considered a problem in plane strain.

4- plane vertical sections remain plane.

5-The elastic deformation of the sheet is negligible in comparison with the plastic deformation.

6- The distortion –energy criterion of yielding for plane strain will be used[3,5].

7- Back and front tensions will be ignored.

The roller is made of high-carbon steel of isotropic elastic material,[18]. The parameter of the roller is shown in table (1). Two types of material is rolled the first is mild steel and the second is aluminum(3003). The parameter of these material is shown also in tables(1).

**Generating the Contact** Although some of the first complex contact problems have been solved, using the Finite Element method quite some time ago, much interest exists in the research and solution of contact problems. The analysis of contact problems is computationally extremely difficult, even for the simplest constitutive relations used. Much of the difficulty lies in that the boundary conditions of the bodies under consideration are not known prior to the analysis, but they depend on the solution variable.

Contact problems are highly nonlinear and require significant computer resources to solve. It is important to understand the physics of the problem and take the time to set up the model to run as efficiently as possible. Contact problems present two significant difficulties:

First, the regions of contact is not known until the problem is run. Depending on the loads, material, boundary conditions, and other factors. Surfaces can come into and go out of contact with each other in a largely unpredictable and abrupt manner.

Second, most contact problems need to account for friction. There are several friction laws and models to choose from, and all are nonlinear. Frictional response can be chaotic, making solution convergence difficult.

Contact problems can be classified into:

1- Rigid-to-flexible contact problems.

2- Flexible-to-flexible contact problems.

In rigid-to-flexible contact problems, one or more of the contacting surfaces are treated as rigid (i.e. has a much higher stiffness relative to the deformable body it contacts). In general, any time a soft material comes in contact with a hard material, the problem may be assumed to be rigid-to-flexible. Many metal forming problems fall into this category.

Three contact models can be used:

2- Node-to-node contact .

1- Node-to-surface contact .

3- Surface-to-surface contact .

Surface-to-surface contact is used for both rigid-to-flexible and flexible-to-flexible. This contact uses a target surface and contact surface to form a contact pair .The rigid surface is referred as the target surface, in this work it is modeled with target 169 element. The surface of the deformable body is referred as the contact surface and is modeled with contact 172 element [19].

In cold rolling simulation, rigid-to-flexible contact problem, and surface-to-surface contact model are used. The roller is the rigid material(target surface), and the work piece is the deformable (contact surface). that means. A half model with symmetrical constraints produce the same results as the analysis of the full model[20].

## Result and Discussion

### Calculation of rolling force

A reduction ratio ranged from 1% to 25% for Aluminum and Mild steel was used to calculate the rolling force to check the accuracy of both the theoretical result using(Avitzur) theoretical equations , number(5) and the numerical results using ANSYS program version 10.0 and the matching of them to find the limit of % reduction that the theoretical equation can be used for.

$$F = \frac{2}{\sqrt{3}} \cdot \frac{t \cdot \sigma_o \cdot B}{\mu} \cdot \left[ \exp\left( \frac{\mu \cdot L}{t} \right) - 1.0 \right] \qquad (5)$$

The results of force calculations for aluminum and mild steel are shown in figures (1)-(2). The percentage errors between the theoretical and numerical results of force for aluminum are ranged from(13.1%)for (1%) reduction to (17.8%) for (5%) reduction to(42.4%) at (25%) reduction while that for mild steel are (12.7%) for(1%) reduction and (17.4%) for (5%) reduction and (42.1%) for (25%) reduction.

It is known from previous figures that theoretical equation is not accurate for large reduction ratio because it uses the average value of thickness at entry and exit zone in order to be used in a linear equation and the roll gap angle (L) increased with increasing of the reduction ratio.

Tirosh (21) presents a comparisons between measured, predicted and computed roll torques verses percentage reduction for steel, figure(3). Table(2) is extracted from this curve to show the percentage error between computed and measured and predicted and measured values at (5-20%) reduction . The results of present are inserted in this figure and it can be concluded that the results of present work are good enoughon comparisons with Tirosh , and the theoretical equation (5) is helpful in giving the force estimation up to 5% reduction.

Nodal solution of Finite Element Modeling using ANSYS program version (10.0) for the two materials for (2.5%) reduction and up to (25%) reduction ,are shown in ordinary view and zoom view in figures (4) to (5),for aluminum and mild steel material.

## Calculation of Neutral Point Angle

The neutral point may be calculated using equation :

$$\alpha_n = \sqrt{\frac{t_f}{R}} \cdot \tan \cdot \left[ \sqrt{\frac{t_f}{R}} \cdot \frac{X}{2} \right] \qquad (6)$$

The result of Finite Elements Modeling for (2.5%) reduction and up to (25%) reduction using contact technique between the roll surface and the work piece surface to finds the neutral point for aluminum and mild steel materials.

The results for aluminum material are drawn in figure (6) and the results for mild steel material are drawn in figure(7). Figure (8) shows the nodal solution of Finite Element Modeling(FEM) using ANSYS program showing the contact frictional stresses for aluminum and mild steel material respectively.

## Conclusions

The results of this work leads to some important conclusions as follows:

1-The ANSYS program was applied and a model of the cold flat rolling process using contact-pair technique between surfaces in two- dimensional was achieved.

2-The theoretical equation can be used for small limit of reduction up to (5%).This is achieved after comparison with experimental and theoretical results of other researchers.

3-The model that is used in this work show accurate values precession exactness in calculation the roll forces and the torques for high reductions up to (25%).

4-The roll force and torque increases with any increase in reduction ratio due to the increase in the gap angle because the increase in the area during rolling process.

5-Angle of the neutral point decreases with the increase in the reduction ratio due to the increase in the area of the sticking zone with respect to the area of slipping zone.

## References

[1] **Schey; J.** "Introduction to Manufacturing Process", McGraw-Hill,1977.

[2] **Oduguwa; V. and Roy; R.,** "A Review of Rolling System Design Optimi zation ", School of Industrial and Manufacturing Science, United King-dom(UK),2003.

[3] **Avitzur; B.,** "Metal Forming Process and Analysis", 3rd edition, McGraw-Hill Book Company, New York, 1968.

[4] **Groover; P.,** " Fundamental of Modern Manufacturing", john Wiley and sons,inc.,2rd edition,USA,2002.

[5] **Larke;E.** " The Rolling of Strip ,sheet and plate", Chapman and hill,ltd,london,pp.325-330,1987.

[6] **Wasatowski;Z.**, "Fundamental of Rolling ", Pergamon press ,New York, 1969.

[7] **Freshwater; I.**, " Simplified Theories of Flat Rolling, Calculation of Roll Pressure, Roll Force, and Roll Torque" ,Int. J. Mech. Sci.Vol.38,No.6,pp.633-648,1996.

[8] **Row; G.**, "Principles of Industrial Metal Working Process", $4^{ed}$ ,london,1977

[9]جبير محمد شمران " دراسة تأثير الشد الأمامي على انسياب المعدن خلال عملية الدرفلة وباستخدام طريقة اللدونة المرئية " ، أطروحة مقدمة إلى قسم هندسة الإنتاج والمعادن، الجامعة التكنولوجية ، 2004 م

[10] **Sims**, " The Effect of Strain Rate and Aluminum , Copper and Steel to Compartion", J.Inst.Met.,Vol.83,1954.

[12] **C.Liu,P.Hartley, C.E.N. Sturgess and G.W. Rowe**, "Elastic-Plastic Finite Element Modeling Of Cold Rolling Of Strip", Int. J. Mech. Sci .Vol. 27,No. 7/8,pp. 531-541,1985.

[13] **Fei-chin jan** and **Oladipo Onipede Jr**, "Simulation of Cold Roll Forming of Steel Panels ", Mechanical Engineering Department, University of Pittsburgh,USA,2000.

[14] **Zavalingos; A. and et al.**, " Analysis of Powder Processing in the Roller Press Using Finite Element Modeling", xxii international Mineral Processing Congress will be held from 28 September-3 October 2003 in cape Town, South Africa.

[15] **Gerarado; L.**, "Simulation and Validation Cold Rolling Process of Low Carbon Steel with Software ABAQUS", Journal of Engineering,Vol.v11,No.24,July 2004.

[16] **Albert Sedlmaier**, "Development and Optimization of Cold Roll Formed Profiles ", Dipl. – eng. Managing director of data M software + Engineering Gmbh,83626 valley,Germany,2005.http://www.datam.de

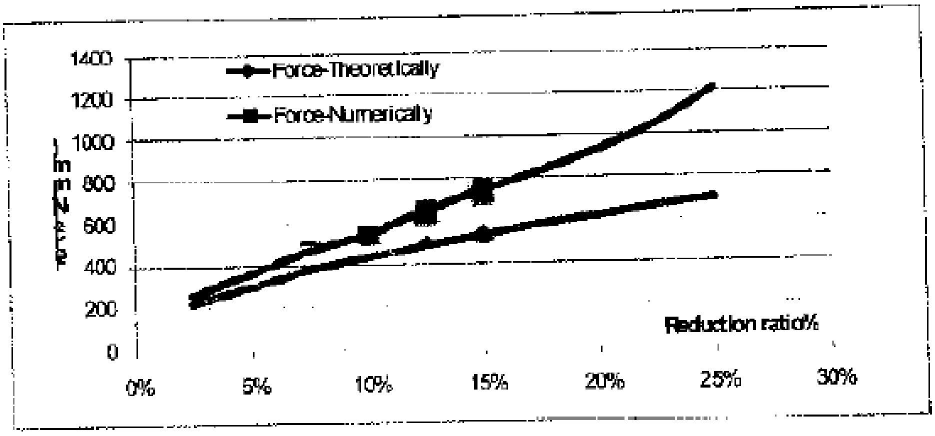
[17] **Tieu; A., and et al.**, "Material Resistance and Friction in Cold Rolling", $6^{th}$ World Congresses of Structural and Multidisciplinary, Rio de janeiro , Brazil, 2005.

[18] **HAN Zhi-wu and et al.**, "Computer simulation of Rolling Wear on Bionic non-Smooth Convex Surfaces", J. of Bionices Engineering,Vol.1 No.4 ,pp 241-247,2004.

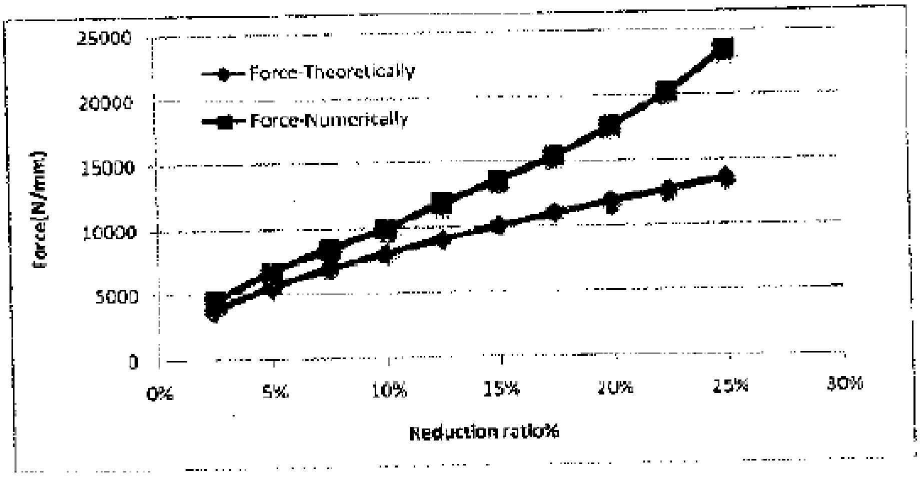
[19]**Stolarski; T. and et al**, " Engineering Analysis with ANSYS Software", Dept. Mech.Eng., U. of Scienc,Tokyo,2007.

[20] **Chumachenko;E.**, "Application of the Finite-Element Analysis to the Pass Rolling Process", Moscow Siate Institute of Electronics andMathematics (Technical University),IKI Seminar (Mechanics, Control and Informatics), Moscow,2005.

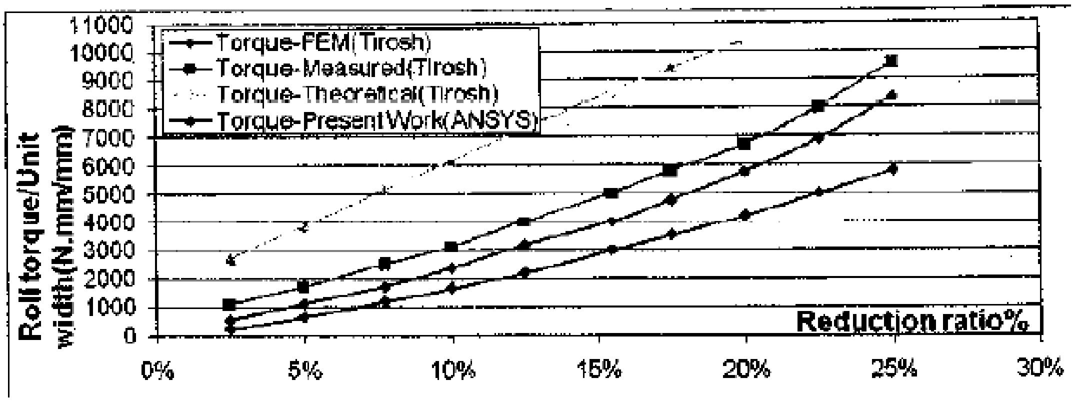
21] **Tirosh; J.**"The Mechanics of High Speed rolling of Viscoplastic Materials" ,J. of Applied Mech.",Vol.52,pp. 309-316,Joune 1985.



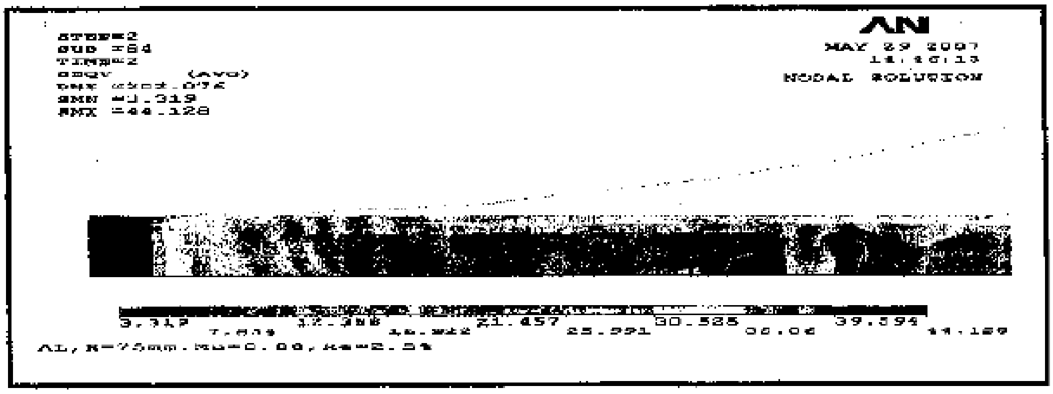
Figure(1) Roll force versus % reduction for Aluminum material



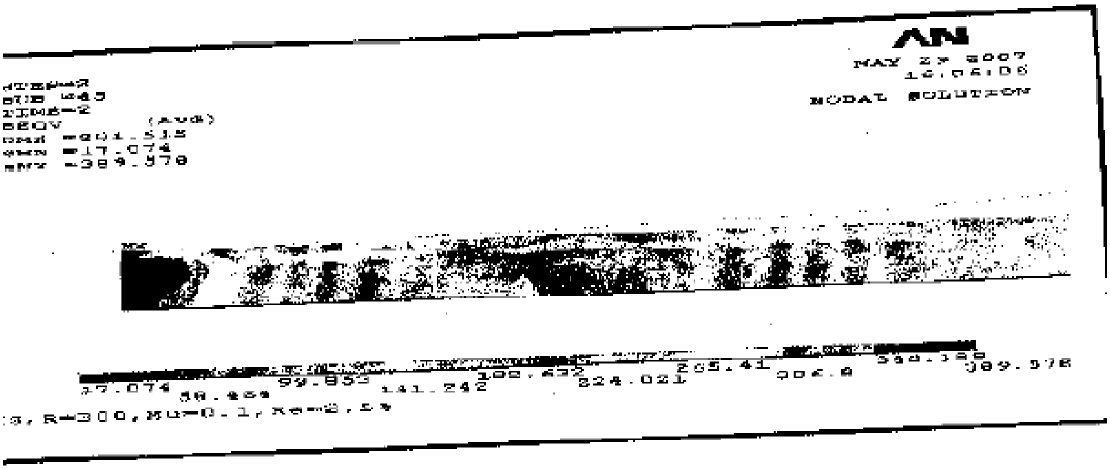
Figure(2) Roll force versus % reduction for Mild Steel material



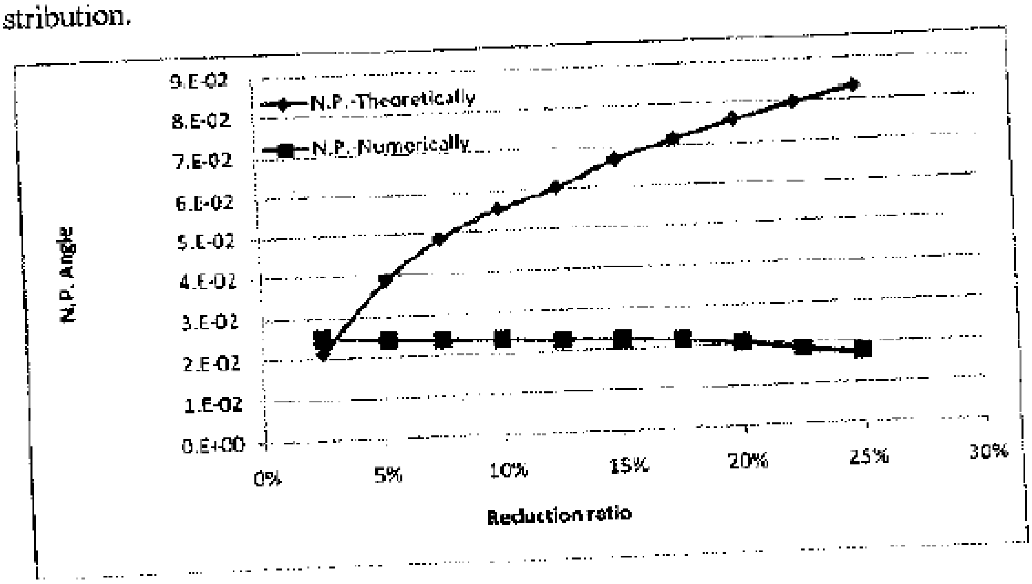
Figure(3) Comparisons between measured, FEM, theoretical and present work(ANSYS), roll torque versus reduction[21].



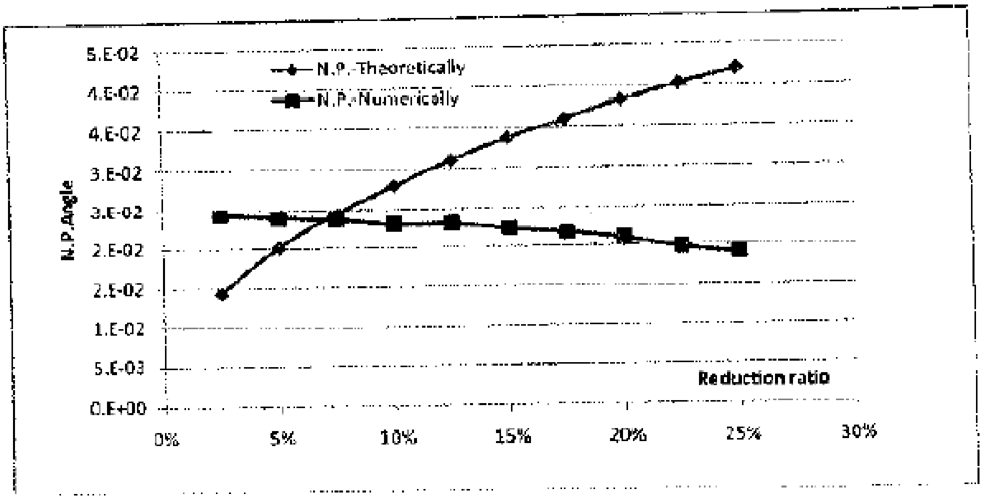
Figure(4) Zoom for slab Aluminum material during2.5% reduction to view stress distribution.



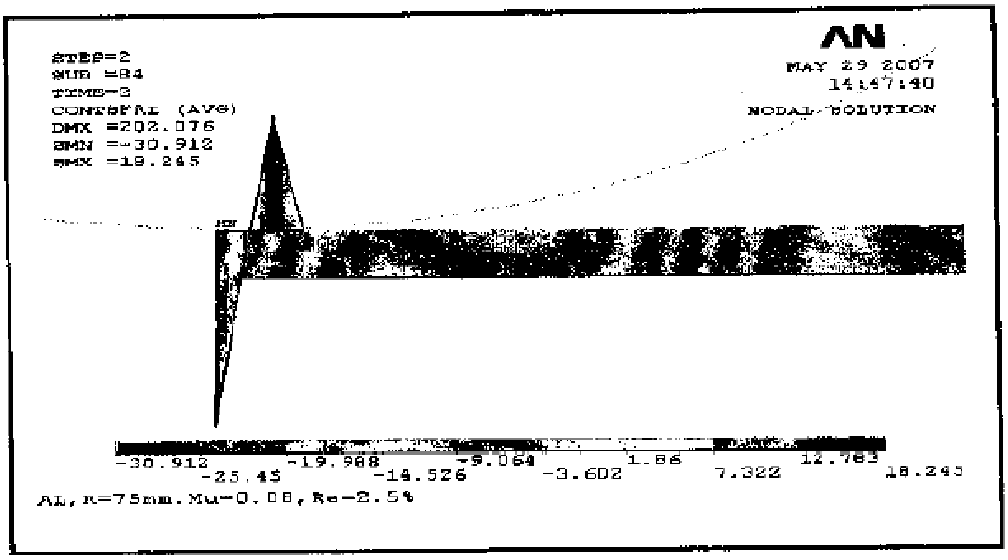
Figure(5) Zoom for slab Mild Steel material during 2.5% reduction to view stress distribution.



Figure(6) Theoretical and Numerical angle of the Neutral Point for Aluminum material



Figure(7) Theoretical and Numerical angle of the Neutral Point for mild steel material



Figure(8 Zoom for the angle of the neutral point of Aluminum material at 2.5% reduction.

Table(2) percentage reduction errors

| [illegible] | [illegible] | [illegible] |
|---|---|---|
| 5% | 43% | 62.5% |
| 10% | 63% | 63.4 |
| 15% | 35% | 52.9% |
| 20% | 40.2% | 60% |

Table(1) Parameter of materials used .

| [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|
| [illegible] | 68900 | 198910 | 210000 |
| [illegible] | 41.4 | 365.9 | |
| [illegible] | 2.73*10-9 | 7.83*10-9 | 7850*10-9 |
| [illegible] | 110 | 532.4 | |
| [illegible] | 0.33 | 0.28 | 0.29 |
| [illegible] | 75.8 | 73870 | |