Computer-Aided Evaluation of Cross Wedge Rolling Parameters

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ABSTRACT

COMPUTER-AIDED EVALUATION OF CROSS WEDGE ROLLING PARAMETERS

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Cross Wedge Rolling (CWR) is a metal processing technology in which a cylindrical billet is plastically deformed into an axisymmetric part by the action of wedge shape dies moving tangentially relative to the workpiece. The CWR process offers several innovative features over traditional machining operations such as; production capacity, less waste material, strength of product, environmental effect and better product quality.

In this thesis, it is aimed to investigate the cross wedge rolling parameters. For this purpose, two set-up has been constructed and extensive experimental investigations have been performed on that constructions. In the first type, flat wedge tools are so constructed that wedges move in opposite directions. In the second type, one of the wedge moves back and forth and the other is stationary. Main phase of this study focuses on the geometry of the wedge. Four zones, namely, knifing, guiding, stretching and sizing zones and two main angles forming and stretching angles are the main considerations.

It is believed that improvements in CWR will make it more viable manufacturing process in Turkey.

Keywords: Cross Wedge Rolling, CAD/CAM, Metal Forming

ÖZET

BİLGİSAYAR YARDIMIYLA ÇAPRAZ KAMALI HADDELEME PARAMETRELERİNİN DEĞERLENDİRİLMESİ

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Çapraz Kamalı Haddeleme (ÇKH) yöntemi, dairesel iş parçalarının düz plaka ya da merdaneler üzerine monte edilmiş kamalı kalıpların arasında deforme edilerek eksenel simetrik şekil verme işlemidir. ÇKH yönteminin diğer geleneksel imalat yöntemleri ile karşılaştırıldığında üretim kapasitesi, malzeme sarfiyatı, ürün mukavemeti, çevresel etki ve ürün kalitesi gibi birçok konuda üstünlüğü bulunmaktadır.

Bu tezde, çapraz kamalı haddeleme parametrelerinin incelenmesi amaçlanmıştır. Bu amaç için iki farklı deney düzeneği tasarlanmış ve deneyler yapılmıştır. İlk deney düzeneğinde her iki kama karşılıklı olarak hareket etmektedir. İkinci düzenekte ise kamalardan birisi ileri geri hareket ederken diğeri sabit tutulmaktadır. Bu çalışma kama geometrisi üzerine yoğunlaşmaktadır. Kesme, kılavuzlama, gerdirme, boyutlandırma bölgeleri gibi dört bölge ve şekillendirme ve gerdirme açısı gibi iki önemli açı, kama geometrisinin esasını oluşturmaktadır.

Çapraz Kamalı Haddelemedeki ilerlemelerin Türkiye'de bu yöntemin daha yaygın bir imalat yöntemi olarak kullanılmasını beraberinde getireceği düşünülmektedir.

Anahtar Kelimeler: Çapraz Kamalı Haddeleme, BDT/BDÜ, Metal Şekillendirme

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LIST OF SYMBOLS

Ro	Radius of Billet
R	Last Radius of Billet
α	Forming Angle
β	Spreading Angle
γ	Ramp Angle
δ	Relative Reduction on Diameter
λ	Rolling Coefficient
μ	Friction Coefficient
mb	Friction Factor on the Side Surface
mk	Friction Factor on the Sizing Surface
m	Shear Friction Factor on Forming Area
qm	Mean Contact Pressure
qc	Drawing Stress
Qz	Radial Components of Rolling Force
C	Relative Rolling Pitch
L	Rolling Length, Width of a Sizing Belt
Lz	Substitute Width of a Sizing Belt
Axz, Axy	Projected Contact Areas in Radial and Axial Directions
k	Shear Yield Stress
σ_o	Yield Stress
τ	Shear Stress

CHAPTER 1

INTRODUCTION

1.1. INTRODUCTION

In this chapter, the place of cross wedge rolling in metal forming processes is explained. Purpose and domain of the thesis and the organization of the chapters are outlined.

1.2. PLACE OF CROSS WEDGE ROLLING IN METAL FORMING

In recent years, many manufacturing methods are in use. These are named as with chip and chipless manufacturing methods. The importances of the chipless manufacturing methods are gradually increased as present technologies are targeted to the cheapest and best quality products. Chipless manufacturing ways are mainly named as; forging, rolling, extrusion and wire drawing. Forging is manufacturing process which giving shape to the material plastically using the force between dies. In rolling process the material is taken shape plastically by the compression between the roller which is turning their own axes. Cross Wedge Rolling can be classified as the combination of forging and rolling because of shaping of the work pieces.[1]

Cross Wedge Rolling is a process of plastic working, during which a forging or preform is being formed as a result of the actions of the tools, that are wedge segments on rolls of cross rolling machines. Cross wedge rolling sometimes called transverse wedge rolling, refers to a metal forming process in which a cylindrical billet is plastically deformed into another ax symmetrical shape by action of wedge shape tools moving tangentially relative to each other [1,2].

It can be used to produce one or more axisymmetrical shaped shafts, ball studs, pins and other components during a single operation. In comparison with other metal forming process, cross wedge rolling is a relatively new commercial term.

The development of better and more advanced material processing aimed at high quality products at lower material and energy consumption, is continuing area of research. It is particularly visible in metal forming processes, among which the modern technology of cross wedge rolling has attracted attention.

This method is characterized by high productivity (being limited only by the capacity of the heating unit) and process effectiveness. Finished products are characterized by high accuracy, good surface and increased strength properties. Material savings that resulted from the present process amount to 20-60% compared to other forming methods for axially symmetric products, i.e. open die and multi cavity die forming and longitudinal roll forging or machining [3].

Despite the intensive development of the process, many phenomena occurring the CWR process have not been modeled theoretically. In particular, such features as the kinematics of material flow and the problems of the increase of product diameters, the determination of material flow and the problems of the increase of product diameters, the determination of material tool contact extent and conditions, the influence of technological conditions on the forming process stability and the problem of the formation of central cavities need attention. Because of the complexities associated with the deformation, theoretical analysis of CWR process tend to employ only approximate solutions which are based on many simplifying assumptions.

CWR has been studied for the past thirty years. However, despite all effort that has been expended, there are still no formalized systematic methods for designing rolling tools for practical applications. This is because the kinematics of and geometrical changes occurring in cross wedge rolling are complex and defy accurate description.

Process planning and die design, in common with other processes that employ dies or tools for the shaping of components, are carried out with heavy reliance on the skills of experienced designers and personnel who are scarce in supply for industries. However, no reliable theoretical calculation methods have been available to date, due to the complicated three dimensional nature of billet deformation during the process. Inappropriate decisions at both the process and die design stages can influence significantly the difficulty and consequently the cost of forming a particular part. Lack of experienced designers and personnel is holding up to the development of cross wedge rolling. In this view, CAD/CAM application, FEM and UBET applications are needed for the industry.

The purpose of this study is to evaluate the cross wedge rolling parameters. In this study, the principle and tooling configurations of Ref. [7-11], evaluation of deformation parameters and applications to part shapes [12-14] will be considered. It is noted that the deformation of material depends on the geometric parameters of the rolling tools such as;

i) Forming angle
ii) Stretching angle
iii) Ramp angle
iv) Rolling depth
v) Length of wedge

All of the above geometric parameters are encountered in the study. Apart from these parameters the important headlines will be as follows:

Tooling: CWR machines are classified according to tool configuration. These are one-roll, two-roll, three –roll, concave wedge and flat wedge. These tooling configurations are designed according to the forming wedge mounted on the surface of the wedge base. In this work , flat wedge rolling is performed.

Practical aspects: To reduce rolling forces and ease metal deformations raw material is heated to certain degree according to the material type. Therefore, cold, warm, and hot wedge rolling can be performed by the CWR machines.

1.3. SCOPE OF THE THESIS

Cross Wedge Rolling is a manufacturing process which has been used industrially for many years although research and developments have been ongoing for many years. While it is not a well known metal forming process in our country due to the restricted know-how and high investment expenses, it has very good attractions in international market because of being economical production way and high strength ability in symmetrical parts.

Over the last 30 years, most developments of cross wedge rolling have taken place in Eastern Europe, Japan and recently China. At present more than 200 cross wedge rolling machines are working in 15 countries [2].

In this thesis; it is planned to introduce our university and our country with this new metal forming method with its advantages, disadvantages and working principles. The relationships between the parameters of the cross wedge rolling are evaluated. Throughout these evaluations, the relationships between CWR parameters are carried out. The behaviors of the material being formed with different tool constructions are also controlled by experimental setup. An extensive experiments were conducted by varying the area reduction, forming angle, stretching angle and length of the zones.

1.4. ORGANISATION OF THE THESIS

This study is started with an introduction of Cross Wedge Rolling and its place in metal forming. It is tried to find the place of this new manufacturing way in other metal forming methods.

In chapter 2, the previous works about cross wedge rolling are discussed briefly.

In chapter 3, the theory of the cross wedge rolling is put in to the perspective. The working principle and tooling types of this manufacturing method are explained in details.

In chapter 4, cross wedge rolling parameters are discussed. Energy requirement and load equations are derived. In this part of thesis the relationship between the parameters and tooling configurations has been explained.

In chapter 5, the experimental setup which has been constructed for this thesis is shown in details. The experiments which were made with different materials are presented results are discussed in this part of thesis.

In Chapter 6, discussion and conclusion of the experimental results are presented. In this chapter future works and advices can be found.

CHAPTER 2

LITERATURE SURVEY

2.1. INTRODUCTION

In this part of the thesis the previous studies about cross wedge rolling is explained briefly.

2.2. PREVIOUS WORKS ON CROSS WEDGE ROLLING

Zb. Pater [1] studied on method of modelling the process of cross wedge rolling (CWR) with upsetting. The method developed is based upon a division of a forming zone into a set of layers that are than analyzed in the conditions of plane state of strain as typical rotary compressing processes. It allows for determining the distributions of: forces, areas of material-tool contact, rolling radius, as well as the geometry of the object formed during the whole formation process. In addition, the method gives the possibility of determining the moment of certain effects emerging (slipping or buckling), restricting the balanced course of the process.

X. P. Fu and T. A. Dean [2] studied on a general looking of cross wedge rolling by investigating past developments, current applications and trends. It is started with the principle of and tooling configurations of CWR followed by the developments in machines, research in work piece deformation and applications to part shapes. Future trends in research and applications are also discussed.

Zb. Pater, W. Weronski, J. Kazanecki and A. Gontarz [3] studied on a phenomenon which is described by mathematical equations included for selection of the geometrical parameters of the CWR segments. The phenomena limiting CWR process stability, i.e. slipping, necking, buckling, lapping and central cavities have been described in the study. On the basis of professional literature and analyses of the present authors, equations for the CWR process conditions under the individual criteria have been determined. Using these conditions, the method has been presented to determine the ranges of the forming angle and the spreading angle assuring CWR process stability at a presumed relative reduction. The present considerations can be used for the designing of systems aiding the selection of the parameters of the tool segments used in CWR processes.

Zb. Pater [4] developed a summary of the cross wedge rolling process method. The forming zone has been divided into several layers to calculate their contact pressure as in the case of rotational compression process. To verify the accuracy of the proposed calculation method, a WPK-1 experimental rolling stand has been designed and equipped with seven sets of tooling segments having various parameters. Satisfactory consistency has been demonstrated by comparison of predicted theoretical values and results obtained from experiments.

Zb. Pater, A. Gontarz, W. Weronski studied for describing the research and implementation of works completed in the framework of new thread rolling technology developed for sleeper fixing screws. Described thread rolling method consists in thread forming by means of two flat wedges provided with special grooves designed for thread forming. The results obtained from numerical simulation thread rolling process are presented. The calculations have been completed using finite volumes method (FVM) and finite element method (FEM). Furthermore experimental tests consisting in thread forming on the bars made of commercial lead in laboratory conditions and results of industrial tests with simultaneous thread forming on two screws have been described.

Minting Wang, Xuetong Li, Fengshan Du and Yangzeng Zheng carried out the tests of constant strain rate compression on AISI 5140 using the Gleeble-3500 thermo mechanical simulator. The mechanical behaviour and the dynamic structure changes were investigated metallographically in the temperature range from 900 to 1100 ^{0}C and at the strain rate ranging from 0.1 to 10 s^{-1}. A dynamic recrystallized grain size model and volume of fraction model were presented as well as a diagram of dynamic microstructure state. The cross wedge rolling process for shafts was simulated through establishing a theoretical model on the finite element software DEFORM. The distributions of different field-variable, such as effective strain, effective strain rate and temperature, were obtained. Meanwhile, mean grain size distribution after rolling was presented.

Zb. Pater [7] developed a new method for the numerical simulation of cross wedge rolling (CWR) process including upsetting is described. During the calculation sequence the strain area has been divided into several layers to be analyzed successively for a plane state of strain as typical for rotary compression process. The results of calculations based upon the upper bound method have enabled distribution diagrams to be obtained for: the rolling forces; the contact surface between the material and tool ; and the rolling radius with in the total range of forming process. Furthermore, phenomena have been predicted (slipping and buckling) impairing process stability as well as the dimensions of the product obtained as a result of cross wedge rolling process.

Yaoming Dong, Kaveh A. Tagavi, Michael R. Lovell and Zhi Deng [8], used the previously developed finite-element model for the cross wedge rolling to process to characterize the work piece material stress and deformation behaviour. Particular attention has been paid to center and mid-radius points of the billet where internal defects (i.e. internal cracks and porous voids) often occur. Several failure criteria in the solid mechanics theory are summarized. The effect of the important CWR parameters, namely the forming angle, the area reduction and the friction coefficient, on the field of variables investigated, including the first principle stresses, maximum shear stresses, etc. A total of 14 rolling conditions are analyzed for the billet material aluminium alloy 1100. After initially verifying the numerical results, several tendencies for the CWR process, as related to failure, are ascertained and discussed

J. C. Choi, B. M. Kim, S. W. Kim and C. H. Kim [9], described some developments of an automatic forging-die design system for two dimensional components and discusses several applications of the system. According to the design sequences, empirical guidelines which are concerned with the design of the forging and the finisher die, obtained from an extensive literature review, were first compiled in structured and systematic form as design rules and database, some of them being introduced by the this study. Two-dimensional cross sections (axisymmetric and plane- strain sections) can be dealt with by this system, being automatically decomposed, recognized and modified for the design of the forging and finisher die. Accordingly, forging design which considers the geometric features of the section of the machined part can be carried out. The results obtained from the system developed at authors' laboratory have been compared with those from other sources, the results corresponding well, apart from a few minor differences. The design results of the system were investigated according to forging type, forging material and flat-web location.

Zb. Pater [10], presented the possibility has been explored of applications for optimization techniques for the techniques for the designing of the shapes of tools applied in CWR processes. Detailed discussion of problems associated with the selection of basic wedges parameters (i.e. forming angle α, and spreading angle β) as well as in the designing of the shape of the wedge side profile has been included. Non-gradient optimization techniques and a layer modelling method for CWR processes modeling have used. The optimization procedures presented herein are introduced into a Wedge Roll computer system aiding the designing of CWR processes.

Zb. Pater [11], developed a new method no determine the mean unit contact pressures on a material-tool contact surface in cross wedge rolling processes (CWR). The dependencies worked out on the basis of the energy and the upper bound methods permits rolling forces to be determined which are comparable to experimentally measured ones. The analyses provides equations which relate the mean contact pressure qm to the basic process parameters, namely the forming angle α, the spreading angle β , the relative reduction of a portion δ and the shear friction factors m and mk.

J. Bartnicki, Zb. Pater [12], presented the results of numerical calculations of CWR processes of hollowed shafts are presented. Worked out FEM model was c-validated in laboratory stand and tests. The comparison of chosen parameters of the CWR process, calculated and experimentally measured, has confirmed the possibility of Fem applications for verifications dependencies in this type of works. It was noticed that in the case of tubes rolling with too small wall thickness (at small deformation ratio) the existing ovalization is not removed and the stability of process is limited by the rolling over phenomenon. It is accorded with the experimental results obtained by Celikov [17]. In the case of bigger deformation ratio the stability of process could be damaged by squeezing of rolled part (in the case of thinner wall)or by necking phenomenon for the bigger wall thickness. For the presentation of quantity dependencies between main parameters of process and the dimensional ratio h/d_0 , at which the process is running stable, many additional, numerical and experimental analyzes will be realized.

F. Q. Ying, Y. M. Bao and X. Y. Pan [13], developed a three dimensional thermal elastic-plastic finite element model to simulate the cross wedge rolling processes. The parameters of forming angle, spreading angle and reduction of area of cross wedge rolling are adopted as simulating parameter with MSC Mark software. The influence that angles reduction of area on rolling force, rolling moment, temperature and friction factoring the rolling process is analyzed in detail. The results are very helpful to understand the forming theory of cross wedge rolling thoroughly, to chose the parameters of force and energy of cross wedge rolling machine appropriately, and to design the die cross wedge rolling fitly.

Shu-Chun Wang and Jiang Chen [14] presented a structured method for extracting knowledge in building expert systems for designing precision forging dies. An unvaried pattern with four steps is proposed. In addition, a new learning method and a belief evaluation method for improving the reliability and intelligence of the system are discussed.

Michael Lovell and Qiang Li [15] developed a numerical model for cross wedge rolling which determine the critical interfacial friction in a two roll CWR machines. Function of the tool geometry and area reduction for the critical rolling condition CWR machines are expressed. The morphology of the void generation and growth in CWR ascertained and discussed. Definition of a deformation a coefficient for predicting the likelihood of void formation based on the experimental results.

N. F. Yılmaz, T. Dereli and A. F. Çağlar [16], expressed the CWR technology generally which is not well known in Turkey while it has been used long term in Asia and Europe. The working principles, advantageous and disadvantageous of the CWR explained with general looking.

Jaroslaw Bartnicki [17], presented the ovalization phenomenon of work piece in cross wedge rolling process for hollowed shaft. The ovalization phenomenon reducing field of stability of CWR process parameters for hollowed shafts. The numerical results obtained by Fem method are confirmed by stand tests. The knowledge of these problems permits in the future imposes data for designing of CWR technology.

S. Urankar, M. Lovell, C. Morrow, Q. Li, K. Kawada [18], developed an analytical model for determining the critical friction condition in the cross wedge rolling of hollow shafts. Utilizing specialized experiments, critical friction values were determined using the derived expressions for Aluminium 6061 T6 materials for both solid and hollow billets. A comparison between the two types of billets indicated that the critical friction coefficient for the hollow billets was more than two times greater than that for the solid billets. Such a tendency is due to the fact that the hollow billets have substantially less radial rigidity than the solid billets and actually maintain an elliptical cross section throughout much of the forming process. In conjunction with the experiments, an explicit dynamic finite element method of the flat wedge process being studied was created. The finite element results for the critical friction correlated very well with the analytical model, especially for larger are reductions.

Zb. Pater, J. Bartnicki, A. Gontarz and W. S. Weronski [19], presented the calculations of numerical analyses and experimental work of the CWR processes hollowed shafts, realized with mandrels and without them. On the basis of these analyses it was stated that in these CWR processes (as opposed to rolling of full charge) very often excessive and irremovable ovalization of the normal cut appears. It was also claimed that for CWR processes with two tools there exist such pairs of angles: forming and spreading at which this ovalization is removable. However, numerical value of these angles depends on the rest of parameters in the process, such as the charge wall thickness or the reduction of billet diameter. Each time this value should be determined on the basis on calculations. Generally, it can only be stated that during designing of wedges for two-tool CWR method, the maximal values of forming angles should be assumed. In the result of calculations, application of three wedges in the CWR processes of hollowed shafts was regarded as necessary. In this method of rolling there is no undesirable ovalization of normal cut. Hence, during tool designing, rules for the rolling processes of full charges can be used.

Zb. Pater, J. Bartnicki, G. Samolyk [25], started that on the basis of numerical calculations, there is the possibility of forming ball pins rolled in the double system by means of CWR method. The application of rolling proposition which assumes the use of guiding devices limiting free flow of material in the axial direction, results in the CWR process realized almost without discards. The present works are done connected with the implementation of the rolling process of ball pins in the industrial condition.
On the basis of conducted analysis it was also shown that personal computers and software FEM are necessary in designing of such complex metal forming processes as CWR. Hence, It should be expected that in the effect of more widely applied numerical analyses in research and development departments, limits connected wit h designing of new technologies basing on CWR will soon be effectively removed.

Zb. Pater [20], described the method of layer simulation for the CWR process using the upper bound method. Using the calculations, several diagrams have been drawn to be used for the assessment of an average contact pressure value versus basic process parameters, i.e. angles α and β and relative reduction δ. A summary of theoretical calculations and experimental results provides evidence of suitability of the developed calculational method for a simplified simulation of the CWR process.

R. Neugebauer, R. Glass, M. Kolbe and M. Hoffman [21], developed a controller which is used for process guidance in spin extrusion. The essential solution components are a model-based process planning procedure supported in its control functions and modules for process control (closed-loop). With these control components, successful process guidance was also possible for steel parts for first time. Particularly the danger of buckling in the starting phase could be removed almost completely. The results of the tests show that the entire process exhibits a distinctly non-linear behaviour, among other things caused by disturbances in the starting of stage that influence the whole process and even intensify during the process.

The forming technologies presented and their combined applications provide new opportunities. Design effectives and compact manufacturing sequences simultaneously improve the quality of the manufactured parts. An increase in process stability, quality assurance and an optimal processing route adjustment combined with high flexibility are the targets of further process development.

Zb. Pater, A. Gontarz and W. Weronski [28], showed that on the basis of the experimental research and numerical calculations, it was shown that due to application of one wedge and two profiled rolls, axisymmetric part scan be formed. The precision of forming by means of this method called wedge rolls rolling process, in the case of forming from full billets was compared to the precision, obtained in typical CWR processes.

Y. Dong, M. Lovell and K. Tagavi [23], presented an extremely verified finite element model of a flat wedge CWR process. From the experimental and numerical investigations some results were carried out. Experimental prototyping of CWR, for the purpose of understanding the physical nature of the CWR process, was found to be a viable research tool. Experimental studies were performed with a flat wedge CWR prototype machine using aluminium 1100 work pieces. It is shown that the numerical modelling of the complex phenomena involved in CWR, which include large plastic deformations and variable interfacial friction, could be performed. In this work, a CWR forming process is modelled using the explicit dynamic finite-element method. It is also determined that CWR process can be adequately represented by parameters such as area reduction, tool angle and friction coefficient between the tool and the work piece.

In order to validate numerical result with experimental data, the concept of tool-work piece 'slip' is introduced. Slip is defined as the overall difference between the tool translation and the work piece rotation in CWR. Slip is calculated experimentally and numerically for specific tool geometry at three area reductions values. The experimentally measured tool-work piece slips are in good agreement with those predicted by the Fem developed in this work.

From the close agreement between the experiment and numerical results, it may be concluded that all of the important physical phenomena in the complex deformation process of CWR have been included in the FEM. It was observed in this study both experimentally and numerically, that the slip between tool and work piece monotonically increases as the forming process progress. Additionally, lower area reductions yield higher amount of slip. Having established that advanced explicit dynamic numerical techniques can accurately model the CWR process, a wide range of rolling conditions (i.e. work piece material, tool geometry, surface finish and initial temperature) can be investigated.

CHAPTER 3

THEORY OF CROSS WEDGE ROLLING

3.1. INTRODUCTION

In this chapter the cross wedge rolling is introduced generally. Tool geometry, die configuration, failure mechanisms and advantages and disadvantages of this metal forming method are presented.

3.2. CROSS WEDGE ROLLING

Cross wedge rolling (CWR) process is a modern metal forming method which is giving shape to workpiece plastically by means of wedge tool segment moving tangentially.

The CWR process widely applied for the production of stepped shafts or axes being the axisymmetric parts. This process is also used for the production of preform to be formed by means of forging presses [4].

At first; cross wedge rolling was used to prepare samples by giving shape to the metals. But after the developments on this area, it was used to produce the end products. In order to get high quality final products in cross wedge rolling method the tool configurations and workpiece dimensions should be calculated carefully. Moving of the designed wedge tools in a good harmony is another important consideration for producing high quality end products.

In Fig. 3.1 some of the products which is possible to produce by CWR process are shown. [16]. Axisymmetric circular parts which have a diameter of 3-125 mm and length of 3-2000 mm can be produced.[16]

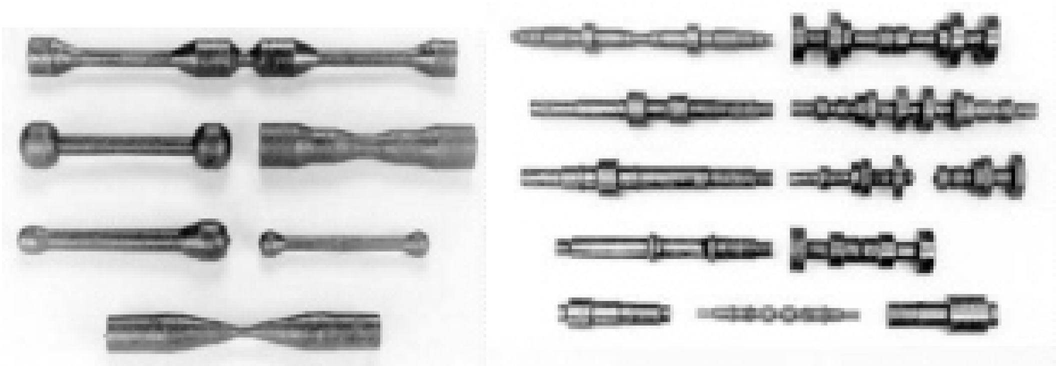


Fig. 3.1 Some items produced with CWR process [16].

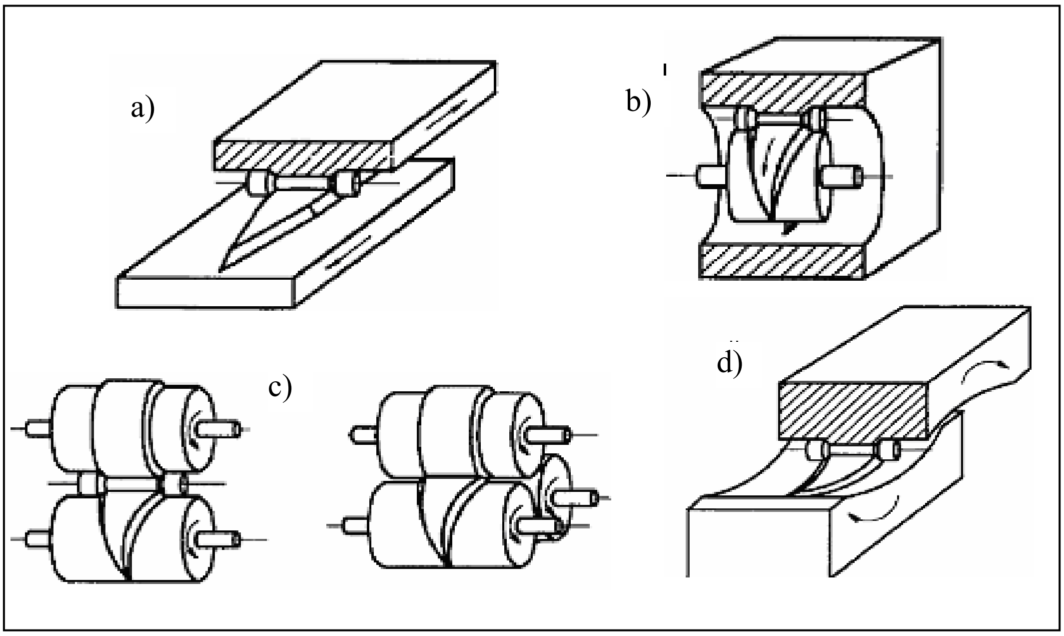
In cross wedge rolling process it is needed to design different tool geometry for different work pieces. Each tool geometry has very close relationship with the finished product. Thus; workpiece geometry, workpiece material, die shape, friction, applied load and the rate of the load have vital importance. In order to make easy to calculate and put into perspective all these parameters and effects to the end products, both experimental and theoretical studies must be carried out. In present day, tool design, planning and configurations for wedge tools are produced by iteration method or using the advices of some professional person who has experience on this subject.

FEM (finite Element Method), UBET (Upper Bound Elemental Technique) are used for designing tool geometry of cross wedge rolling [31]. Flat type and two roll cross wedge rolling machines are currently in the field of interest of some researchers. [1,3,14]. The studies are concentrated on rate of loading, applied load, workpiece deformation parameters like forming angle, spreading angle, rolling depth and friction.

Another subject dealt by authors is internal external defects of the products. Affecting factors are not yet known completely. These are some judgements but studies are continuing on this subject. The microstructure of the products must also be investigated with different forming methods like cold, warm and hot rolling [22,29].

3.3. CROSS WEDGE ROLLING TOOL GEOMETRY

Cross wedge rolling is a process of metal forming where a product (a forging or a preform) is worked as a result of the operation of tool wedge segments located on rolls or concave or flat penal on rolling mills. There are five types of tool configurations [2]. These are one roll, two roll, three roll, flat and concave types which are shown in Fig. 3.2.



a) flat b) one roll c) two and three roll d) concave

Fig. 3.2 Cross Wedge Rolling Tool Configuration Types

3.3.1. Flat Wedge

Flat wedge tools are unfolded rolls that move in opposite directions or one moves back and forth and the other is stationary. Flat wedge rolling machines require 40% of their cycle times for the return stroke [2].

The schematic drawing of flat wedge tool is shown in Fig. 3.3.

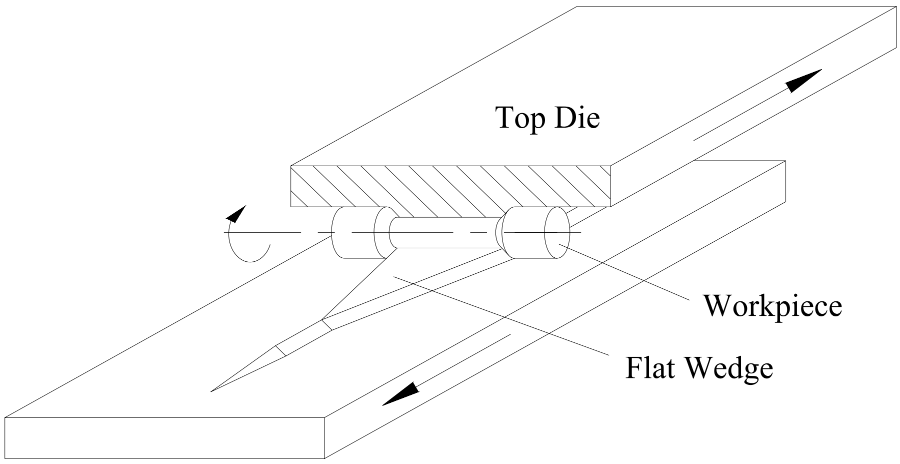


Fig. 3.3 Flat Wedge Type Cross Wedge Rolling

3.3.2. One Roll

This type of configuration consists of a roll with the forming wedge mounted on its surface and concave wedge base. The workpiece is deformed between the rotating roll and the stationary concave wedge. In this type of tooling, there are some difficulties in die making and therefore it is not widely used in industry

3.3.3. Two and three-roll

All the axes of the rolls are parallel and they rotate in the same direction. With two roll tooling, the stock can be inserted from either the outside or the side of the rolls with its axis parallel to the roll axes. The three roll tooling configuration allows the stock to be fed into rolls from only the side. Cut billets or long bars can be used in two-roll and three roll tooling. Owing to geometrical constraints on three roll tooling, the length of deforming wedges on roll surfaces and the smallest diameter of a product restricted compared to two roll tooling [2]. Two roll cross wedge rolling machine and two roll tools are shown in Fig. 3.4.

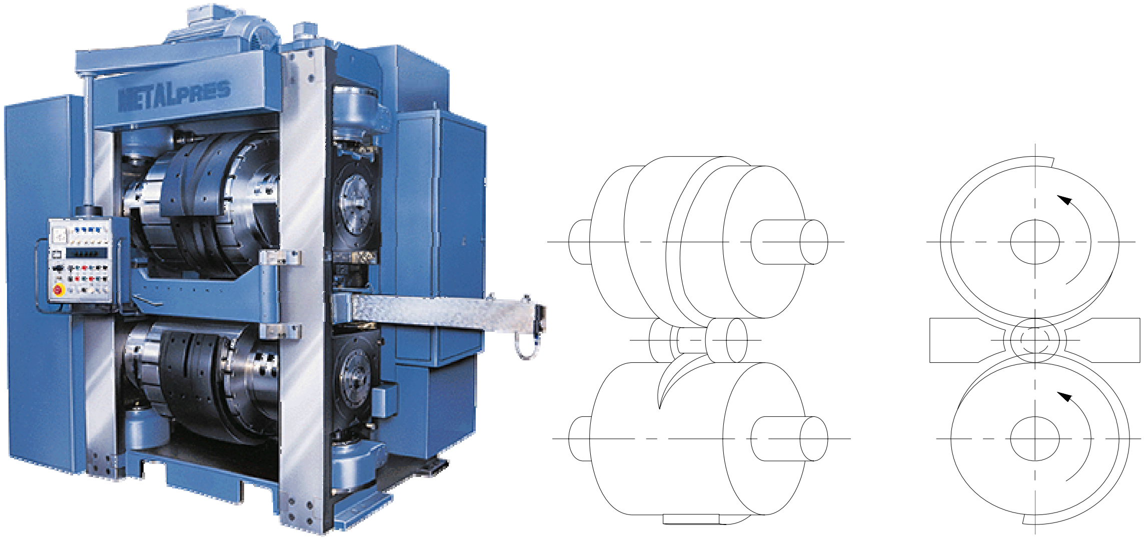


Fig. 3.4. Two Roll CWR Machine and Two Roll Tools

3.3.4 Concave Wedge

Wedge tools are mounted on the concave surfaces of two plates by means of bolts. To keep the wedges processing into the workpiece during rolling, the two plates with their concave wedges are required to rotate eccentrically in the same direction.

3.4 FLAT CROSS WEDGE ROLLING DIE CONFIGURATION

Deformation of the material depends on the tool geometry. Wedge tool consists of four main zones. They are namely; knifing zone, guiding zone, forming zone (spreading zone) and sizing zone. In addition, forming angle α, spreading angle β, ramp angle γ, rolling depth Δr and rolling length 2L are the other parameters which effect the material deformation. These parameters and CWR zones are shown in Fig. 3.5.

3.4.1 Knifing Zone

In the knifing zone the tool bites into the surface of the billet and reduces the billet diameter to the required portion diameter. This zone consists of a knife which is starting from zero height and finished at the processed total length of the work piece

Δr. The angle which is caused by this inclined area is named as ramp angle γ. Knifing zone duty is giving V shaped channel to the workpiece before entering to the guiding zone.

3.4.2 Guiding Zone

V-groove which was produced in knifing zone is enlarged in this zone. While the depth of the V-groove is also increased in this zone the tool profile is not changed. When the workpiece arrive to the end of this zone the circumstances of the workpiece have a regular shaped V-groove.

3.4.3. Forming Zone (Spreading Zone)

This zone which gave shape to the workpiece is the most important part of the tool. Spreading angle β and forming angle α are the important parameters in designing the tool geometry. In this zone the workpiece is forced to flow to the ends of the tool.

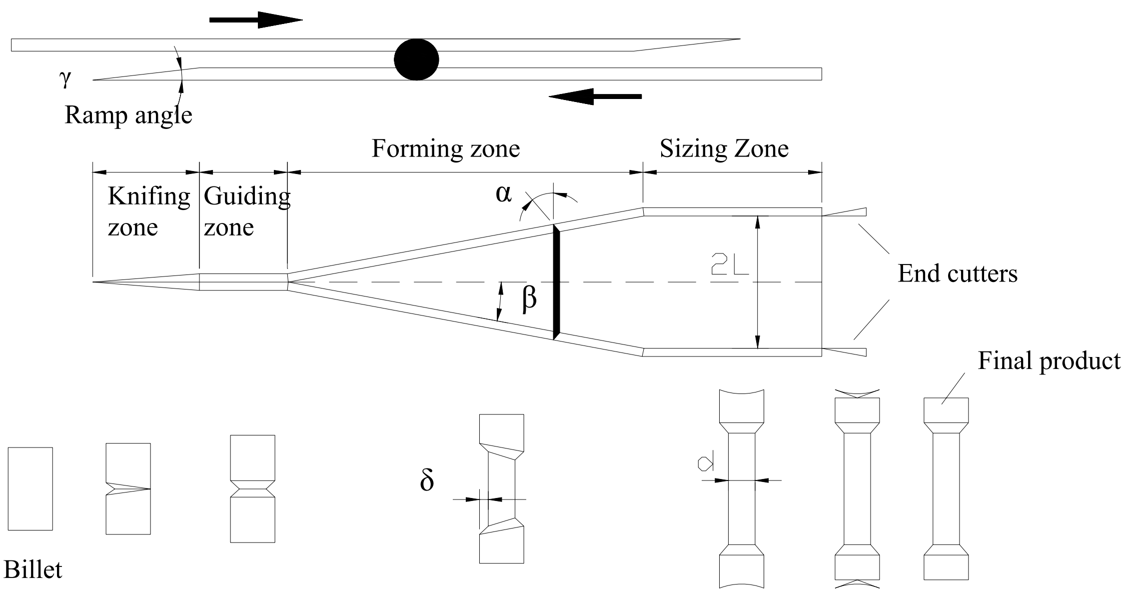


Fig. 3.5 Tool Geometry in CWR

3.4.4. Sizing Zone

The dimensional tolerance and surface quality of the product are adjusted in this zone. The waste parts which become at the ends of the product are cut by end cutter located in the end of the sizing zone. Fig. 3.6 shows an example of product produced by CWR method.

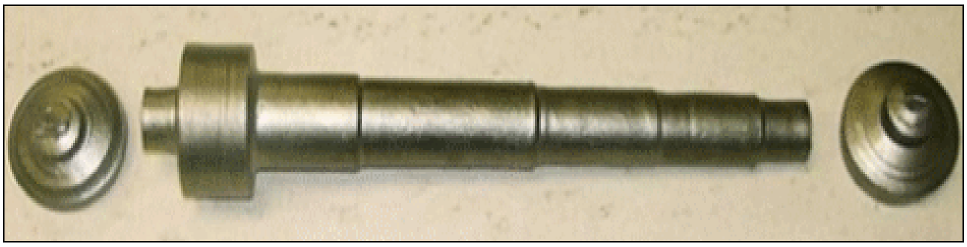


Fig. 3.6 A product made by CWR method.

3.5. ADVANTAGES AND DISADVANTAGES OF CWR

Cross wedge rolling has significant advantages over other metal forming methods. This metal forming method has also some difficulties on usage, tool design and cost.

In comparison with conventional manufacturing processes i.e. machining, forging or casting, the cross wedge rolling process is characterized by many advantages, particularly the following: high efficiency, better material utilization, higher strength parameters of the products, reduced energy consumption, facilitated automation and environment harmlessness.

3.5.1. ADVANTAGES

CWR advantages are generally about capacity and material saving. It is also very efficient metal forming method for environmental protection and health.

a) Production Capacity: In every moving of the tool, more than one work piece can be processed. If the product geometry is not complex then two work piece can be produced at the same time symmetrically. When the rollers are turning, one work piece can be processed in each cycle. By this way the production capacity increases 5-20 times against other metal forming methods like lathing [2]. The dimension, material type and complexity of the geometric shape are effective parameters for increasing or decreasing the production capacity.

b) Waste material: In CWR method the waste material due to become out in end cutting and grinding processes in CWR method is less than 10%. But in the other chip formation methods this ratio can tends to 40%. Because of this reason CWR method is minimizing the waste material expenses. It is obvious that minimized waste material reduces the cost of the product.

c) Strength of the product: Cross wedge rolling is metal forming process in which the shape of the product is given by material flow plastically. The work piece is rolled under the radial and axial forces so that the forces between grains is reason of increasing the strength of the product.

d) Environmental Effect: If CWR is compared with other manufacturing methods it has lower noise ratio compared to others. The importance of the noise in forging workshop is well known. Another important factor is the cooling liquid. In CWR method is no need for cooling or lubricant during the production process.

e) Automation and Cost: In CWR method, the shaping of the workpiece and cleaning the waste parts can be cleaned out in one cycle of the process. These processes are made simultaneously and therefore no need to other turning process after rolling operation.

f) Better Product Quality: In CWR the metal fabric is continuous, due to the fine control of plastic deformations and the forming temperature. Final product quality is satisfactory.

3.5.2. DISADVANTAGES

a) Investment cost: Because of being CWR is a new developed metal forming technology there is limited number of machine producers on this process. The prices of CWR machines are very expensive as the market share is very small. So that the investment to make production with CWR method is high if it is compared with other technologies.

b) Usage ratio: CWR method has seldom usage because having no experienced technical personnel and being not a well known production process. There is a difficulty for finding educated staff in the market.

c) The difficulty on designing the tools: In order to make production with CWR method, firstly die design has to be performed. The production ability with CWR method depends on the tool design because of having not enough know –how about this new technology. It is also shown in this thesis that there are many factors and parameters which are effecting the die design. All these parameters depends each other and related with end product geometry.

3.6. FAILURE IN CWR PRODUCTS

Failure and affecting parameters are discussed below. The failure mechanisms encountered in CWR are direct functions of the process parameters such as the forming angle α, the stretching angle β, and the area reduction ΔA (see fig. 3.7)

3.6.1. Defects in CWR

The failures encountered during the CWR are separated into three categories: (1) improperly formed workpiece cross-section, (2) surface defects, (3) internal defects [22]. It is important to note that each of these failures are repeatable when encountered at a specific set of operating conditions.

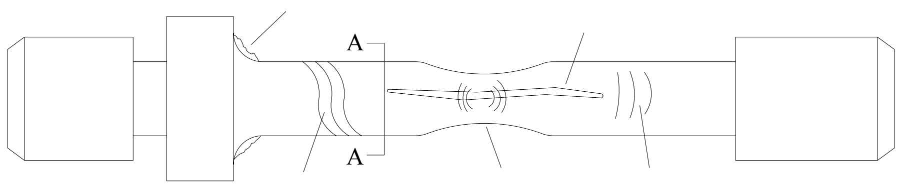


Fig.3.7 Common CWR Failures. [22]

3.6.1.1. Excessive Slip

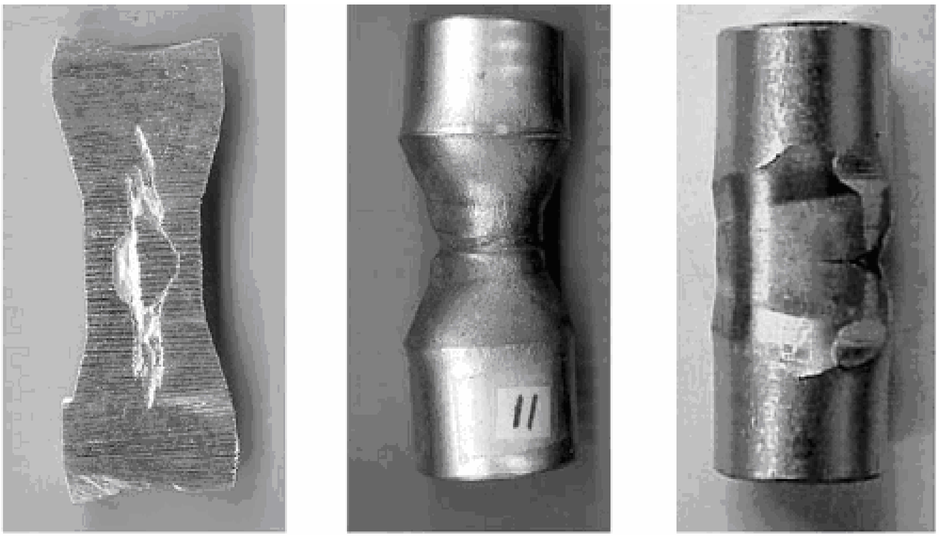
Improperly formed cross sections develop in the CWR process due to excessive slip between the forming tools and the work piece [1,22]. The normal tangential forces at the two rolling workpiece interfaces form couples in opposite directions. If the tangential force couple acting on the workpiece is larger than the normal force couple, rotation will not occur and the billet will slip between the surfaces of the forming tools. Undesirable amounts of slip in the early stages of the CWR process can lead to workpiece misalignment and ultimately inconsistent or incorrect final cross section formation. The amount of slip, particularly in the knifing and guiding zones, is a critical factor in determining the final shape of the workpiece and influences the required length of each section of the forming tool [22,23].

3.6.1.2. Internal Defects

The final failure found in CWR production, internal defects; include the formation of internal cavities and cracks that develop during CWR process. These defects significantly reduce the strength of the formed part and can ultimately lead to product failure [2, 15, 22]. See Fig. 3.8 (a)

3.6.1.3. Surface Defects

The third common failure type in CWR operations is the occurrence of surface defects. Surface defects include the formation of spiral grooves, excessive thinning or necking, and overlapping of the work piece. The appearance of twisting spiral grooves in CWR is due to the opening of cracks that exists near the outer surface of the billet [2,16, 22]. See Fig. 3.8



(a) Internal void (b) Necking (c) Excessive slip

Fig. 3.8 Failure samples showing the three main defects

3.6.2. Effect of Tool Geometry on Failures

The forming angle α, the spreading angle β and total area reduction ΔA are the most important parameters on the final geometry of the work piece in CWR process. These parameters have also important role on occurring internal defects. Here the effect of each parameter is discussed.

3.6.2.1. Effect of Forming Angle

The forming angle controls the size of the contact area between the tools and the work piece in the knifing and guiding zone. In these zones, a smaller forming angle signifies a sharper tool, which increases the contact area and produces a more localized plastic deformation. In the stretching and sizing zones, the forming angle establishes the geometry of the shafts shoulder such that a large value of α leads to a large draft angle. Therefore, smaller forming angles can accelerate the formation and enlarge the size of internal voids [8, 22, 24]. Maximum values of α angle are recommended to reduce the possibility of cracks, which may appear in the axial zone of the rolled product. The upper limit of α angle is associated with the possibility of necking the work piece core and occurring the laps on the surface [10].

3.6.2.2. Effect of Spreading Angle

The spreading angle β is another important tooling parameter in CWR process. It determines the amount of axial deformation experienced by the workpiece. Larger stretching angles within the tool lead to more elongation of the work piece [22]. Generally lower values of the spreading angle β are associated with a greater length of higher speed of the forging required to achieve an assumed relative reduction ΔA resulting in increased probability of inner cracks. On the other hand, large values of spreading angle β are potential reason of uncontrolled slip between the rolled work piece and the tool [10].

3.6.2.3. Effect of Area Reduction

The final parameter ΔA is simply a measure of the amount of radial reduction of the work piece. The larger the value of ΔA, the larger compression experienced in the literature experiences. Since CWR is a volume conservative process, larger area reduction values will increase the overall length of the work piece [22].

CHAPTER 4

EVALUATION OF CROSS WEDGE ROLLING PARAMETERS

4.1. INTRODUCTION

In this chapter, parametric solution for cross wedge rolling parameters is presented. Relationship between the parameters and die design considerations are also discussed in this section.

4.2. PARAMETERS OF CROSS WEDGE ROLLING

Cross wedge rolling have two main groups of parameters:

a) Geometrical parameters
b) Forming parameters

4.2.1. Geometrical Parameters: Die configuration parameters are considered in this group. These are also subgrouped into two, such as length and angle. This structure can be presented by the following schematic diagram (Figure 4.1).

4.2.2. Forming Parameters: Required load, rate of loading, friction effect and strain are the important factors affecting the forming of the workpiece.

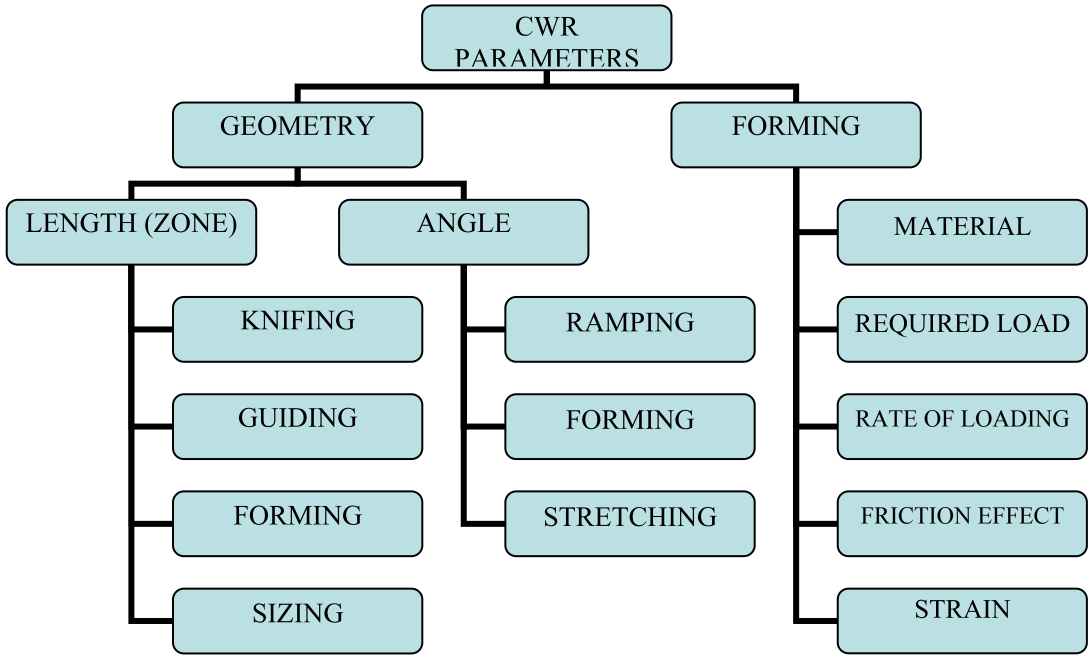


Figure 4.1 Parameters of CWR

In Figure 4.2 geometrical parameters can be seen.

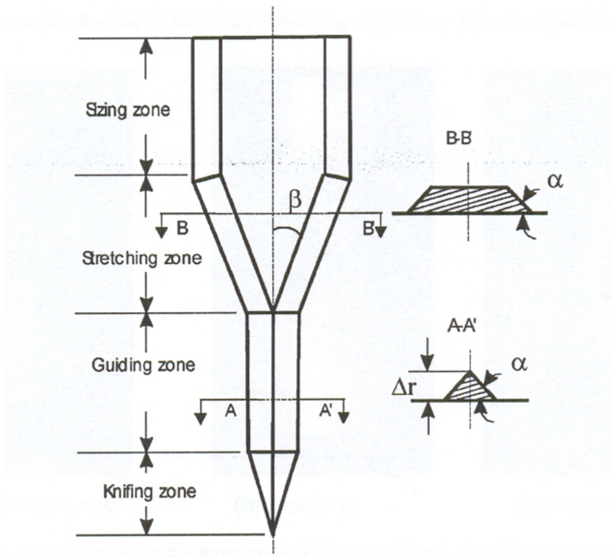


Figure 4.2. Geometric Parameters of Die Configuration

In ***knifing zone***, billet is cut by the tool to reach the required depth and therefore, tool gradually reduces the diameter from initial diameter to desired diameter. Billet passing from the knifing zone enters the ***guiding zone*** to enable the reduction of area to the whole perimeter of the product. Actual forming of the workpiece is given throughout the ***forming zone***. Length and the angle of the forming zone have vital importance. Improper design of length and angle cannot form the workpiece within required geometry. ***Sizing zone*** ensures removal of any undesired curvatures generated in previous phases of the process. Side cutters are often incorporated after the sizing zone in order to separate deformed ends of the forged part or a cutter separating the products in case simultaneous forming of two forged parts.

The ***forming angle (α)*** controls the size of the contact area between the tools and the workpieces. In these zones a smaller forming angle signifies a sharper tool which increases the contact area and produces a more localized plastic deformation. In the streching and sizing zones, the forming angle establishes the geometry of the shafts shoulder such that a large value of α leads to a large draft angle.

The ***spreading angle (β)*** is another important tooling parameter in the CWR process. It determines the amount of axial deformation experienced by the workpiece. Larger stretching angles within the tool lead to more elongation of the workpiece. For large *β*, the billet enlarges rapidly in the axial direction, which accelerates the growth of small internal voids created in the knifing and guiding zones.

4.3. THEORETICAL ANALYSIS OF CROSS WEDGE ROLLING

The modeling concept of the CWR process has been developed using the following assumptions:

- The strain area is simulated by successive material layers;
- Behavior of the material being formed is similar to that of a perfect rigid-plastic strain hardened material;
- No friction forces caused by the guide strips/rolls;
- Constant value of the friction factor along the whole material-tool contact surface [11].

Theoretical analysis of CWR well suits upper bound elemental technique, since UBET is the most suitable approach for axisymmetric metal forming [34]. The upper bound element technique (UBET) is used to determine the optimum intermediate shape for profile rolling using backward simulation. The lowest energy rate is the key issue in achieving the optimal intermediate shape as well as the backward simulation of the process. The plastic flow of material in rolling is assumed to be a sequence of successive closed-die forging processes. The ring is divided into features, which provide an approximated profile consisting of a number of rectangular elements. The simulation of the profile ring rolling was tested with different profiles of rolls, and two such cases are presented here. As the results show, this technique is capable of solving the backward simulation of profile ring rolling problems in a much shorter time compared to the finite element method (FEM), which cannot easily simulate profile ring rolling. Moreover, as an engineering tool, this approach can be applied effectively to the profile ring rolling process and can serve as a useful tool in industrial applications. One of the most popular methods of simulating the metal forming process today is the finite element method (FEM). It has shown promise in delivering more accuracy, however at the expense of increased computational costs.

The upper bound elemental technique (UBET) has the advantage of turning around relatively rapid solutions at a lower rate of accuracy but is more economical than the conventional FEM. UBET combines the advantages of both the upper bound and the FEM methods to provide fairly accurate and rapid predictions of important parameters such as strain rates, die load, and the extent of die cavity filling when compared to the other methods. UBET is ideal for initial stages of optimization algorithms with fewer elements than required by the FEM, the object being able to reach near-optimum solutions in as short a time as possible.

Unlike FEM, UBET allows internal shearing between adjacent elements, helping to reduce the number of UBET elements used in the analysis. Parts produced by the ring rolling process can be quite complex, as demonstrated in Figure 4.3. The ring cannot generally be deformed or rolled to the final shape, with a desired ring diameter, in a single pass. To avoid problems such as foldovers, localized deformation, and improper roll fill, the workpiece (ring) should be deformed into one or more intermediate shapes before a product of the desired shape is obtained. The proposed backward simulation technique helps the engineer avoid unnecessary internal shearing in an effort to obtain the desired final shape. An optimum intermediate shape ensures that the various cavities in the roll profile get filled simultaneously. The main objective of this research is to develop an analytical method for the profile ring rolling process in order to establish a new approach to determine the intermediate shapes of the ring profile using UBET. Comparison of the UBET results against experimental results is also presented here to check the accuracy of the UBET results. There is no unique method of arriving at an intermediate shape because the only parameters known in advance are the final product shape, the final diameter of the ring, and the material with which it is to be made. Experimental data as well as previous experience also play a major role in deciding the appropriate intermediate shapes.

The basic concept of UBET is to break up the workpiece into a number of regions [11]. Figure 4.3 is an idealized representation of the actual cross-sectional geometry of the type shown in Figure 4.3, which is based on constant volume. However, the analysis is actually three-dimensional. During the ring rolling process, the cross-sectional area of the ring reduces at each time step, resulting in a corresponding increase in diameter of the ring due to the material incompressibility. The material flows across the boundary of an element into its neighbouring element, while satisfying volume constancy.

The objective of formulating the UBET is to minimize the total energy rate, all the elements constituting the workpiece. Moreover, a kinematically admissible velocity field is constructed for each element during each time step. The total consumption of energy is calculated by summing up the consumption values for all the elements.

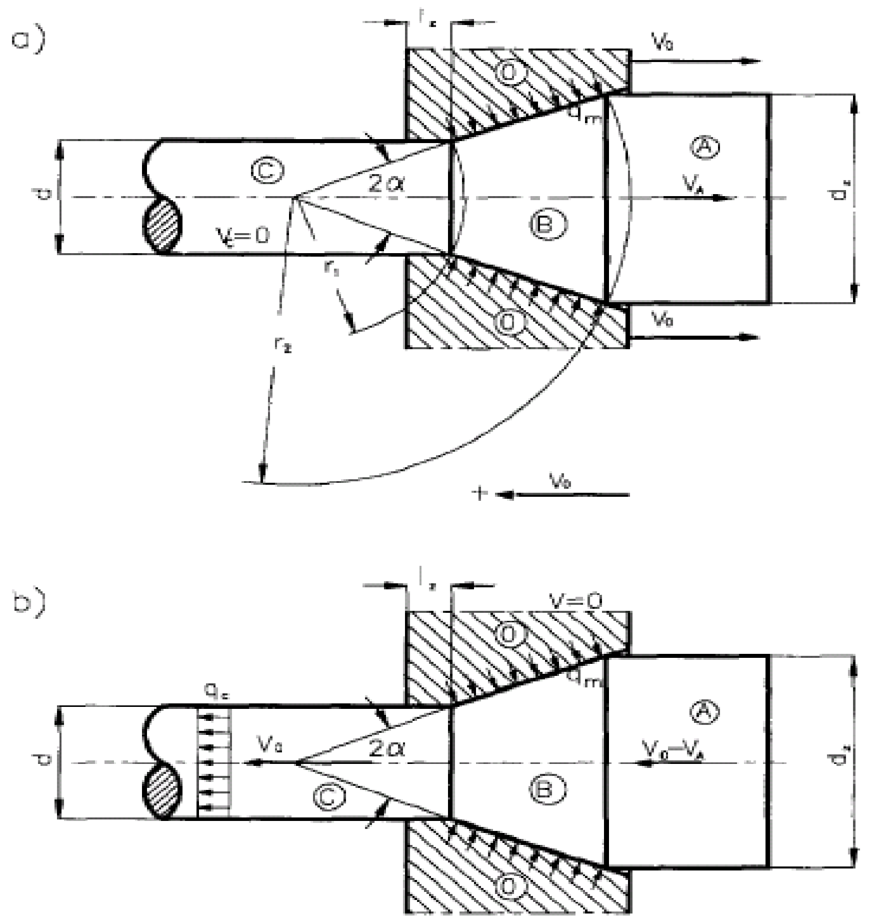


Figure 4.3. Analysis of Rod Reducing Process Using the Upper Bound Method

Calculations can be done by the following equations using UBET;

$$\delta = \frac{Do}{D} \tag{4.1}$$

$$\sin\beta = \frac{0{,}09 * \mu}{\sin\alpha} \qquad \mu \text{ is assumed 0,4 up to 0,5} \tag{4.2}$$

$$f(\alpha) = \frac{1}{2}\left[\sqrt{12} - \cos\alpha * \sqrt{1 + 11 * \cos\alpha^{2}} + \frac{1}{\sqrt{11}} * \ln\left(\frac{\sqrt{11} + \sqrt{12}}{\sqrt{11} * \cos\alpha + \sqrt{1 + 11 * \cos\alpha^{2}}}\right)\right]$$

(4.3)

$$\frac{qm}{\sigma_0}=\frac{1}{\delta_Z^2-1}*\frac{2}{\sqrt{3}}\left[\left(\frac{f(\alpha)}{\sin\alpha^2}+m*\frac{1}{\tan\alpha}\right)*\ln\delta_Z+\frac{2\alpha-\sin 2\alpha}{2\sin\alpha^2}+2*m_k*l_Z/d\right]$$

(4.4)

$$\delta z=\frac{\delta+1}{2} \quad (4.5)$$

$$\lambda=(2{,}587-1{,}557*\delta^{0,3528})*(0{,}00355*\alpha+0{,}927)*\beta^{0,0568} \quad (4.6)$$

$$Lz=\Pi*r_0*\lambda*\tan\beta/2*\delta \quad (4.7)$$

$$C=\frac{\pi*\tan\beta*\tan\alpha*\lambda*\delta}{\delta-1} \quad (4.8)$$

If C≤1

$$Axy=1+\frac{2}{3}*r_O{}^2*\frac{\cos\beta}{\tan\alpha}*\sqrt{\frac{3}{1\pm\frac{r_o}{R}}*\frac{\delta-1}{\delta}}*\left[1+c*\frac{\delta-1}{\delta}\left(1+\sqrt{\frac{2+c*\delta-c}{2\delta}}\right)-\sqrt{\left(\frac{1+c\delta-c}{\delta}\right)^3}\right]$$

(4.9)

$$Axz=\frac{2}{3}\cos\beta*r_0{}^2\sqrt{\frac{3}{1\pm\frac{r_0}{R}}*c*\frac{\delta-1}{\delta}}\left[1-\sqrt{\left(\frac{1+c*\delta-c}{\delta}\right)^3}+c\frac{\delta-1}{\delta}\right] \quad (4.10)$$

If C>1

$$Axy=\frac{2}{3}*\cos\beta*r_0{}^2*\frac{\cos\beta}{\tan\alpha}*\frac{\delta-1}{\delta}*\sqrt{\frac{3}{1\pm\frac{r_0}{R}}}\left[1+\frac{3}{2}(c-1)+\sqrt{\frac{\delta-1}{\delta}}\right] \quad (4.11)$$

$$Axz=\frac{2}{3}*\cos\beta*r_0{}^2*\frac{\delta-1}{\delta}*\sqrt{\frac{3}{1\pm\frac{r_0}{R}}+\frac{\delta-1}{\delta}} \quad (4.12)$$

$$Qz=2*(qm*A\,xy-\tau*\sin\beta*A\,xz) \quad (4.13)$$

$$\tau = \mu * \sigma_0 / \sqrt{3} \tag{4.14}$$

Another solution: find qm different ways.

$$\frac{q_m}{\sigma_o} = \frac{8}{\sqrt{3}\left[(\delta+1)^2 - 4\right]}\left[\left(\frac{f(\alpha)}{\sin\alpha^2} + m * \frac{1}{\tan\alpha}\right) * \ln\left(\frac{\delta+1}{\delta}\right) + \frac{2*\alpha - \sin 2\alpha}{2\sin\alpha^2} + \frac{m_k}{2} * \pi * \lambda * \tan\beta\right]$$

(4.15)

Drawing stress:

$$\frac{qc}{\sigma_0} = \frac{2}{\sqrt{3}}\left[\left(\frac{f(\alpha)}{\sin^2\alpha} + \frac{m}{\tan\alpha}\right) * \ln\frac{dz}{d} + \frac{2\alpha - \sin\alpha}{2\sin^2\alpha} + 2 m_k * \frac{Lz}{d}\right] \tag{4.16}$$

$$q_c * \pi * \frac{d_z}{4} = qm * \pi * \frac{d_z^2 - d^2}{4} \tag{4.17}$$

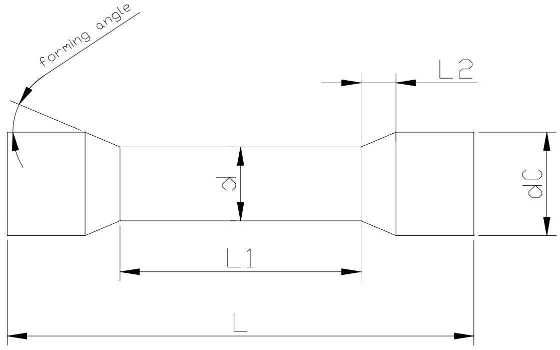
Energy method:

$$\frac{q_m}{\sigma_o} = \frac{8}{(\delta+1)^2 - 4}\left[\ln\left(\frac{\delta+1}{2}\right) + \frac{m_k}{2\sqrt{3}}\pi\lambda * \tan\beta\right] + \frac{m}{\sqrt{3} * \sin 2\alpha} * \frac{(\delta+1)^2 + 4}{(\delta+1)^2}$$

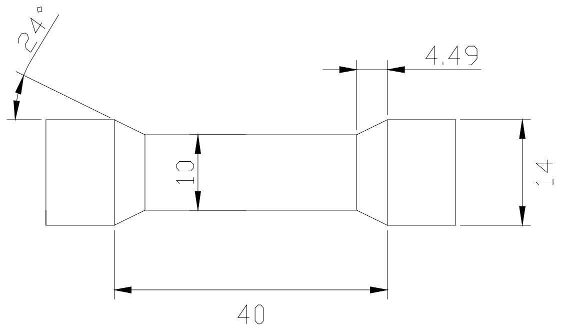
(4.18)

4.4. CASE STUDY

In this case study, a finished product (Fig. 4.4) is considered as an input. By using reverse engineering phenomena, CWR die parameters are presented. Required load is calculated by using Upper Bound Elemental Technique (UBET). Preform dimensions and die parameters are presented in a Table 4.1.



(a)



(b)

Fig. 4.4 Final Component Geometry

(a) Input:

Alfa (α): 24^o

Billet diameter (D): 14 mm

Last billet diameter (d): 10 mm

L1 = 31.02 mm

L2 = 4.49 mm

L= 60 mm

m= 0.7

mk= 0,3

μ = 0.5

(b) Calculation:

sinβ =0,09*0,5/sin24 ⇒ β = 6.35

$$\delta = \frac{D}{d} \quad \Rightarrow \quad \delta = \frac{14}{10} = 1{,}4$$

$$\delta z = \frac{\delta + 1}{2} \quad \Rightarrow \quad \delta z = \frac{1.4 + 1}{2} = 1{,}20$$

λ : Rolling coefficient

λ=(2,587-1,557*$\delta^{0,3528}$)* (0,00355*α+0,927)* $\beta^{0,0568}$

λ =(2,587-1,557*1.4 ^{0,3528})* (0,00355*24*Π/180+0,927)* (6.35*Π/180) ^{0,0568}

λ=0.683

$$Lz = \frac{\pi * (D/2) * \lambda * \tan\beta}{2 * \delta} \quad \Rightarrow \quad Lz = \frac{\pi * 7 * 0,683 * \tan 6.35}{2 * 1.4} = 0,597$$

$$f(\alpha) = \frac{1}{2}\left[\sqrt{12} - \cos 24 * \sqrt{1 + 11\cos 24^2} + \frac{1}{\sqrt{11}}\ln\left(\frac{\sqrt{11} + \sqrt{12}}{\sqrt{11} * \cos 24 + \sqrt{1 + 11\cos 24^2}}\right)\right]$$

f(α)=0,288

$$C = \frac{\pi * \tan 6.35 * \tan 24 * 0,683 * 1.4}{1.4 - 1} \quad \Rightarrow \quad C = 0,372 < 1$$

$$A_{XY} = 1 + \frac{2}{3} * 7^2 * \frac{\cos 6.35}{\tan 24} * \sqrt{\frac{3}{1 + \frac{7}{5}} * \frac{1.4 - 1}{1.4}} * \left[1 + 0,298 * \frac{1.4 - 1}{1.4}(1 + \sqrt{\frac{2 + 0,298 * 1.4 - 0,298}{2 * 1.4}}) - \sqrt{(\frac{1 + 0,298 * 1.4 - 0,298}{1.4})^3}\right]$$

Axy = 20,875 mm^2

$$A_{xz} = \frac{2}{3}\cos 6.35 * 7^2 \sqrt{\frac{3}{1 + \frac{7}{5}} * 0,298 * \frac{1.4 - 1}{1.4}}\left[1 - \sqrt{(\frac{1 + 0,298 * 1.4 - 0,298}{1.4})^3} + 0,298 * \frac{1.4 - 1}{1.4}\right]$$

Axz =4,295 mm^2

$$\frac{q_m}{17,2} = \frac{1}{1,20^2 - 1} * \frac{2}{\sqrt{3}}\left[(\frac{0,2031}{\sin 24^2} + 0,7 * \frac{1}{\tan 24}) * \ln 1,20 + \frac{2 * 24 * \pi / 180 - \sin(2 * 24)}{2 * \sin 24^2} + 2 * \frac{0,3 * 0,597}{10}\right]$$

q_m=87,684*10^6

$$\tau = \mu * \sigma_O / \sqrt{3} \quad \Rightarrow \quad \tau = 0,5 * 17,2 / \sqrt{3}$$

τ = 4,965 Mpa

$Q_Z = 2*(q_m * A_{XY} - \tau * \sin\beta * A_{XZ})$

$Q_Z = 2*(87{,}684 * 20{,}875 - 4{,}965 * \sin 6{,}35 * 4.295)$

Required load: Qz = 2932.4 N

(c) Die Parameters

Knifing zone (L_K) = $2\pi r_0$

L_K= 44 mm

Guiding zone(L_G)= $2\pi r_0$

L_G=44 mm

Forming zone (L_F) =L1 / 2tanβ

L_F= 31.02 / 2tan 6.35

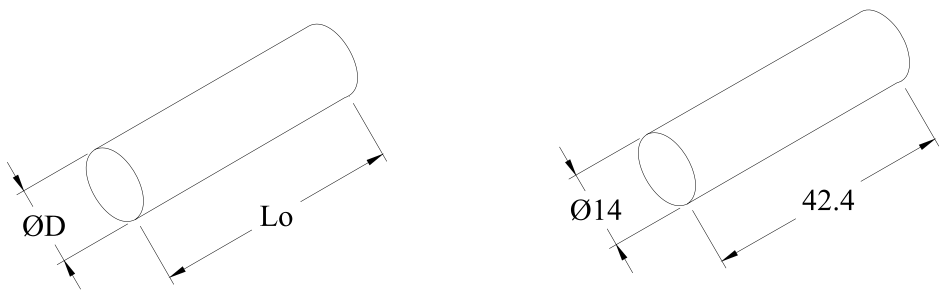
L_F= 139,37 mm

Sizing zone(L_S) = π*D

Sizing zone(L_S) :π*10

L_S=31.41 mm

(d) Preform dimensions:



(e) Die Configuration: The die configuration (Figure 4.5) can be carried out according the final product with above calculations. The Table 4.1 shows the tool parameters according final product. All parameters which needed for the tool geometry design can be found by the calculation which used in above example.

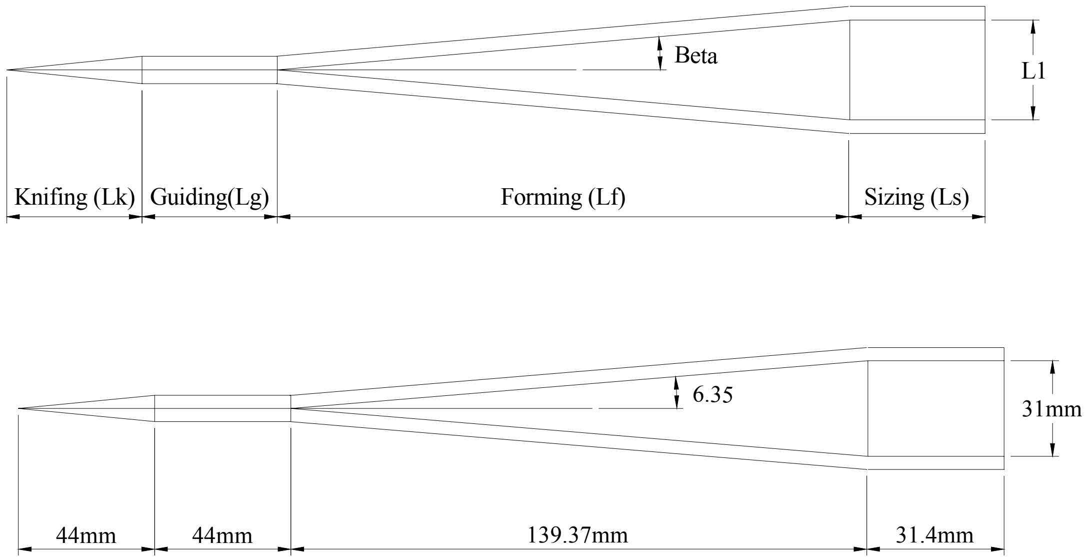


Figure 4.5. CWR Die Parameters

Die geometry values are calculated by Excel sheet. All parameters are put into parametric form. One can define the die parameters by only changing the input values. Print screen of prepared parametric sheet is shown in fig. 4.6

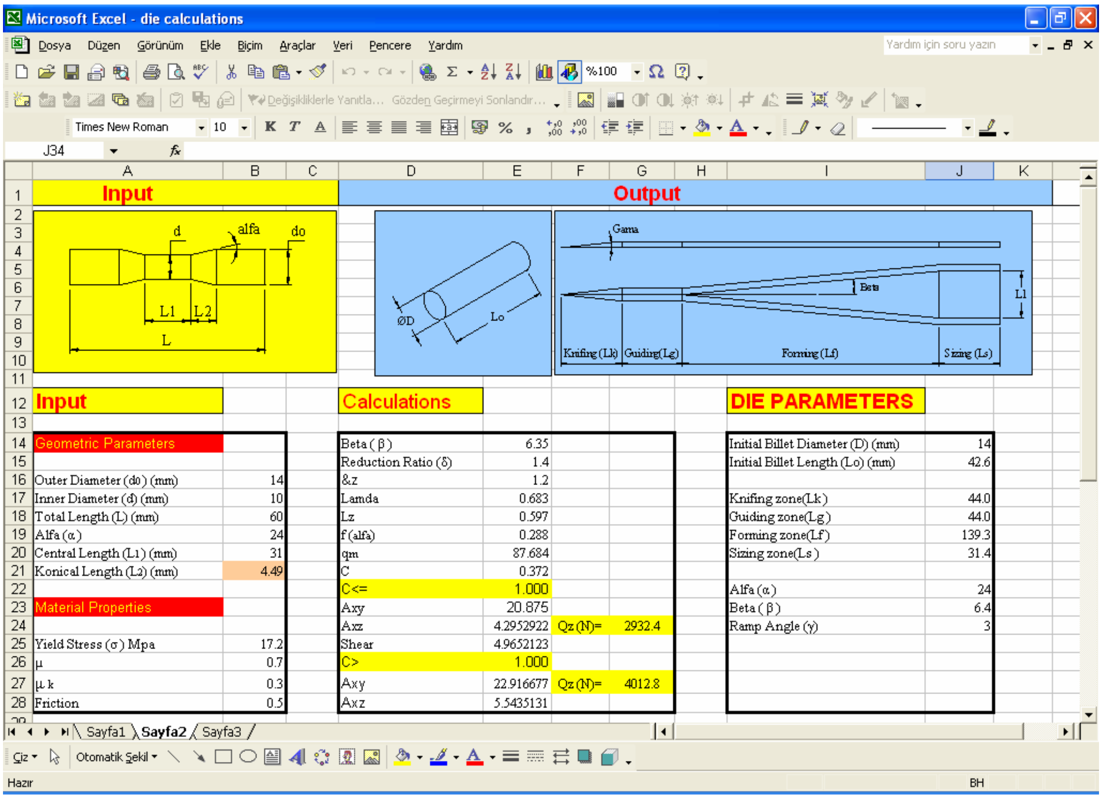
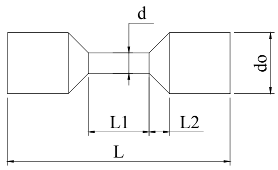
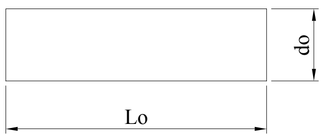
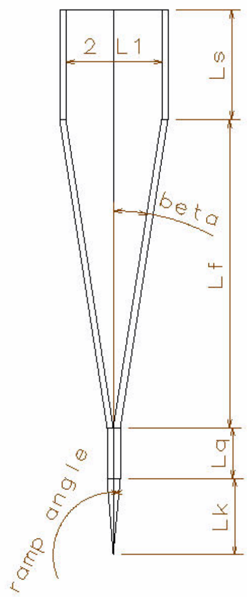


Fig. 4.6 Print Screen of Excel Sheet

Table 4.1. Wedge tool values according to final component given in Fig. 4.4

Product	
Billet	
Die	

d_o= 14 mm

d= 10 mm

L_1= 31.02 mm

L_2= 4.49 mm

L= 60 mm

α= 24^0

γ= 3^0

β= 6.35^0

F(Load)= 2932 N

L_K= 44 mm

L_G= 44 mm

L_F= 139.37 mm

L_S= 31.4 mm

CHAPTER 5

EXPERIMENTAL STUDY

5.1. INTRODUCTION

For experimental study, a prototype of cross wedge rolling (CWR) machine was constructed. In this chapter structure of the prototype CWR machine is explained. Photographs of dies and the workpieces and some graphical results are also presented.

5.2. DESIGN AND CONSTRUCTION OF EXPERIMENTAL SET-UP

In order to validate the theoretical results with the experimental results, a prototype of flat wedge CWR machine was designed and constructed. This apparatus, which is modelled after a CWR process is depicted in Fig. 5.1. A brief description of the CWR testing procedure follows. A cylindrical workpiece initially placed into the center of the apparatus, equidistant from a pair of flat wedge forming tools. The forming tools are then driven in the horizontal direction with enough force to fully shape the billet material while maintaining a constant velocity. This is accomplished using two pneumatic cylinders that are attached to air source. When the pneumatic cylinders activated at the onset of the experiments, the cylinders extend, moving the forming tools into the billets. The billet then deforms and rotates due to the tangential forces that develop between the tool and the workpiece. The final deformed shape of the billet material is controlled by the geometry of the forming dies.

The pneumatic cylinders have Ø 63 X 350 mm stroke and placed onto the U beam carbon steel which has length of 2000 mm.

Two carriage & guider type of bearing equipments were used for each plate. To move the wedge tools, wedge tools were assembled to the carrier plates. According to the forming length of the die, longer plates may be required. During the forming process front and back side of the plate is positioned directly in line with the intersecting point of wedge nose and midside of the workpiece.

Air entering to the cylinders has to be provided equally and regularly. For this reason, air regulators were assembled to the inlet and outlet of the cylinders. Moving control of the wedge tools made by a 5/3 manual type air controlling valve. By this valve, at any stages of the rolling process movement of the plates can be stopped and the deformation stage and shaping of the workpiece can be checked easily.

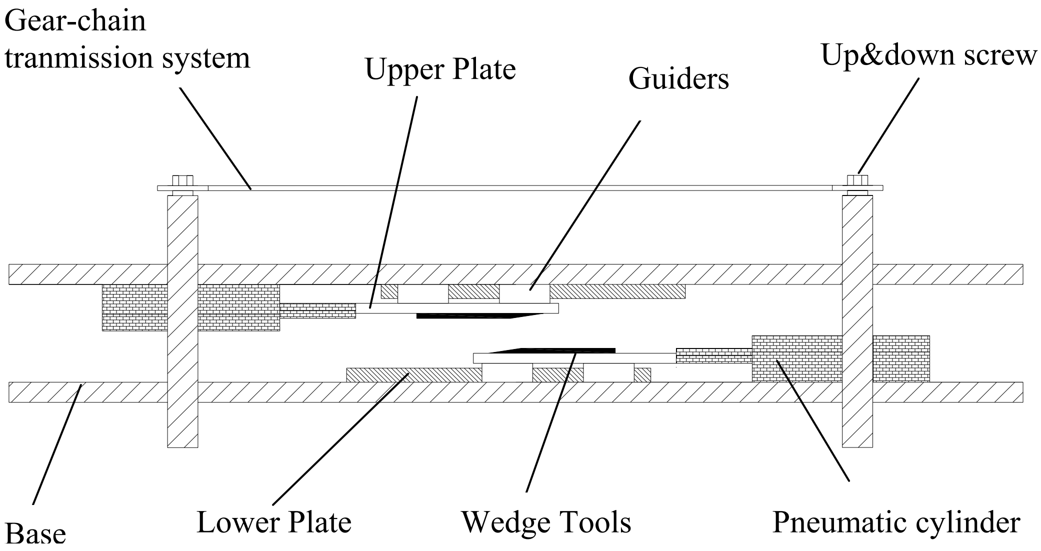


Fig. 5.1 A schematic Drawing of Experimental Setup

In order to drive the billet through the dies, billet must be placed firmly between the upper and lower plates. Since the diameters of the billets are different, which were used in the experiments, it is needed to adjust the vertical distances between the dies. In the experimental set-up this vertical movement is achieved by up&down screw and parallel connected chain-gear type transmission system.

Photographs of CWR machine can be seen on figures 5.2 to 5.5

Fig. 5.2. Front View of Prototype CWR Machine

Fig. 5.3. Flat Wedge

Fig. 5.4. Gear-Chain Transmission System

Fig. 5.5. General View of the CWR Machine

The maximum air supply to the cylinder is 10 bars. Force is held by 63 mm inner diameter of pneumatic cylinders. Force can be calculated by the following equations 5.1 and 5.2.

$$F = P \times A \qquad (5.1)$$

P= 10 bars = 10 × 10^5 Pa (N/m^2)

$$A = \frac{\pi d^2}{4} \qquad (5.2)$$

$$F = \frac{10 \times 10^5 \times \pi \times 0.063^2}{4}$$

Total force produced by cylinders is ;

F= 3117.24 N

5.3. EXPERIMENTAL STUDY

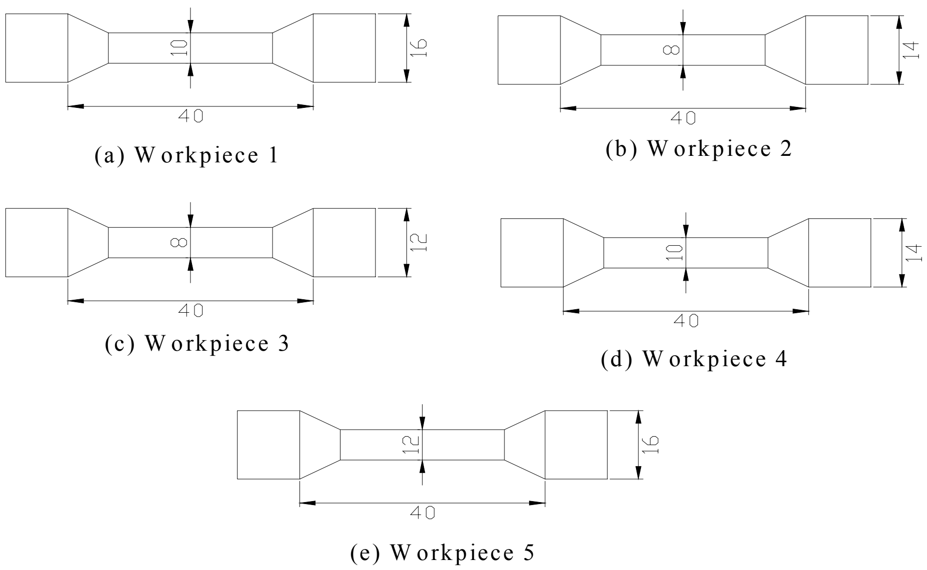
In the experiments, different sizes of workpieces ie 12, 14 and 16 mm diameter of billets were tested. According to the calculated die parameters, wedge tools were manufactured. These tools are firstly cut by laser and then forming angle was given by milling machine. Two different type of billet material were used; plasticine and lead.

Following Table 5.1 shows the sizes of wedge tools which have been manufactured for this experimental study. 15 different wedge tools are desired to manufacture. In these tools it is tried to find the effects of parameters on forming the workpiece. For this reason different forming angle, spreading angle and reduction ratios were encountered.

Table 5.1 Wedge Tool Dimensions for Experimental Works

workpiece no	wedge tool	α	β	δ	Lk=Lg (mm)	Ls (mm)	b (mm)	bs=2l (mm)	Lf (mm)	Lt=Lk+Lg+Ls+Lf (mm)
	1	22	6,20	1,6	55,29	34,55	40	25,14	115,7	260,83
1	2	24	5,71	1,6	55,29	34,55	40	26,62	132,61	277,74
	3	26	5,3	1,6	55,29	34,55	40	27,69	149,24	294,37
	4	22	6,2	1,75	48,38	27,64	40	25,14	115,7	240,1
2	5	24	5,71	1,75	48,38	27,64	40	26,52	132,61	257,01
	6	26	5,3	1,75	48,38	27,64	40	27,69	149,24	273,64
	7	22	6,2	1,5	41,46	27,64	40	30,09	138,49	249,05
3	8	24	5,71	1,5	41,46	27,64	40	31,01	155,06	265,62
	9	26	5,3	1,5	41,46	27,64	40	31,79	171,34	281,9
	10	22	6,2	1,4	48,38	34,55	40	30,09	138,49	265,34
4	11	24	5,71	1,4	48,38	34,55	40	31,01	155,06	281,91
	12	26	5,3	1,4	48,38	34,55	40	31,79	171,34	298,19
	13	22	6,2	1,33	55,29	41,46	40	30,09	138,49	290,53
5	14	24	5,71	1,33	55,29	41,46	40	31,01	155,06	307,1
	15	26	5,3	1,33	55,29	41,46	40	31,79	171,34	323,38

In above table; the dimensions were tabulated by using the formulas [10]. Figure 5.6 shows the workpieces which have a different reduction ratio values and tried to be produced with that wedge tools.



(a) Workpiece 1

(b) Workpiece 2

(c) Workpiece 3

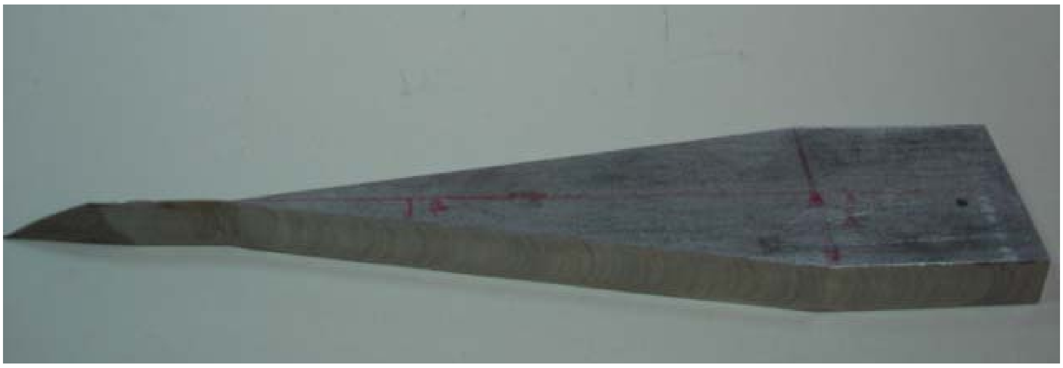
(d) Workpiece 4

(e) Workpiece 5

Fig 5.6 Workpieces in Different δ Values Tested on Experimental Setup

As a first experiment following wedges are manufactured (Figure 5.7). This wedges have geometric values of $\alpha=60^0$, $\beta=9^0$, Lk=20mm, Lg=33mm, Lf=132mm, Ls=50mm. As a friction coefficient $\mu=0.45$ is assumed and billet diameter is 26mm. As it is seen from Figure 5.8, the obtained finished product has lots of failure in both geometrical size and structure. This is due to the improper selection of the die parameters.

(a)



(b)

Fig.5.7(a, b) First Manufactured Wedge Tool

Fig.5.8 Workpiece Failure Obtained from the Wedge in Figure 5.7.

In order to give the shape to the full circumference of workpiece, 12mm and 14mm diameter of workpieces were used. Wedges can be seen in Figure 5.9 which have a geometrical parameters of α=24, β=5.7 and δ=1.6. Thickness of the wedge is 3 mm, diameter of the billet is reduced from 16 mm to 10 mm. Figure 5.10 shows the photographs of finished product.

Fig. 5.9 Wedge Tools Numbered by 2 in Table 5.1

(a)

(b)

Fig. 5.10. Photographs of Plasticine Obtained from the Wedges in Figure 5.9

In the following Figure 5.11 reduction ratio is changed from 1.6 to 1.5. The other parameters such as forming angle and the stretching angle are the same with the wedges presented in Figure 5.9, but forming length is longer. Thickness of the wedge is 2 mm and diameter of the billet is reduced from 12 mm to 8 mm. Forming length is increased from 132 mm to 155 mm.

Fig. 5.11 Wedge Tools Numbered by 8 in Table 5.1

(a)

(b)

(c)

Fig. 5.12 Photographs of Plasticine and Lead Obtained from Wedges in Fig. 5.11

(d)

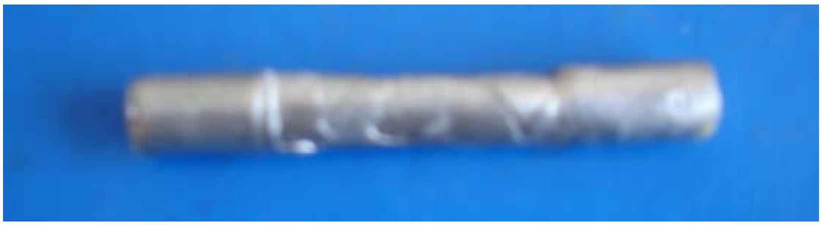
Fig. 5.12 Photographs of Plasticine and Lead Obtained from Wedges in Fig. 5.11 (cont.)

In the following Figure 5.13 reduction ratio is arranged to 1.4. The other parameters such as forming angle and the stretching angle are the same with the wedges presented in Figure 5.9, but forming length is longer. Thickness of the wedge is 2 mm and diameter of the billet is reduced from 14 mm to 10 mm. Forming length is 155 mm.

Fig. 5.13. Wedge Tools Numbered by 11 in Table 5.1

(a)

Fig. 5.14 Photographs of Plasticine and Lead Obtained from Wedges in Fig. 5.13



(b)

(c)

Fig.5.14. Photographs of Plasticine and Lead Obtained from Wedges in Fig. 5.13 (cont.)

Fig.5.15. Wedge Tools Used Experimental Setup α=20, β=7 and Thickness 2mm

Fig.5.16. Wedge Tools Used Experimental Setup α=25, β=9 and Thickness 2mm

Fig.5.17. Photograph of Plasticine Obtained from Wedges in Fig. 5.15

5.3.1 Experimental Results Load Values

Required load for forming is calculated by the equations from eq.4.1 to eq.4.18. Table 5.2 shows the comparison of these calculated load by literature [11]. It is clearly seen that there is close relationship between the tool parameters of cross wedge rolling on loading . Results were compared with the theoretical results which is estimated by the authors in previous works [3,11]. While the forming angle and spreading angle were kept constant and increase the relative reduction only; the loading force increase gradually for the workpieces which had same diameter. The forming angle is one of the most effective parameter for loading force. This case can be seen clearly from the table like;

* While other parameters are kept constant and increasing the forming angle to 30^0 than the loading force amount decrease gradually. (see test no:6,7,8,9,10)

* When the spreading angle start to decrease than the radial force amount decreases.

Theoretically calculated load values are very close to the values obtained from literature. The ratios between the loads are presented in Figure 5.18.

Table 5.2 Calculated and Theoretical Parameters of Some CWR Tools for Calculation of Forming Load

Test no	Alfa(α)	Beta(β)	δ	Radius	Q(calculated)	Q(paper)	Qc/Qp
1	20	9	1,29	9	5653.9	5367	1.05
2	20	9	1,40	7	3476.5	3599	0.97
3	20	9	1,5	9	5584.4	5493	1.02
4	20	9	1,67	10	6599.3	6630	1
5	20	9	1,8	9	5140.3	4925	1.04
6	30	9	1,29	9	4477.5	4609	0.97
7	30	9	1,43	9	4395.1	4736	0.93
8	30	9	1,46	8,4	3824.1	3915	0.98
9	30	9	1,50	9	4331.6	4357	0.99
10	30	9	1,56	9	4263.7	4167	1.02
11	40	3	1,27	7	1917.7	1957	0.98
12	40	3	1,40	7	1922.6	2210	0.87
13	40	3	1,43	10	3750.8	4104	0.91
14	40	3	1,50	9	3056.8	3283	0.93
15	40	6	1,43	10	4197.8	4167	1.01
16	40	9	1,50	9	3710.9	4167	0.89

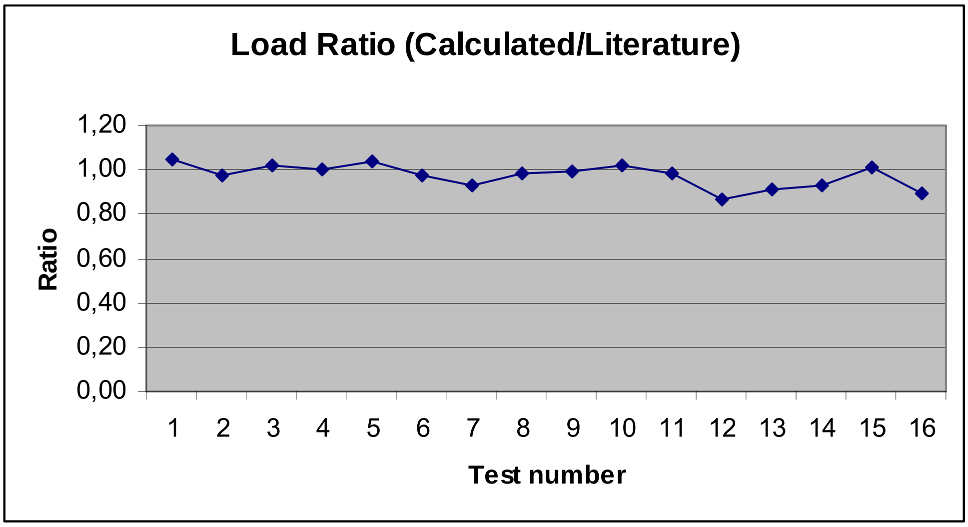


Fig. 5.18 The Ratio of the Radial Force Between Theoretical and Calculated Values

In the following Figure 5.19, effect of forming angle with respect to forming load according to different reduction ratio can be seen. In this Figure, spreading angle has been kept constant and thus, corresponding load value was recorded. Form this figure it is observed that increment in forming angle results to decrease the load. Calculations are carried out according to Upper Bound Elemental Technique which is presented in Figure 4.6. On the other hand effect of spreading angle with respect to forming load according to different reduction ratio can be seen in Figure 5.20. It is observed that increment in spreading angle results to increase the load.

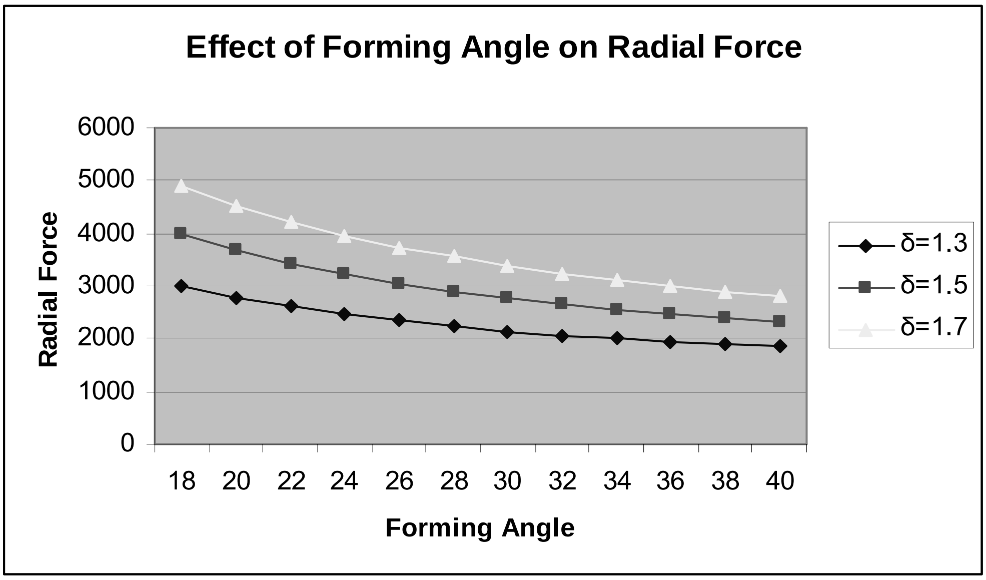


Fig. 5.19 Effect of Forming Angle on Radial Force where δ=1.3, δ=1.5 and δ=1.7

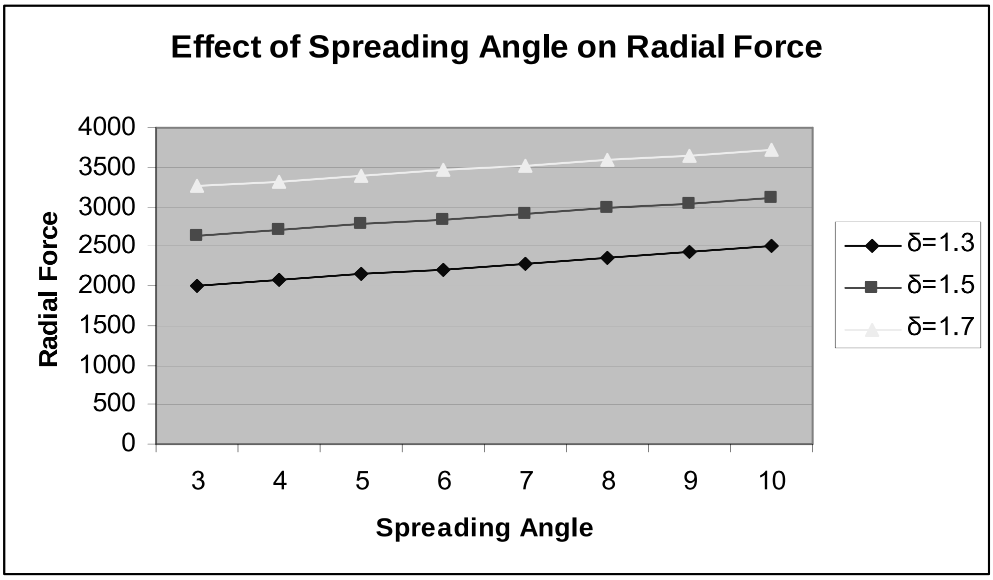


Fig. 5.20 Effect of Spreading Angle on Radial Force where δ=1.3, δ=1.5 and δ=1.7

5.4 SINGLE DIE MOVABLE EXPERIMENTAL SETUP

In this type of flat CWR set-up, cylindrical billet is plastically deformed into an axisymmetrical part by the action of wedge shaped dies. Bottom die is moving back and forth and while the other is stationary. A new experimental setup is constructed to see the rolling performance with different apparatus. For this purpose, vertical milling machine was used. Bottom wedge tool is mounted to the base of the milling machine and top wedge tool is fixed by the tool head. The photographs of this construction can be seen in Fig. 5.23

(a)

Fig.5.21. Photographs of Experimental Setup Single (Bottom) Die Moveable

(b)

(c)

Fig.5.21. Photographs of Experimental Setup Single (Bottom) Die Moveable (cont.)

(d)
Fig.5.21. Photographs of Experimental Setup Single (Bottom) Die Moveable (cont.)

Same wedge tools which were used on early experimental setup was tested on new setup shown in fig. 5.22 and 5.24. Plasticine, lead and aluminium were tested. In addition; Aluminium workpieces also tested in this setup by heating the workpieces to 400 C.

Fig. 5.22 Wedge Tools Used Experimental Setup (Fig. 5.24) α=25, β=9 where thickness is 2mm

Fig. 5.23 Photograph of Plasticine Obtained from Wedges in Fig. 5.22

Fig. 5.24 Wedge Tools Used Experimental Setup (Fig. 5.23) α=30, β=7 where thickness is 4mm

Fig.5.25 Photographs of Aluminium Obtained from Wedges in Fig. 5.24 with Cold Rolling

Fig. 5.26 Photographs of Aluminium Obtained from Wedges in Fig. 5.24 with Heating the Workpieces to 400 C

Fig. 5.27 Photographs of Aluminium Obtained from Wedges in Fig. 5.24 with Heating the Workpieces to 400 C

Fig. 5.28 Photograph of Plasticine Obtained from Wedges in Fig. 5.24

Lead workpieces manufactured by wedges which have a values of α=25, β=7 and thickness 3 mm are shown in figures 5.29.

(a)

(b)

Fig.5.29. Photographs of lead obtained from wedges with α=25, β=7 and thickness 3 mm.

CHAPTER 6

DISCUSSION AND CONCLUSION

6.1. INTRODUCTION

The results of the experimental studies are concluded in this chapter to asses to what extent the objectives have been met.

6.2. DISCUSSION AND CONCLUSION

In this study, the parameters of CWR are investigated and an experimental setup has been constructed for testing of billets by different wedge tools. Wedge tools were designed in different forming angle and spreading angles. These tools were used for testing of billets materials lead, aluminium and plasticine. Different area reduction ratios were also carried out during the experiments. Following conclusions can be drawn after theoretical and experimental studies.

It is observed that in cross wedge rolling process there are four zones in the work piece deformation process corresponding to the four zones of wedged die geometry, i.e. knifing zone, guiding zone, stretching zone and sizing zone. The effects of these zones can be explained by the followings:

- The first zone, knifing zone, is mainly to shape a V-shaped groove, whose height starts at zero and increases to the total reduction of height, and drives the billet.

- In the guiding zone the die geometry has no change comparing to the end of the knifing zone in order to obtain a uniform V-shaped groove around the workpiece surface.
- The spreading zone is playing an important role in deforming workpiece. In this zone, the work piece material is stretched and forced to flow to the ends so that the shoulders of the billet can be formed.
- The dimensional tolerance and surface quality of the product are finely given in the sizing zone where the cross section of the die remains uniform.

The spreading angle is considered as one of the important factor for the amount axial deformation on workpiece. As spreading angle β increases , the amount of axial stress and plastic deformation experienced by the work piece increases.

The forming angle controls the size of the contact area between the tools and the work piece in the knifing and guiding zone. In these zones, a smaller forming angle signifies a sharper tool, which increases the contact area and produces a more localized plastic deformation.

The area reduction, is named from the amount of reduction in cross section of the workpiece. Larger are reduction created is the larger radial deformation of workpiece. The increased rolling load results from increase of basic process parameters, i.e. forming angle, spreading angle and relative reduction.

It is determined that the cross wedge rolling process can be adequately represented by the parameters such as; knifing zone, guiding zone, forming zone, sizing zone, ramping angle, forming angle, stretching angle, material, required load, rate of loading, friction effect and strain. As it is seen from the experimental works and theoretical calculation which was shown in previous chapters there is a significant relationship between tool geometry parameters.

The influence of forming angle, spreading angle, and the reduction area parameters on force and energy analysed that parameters of force and energy decrease with the forming angle increase with spreading angle, while the influence of the reduction of area is more complicated.

6.3 RECOMMODATION FOR FUTURE STUDIES

Utilization of the following items will be useful for extension of the present work;

- It is observed that the better way for producing the wedge tools (dies) is cutting from whole plate by CNC machines.
- The billets and wedge tool geometries are needed to design according to each different product geometry.
- Measurement capabilities of the set-up should be improved.
- Speed of the wedges should be controlled.
- Applied load and rate of load should be adjusted.
- Experiments can be carried out by different materials with different forming (cold-warm-hot) conditions.

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