# ANALYSIS OF COINING PROCESS IN PRODUCTION OF MEDALLION

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# ABSTRACT

ANALYSIS OF COINING PROCESS IN PRODUCTION OF MEDALLION

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Coins and medallions are manufactured by using coining process which is a metal forming process. In coining of medallions, there is a strong need to shorten the production time and reduce the production cost and waste of material in conventional coining method. An alternative coining method may be considered in order to reduce the production time and the manufacturing cost. In this study, a new method has been proposed. In the proposed method, design of the medallion is performed by utilizing computer aided engineering (CAE) environment and the master die is manufactured by means of NC codes.

The modular designs of blanking and coining die sets for medallions with a diameter in the range of 30-90 mm have been realized. Coining and blanking processes for production of the medallion have been simulated by using a commercial finite volume program. Moreover, a commemorative medallion for the opening ceremony of METU-BILTIR Center Forging Research and Application Laboratory has been designed.

After die sets have been manufactured, the real-life experiments have been conducted by using 1000 tones mechanical forging press and 200 tones eccentric press available in Forging Research and Application Laboratory of the METU-BILTIR Center. The results have been compared with the computer simulations. After the real-life experiments, it has been observed that medallions have successfully been obtained by employing the new proposed method. Therefore, the new proposed method for coining has been verified.

**Keywords:** Coining, Blanking, Medallion, Finite Volume Method

# ÖZ

## DÖVME YÖNTEMİ İLE MADALYON ÜRETİMİNİN ANALİZİ

Akkuş, Derya

Yüksek Lisans, Makine Mühendisliği Bölümü
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Madeni para ve madalyonlar, bir metal şekillendirme yöntemi olan dövme baskı yöntemi ile üretilmektedir. Geleneksel madalyon basımında, üretim süresinin kısaltılmasına, maliyetlerinin düşürülmesine ve atık malzeme miktarının azaltılmasına şiddetle gereksinim bulunmaktadır. Üretim sürelerini kısaltmak ve üretim maliyetlerini düşürmek için alternatif bir baskı para üretimi yöntemi uygulanabilir. Bu çalışmada baskı için yeni bir yöntem önerilmiştir. Önerilen yöntemde, madalyonun tasarımı bilgisayar destekli mühendislik (BDM) ortamında yapılmakta ve ana kalıp NC kodları ile üretilmektedir.

Çapları 30-90 mm arasında değişen madalyonlar için modüler dövme kalıp ve pul üretim kalıpları gerçekleştirilmiştir. Madalyonun dövme işlem süreci ve pul üretimi ticari olarak piyasada bulunabilen bir sonlu hacim programında benzetimli olarak gerçekleştirilmiştir. Ayrıca, ODTU-BILTIR Merkezi Dövme Araştırma ve Uygulama Laboratuarı açılışı anısına bir hatıra madalyon tasarlanmıştır. Kalıp setleri ve pul malzemeler üretilmesinden sonra. deneyler ODTU-BILTIR Merkezi Dövme Araştırma ve Geliştirme

Laboratuarı'nda bulunan 1000 tonluk mekanik pres ve 200 tonluk eksantrik pres ile yapılmıştır. Deney sonuçları bilgisayar simülasyonları ile karşılaştırılmıştır. Yapılan deneylerden sonra, önerilen yöntem kullanılarak madalyonun başarılı ile elde edilebildiği gözlemlenmiştir. Bu da gösterir ki, baskı yöntemi için önerilen yöntem hayata geçirilmiştir.

**Anahtar Sözcükler:** Baskı Dövme, Metal Şerit Kesme, Madalyon, Sonlu Hacim Yöntemi

To My Family

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# TABLE OF CONTENTS

## LIST OF TABLES

TABLES

## LIST OF FIGURES

FIGURES

# CHAPTER 1

# INTRODUCTION

## 1.1 Coining Process

Coining is used to produce decorative items such as coins, medallions, patterned tableware, metal buttons and other products where exact size, fine details and also tight tolerances are required in a product. When articles with a design and a polished surface are required, coining is the only practical production method to use [1,2].

The process is a closed-die forging operation generally performed at the room temperature by means of a positive displacement punch while the metal is completely confined within a set of dies. The metal forming operation in which the material is displaced in a small amount compared to the total volume of the part is also called coining [1]. History of coining is provided in Appendix A.

## 1.2 Observations from Turkish Mint

The Turkish Mint in Istanbul was visited and the conventional coining process was carefully observed by the author. In Turkish Mint, in order to form a decorative coin, token or a medallion, many operations are applied in different workshops. Firstly at Art Workshop, the sculptor and a design team conduct a study which includes history and important items of the occasional event or gathering information about the person for whom the coin will be made for. After preparations are completed, the design is sketched with a certain larger scale on paper by the sculptor. The design team determines the most appropriate design as designated the shape considering different type of alternatives of the coin or medallion that is being worked on. After that, the sketch is engraved on plaster that is easy to change its shape after drying and to adjust its hardness. Then the work on plaster is transferred to gypsum which is used as positive modeling material. The process can be seen in Figure 1.1. Sculptors work on the detail of the positive gypsum mold [3].


**Figure 1.1 The Transfer of the Plaster Sketch to Gypsum Mold [3].**

As seen from Figure 1.2, after the positive gypsum mold is cast, a negative gypsum mold is created from the first one in order the details to be transferred on acrylic mold which is a rigid thermoplastic sign material relatively tough. The mirroring step of negative gypsum to acrylic creates a positive mold.


**Figure 1.2 The Transference of the Gypsum Mold to Acrylic Male [3].**

Secondly, in the Die/Mold workshop, the relief is read by laser reader of the engraving machine. The old engraving machines are mechanical machines that reduce the size, height and detail of the relief proportionally by simultaneously moving mechanical probe and tool. According to dimensions and detail of the mold, this process could last at least 36 hours. Because dies that will be used for manufacturing of master die have to remain in the same axis with the pioneer part during manufacturing, the relief of the die could not be produced within the desired tolerance zone [3]. The machine is shown in Figure 1.3.

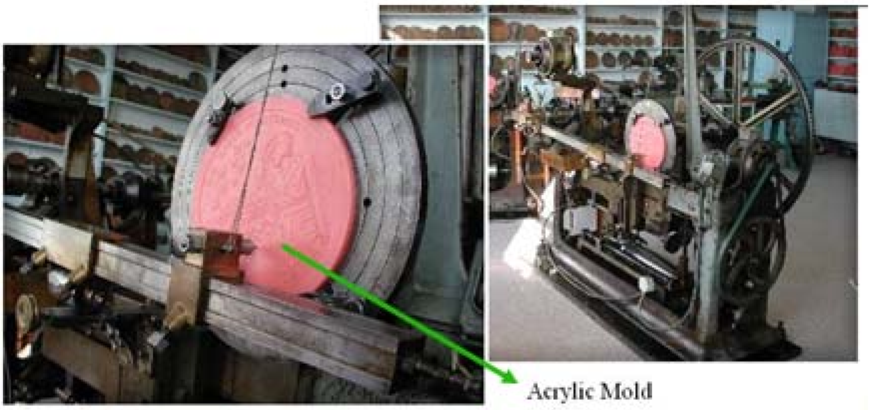



**Figure 1.3 The Mechanical Engraving Machine [3].**

With the developing technology, CNC engraving machines which can be seen in Figure 1.4 are being used in Turkish Mint. Compared to the mechanical machines, this type of production of dies shortens the set up times and increase production. It utilizes a mechanical probe to digitize any surface quickly for high quality 2D and 3D engraving, keep the data in the memory and produce a die which will be used for producing of a master die in the same machine with the data obtained. It warrants smooth and quiet operation while providing high-quality surface-finish engraving [4]. This process provides extremely high precision in details due to the combination of maintenance-free stepper motor and precise axes adjustment [3].

After manufacturing of the master die, surface quality and detail precision of the die is again manually controlled. If there is any unwanted material or defect on the face of the die, a thin layer of material are removed from surface and surface is polished.

**a) Reading of plaster**

**b) Manufacturing of guide die in the same machine**

**Figure 1.4 The CNC Engraving Machine [3].**

A master die is produced from the reduction punch using a cold forging process called hobbing. This is achieved by pressing the design into another piece of soft steel using very high forces in a hydraulic press. This master die is then hardened and used in the same way to produce a ‘positive’ tool called a hob or hub [5].

An electro-plating process is applied to the tool to deposit hard chromium on the surface of the die to reduce wear in the coining process and to extend the life of the dies. Afterwards, dies to be used in minting are manufactured according to master die details and brought to the desired hardness by heat treatment. As a last process polishing is done on the dies that will be used in mintage.

Firstly in the mint, alloy material is cast and rolled to the desired thickness or purchased from the suppliers. Blanks are cut from the rolled metal alloy, which usually consists of a mixture of base metals. The composition of these alloys is carefully controlled.

During the rolling, work hardening is naturally applied to the blank metal. Before the coinage, the blanks need to be softened slightly in a furnace by bring blanks up to a certain temperature and then cooling them again. This provides metal to relieve thermal stresses. After annealing, the blanks are burnished to make their surface brighter, remove any discoloration and in some cases apply a minute amount of lubricant to assist in coining. In the burnishing machine, surfaces of blanks are etched and polished by tumbling inside a mixture of small steel balls and ceramic media combined with special chemicals. After burnishing, the blanks are dried with hot air.

The web sites of Australian Mint have also been examined [5].

After blanks are prepared; they may be fed automatically into the tungsten carbide collars. The collar which can be seen in Figure 1.5 locates the blank prior to striking and controls the finished size and shape of the edge of the coin. If notch shape is wanted on the outside of the coin to be formed, collar which has the mirrored notches is used. To produce the obverse and reverse designs, the blank is struck simultaneously with two dies during coining. This edge detail is transferred to the workpiece by first machining the retaining ring and then coining. While mounting the dies, upper and lower dies should be properly aligned. Otherwise, coining defects may be encountered.

Several different types of coining presses are operated for general circulating coins. The coining capacity of these presses ranges from 100 to 500 tones force. The choice of press depends on the size and alloy (metal) of the struck coin. The larger the coin and harder the metal, the more pressure required, which usually means a slower strike rate. Defected blanks are automatically rejected by the press without slowing down the production process.

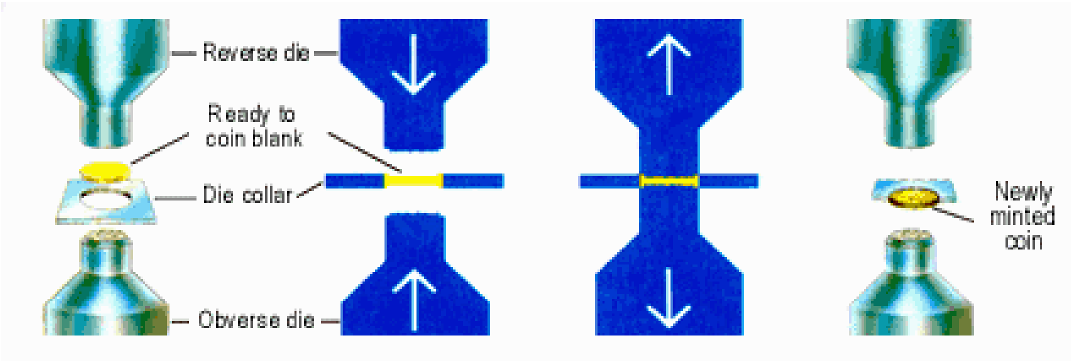



**Figure 1.5 Coin Strike Operation [5]**

During the striking, generally no lubricant is used because lubricant can be struck between the die and blank and form a dip called surface pocket. Therefore, this formation affects the surface quality and internal stresses inside the dies [6].

Coins are first counted electronically to control whether the last product is below from the accepted standards. After bagging, are weighed as an additional check.

### 1.3 Some Previous Studies on Coining

Some previous studies have been conducted on coining. Choi, *et. al*. [7] developed a finite-element analysis program using the rigid–plastic method for process design in three-dimensional plastic deformation. Applying the developed program to a precision-coining process, the amount of deformation was obtained.

To produce a smaller and more functional precision electrical component in the electronic guns of TV tube, Byun, Huh and Kang [8] developed a multi-operation process sequence improving the conventional manufacturing. Finite element method was used for the design and analysis of the developed process. By conducting a series of experimental forming, numerical results are validated by using precision measurement techniques.

Ike [9] has studied the fundamental effects on the formation of surface microgeometry in coining process. The local contact pressure, bulk plasticity, combined stresses and relative sliding on the forming surface can be counted as the major factors. Experimental productions have been done for the effects separately and compared with the data on literature so that the results were in the acceptable range.

Wang, *et. al*. [10] coined the pure aluminum to monitor the effects of die cavity dimension on the microforming ability of various microparts in the production of micro electro mechanical systems (MEMS). The results of the experimental production can be evaluated with the use of the grain structure of the microforming billets. According to well-produced microgears which were soon heat treated, it was seen that small die details could be completely formed.

Choi, Kim and Kang [11] has applied precision coining operation to develop the finite element method called backward tracing scheme in which forward loading simulation and backward tracing of a rigid plastic forming operation in the three dimensional metal forming. During the experimental coinage, the shape and location of the central piercing hole was examined. Results showed that the geometrical tolerances of the production were reasonable and the method could be used in industrial applications easily.

Thome, Hirt and Rattay [12] have studied the sheet metal production by means of coining process to design and support the geometrical properties of dies. Considering the dies separate, forming as inserts, instead of one-pieced dies, the relation between geometric characteristics of the tools and finished product was analyzed. In the analyses, the comparison factor was the coining force levels.

Davis, *et. al*. [13] evaluated and improved the current coining process in which a one-dimensional sinusoidal shape is coined onto a thin circular blank so that presses were used feasibly. With the new technique developed, finite element simulations were stated and a coining tool were designed and manufactured. By means of this mechanism, alternative materials were tested and a sample of special nuclear material was coined as the experimental study.

### 1.4 Scope of the Thesis

The conventional coin production is very challenging procedure considering the formation of surface details and transference of the detailed shape from sketch which is the design on the paper to master dies. It requires tight dimensions and tolerances as well as a proper way of micro production. However, transferring design by multistage operation is time consuming and there is an increase of tolerance values all along the production line.

The design of medallions and coins are still performed by sketching the paper and transferring to the dies by several intermediate steps in mints. This time consuming procedure results in material waste and time consumption.

The scope of this study is to analyze the coining process, to introduce an alternative method which includes CAD/CAM applications to the design and production phases and to introduce modular design for both blanking and coinage dies. In this study, coining process of the commemorative medallion of the opening ceremony of METU-BILTIR Center is designed and produced.

Basic principles of coining and blanking will be given in Chapter 2 to provide a basis for the study.

In the study, the modular dies for both blanking stage and coining process will given in Chapter 3 and Chapter 4 in the order.

In Chapter 5, finite volume analysis for manufacturing of commemorative medallion of the opening ceremony of METU-BILTIR Center Forging Research and Application Laboratory will be presented. In this chapter, there will be also production of the modular coining die set and the medallion.

Current production of modular blanking die set and blanks will be given in detail in Chapter 6. In the same chapter, finite volume analysis of the proposed procedure for blanking will also be given.

The details of modeling, simulation and manufacturing of an experimental coin for observe the parameters of coining process will be given in Chapter 7.

Conclusion, discussion and recommendations for the future work will be given in Chapter 8.

# CHAPTER 2

# CHARACTERISTICS OF DECORATIVE COIN MANUFACTURING AND BLANKING

## 2.1 Introduction to Coining

The word “coin” derives from Latin *cuneus*, meaning wedge or punch, and a literal meaning of the word coin would be something that has been struck. But this definition would exclude modern coinage as well as ancient Chinese iron coins that were cast rather than struck. A satisfactory, if somewhat restrictive definition would be a round, flat piece of some recognized metal bearing the stamp of an issuing authority to guarantee its weight, fineness or value [14].

Minting is the process of transferring a design with relief features from a die onto a blank piece of metal.

Coins have a special terminology. To clarify the terminology, a sample coin is shown in Figure 2.1. The terms that are stated below can be generalized for all coins and medallions.

- **Obverse (Head):** the front or heads side of a coin or medal; generally bearing the date, mint mark, allegorical figure and main design.
- **Reverse (Tail):** Reverse is the back or tail side of a coin or medal regarded as of lesser importance. In the 1800's obverse and reverse meant the opposite of what they mean today [15].
- **Relief:** The part of the design that is raised from the surface of the coin is denoted as relief which is the opposite of incuse.
- **Edge:** Edge is the outer border of a coin; it can be also considered as the third side of the coin. On some coin edges, there may be letters, reeds

which is an edge with small lines on it, ornamental designs or plain edges. This part is formed with the design of collar.

- **Rim:** Rim is the raised edge on both sides of a coin. The idea being that if the edge on both sides of the coin is raised like the design it will help protect the coins design from wear.
- **Field:** The background portion of a coin's surface which is not used for design or inscription is called the field.
- **Legend:** Legend is the main lettering on a coin.
- **Mint mark:** Usually there is an additional small letter on a coin which denotes the place of minting. This letter is referred as the mint mark.

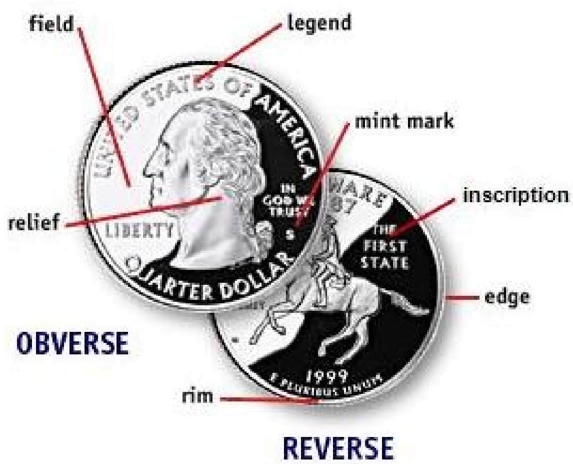



**Figure 2.1 The Main Parts of a Coin [16].**

In addition to the above terminology items, for some coins "incuse" may exist. Incuse is **r**ather than the coin's design being raised up off of the surface of the coin, it is pressed into the metal as cavity.

In closed-die coining, all surfaces of a prepared blank is compressed between the coining dies while it is retained and positioned between the dies by a ring or collar, resulting a well-defined imprint of the die on the workpiece. It is also a restriking operation that is used to sharpen or change a radius or profile, depending on the purpose, sizing or bottom or corner setting [2, 17] In Figure 2.2, orientation of the dies and necessary parts for operation can be seen.

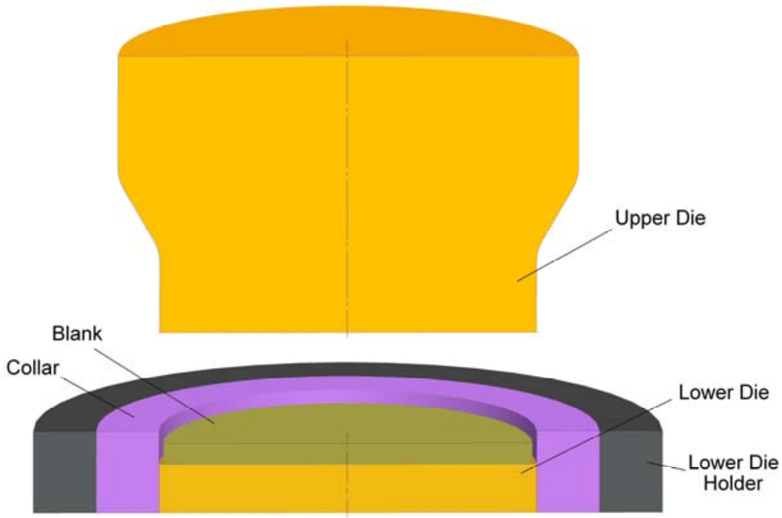



**Figure 2.2 Schematic Representation of the Die Setup Utilized for Coin and Medal Production**

The volume of the metal and the volume of the enclosure between the dies when they are confined should remain the same. Excessive loads that developed inside the dies do not damage the press and dies themselves unless the metal volume exceeds the space between upper and lower dies when closed. In order to ensure that volume of the blank remain constant, the weight, which is easily measured and converted to volume should be carefully controlled. Because of the confinement of the metal and the positive displacement of the punch, there is no possibility for excess metal to flow from the die; therefore production occurs without flash [1].

Generally, after production of definite number of coins, approximately 300,000, there is a possibility of die wear. To enable an effective production, die dressing is required to be minimized, keeping the relief of the coin design low. Compressive work hardening of the metal ensures the coin to have good wear resistance. Raising the edge of the coin, also called as milled edge, prevents the wear of the coin face.

A typical coining manufacturing operation has the procedure as follows:

- Blanking of coin disks from sheet metal is performed with surface finish and thickness that is determined for coin.
- The disks are barrel tumbled to deburr so that desirable surface finish and to control weight can be achieved.
- The disks are fed to the press.
- With the movement of the upper or lower die rather than by use of a conventional ejector. The coins are ejected from the retaining ring.

In the coinage, these steps can also be used for the processing of medallions, with some additional processes. Unless the design details are in high relief, edging operations are not required in production of medallions. In such a case, the full development of details may require restriking [2].

Since strain hardening occurs very quickly, only relatively thin annealed parts which have Brinell hardness value smaller than 100 can be produced in a single operation in cold coining process. Inside the cavity of coining dies, the prepared blank is loaded above the compressive yield strength and is held in this condition during coining. Dwell time under load is important for the development of dimensions in sizing and embossing; it is also necessary for the reproduction of fine detail, as in engraving [2].

Since coining process has a close relation with common hardness test, the required forces which start the initiation of cracks are well known. Practical limits on workpiece size are mainly determined by available press capacities and properties of the die material. Any contour on the blank can be formed by a certain amount of pressure on the projected area depending on the mechanical properties of the material and depth of indentations. The magnitude of this certain pressure varies between 500 and 3000 times the Brinell hardness or two and five times the tensile or compressive strength of the metal. For example, work metal with a compressive yield strength of 690 MPa loaded in a press of 22 MN capacity can be coined in a maximum surface area of 0.032 $m^2$. From the stress formula, as the yield strength increases, the area that can be coined using the same press decreases proportionately. However, an increase in strength of the workpiece should be limited so that plastic deformation of the die does not take place [1-2].

In coining process, the extruded projections are limited as to their minimum cross-sectional area and the minimum radii at their ends since producing a sharp design on either the raised surface portion or on the edge of a coined part requires very high pressures. In addition, during the deformation, the average thickness of a coined part should be restricted and should be kept nearly constant and not vary greatly from the edge to the center [1].

### 2.2 Type and Capacity of Machine Used in Coining Process

In coining, the workpiece is squeezed between the dies so that the entire surface area is simultaneously loaded above the yield strength. Because of the area loading requirement and the great stress needed to ensure metal movement, press loading for coining is frequently approach the capacity of the equipment used, with consequent danger of overloading.

Some coining equipment, such as drop hammers, cannot be readily overloaded. If a mechanical press is used in order to perform the coining process, an amount of stroke which is slightly more than the stroke that is necessary to fill the die cavity produces large pressures which may result in a failure in the tools and the equipment. This is most likely to happen if more than one blank is fed to the coining dies at a time. Such overloading can break the dies and even the press, and it will certainly shorten the life of the dies.

Overloading may be prevented by the use of overload release devices, and many presses are equipped with such devices. However, the usual means for avoiding excessive pressures and preventing overloading in presses is careful control of workpiece thickness, which must be sufficient to allow acceptable coining, but not enough to lead to press overloading. Such thickness control, combined with blank-feeding procedures designed to minimize double blanking, is normally adequate to prevent overloading.

Coining may be satisfactorily undertaken in any type of press that has the required capacity. However, the flow of metal during the coining is accomplished during a relatively short portion of the stroke, so that a coining load is required only during a small portion of the press cycle. Drop hammers, and knuckle-type and eccentric-driven mechanical presses are extensively used in coining. High-speed hydraulic presses also are well adapted for coining, especially when progressive dies are used. Large-capacity hydraulic presses are ideal for coining and sizing operations on large workpieces [1,2].

### 2.3 Lubrication in Coining Process

Whenever possible, lubricant is not preferred in coining operations. If entrapped in the coining dies, lubricant cause flaws in the surface. These struck lubricant particles are called lubricant pocket and they prevents the material to entirely fill the mating die covering the surface of the recesses and reproduction of fine die surface details. As dies get together, metal cannot be squeezed out of the die. For example, under conditions of constrained plastic flow, an entrapped lubricant will be loaded in hydrostatic compression and will interfere with the transfer of die detail to the workpiece. In many coining operations, however, because of work metal composition or the severity of coining, or both, the use of some lubricant is mandatory to prevent defects or seizing of the dies and the work metal [1,2].

No lubricant is used for coining teaspoons, medallions, or similar items where the high surface quality is required. Some type of lubricant is ordinarily used for coining copper and aluminum and their alloys and for coining stainless, alloy, and carbon steels. When coining intricate designs, such as the design on the handles of stainless steel teaspoons, the lubricant must be used sparingly. A film of soap solution is usually sufficient. Excessive amounts of lubricant adversely affect workpiece finish and interfere with transfer of the design [2].

## 2.4 Coin Defects

With uniform designs, the exact replication of the official design is not so easy to achieve. Despite the objective of complete uniformity, variations do occur. Varieties can originate from just about any stage of the minting process and errors of the stages.

There may be errors during the coining process due to the certain defects in the blank structure or misadventure during operation. Despite the fact that most errors can be filtered out by post strike inspection, an error coin may still get missed and pass into circulation. Some of the errors can be stated as follows:

- Brockage
- Mistrike
- Cud
- Clashed dies
- Clipped blank
- Double strike
- Mule

Wrong blank can be described as a brockage that is formed when a coin is not ejected from the press and remains in place while another blank is struck. The result is that the first coin acts as a die for the second one and makes an incuse impression of the exposed face. Image that can be seen in Figure 2.3 is of a hollow face.


**Figure 2.3 Sample of Coin with Wrong Blank [18]**

Mistrike is a fairly common error in which the blank has not engaged properly in the collar and so is struck off-centre which can be seen in Figure 2.4. In order the coin to be minted without this defect, blank should be located concentrically in the dies.


**Figure 2.4 Sample of Coin with Mistrike [18]**

Sometimes a die crack becomes so severe that a piece of the die can break away. In such a situation a cud is formed on the part blank. Figure 2.5 constitutes example of this type of defect.

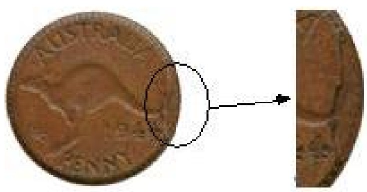



**Figure 2.5 Sample of Coin with Cud [18]**

The hammer and anvil dies may come into direct contact with each other in case a blank is not fed into the press accidentally. In this situation the harder die will leave its projection on the other one. In this example that can be seen in Figure 2.6, both true image and mirror image of Victoria can be seen on sides of the coin since harder die had left its impression the softer die due to a misfed blank.


**Figure 2.6 Sample of Coin with Clashed Dies [18]**

If a blank fails to feed into the press or fed of blank slips in the blanking press, clipped blank error which can be seen in Figure 2.7 occurs in which blank has struck more than once so circular shape of the blank damages. Clipped blank is a type of error in which the blank is punched from the edge of the strip caused by the misalignment of the metal strip in the blanking press.


**Figure 2.7 Sample of Coin with Clipped Blank [18]**

Double strike is a defect caused by a misalignment of the metal strip in the blanking press such that the blank was punched from the edge of the strip or delay of the removal of the coined blank. An example of the defect can be seen in Figure 2.8.


**Figure 2.8 Sample of Coin with Double Strike [18]**

After the first strike, if a coin cannot be fully ejected from the reach of the dies, the metal partly remain in the incidence of the dies. In the continuing strikes, the coin subsequently received a second blow which can be seen in Figure 2.9.


**Figure 2.9 Sample of Coin with a Second Blow in the Right Edge [18]**

## 2.2 Introduction to Blanking

Blanking is a shearing process wherein the shearing blades take the form of closed, curved lines on the edges of a punch and die. In blanking process, the primary sheet metal falls out as scrap and the punched part remains dropping through the die as the desired workpiece [19]. The illustration in Figure 2.10 shows a typical blanking process.

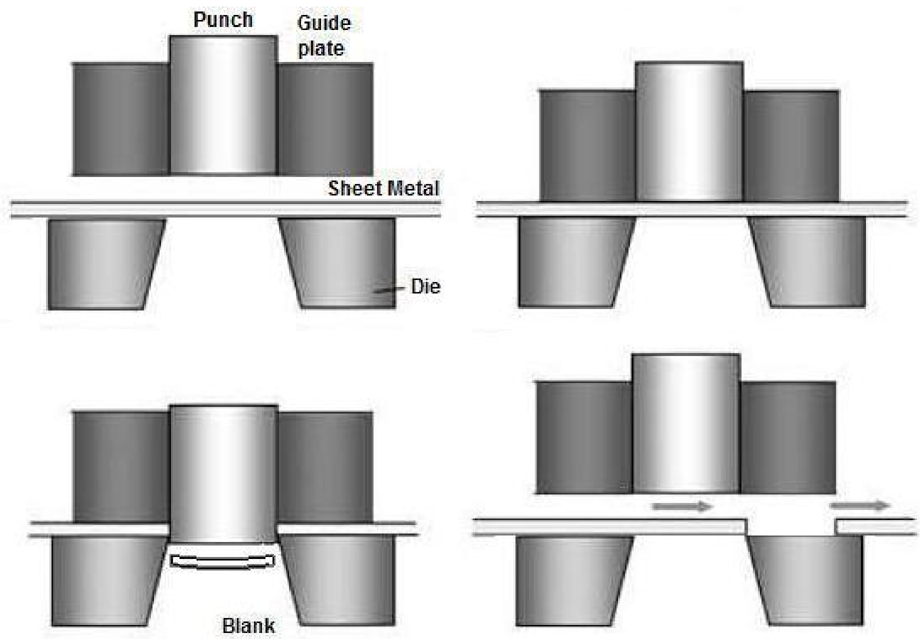



**Figure 2.10 Blanking Process**

It can be said that there are five stages in the blanking. In the beginning of the process blank material is elastically deformed by forcing the sheet material throughout the die. Until the process continues to reach the yield strength of the material, the outer fibers are deformed. Then, all the fibers in the zone between the area of punch and die are deformed. The plastic deformation causes rounding of the edge of the blank and thinning of the material which is under the punch. After this stage, crack formation occurs and friction outspread the contact area when pushing the blank through the die hole [20]. Cracks finally results in separation of the cut area off the sheet [21].

### 2.2.1 Clearance in Blanking Operation

The main objectives of the process design in blanking are to choose the process parameters which are the clearance, the tool wear state and the sheet thickness in an optimal way to ensure the quality of the blanked part [22].

If correct clearances between the punch and die are chosen, almost perfect edge surface may be obtained. When the clearance amount increases, excessive burrs occur on the side edge surface of the part. In Figure 2.13, clearance in shearing for good and bad conditions can be seen.

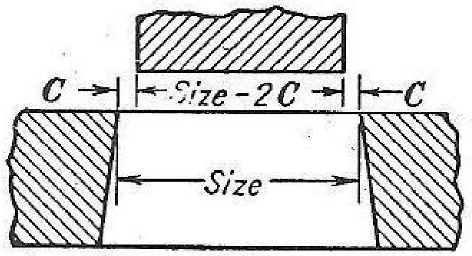



**Figure 2.13 Clearance in Shearing [21]**

The amount of cutting clearance between the punch and the die is of great importance in all sheet metal work. It is usually given as a percentage of the thickness of cut material, as shown in Table 2.1 [21].

**Table.2.1 Cutting Clearance of Material Thickness [21]**

| Material | Hardness HV | Clearence as a % of thickness |
|---|---|---|
| Mild Steel | 94-144 | 5-10 |
| 70/30 Brass | 77-110 | 0-10 |
| Copper | 64-93 | 0-10 |
| Zinc | 61 | 0-5 |
| Aluminum | 21-28 | 0-5 |

### 2.2.2 Calculation of the Shearing Force in Blanking Operation

The amount of force needed to produce blanks from the sheet metal has to be calculated in order to determine the size of a press to use.

At the beginning of the process, the press tonnage should be determined. If a press has lower tonnage than necessary is chosen, excessive stresses may be created during the process. With a much more tonnage, extra force will be inefficient [21].

Tonnage can be simply evaluated by using

$$F_{BL} = L \times t \times S_S \tag{2.1}$$

where L indicates the total length of a cut, t indicates the material thickness and $S_S$ is the shear strength of the material.

# CHAPTER 3

# MODULAR DESIGN FOR BLANKING DIES

## 3.1 Proposed Blanking Die Design

Medallions are produced by using blanking and coining processes. Medallions may have different outer diameters, generally in the range of 30-90 mm. In the study, a modular die set for producing of the blanks with different outer diameters has been designed. The blanking die set has mainly 10 components as seen in Figure 3.1, which are;

- Upper Supporting Die
- Interchangeable Component of Upper Die (i.e. punch)
- Fixed Component of Upper Die (i.e. punch)
- Bolt which fixes Interchangeable Component of Upper Die to Fixed Component of Upper Die
- Upper Die Support
- Bolts which fix the Upper Support to the Upper Supporting Die
- Guide Plate
- Lower Die
- Lower Supporting Die
- Bolts that fix the Guide Plate to the Lower Supporting Die

As seen from the figure, the upper die can be adopted to the different values of the diameter of the medallions. This design allows us to produce blanks with the outer diameter of 30-90 mm by changing the interchangeable component of upper die, guide plate and lower die.

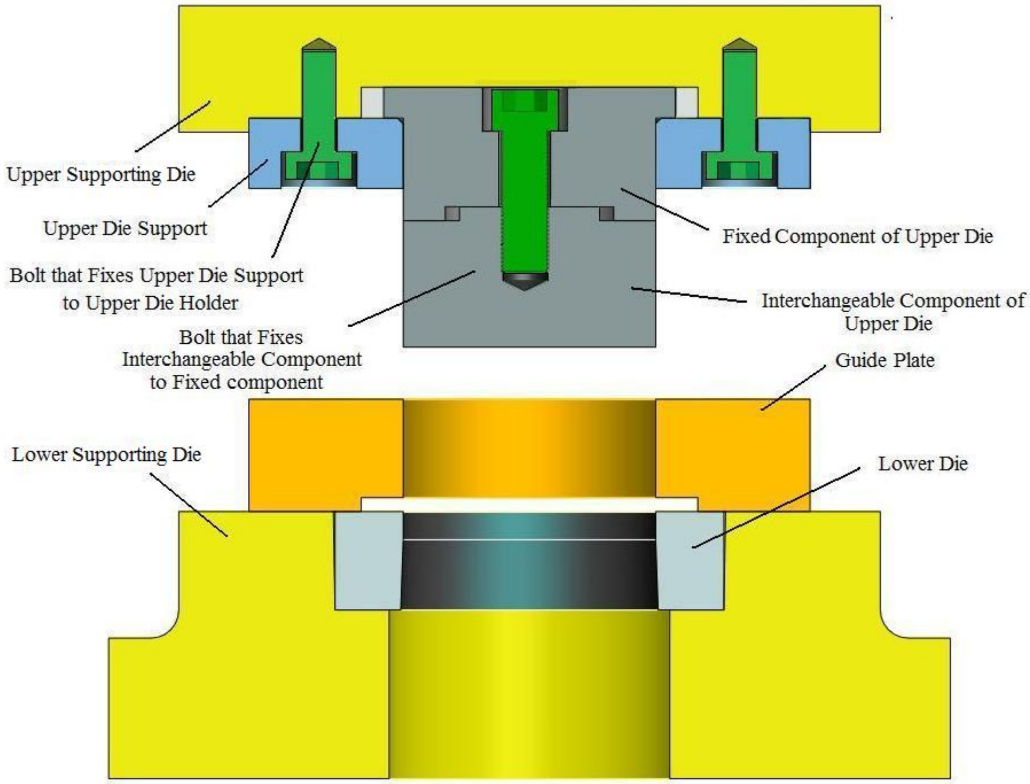


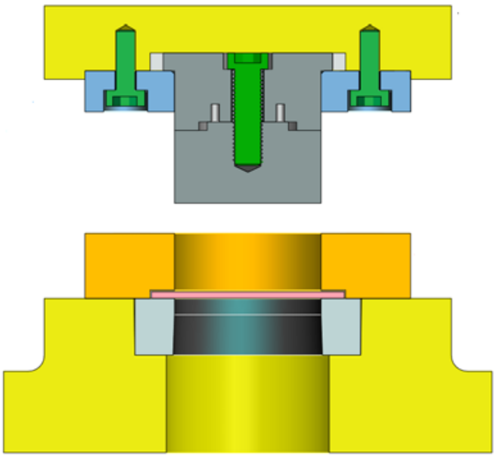

**Figure 3.1 Blanking Die Set**

The objective of the design is cutting the blanks with the desired shape and geometry without any deformation or burr formation by the use of shear force.

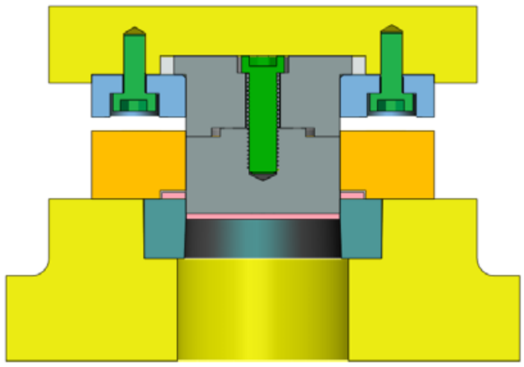
The dies, die supports and holders that are modeled in Pro/Engineer Wildfire III [23] are designed according to the dimensional limitations of Dirinler 200 tones trimming press available in METU-BILTIR Center Research and Application Laboratory.

At the start of the production of blanks, operator places the metal strip through the guide plate which guides the upper die and prevents the sheet metal to slip away. Subsequently, the upper die which is mounted on the ram moves down and it enters through the hole at the center of the guide plate.

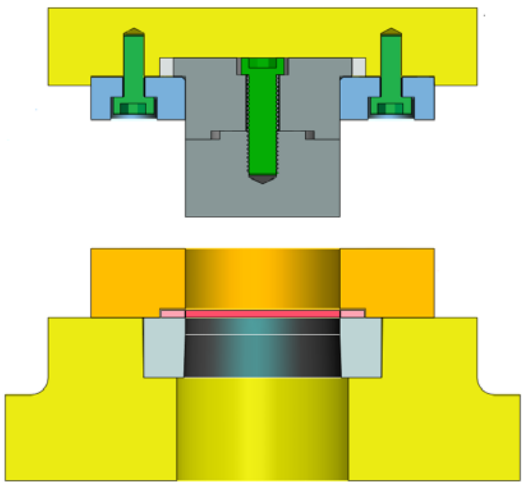
When the upper die touches the sheet metal, deformation stage starts and as the ram advance to the bottom dead center, the shear force pulls the metal downwards and causes it to cut off. The blank falls off the space in the lower supporting die. The production steps can be seen in Figure 3.2.



**a) Before punch hits the blank**



**b) Blanking operation**



**c) After blanking**

**Figure 3.2 Performing the Blanking**

### 3.1.1 Upper Die Assembly

The upper supporting die, the upper die support, the fixed component of the upper die and the interchangeable component of upper die together form the upper die set are shown in Figure 3.3. These three parts has been manufactured separately and then assembled.

The design of the upper supporting die has been considered according to modularity of the die set. The upper supporting die has a hole suited for the flanged geometry of the fixed component of the upper die which can be seen in Figure 3.4. The hole serves the function of mounting. By using a support part which attaches the fixed component of upper die to the supporting die by using four bolts, the upper die can be easily. Four bolts which are located with an angle of $90^{\circ}$ to each other. The interchangeable component of the die provides the advantage of producing blanks with any other diameter smaller than 90 mm. The support part can be seen in Figure 3.5.

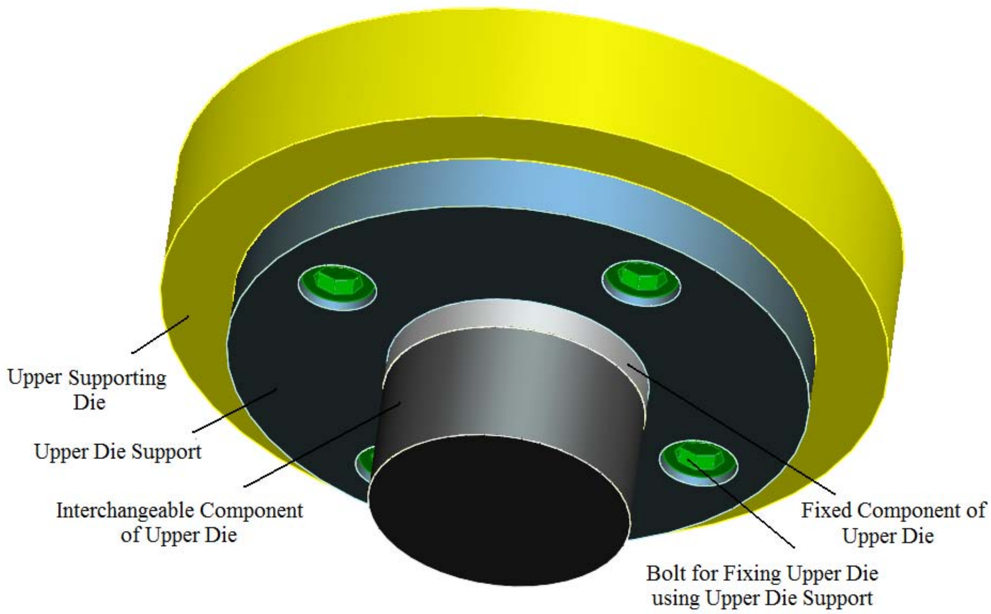



**Figure 3.3 Assembly of Upper Die Set**

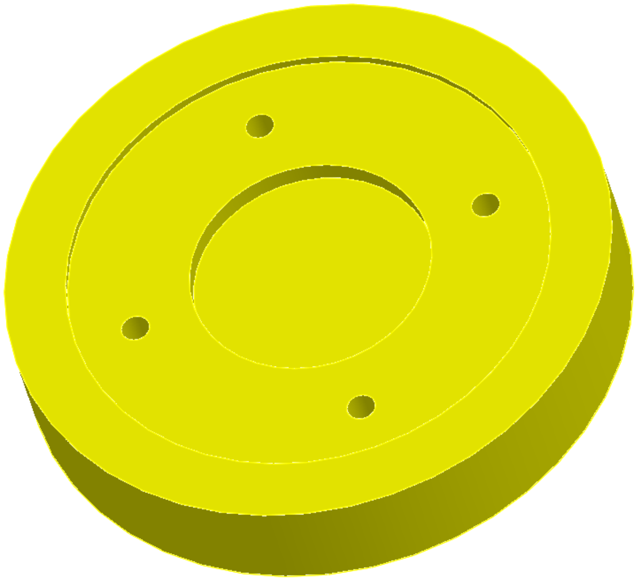


**Figure 3.4 Upper Supporting Die**

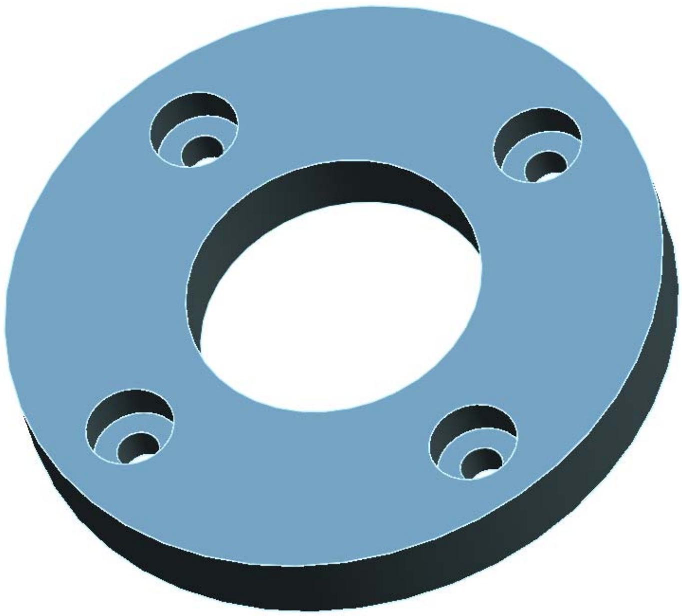


**Figure 3.5 Upper Die Support**

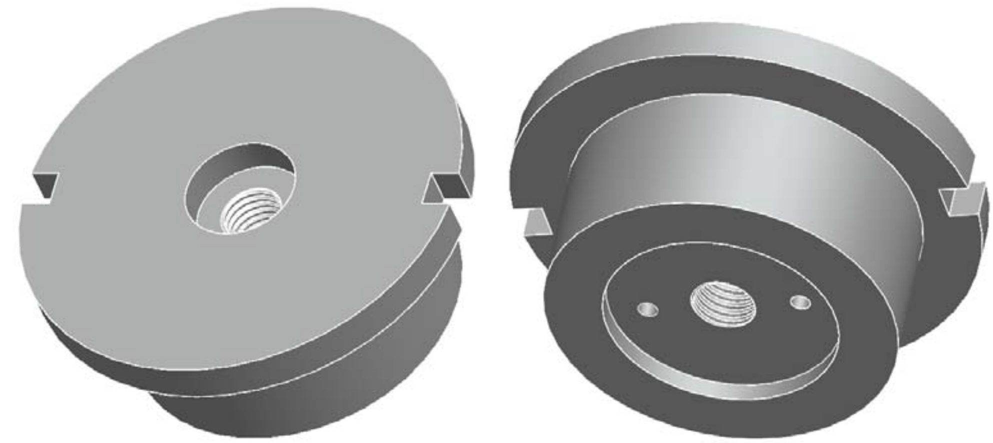


**Figure 3.6 Fixed Component of Upper Die**

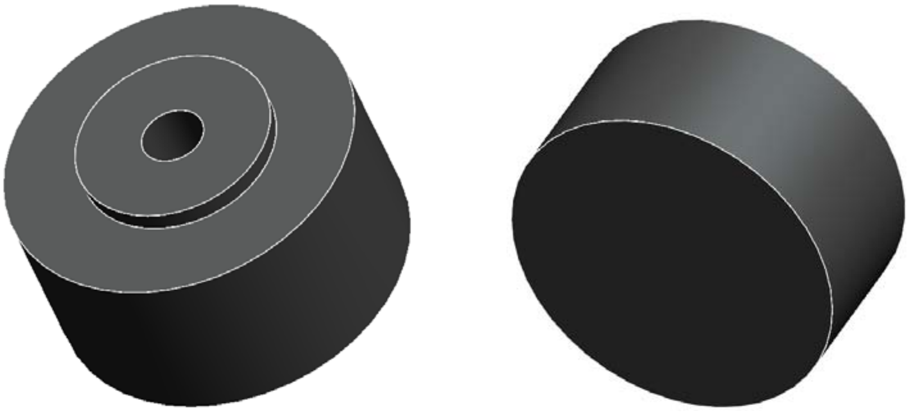


**Figure 3.7 Interchangeable Component of Upper Die**

The whole upper die assembly moves together and the interchangeable component should only be changed in case of blank with smaller diameter, as a requirement of the modularity.

The fixed component of upper die (Figure 3. 6), the interchangeable component of the upper die (Figure 3.7) are fastened tightly by a bolt as shown in Figure 3.6.

Bolt and thread on the dies should be manufactured very carefully to provide the perpendicularity of the face of the upper die that contacts the workpiece surface.

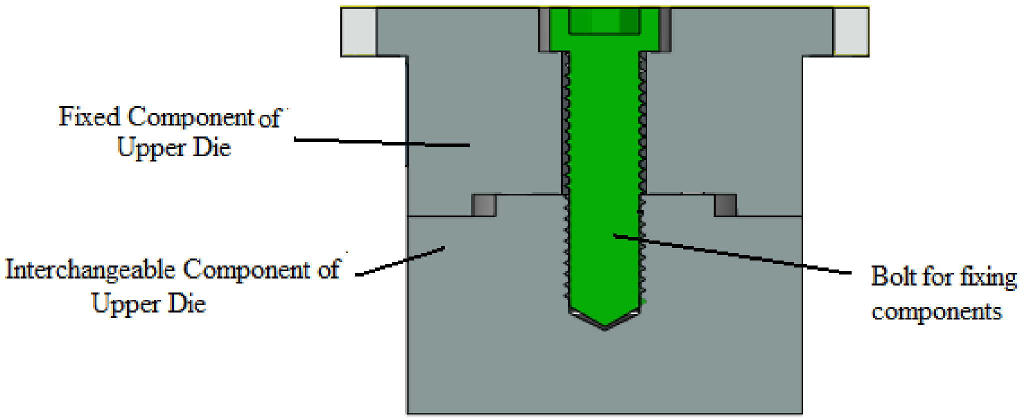



**Figure 3.8 Upper Die Assembly**

The surface quality of the upper die part that cuts out the blanks is extremely important. The geometric tolerance of position should be restricted to a certain limit, in order to be sure that the edges are perpendicular to the large coinage surface of the blanks. This may affect the being filled up of the coining dies.

### 3.1.2 Lower Die Assembly

The lower die set consist of three parts which are the guide plate, the lower die and lower supporting die as shown in Figure 3.9. These three parts has been manufactured separately and assembled later.

As the design is modular, the modules can easily be changed in the case of different blanks with different dimension or in case of die wear and fracture.

Moreover, design modifications can be made by only changing the interchangeable modules.

The guide plate, which can be seen in Figure 3.10, leads both the upper die and sheet metal in order to avoid misalignments. As a result, the tolerance values between guide plate and upper die or workpiece is critical and should be properly produced. The guide plate attaches the lower die to the lower supporting die by using four bolts as seen in Figure 3.9. A taper clearance of 2$^{\circ}$ is applied for the lower die.

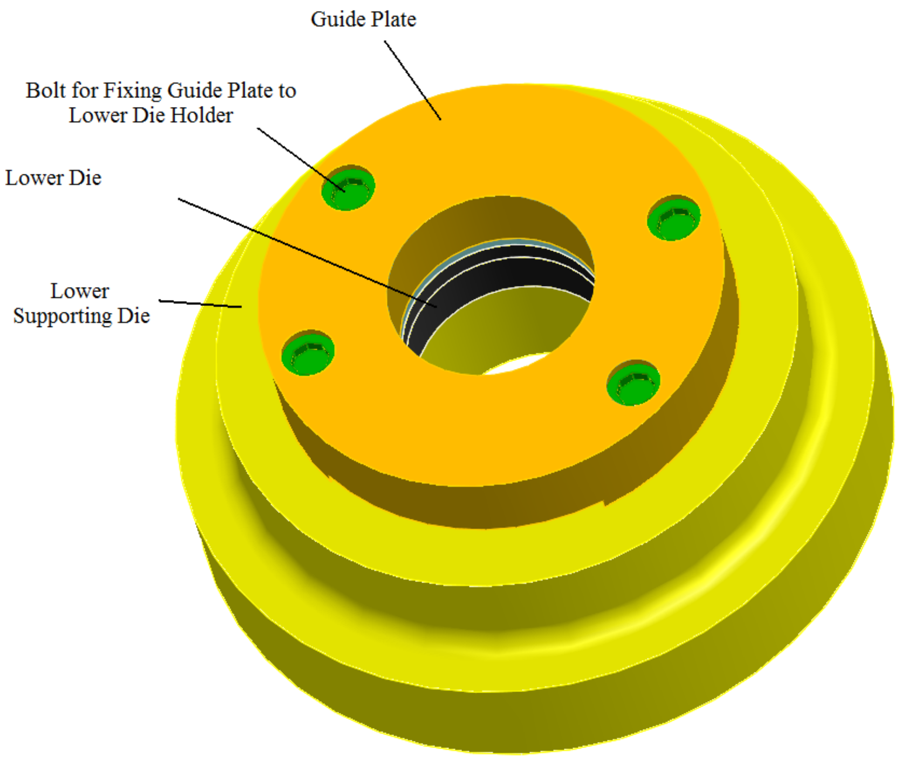



**Figure 3.9 Lower Die Assembly**

For the mounting of the lower die, the guide part fastened with four bolts. The lower supporting die can be shown in Figure 3.11. The positions of the die adjustment bolts are seen in Figure 3.12.

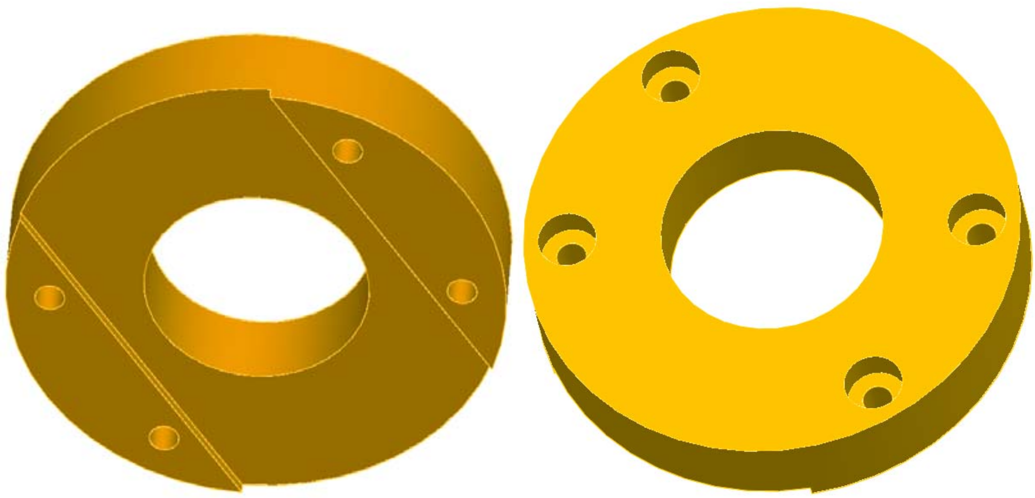


**Figure 3.10 Guide Plate**

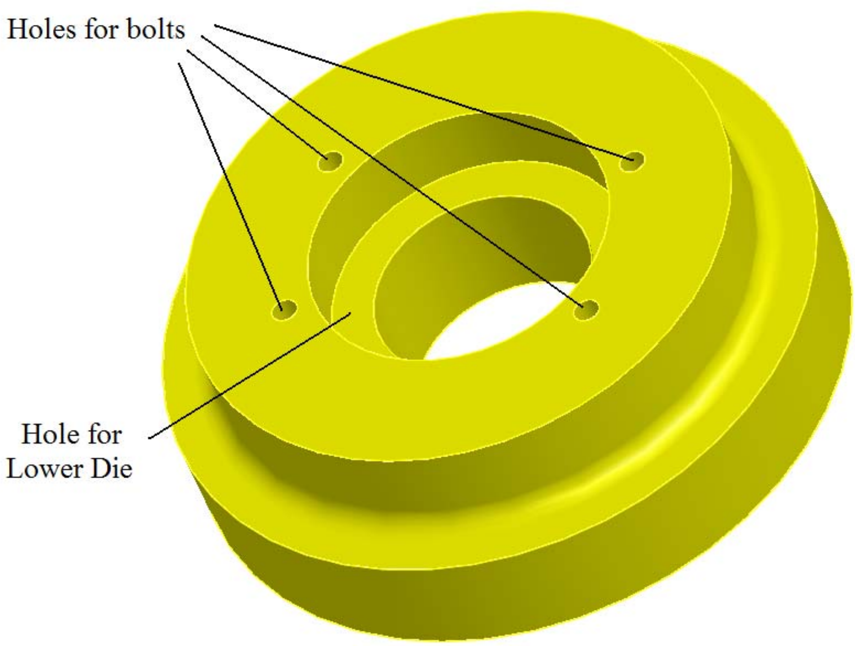



**Figure 3.11 Lower Supporting Die**

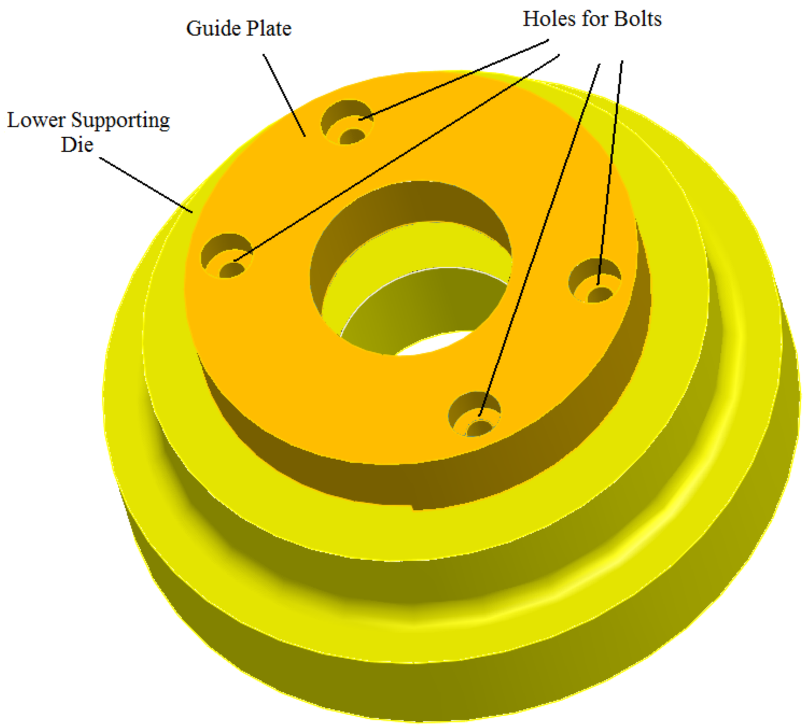



**Figure 3.12 Key Position of Lower Die Assembly**

Just before the upper die hits the workpiece, the upper die enters to the cavity of the lower die. Positioning and the guidance of the dies are highly important. Slight adjustment errors of the dies before blanking may cause the production of defected medals in coining stage.

In coining stage, the material movement in the coining die is initially from the center to edge without any filling of reliefs, then from down to up until the die is fully filled. In order to fill die cavities, the diameter of the blanks should be smaller than the desired medallion diameter. The blanks are cut from the sheet with a width of D+2b mm and a pitch of D+5 mm which is the sum of the blank diameter (D) and the distance between blanks that will be cut out (b). Therefore, sheets that are fed to the press must have the same width. The dimensions of the workpiece that must be fed can be seen in Figure 3.13.

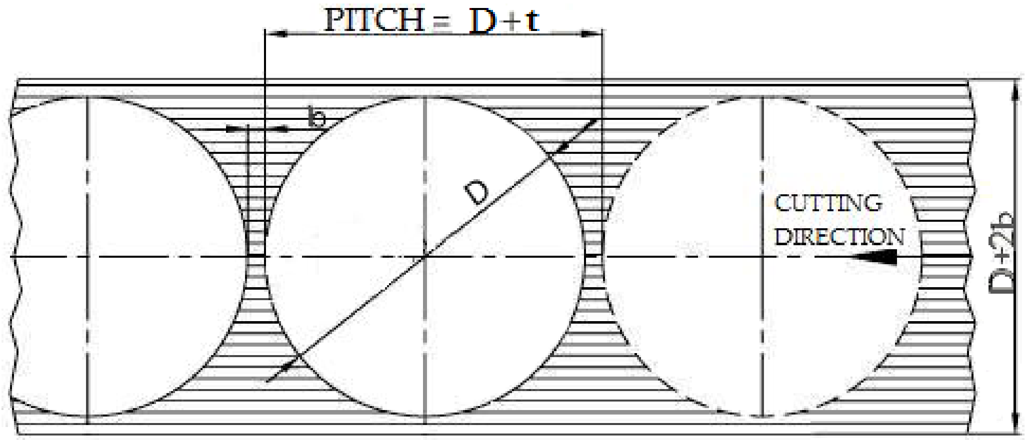



**Figure 3.13 Dimensions of Sheet Material [24]**

In the closed die forging applications, the dies fracture or damaged during the process due to stresses which are caused by the excessive force on the dies themselves. Therefore, before the manufacturing of the blanking dies, blank volume will be calculated in Pro/Engineer Wildfire 3.0 [23] which is the CAD/CAM program available in METU-BILTIR Center to check if the blank volume is not more than the completely closed volume of dies after the press adjusted to the coining conditions.

# CHAPTER 4

# MODULAR DIE DESIGN FOR MEDALLION

## 4.1 Design of Modular Die Set for Medallion

A modular die set for the particular coining operation which can be interchangeable according to the outer diameter of the blank has been designed. The main objective in the design is to provide a completely closed die operation which does not allow any excess material to escape outside of the dies so that avoiding any flash formation.

The proposed coining die set for a medallion with a diameter of 90 mm consists of 10 parts as seen in Figure 4.1, which are

- Upper Supporting Die
- Interchangeable Component of Upper Die (i.e. punch)
- Fixed Component of Upper Die (i.e. punch)
- Bolt which fixes Interchangeable Component of Upper Die to Fixed Component of Upper Die
- Keys for stabilizing the fixed Component of the Upper Die
- Pins that adjust the location of the Upper Die
- Lower Die
- Key that adjust the rotational location of the Lower Die
- Lower Supporting Die
- Ejectors

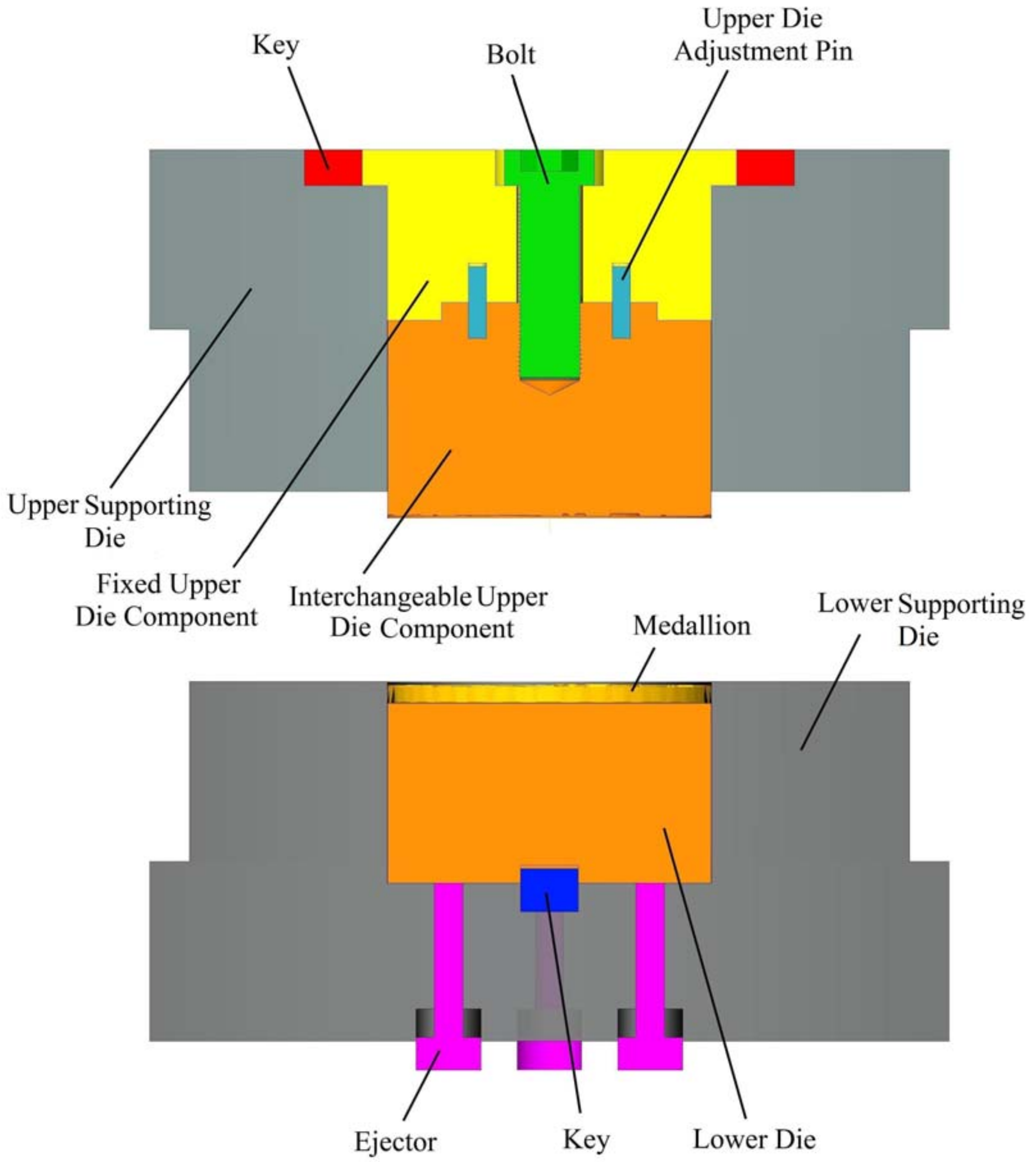



**Figure 4.1 Modular Coining Die Set for a Medallion with the Diameter of 90 mm**

With the help of the rectangular shaped key and two pins attached to the lower die is adjusted to its right position according to the upper die.

The dies and supporting dies which are modeled in Pro/Engineer Wildfire III [23] can also be seen separately from Figures 4.2-4.5.

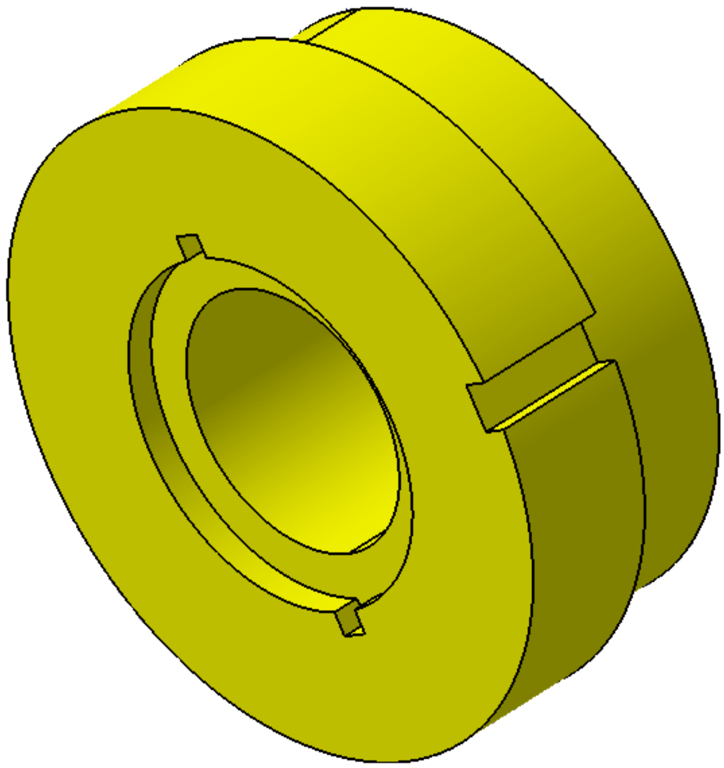


**Figure 4.2 3-D Model of Upper Coining Supporting Die**

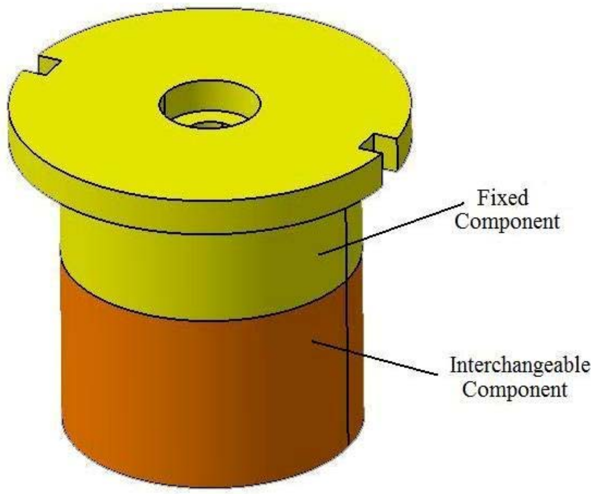



**Figure 4.3 3-D Model of Upper Coining Die Assembly**

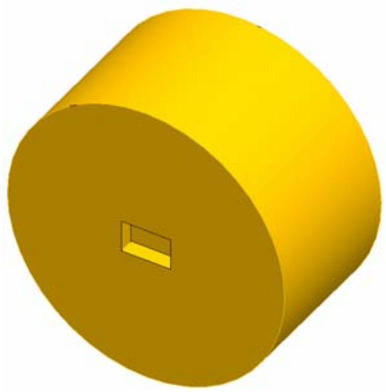


**Figure 4.4 3-D Model of Coining Lower Die**

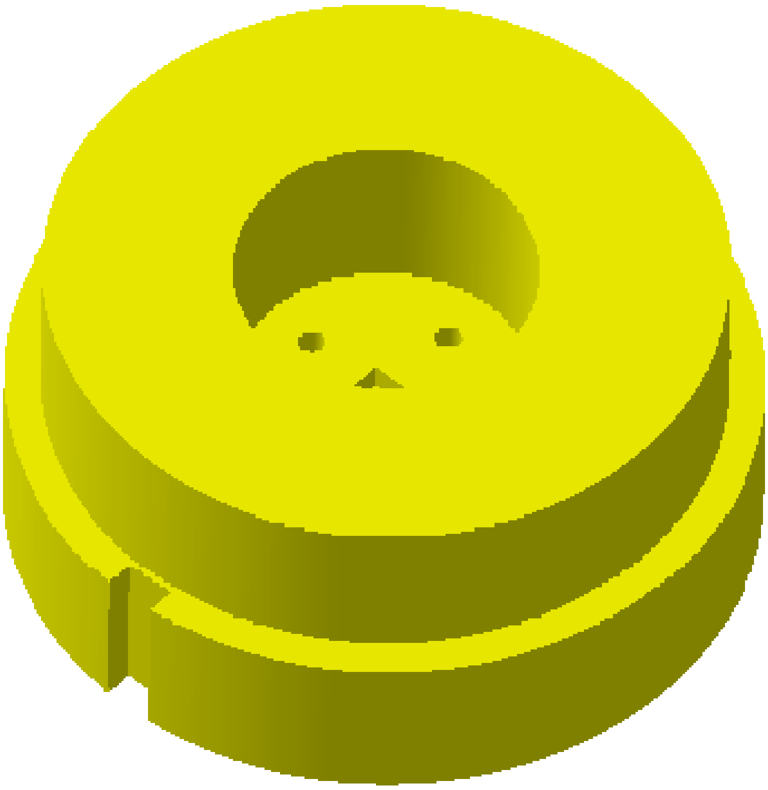


**Figure 4.5 3-D Model of Lower Supporting Die**

At the start of the coining process, operator places the blank onto the lower die by the guidance of the space between lower supporting dies (Figure 4.6.a). Subsequently, the upper die which is mounted on the ram moves down.

When the upper die touches the blank, deformation stage starts and as the ram advances to the bottom dead center, the blank was deformed and takes its final shape (Figure 4.6.b).

When the ram starts traveling from the bottom dead center to the upper dead center, the load on the workpiece is released (Figure 4.6.c).

When the upper die ascends to its initial position, the lower die is moved upwards. The finished product is taken out with the help of the four ejector pins which are connected to each other (Figure 4.6.d). With the help of the key which is placed under the lower die to set lower die and lower supporting die precisely, the lower die goes back to its initial position above the ejectors.

When the upper die goes to its position that the workpiece was completely strike, the coined blank should fill the die cavities and cake the shape of the modular part of the upper die having female relieves. The schematic illustration of the coined medallion after one struck can be shown in Figure 4.7.

The upper die contains one modular and four stable parts which are illustrated in Figure 4.8 and Figure 4.9 which are;

- Upper supporting die
- Fixed part of upper die
- Interchangeable part of upper die
- A fixing bolt for interchangeable component of upper die
- Pins

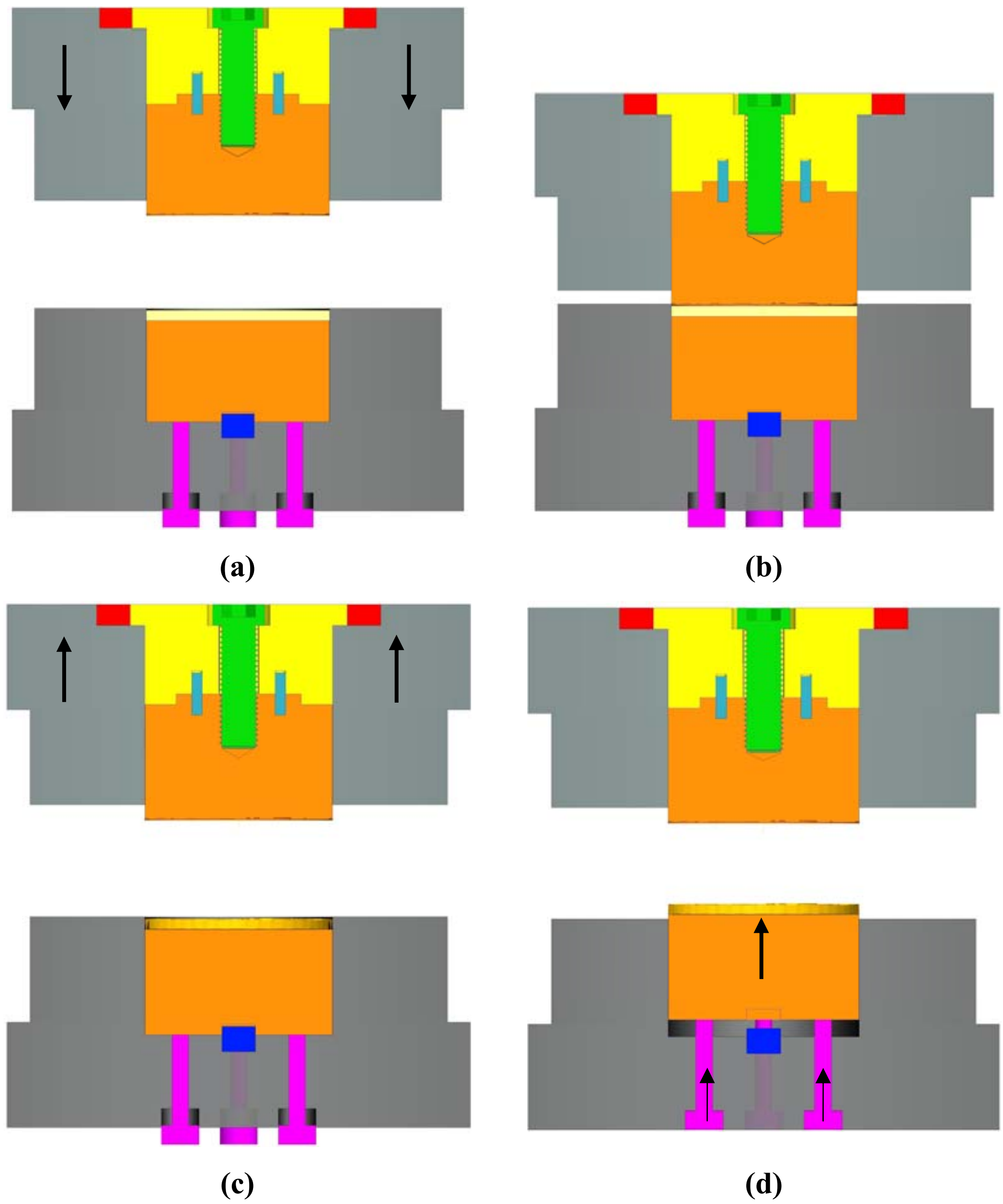


Figure 4.6 Working Principle of Coining Die Set

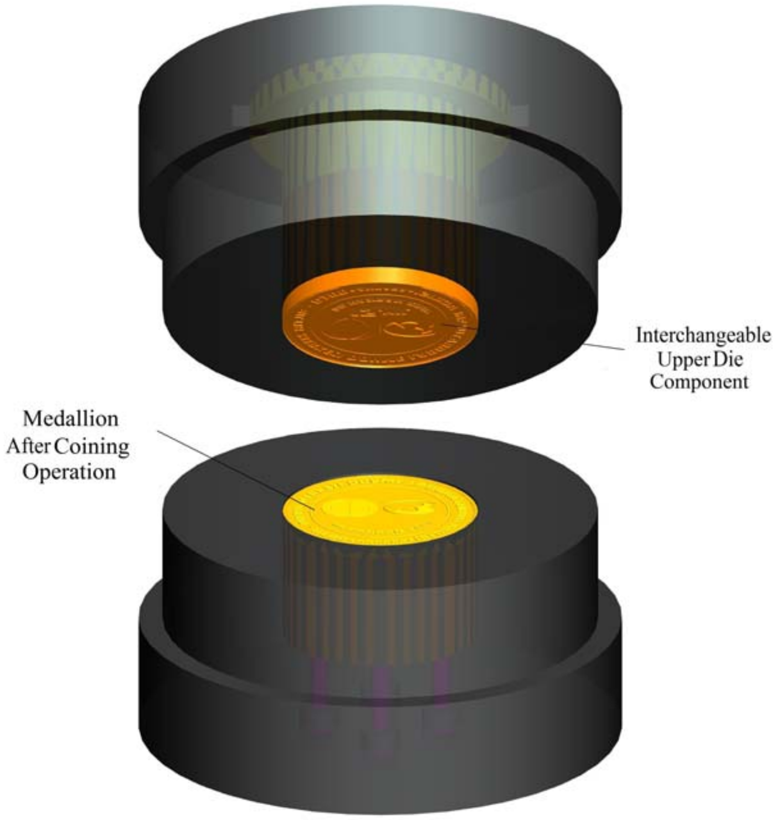



**Figure 4.7 Die Set after Coining Process**

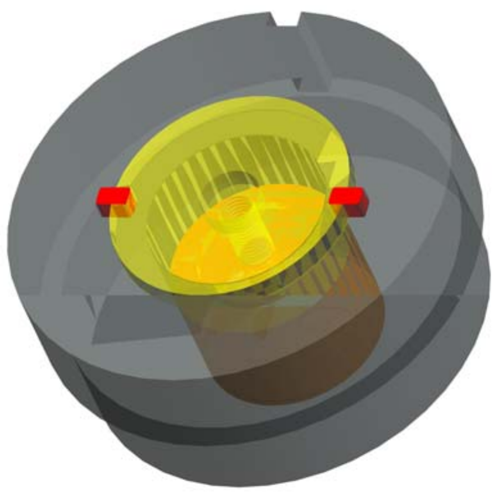


**Figure 4.8 Upper Die Assembly**

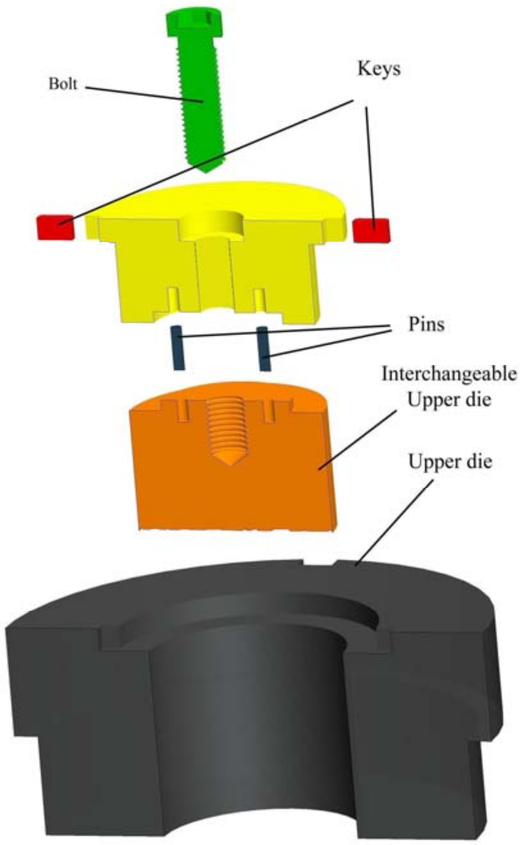



**Figure 4.9 Exploded View of Upper Die Assembly**

Defected medallions and coins will be very high during coining process. To prevent the imperfections in the process, the upper die should be designed with a slightly lower than the medallion diameter so that the tiny rimmed edge can be formed.

There is a fixing bolt which attaches the interchangeable upper die to the fixed upper die as shown in Figure 4.10. Bolt and thread on the dies should be manufactured precisely to avoid the misalignments of the sections in the die assembly. There should be also needed a counterbore for the head of the bolt so that the upper die assembly does not hit the press upper base.

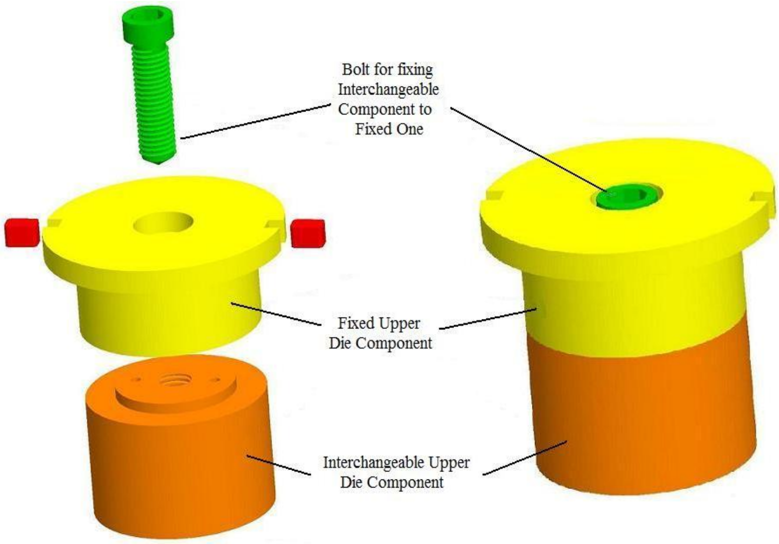



**Figure 4.10 Upper Die Assembly**

Small adjustment errors of the dies may cause imperfect medallions or coins and decreased possibility of the removal of the final products from the dies and jamming of the die. In order to position and guide the dies, two pins and two keys are used in such a location that opposite to each other. This helps the guidance of the dies according to each other as illustrated in Figure 4.11.

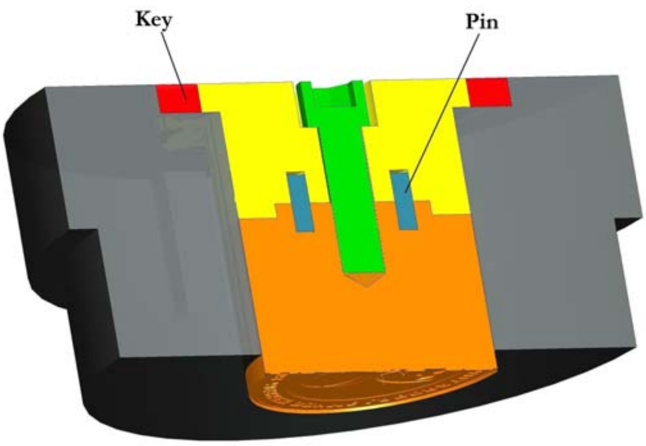



**Figure 4.11 Upper Die Assembly**

Lower supporting die, lower die, key and ejectors are the separately manufactured parts of the lower die set which is formed by the assembly of these parts and shown in Figure 4.12 and Figure 4.13.

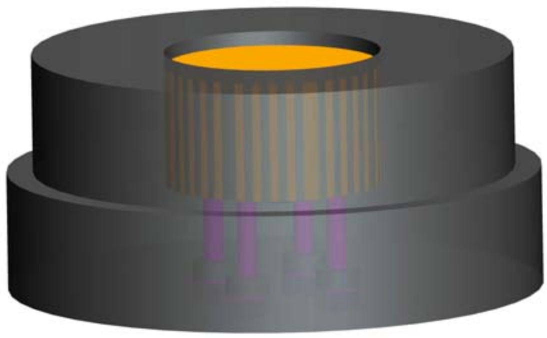


**Figure 4.12 Lower Die Assembly**

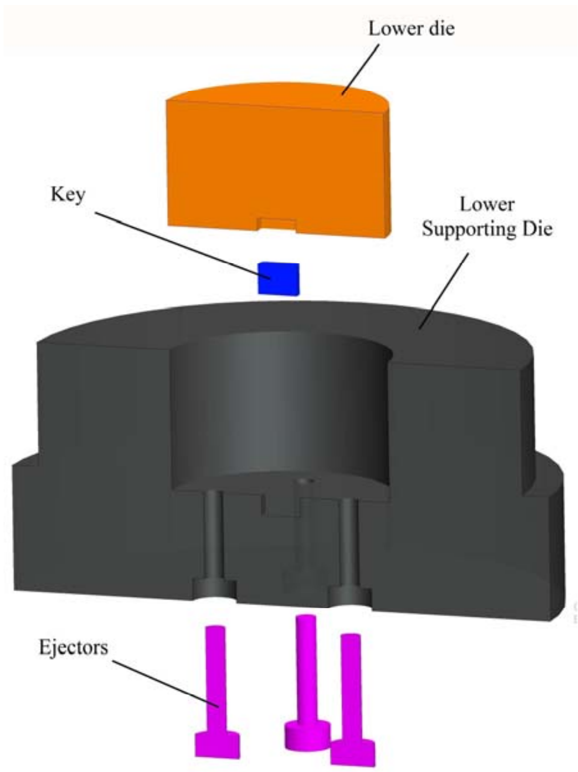



**Figure 4.13 Exploded View of Lower Die Assembly**

During the operation, the outer surface of the finished product is determined by the inner surface of the lower supporting die. The medallion designed with one sided therefore; the other side of the medallion is flat. The 3D model of the lower supporting die and lower die can be illustrated in Figure 4.14.

A rectangular shaped key is used for aligning the lower die according to upper die in the coining operation dies and partially restricting the possible rotation of the lower die rotation. As can be seen from Figure 4.15, the lower die should be placed with respect to lower die detail in order to avoid the coining defect of mistrike which is eccentric positioning the obverse or reverse of the coin.

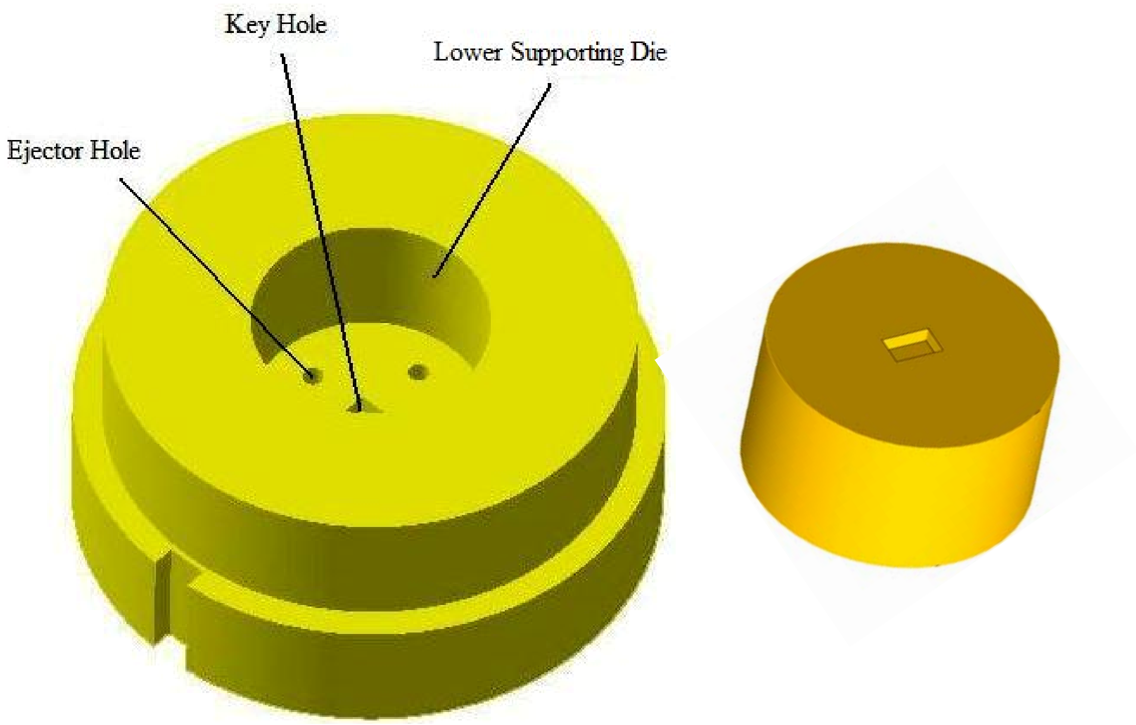



**Figure 4.14 3D Model of Lower Die and Lower Supporting Die**

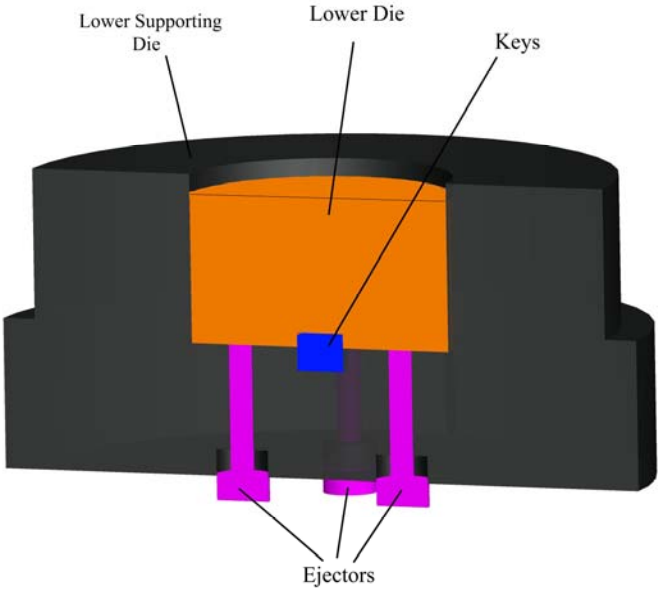



**Figure 4.15 Key Position of Lower Die Assembly**

Removal of the medallion after the coinage process is made by ejector pins moving the lower die upwards. Four ejectors pins that are placed through the base section of the press are used and they provide equal force. The counterbore of the lower supporting die for ejector heads were adjusted according to the ejector length will easily remove the coined blank. The position of ejectors removing the struck medallion can be shown in Figure 4.16.

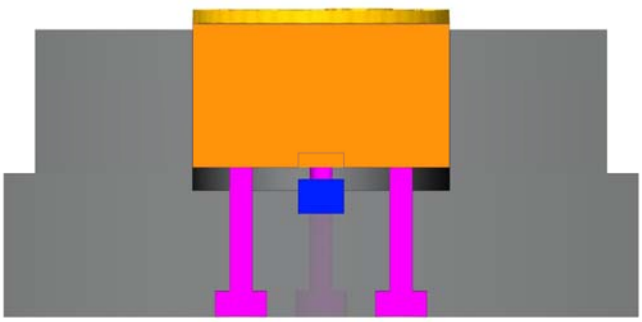


**Figure 4.16 Ejection of Medallion from the Lower Die Assembly**

## 4.2 Design Modifications in Modular Die Set for Medallions with Different Diameter Values

The ejectors on the particular forging press available in METU-BILTIR Center Forging Research and Application Laboratory are on a pitch circle with a diameter of 70 mm. This has affected the design.

As a result of the modularity of the coining die set, different decorative items on the face or a different diameter of the medallion can be produced. For the medallion with a diameter of 90 mm, the inner diameter of the lower supporting die is equal to the outer diameter of the lower die.

However, for the diameters between 90 mm which is the inner diameter of the lower supporting die and 70 mm which is the diameter of the pitch circle of ejectors. As a result, an interchangeable ring should be used. This design can be seen in Figure 4.17. Wall thickness of the stepped outer container will be equal to the difference between the diameter of the medallion and 90 mm.

In this case, the outer diameter of the lower die is smaller than the diameter of pitch circle of the ejector pins. For production of these medallions, a stepped outer container which is placed between the lower supporting die and lower die should be used to provide the completely closed die cavity. The design of die set with an interchangeable stepped outer container can be seen in Figure 4.18.

Wall thickness of the stepped outer container will be equal to the difference between the diameter of the medallion and 90 mm. The height of the stepped section should be equal to the stroke of the ejectors so that ejectors are able to remove the medallion. The geometric features of stepped outer diameter and lower die can be seen in Figure 4.19.

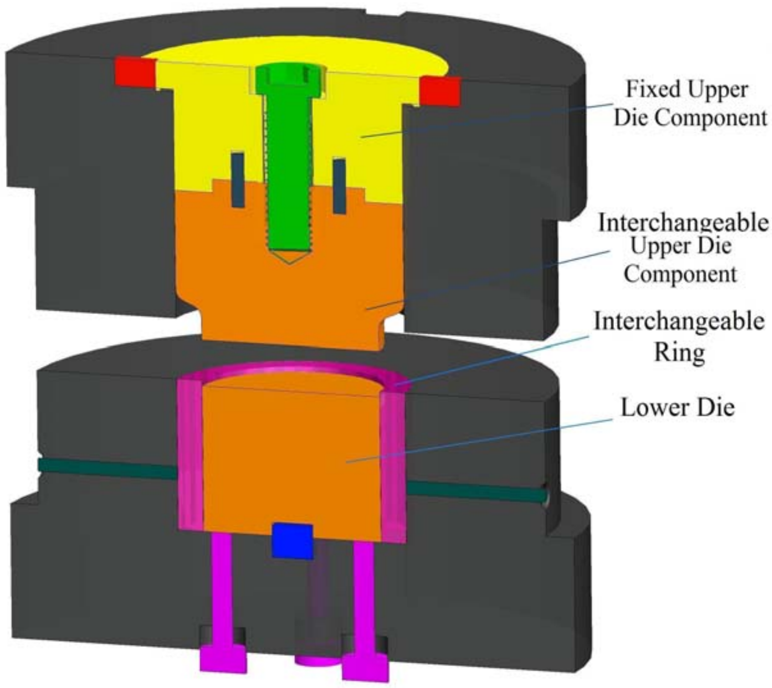



**Figure 4.17 Assembly of Die Set for Coin Diameter of 70 mm**

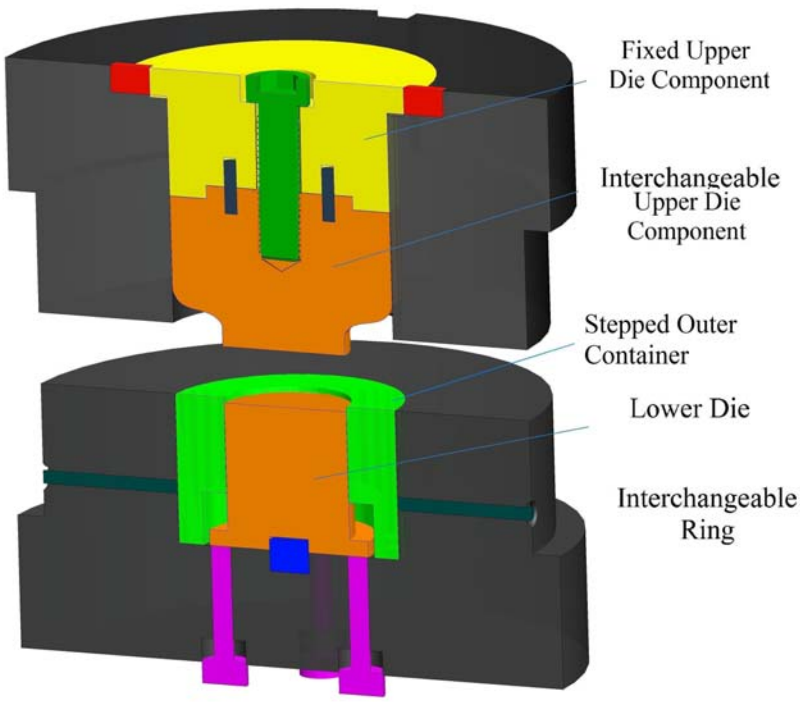



**Figure 4.18 Assembly of Die Set for Coin Diameter of 50 mm**

# CHAPTER 5

# ANALYSIS AND MANUFACTURING OF THE COMMEMORATIVE MEDALLION OF OPENING CEREMONY OF METU-BILTIR FORGING RESEARCH AND APPLICATION LABORATORY

In the previous chapters, design and 3-D modeling of the coining and blanking dies for a particular coining process were explained in detail. In this chapter, design, analysis and manufacturing of the coining die set and the medallion of the opening ceremony of METU-BILTIR Center Forging Research and Application Laboratory will be explained. The finite volume analysis will also be verified by experiments.

## 5.1 Design of the Medallion

In the design stage of the medallion, material of the dies, and available cutting tools in METU-BILTIR Center CAD/CAM Research and Application Laboratory were taken into account.

The outer diameter of the coin was chosen to be 90 mm. The thickness was set as 5 mm and a relief height is set as 0.5 mm. The 3-D model of the medallion can be seen in Figure.4.1.

After modeling the desired shape of the commemorative medallion and the dies by using Pro/Engineer WF 3.0 [23], all of the manufacturing works of the dies were accomplished in METU-BILTIR Center CAD/CAM Laboratory.


**Figure 5.1 3-D Model of the Medallion**

## 5.2 Finite Volume Analysis of Coining Process

Coining is a metal forming process that cannot be considered as a simple process because the process can be characterized by entirely 3-D material deformation and continuously changing boundary conditions. Therefore, production of a full solution requires experienced and challenging people who perform the simulation in relatively short calculation times. In order to predict the flow of metal, stress, strain and temperature distributions, accurate and robust algorithms are required. [25-26].

In this study, MSC.SuperForge which is commercial finite volume software has been used. In the simulation with Finite Volume Method, the grid points are fixed in space. The elements are free in the space in which they are defined by connected grid points. The workpiece material flows through the mesh when the simulation parameters affect the material by transmitting from element to element. During the solution, motion of material and values that are transferred are calculated; therefore remeshing techniques are not necessary to obtain the results of constant volume material [27-28].

MSC.SuperForge provides a simulation of a single-stage cold forging process with the determination of the main features these steps [29]:

- Selection of the process type.
- Import of models of workpiece and dies from CAD environment.
- Positioning of the workpiece and dies with respect to each other.
- Specification of material models of workpiece and dies.
- Selection of press from pre-defined press definitions or enter new one.
- Running the simulation.
- Visualization and evaluation of the simulation results.

For the beginning of the MSC.SuperForge simulation, the process type has been selected as “3-D closed die forging process” is selected as the process category [29].

Because the dies form a completely closed area, the volume of the blanks is important. Detailed 3-D CAD model of the experimental medallion is prepared and blank dimensions are obtained using the volume of this medallion geometry which is modeled in Pro/engineer III. Furthermore the thickness of the blank should be chosen so that mass production can be done by using the standard brass plates.

The stereolithography formatted (STL) models of the upper die, lower die and workpiece geometry are imported from Pro/Engineer to Finite Volume program. In the STL format, the surface model is composed of triangular shaped elements, but the geometry is defined as rigid bodies by MSC.SuperForge [29].

While the upper die gets into the space in the lower supporting die, any deformation will not occur until the upper die hits the blank which is on the lower die. Therefore the upper die and the lower die are simply modeled for the simulation, as seen in Figure 5.1. The positions of the dies and the workpiece are also shown in the figure.

Since the dies are considered to be rigid bodies in the simulation, only heat conduction and heat transfer are allowed in the dies and it is not possible to simulate strains and stresses on the dies. Therefore, the material is assigned for the workpiece only. There is various material models already defined by in the library, in the program. [29].

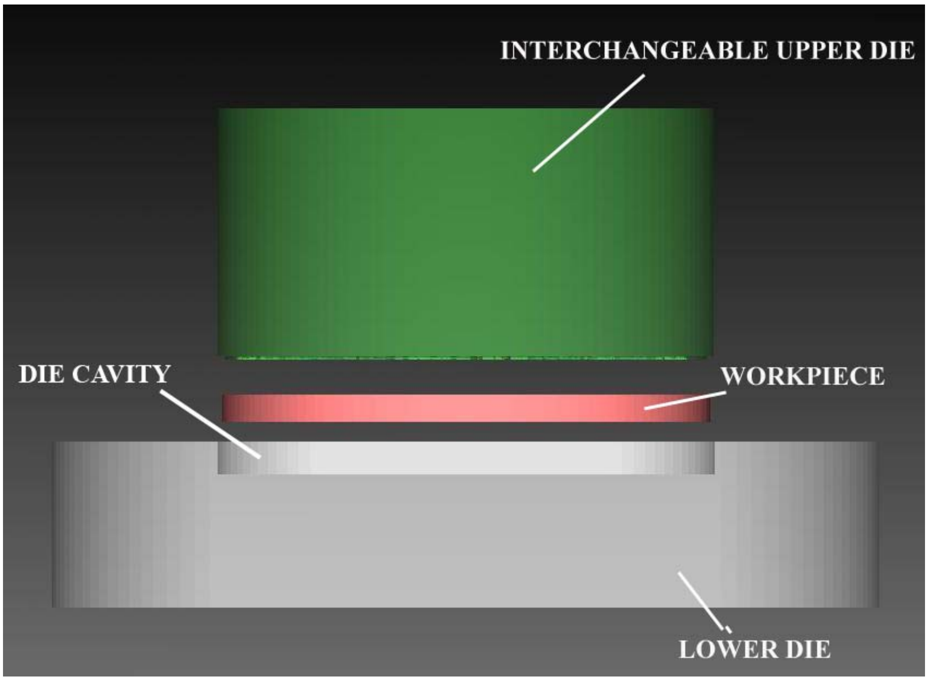



**Figure 5.2 MSC.SuperForge Assembly for Coining Operation**

From the available elastic-plastic models for cold forging in the material library, “CuZn28/CuZn30” has been selected as the blank material. Material properties of this metal have been presented as in Figure 5.3 [30].

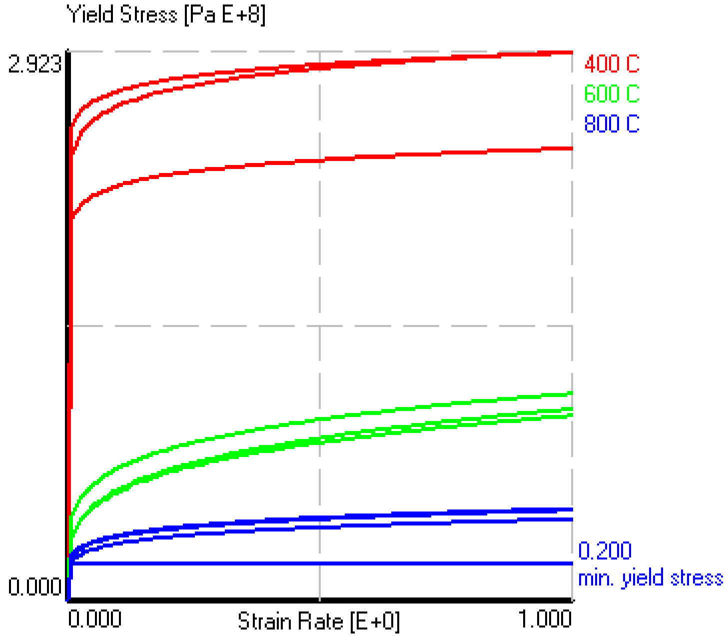



**Figure 5.3 Mechanical Properties of Workpiece Material (CuZn30) [30]**

After the material assignment, the forging equipment of the process is selected. In the study, the mechanical crank press of which the properties are given in Table 5.1 [31], which is available in METU-BILTIR Center Forging Research and Application Laboratory, is selected in the menu of MSC.SuperForge. The properties of the press which can be seen in Figure 5.4 are entered.

**Table.5.1 Properties of Forging Equipment [31]**

| | |
|---|---|
| Crank Radius (R) | 110 mm |
| Rod Length (L) | 750 mm |
| Rotational Speed (Revolution) | 100 rpm |

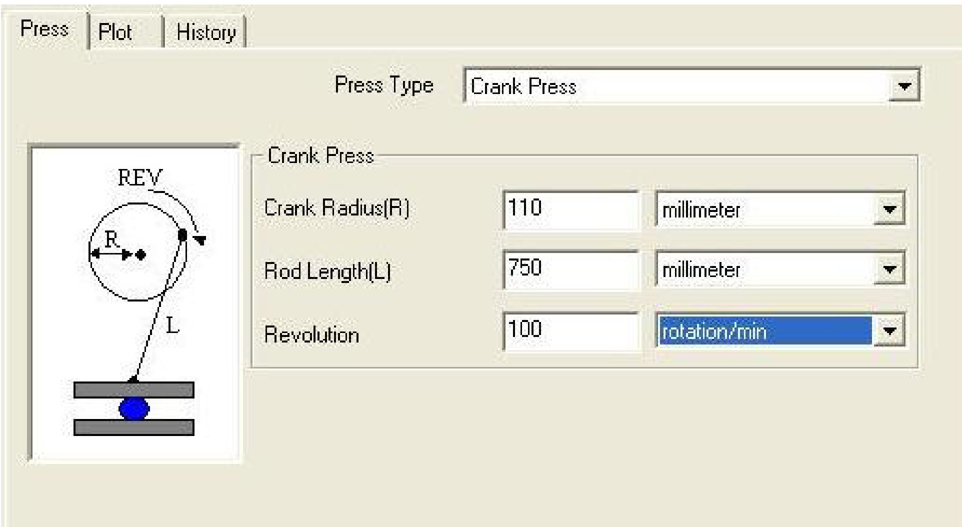



**Figure 5.4 Parameters for Mechanical Press in the Software [31]**

By entering the given parameters, the velocity of the press can be obtained from the software as a function of time as seen in Figure 5.5.

After implementing the press parameters, simulation conditions should be determined as seen in Table 5.2 and these steps should be followed:

- Stroke of the upper die is selected.
- Size of the finite volume workpiece element is entered.

Output step size (as percentage of the process time or in defined stroke step sizes) is incurred selectively.

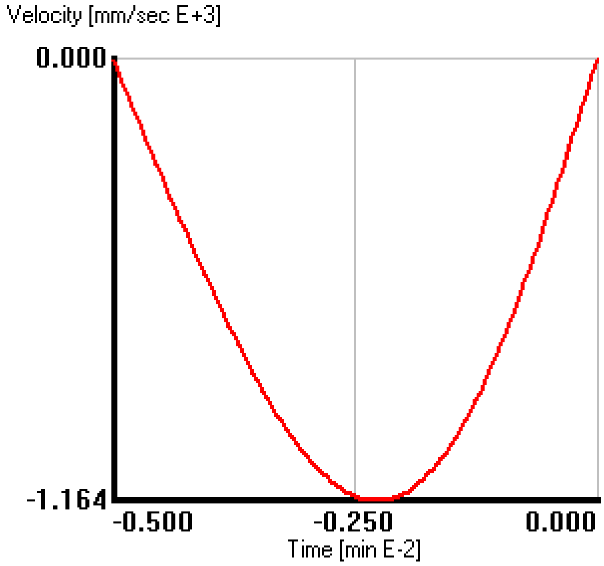



**Figure 5.5 The Velocity of the Mechanical Crank Press as a Function of Time**

**Table 5.2 MSC.SuperForge Simulation Parameters in Finite Volume Analysis of Coining Operation**

| | |
|---|---|
| Workpiece element size | 0.5 mm |
| Die element size | 1 mm |
| Finite Volume Ratio | 0.2 |
| Number of Output Steps | 21 |

When all the previous steps have been completed, die filling analysis simulation can be started. At the beginning of the simulation, MSC.SuperForge performs a model check to control the definition of simulation parameters. In simulation part, the progress can be monitored by the simulation bar on the screen.

In order to obtain the appropriate blank geometry and dimensions for entire die-filling of forging die set for the experimental medallion and the commemorative medallion, certain amount of finite volume simulations have been conducted. The simulation results are given by die contact (die fill) analysis, effective stress analysis and the die loads which are presented in the following sections.

In the die filling analysis, the intensity of the die-workpiece contact is represented by colors. The full contact between the die cavity and the workpiece is designated by red color. If the die does not have contact with the workpiece, then the workpiece is indicated by blue on the screen. In the Figure 5.5 the die fill analysis for the blank of which dimensions are obtained from CAD model and the colored representation are shown.

During the simulation, when die moves downwards along with the workpiece, the edge of the blank is bulked first as there is friction in the contact of upper and the bottom blank surface and the dies. The blank diameter enlarges until the materials touches the inner face of the lower supporting die. Then, the relief is entirely formed while a rim at the circumference is formed. The simulation steps of coining can be seen in Figure 5.6.

Simulations for the medallion have been done. In Figure 5.7, the effective stress distribution for the blanks with a diameter of 89 mm and in Figure 5.8 stress distribution diagram of during the simulation can be seen.

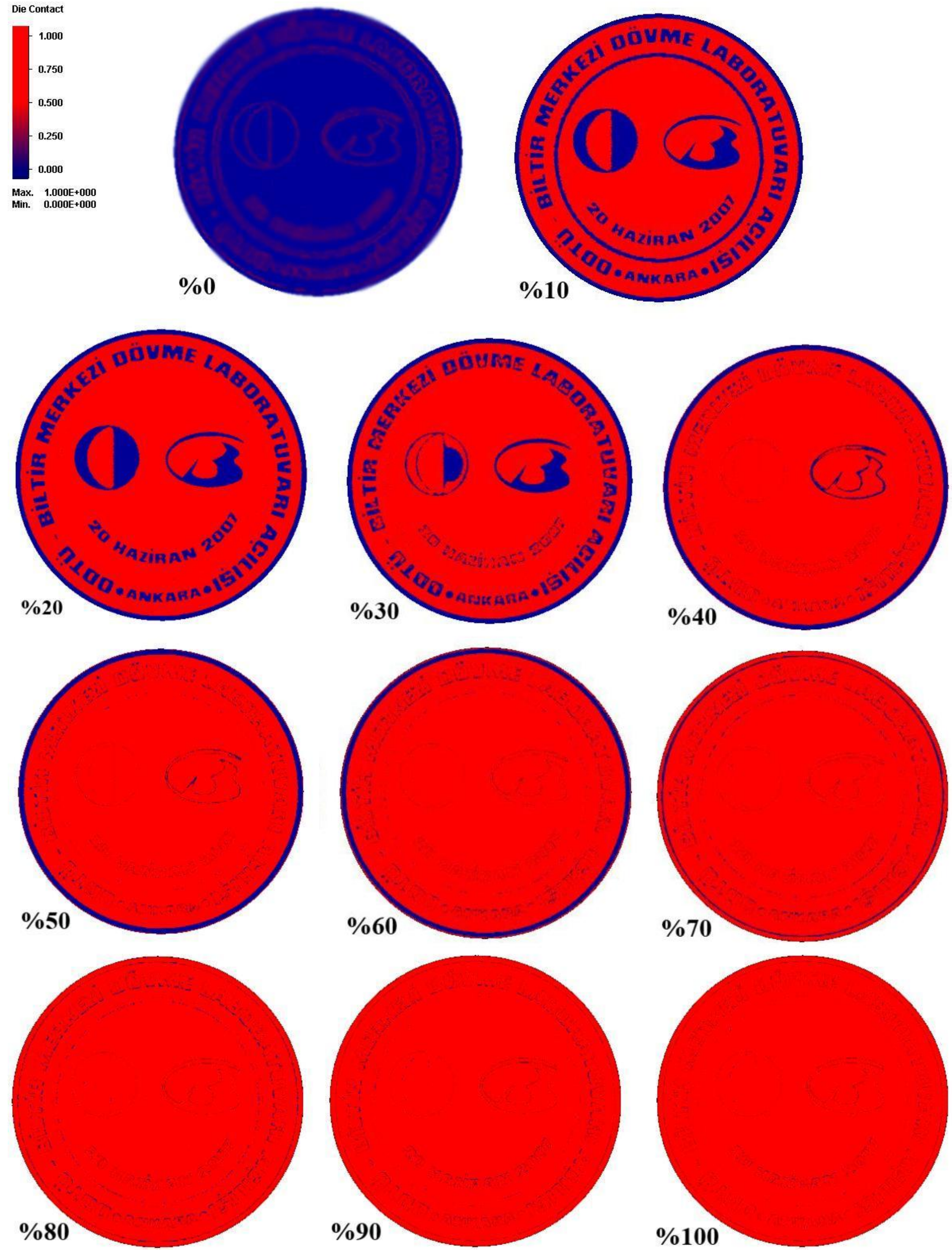



**Figure 5.6 Die Contact (Die Filling) Simulation Steps of the Coin**

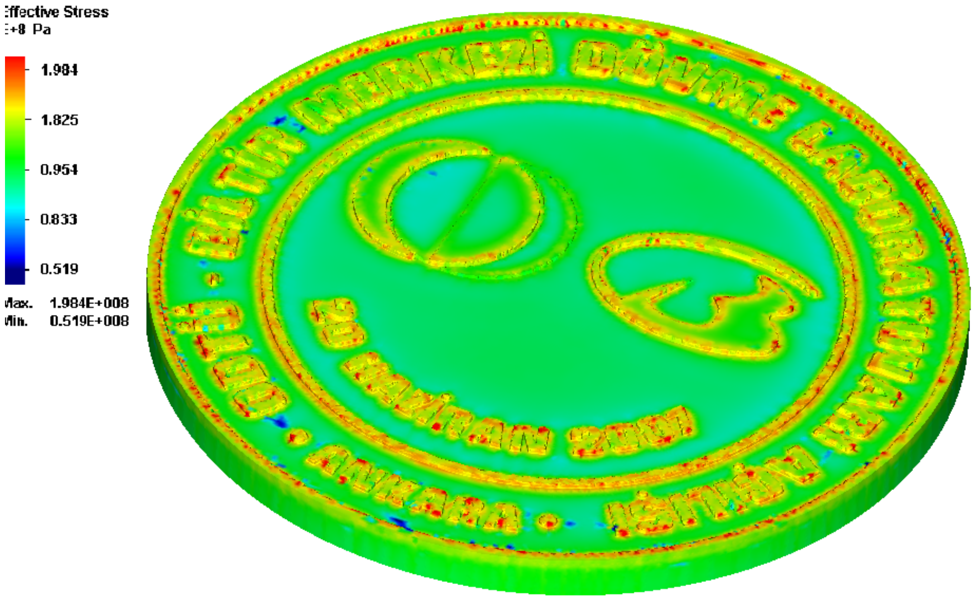



**Figure 5.7 Effective Stress Distribution in the Blank with a Diameter of 89mm**

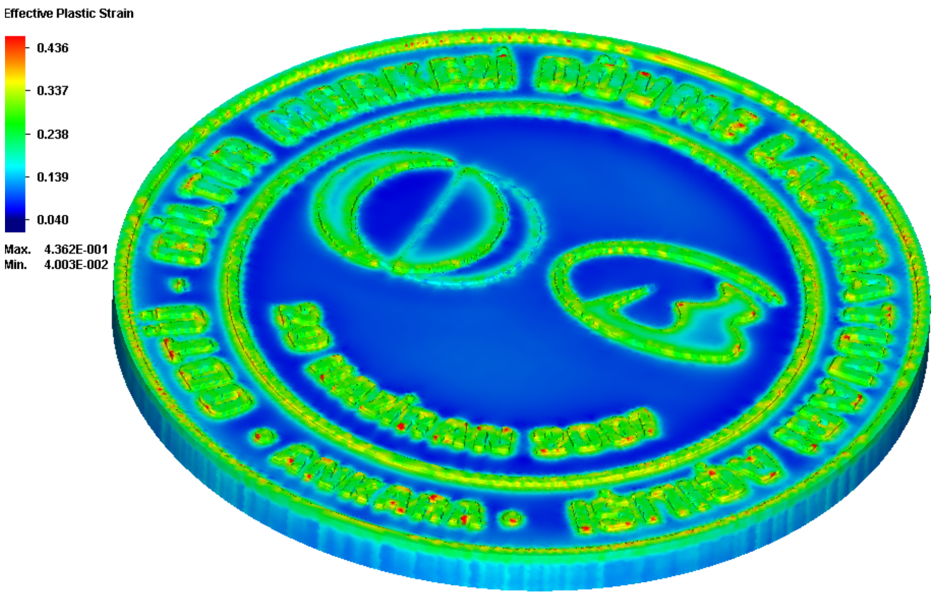



**Figure 5.8 Effective Plastic Strain Distribution in the Blank with a Diameter of 89 mm**

## 5.3 Production of the Coining Die Sets

### 5.3.1 Dimensions of Die Holders on Press

Dimensional requirements of the available 1000 tones SMERAL mechanical press [31] that can be seen in Figure 5.9 limit the dimensions and the geometry of the die set.


**Figure 5.9 A view of Smeral 1000-ton Mechanical Press in METU-BILTIR Center Forging Research and Application Laboratory**

The SMERAL 1000-ton mechanical press, of which the technical data is given in Appendix C, has a ram stroke of 220 mm. The press has a shut height of 620 mm, which is the distance between the ram and the anvil when the ram is at its bottom dead center as seen in Figure 5.10. When the die holder is placed, and the ram is at its position of bottom dead center, the distance between the die locating surfaces of the upper and lower die holders is 200 mm. This means that the total allowable height of upper and lower die assembly is equal to the sum of the upper and lower die heights which is 200 mm when dies are fully closed. This distance should be carefully calculated and controlled during die design to prevent the collision of the dies in coining process. In coining operations, flash formation should be avoided.

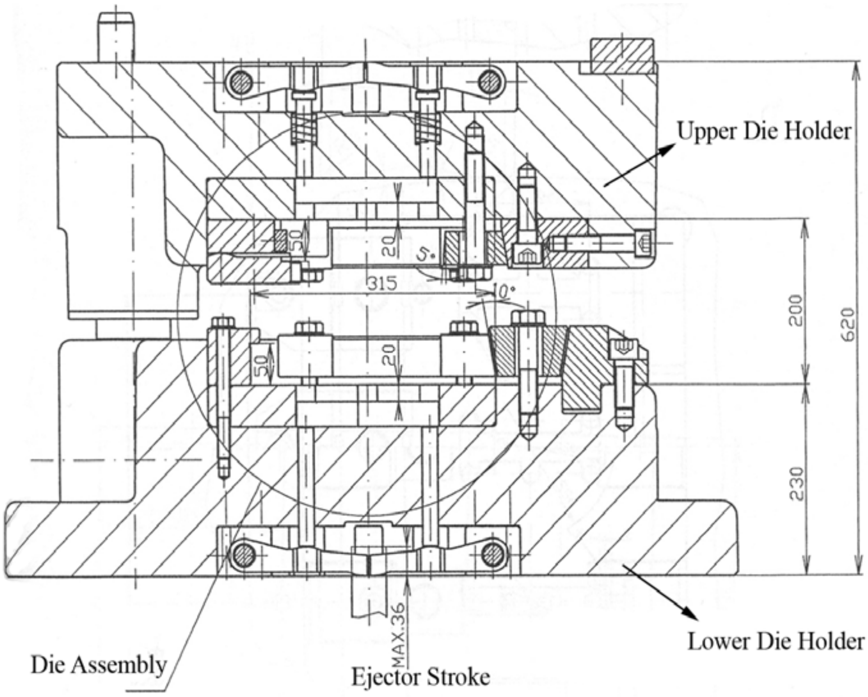



**Figure 5.10 Shut Height and Die Holder of Smeral 1000-ton Mechanical Press [31]**

As seen in Figure 5.11, there is three sections on the lower die holder of the press for three different die sets so that three stages of the operation can be performed. The upper die holder of the press has the same configuration. In coining, a single die set will be located in the middle section of the die holder. The middle section of the die holder which has a diameter of 222 mm is bigger than the sections at both sides which have a diameter of 197 mm. Technical drawings and dimensions of the circular dies appropriate for the die holders are given in Figure 5.12 and Figure 5.13. For each section of die holders, there is an identically placed key seat in order dies to be alligned.

Surface of the die clamping elements mates the larger diameter of the die holders when the clamping elements are fastened by bolts. This large die surfaces that mate with the clamping elements are tapered at an angle of 5 degrees; the clamping elements also have the same angle. Additionally, the key seats with a width of 16 mm have the tolerance of H8 [32]; and depth of 9 mm. These features are designed in the dies to prevent the rotational motion of the dies relative to the die holder.

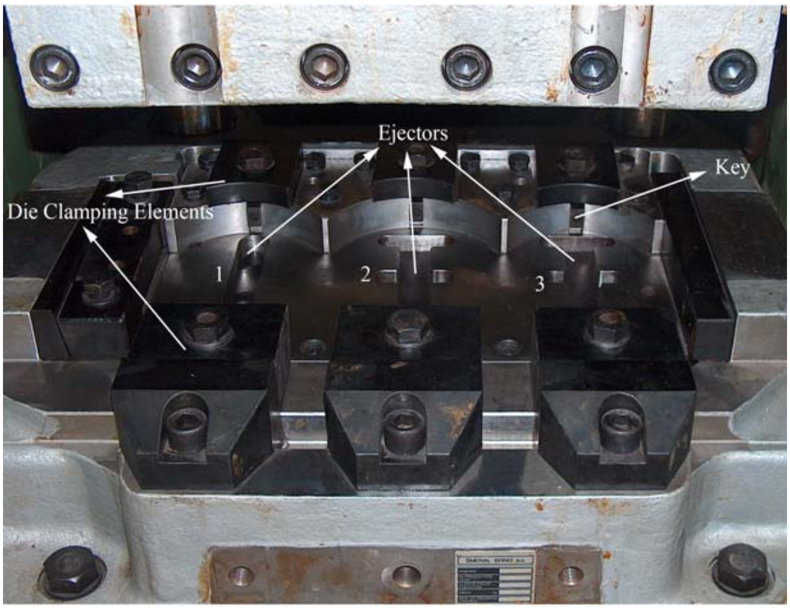



**Figure 5.11 A view of Lower Die Holder**

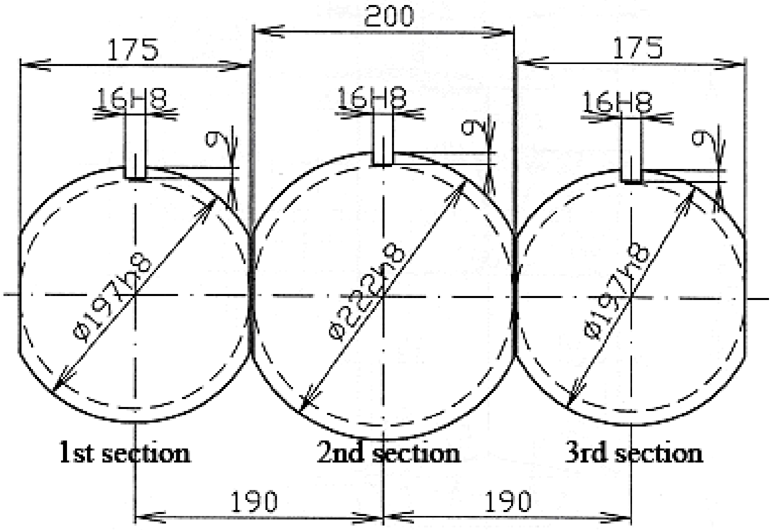



**Figure 5.12 Top view of the Circular Dies [31]**

As seen in Figure 5.13, there is a flange-shaped clamping part which has a 50 mm distance from the die base in order to clamp the die sets to die holder of the press. The clamping elements are mounted on the die holder of the press by bolts.

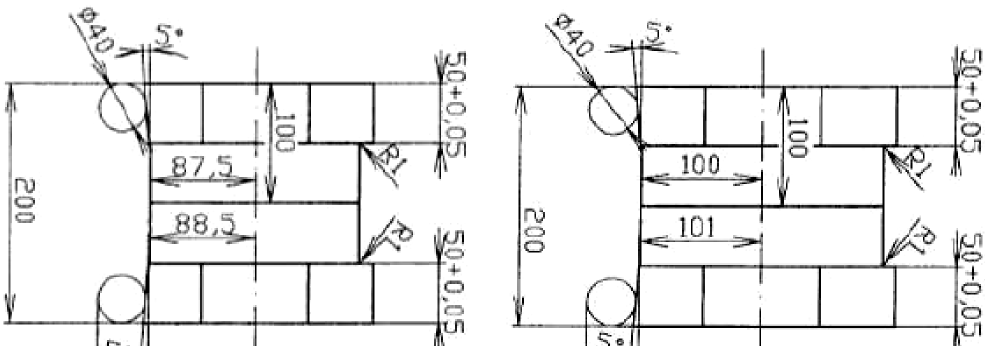



**Figure 5.13 Front view of the Circular Dies [31]**

### 5.3.2 Manufacturing of the Coining Dies

The design details of the medallion and die sets have been described in Chapter 4. After the dies are modeled in Pro/Engineer WF 3.0 and simulation of the coining process is realized in MSC.SuperForge, NC codes to the die sets are prepared using the manufacturing module of Pro/Engineer WF 3.0 [23]. During the code generation, die cavity section for the letter is manufactured by using on end mill with a diameter of 0.8 mm.

Sleipner is selected as the coining die material for interchangeable and fixed upper die and lower die, due to its high hardness after high temperature tempering, high compressive stress, high toughness at room temperature and its good machinability [33]. For other parts, DIN 1.2714 [33] has been used, because of its machinability and cheaper price. The detailed properties of Sleipner and DIN 1.2714 [33] are given in Appendix A.

Manufacturing of the coining dies and blanking dies have been performed in METU-BILTIR Center CAD/CAM Laboratory. After turning raw material to the desired value of the diameter that is a little more than the exact size, the final size of the dies are given in MAZAK Variaxis 630-5X high-speed vertical milling machine, which is available in METU-BILTIR Center CAD/CAM Laboratory.

The raw steel material is soft annealed so that the machining operations can be easily done. After all the manufacturing operations are completed, the interchangeable component of upper die is sent for heat treatment processes of which details are given in Appendix B. as a result of the heat treatment, the hardness of it will be 62 HRC. In Figures 5.14-5.23, the photographs and the technical drawings of the dies can be seen.

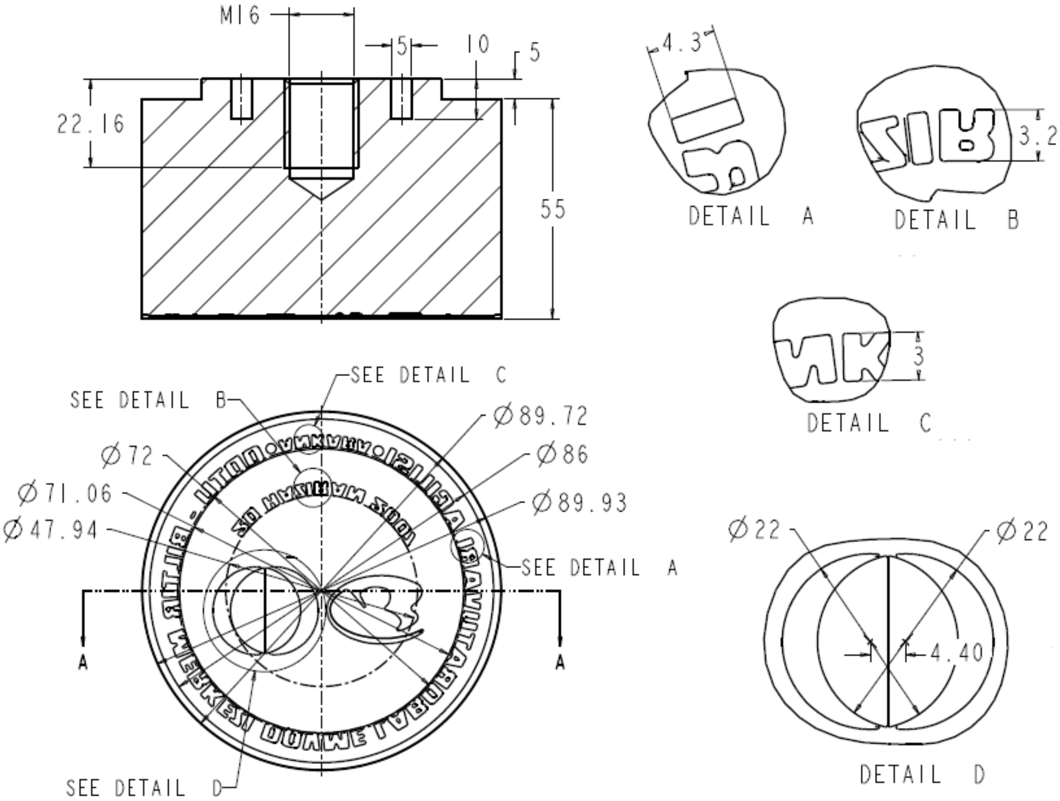



**Figure 5.14 Technical Drawing of the Interchangeable Part of Upper Coining Die**

**Figure 5.15 A view of Manufactured Interchangeable Part of Upper Coining Die**

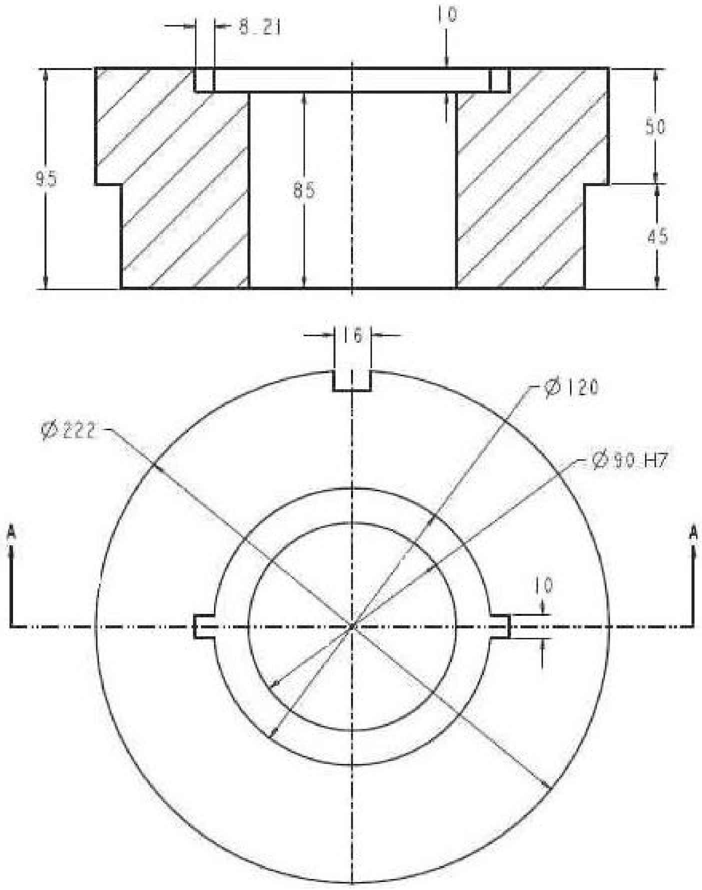



**Figure 5.16 Technical Drawing of the Upper Coining Supporting Die**

**Figure 5.17 A view of Manufactured Upper Coining Supporting Die**

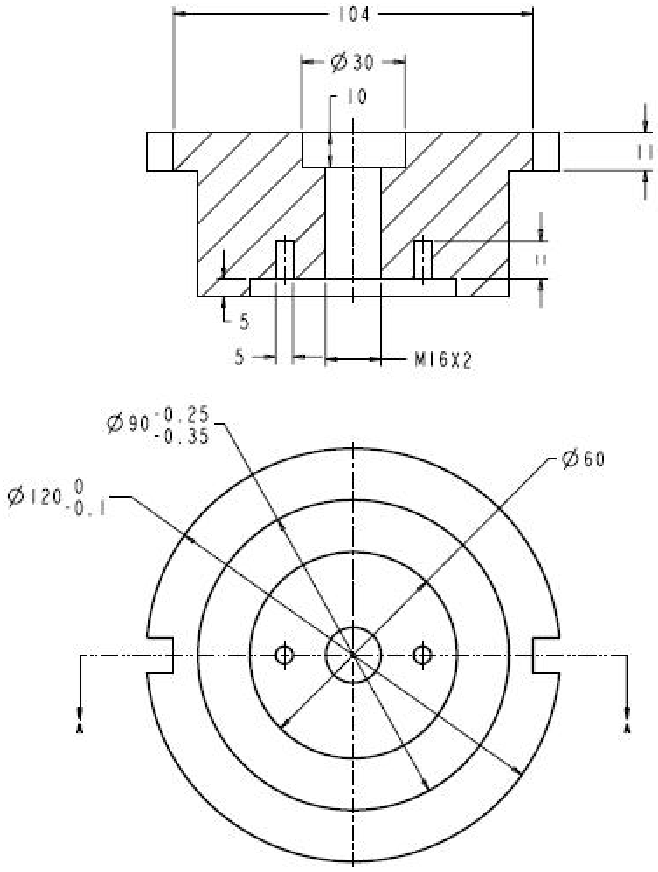



**Figure 5.18 Technical Drawing of the Fixed Part of Upper Coining Die**

**Figure 5.19 A view of Manufactured Fixed Part of Upper Coining Die**

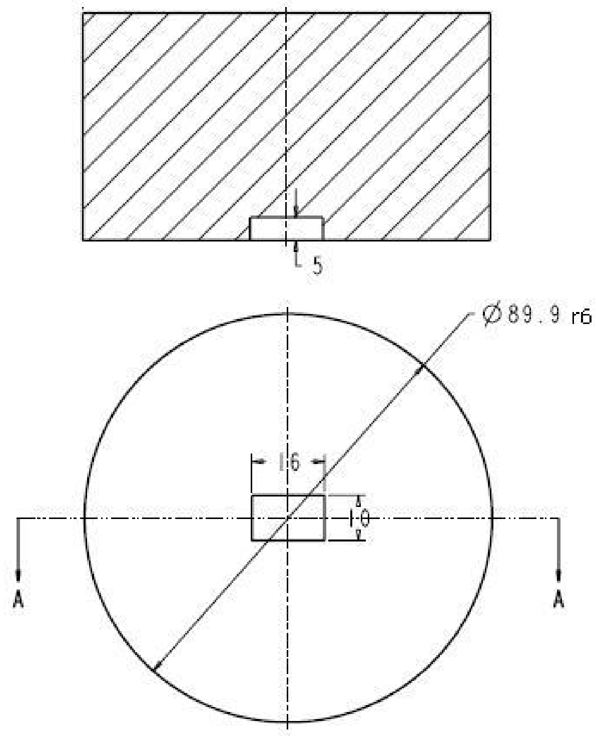



**Figure 5.20 Technical Drawing of the Lower Coining Die**

**Figure 5.21 A view of Manufactured Lower Die of Coining Die Set**

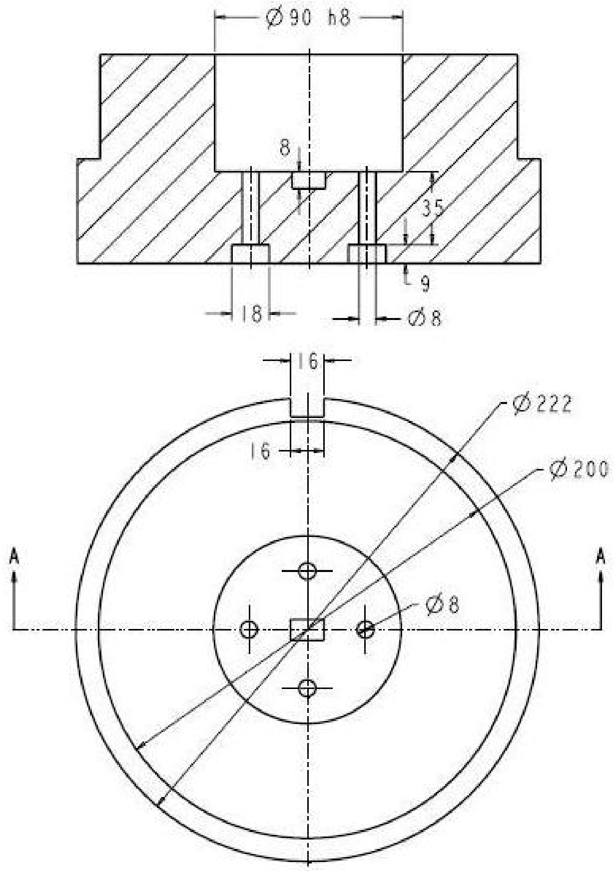



**Figure 5.22 Technical Drawing of the Lower Coining Supporting Die**

**Figure 5.23 A view of Manufactured Lower Coining Supporting Die**

### 5.3.3 Assembly of the Coining Dies

Following the manufacturing the upper and lower die sets, the die sets have been assembled separately and placed to the upper and lower die holder of the press considering the right positions according to each other and the alignment of the ram distance of the press so that the coinage can be done perfectly. The parts belong to the upper and lower die assemblies can be seen separately in Figure 5.24 and Figure 5.25, respectively.

**Figure 5.24 A view of Upper Coining Die Assembly Parts**

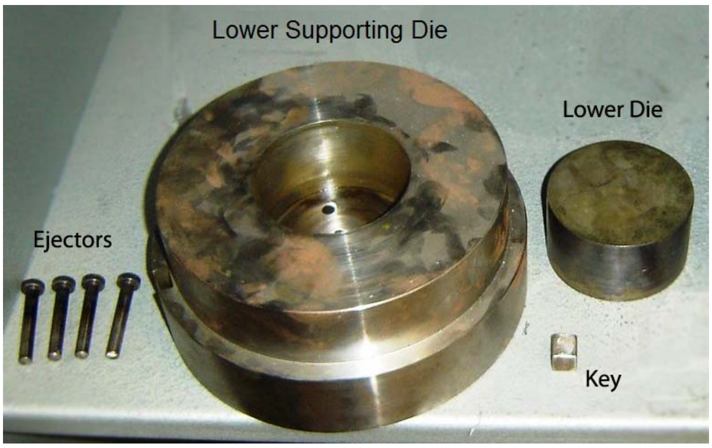



**Figure 5.25 A view of Lower Coining Die Assembly Parts**

The upper die is attached to the upper supporting die with the help of the flange of the upper die. Then, interchangeable upper die which has the male details are stabilized and aligned by two small pins and a M16 fixing bolt.

The two identical pins are placed between the fixed upper die and the interchangeable component in order to provide the alignment of the upper and lower dies with respect to each other for positioning the obverse relief with respect to the reverse detail of the medallion if any. The locations of the keys are shownd in Figure 5.26.

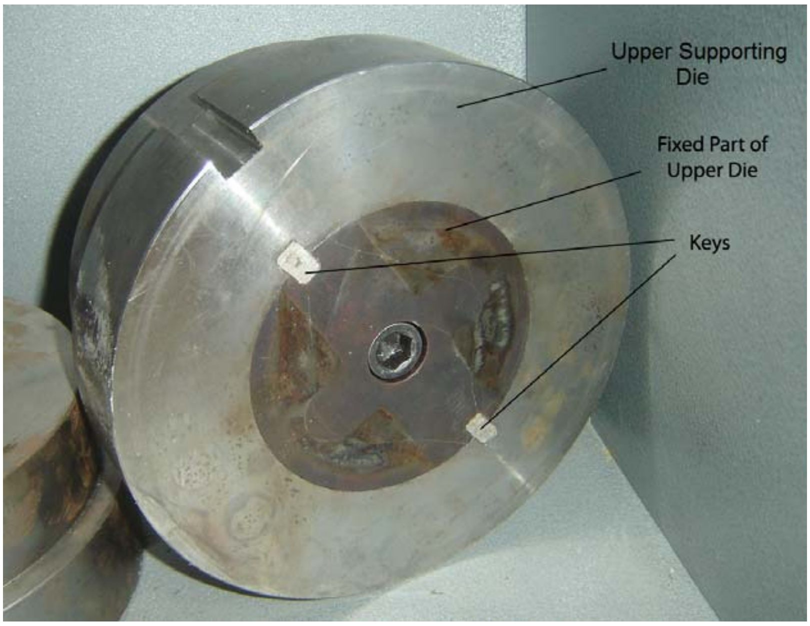



**Figure 5.26 Assembly of Supporting Die and Fixed Part of the Upper Coining Die**

In case of any different design, interchangeable component of upper die (modular die) can easily be changed. A M16 bolt has been used at the center of the die set. The position of the bolt is given in Figure 5.27.

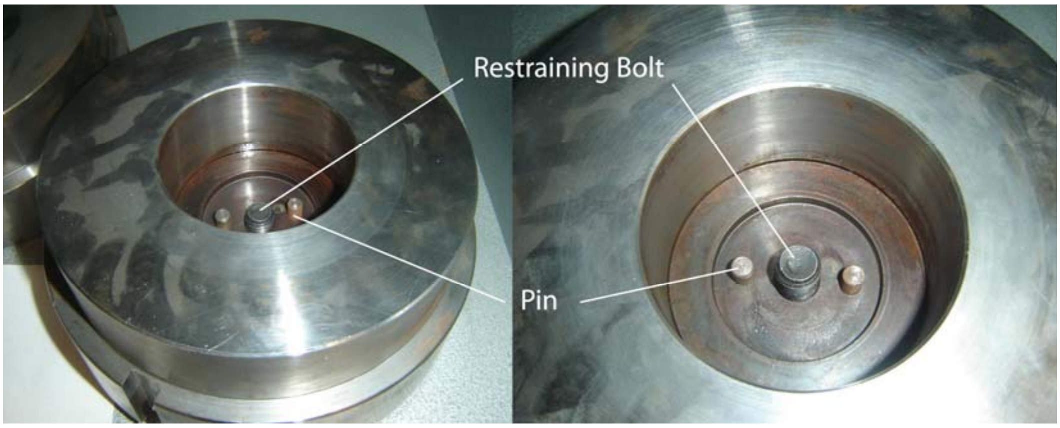



**Figure 5.27 Locations of the Clamping Parts of Upper Coining Die Set**

The key is tight fit to the lower supporting die. There is a keyway on the lower die, in which this particularly key fits. In Figure 6.28, a view of lower coining die assembly is given. The lower die is attached to the lower supporting die with the help of a rectangular shaped key which allows vertical movement and restricts any rotation. The ejectors can move vertically, due to the diameter clearance. The movement of the die helps the coined workpiece removal with the aid of the ejector pins available on the press. The keys and ejector pins are shown in Figure 5.29 and Figure 5.30.

**Figure 5.28 A view of Manufactured Lower Coining Die Assembly**


**Figure 5.29 A view of Manufactured Lower Coining Die Assembly with the Rectangular Key**

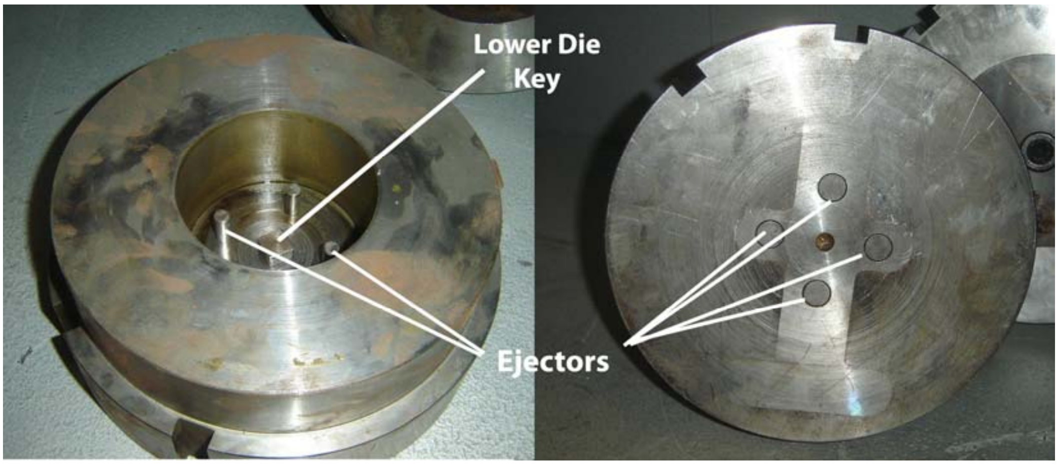



**Figure 5.30 Locations of the Moving Parts of Lower Coining Die Set**

The technical drawings and photographs are given in Figures 5.31-5.34.

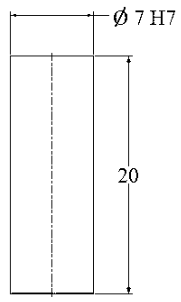



**Figure 5.31 Technical Drawing of the Pin**

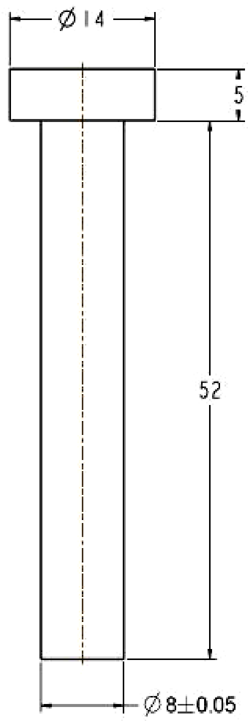



**Figure 5.32 Technical Drawing of the Ejector Pin**

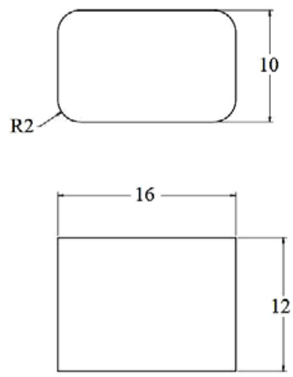



**Figure 5.33 Technical Drawing of the Upper Die Key**

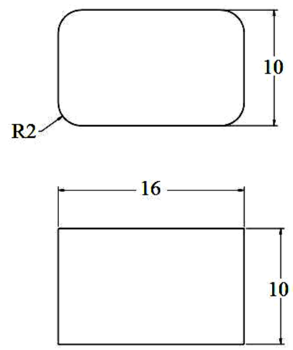



**Figure 5.34 Technical Drawing of the Lower Coining Die Key**

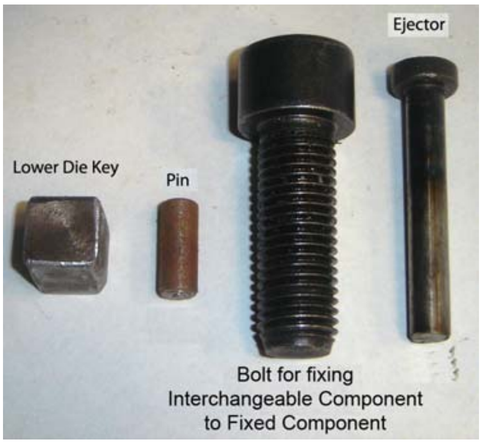



**Figure 5.35 Lower Die Key, Pin, Bolts and Ejector for Coining Die Set**

During the set up of the upper die set, die assembly is lifted by using by a hydraulic jack that is seated on a wedge above the lower supporting die. Then, the supporting die attached to the upper die holder of the press using die clamping elements. After ensuring that clamping elements are placed adequately, die set is fastened with bolts for each clamping elements. Then, the lower supporting die is placed on the lower die holder of the press inserting the keys into the key seats on the lower die holder. Keys prevent rotational motion of the die sets and by this way prevent defect of coinage. The lower supporting die is fixed to the lower die holder using clamping elements and bolts. The mounted die sets can be seen in Figure 5.36.

**Figure 5.36 A view of Mounted Coining Dies on the Press**

After both of the upper and lower dies are mounted, alignment of them is checked with few test shots when the press is in unloaded position. After it is ensured that the alignment of the upper and lower dies is done appropriately, the upper die set is brought to the upper dead center so that shut height can be adjusted for the coining process.

In Figure 5.37, upper die set assembly can be seen. a view of mounted dies can be also seen in Figure 5.38.

**Figure 5.37 A view of Assembled Upper Die Set**

**Figure 5.38 A view of Die Sets before the Coinage**

The standard brass sheet may be bought in the dimension of 2000x660x5 mm or 2000x680x5 mm. In this particular case, the brass sheet with the diameter of 2000x660x5 mm was bought.

The opening ceremony of METU-BILTIR Center Forging Research and Application Laboratory was hold in 20 June 2007. At that time, modular blanking die was not available. Because of it, the limited number of blanks was cut to 89 mm by using WEDM available in METU-BILTIR Center CAD/CAM Laboratory. By considering available space in the tank of WEDM, this standard sheet metal was cut into the smaller pieces as seen in Figure 5.39.

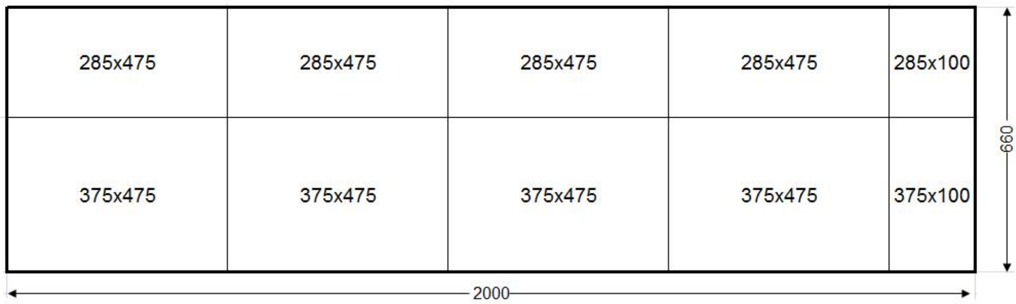



**Figure 5.39 Schematic Illustration of Cutting Dimensions of Sheet Metal for W-EDM**

Diameter and mass of each blank has been measured by using a digital compass and a digital precision scale. The average length of the blanks is 89,017 mm and the average mass of these is 265.44 g. The sheared blank can also be seen in Figure 5.40.

**Figure 5.40 Circular Blanks Manufactured with W-EDM**

### 5.4.2 Real Life Experiments for Coining of Commemorative Medallion

The blank is located into the lower supporting die as seen in Figure 5.41. The manufactured medallion on the die after the coining operation can be seen in Figure 5.42.

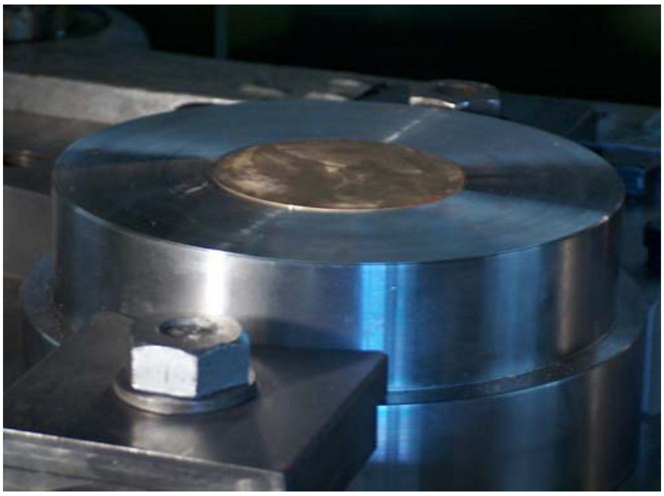


**Figure 5.41 A view of the Blank on the Lower Supporting Die**

**Figure 5.42 A view of Die Sets after the Coinage**

Manufactured medallions can be seen in Figure 5.43. After the coining process, they have been polished and varnished. Views of shinned and varnished medallions are also presented in Figures 5.44.


**Figure 5.43 A view of Coined Medallion without Polishing and Varnishing**

**Figure.5.44. A view of Polished and Varnished Coined Medallion**

After the coining process, outer diameters and thicknesses of the medallions were measured at different locations by using CMM as shown in Figure 5.45. The measured values are given in Table 5.3.


**Figure 6.45 Measurement Points after Blanking**

**Table 5.3 Dimensions of Blanks that are Measured after the Experiment**

| Sample No | Average Diameter | Thickness on Measurement Point | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 89,990 | 4,998 | 4,937 | 4,936 | 4,745 | 4,998 | 5,012 | 4,512 |
| 2 | 89,990 | 4,991 | 4,956 | 4,952 | 4,768 | 4,990 | 4,900 | 4,499 |
| 3 | 90,000 | 4,898 | 4,947 | 4,988 | 4,768 | 4,996 | 5,001 | 4,501 |
| 4 | 89,980 | 4,999 | 4,949 | 4,971 | 4,755 | 4,999 | 5,011 | 4,511 |
| 5 | 90,010 | 4,978 | 4,899 | 4,941 | 4,764 | 4,997 | 5,007 | 4,507 |
| 6 | 89,990 | 4,988 | 4,961 | 4,949 | 4,748 | 4,999 | 5,003 | 4,508 |
| 7 | 89,990 | 4,999 | 4,990 | 4,997 | 4,990 | 4,998 | 5,012 | 4,512 |
| 8 | 90,000 | 4,995 | 4,937 | 4,936 | 4,768 | 4,998 | 5,000 | 4,509 |
| 9 | 90,000 | 4,978 | 4,937 | 4,936 | 4,768 | 4,990 | 4,900 | 4,499 |
| 10 | 90,000 | 4,988 | 4,990 | 4,952 | 4,768 | 4,990 | 5,001 | 4,501 |
| 11 | 90,000 | 4,991 | 4,949 | 4,952 | 4,996 | 4,900 | 5,011 | 4,501 |
| 12 | 90,000 | 4,898 | 4,899 | 4,764 | 4,999 | 4,999 | 5,012 | 4,511 |
| 13 | 90,000 | 4,999 | 4,961 | 4,748 | 4,997 | 4,997 | 5,010 | 4,507 |
| 14 | 90,000 | 4,999 | 4,962 | 4,997 | 4,999 | 4,999 | 5,001 | 4,511 |
| 15 | 90,000 | 4,999 | 4,965 | 4,900 | 4,999 | 4,877 | 5,110 | 4,508 |
| 16 | 90,000 | 4,987 | 4,990 | 4,988 | 4,888 | 4,766 | 5,002 | 4,518 |
| 17 | 90,000 | 4,998 | 4,981 | 4,990 | 4,966 | 4,999 | 5,007 | 4,511 |
| 18 | 90,000 | 4,999 | 4,766 | 4,999 | 4,888 | 4,999 | 5,005 | 4,503 |
| 19 | 90,000 | 4,888 | 4,999 | 4,987 | 4,966 | 4,987 | 5,010 | 4,509 |
| 20 | 90,000 | 4,998 | 4,937 | 4,936 | 4,745 | 4,998 | 5,012 | 4,512 |
| 21 | 90,000 | 4,991 | 4,956 | 4,952 | 4,768 | 4,990 | 4,900 | 4,499 |
| 22 | 90,000 | 4,898 | 4,947 | 4,988 | 4,768 | 4,996 | 5,001 | 4,501 |
| 23 | 90,000 | 4,999 | 4,949 | 4,971 | 4,755 | 4,999 | 5,011 | 4,511 |
| 24 | 90,000 | 4,978 | 4,899 | 4,941 | 4,764 | 4,997 | 5,007 | 4,507 |
| 25 | 90,000 | 4,988 | 4,961 | 4,949 | 4,748 | 4,999 | 5,003 | 4,508 |
| 26 | 90,000 | 4,999 | 4,990 | 4,997 | 4,990 | 4,998 | 5,012 | 4,512 |
| 27 | 90,000 | 4,995 | 4,937 | 4,936 | 4,768 | 4,998 | 5,000 | 4,509 |
| 28 | 90,000 | 4,991 | 4,949 | 4,952 | 4,996 | 4,900 | 5,011 | 4,501 |
| 29 | 90,000 | 4,898 | 4,899 | 4,764 | 4,999 | 4,999 | 5,012 | 4,511 |
| 30 | 90,000 | 4,999 | 4,965 | 4,900 | 4,999 | 4,877 | 5,110 | 4,508 |
| 31 | 90,000 | 4,998 | 4,990 | 4,900 | 4,996 | 4,996 | 5,010 | 4,501 |
| 32 | 90,000 | 4,999 | 4,949 | 4,988 | 4,999 | 4,999 | 5,001 | 4,511 |
| 33 | 90,000 | 4,999 | 4,899 | 4,999 | 4,997 | 4,997 | 5,110 | 4,509 |

**Table 5.3 Dimensions of Blanks that are Measured after the Experiment (Con't)**

| Sample No | Average Diameter | Thickness on Measurement Point | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 34 | 90,000 | 4,988 | 4,889 | 4,999 | 4,999 | 4,999 | 5,001 | 4,501 |
| 35 | 90,000 | 4,999 | 4,961 | 4,748 | 4,997 | 4,997 | 5,010 | 4,507 |
| 36 | 90,000 | 4,999 | 4,962 | 4,997 | 4,999 | 4,999 | 5,001 | 4,511 |
| 37 | 90,000 | 4,999 | 4,965 | 4,900 | 4,999 | 4,877 | 5,110 | 4,508 |
| 38 | 90,000 | 4,999 | 4,766 | 4,999 | 4,888 | 4,999 | 5,005 | 4,503 |
| 39 | 90,000 | 4,888 | 4,999 | 4,987 | 4,966 | 4,987 | 5,010 | 4,509 |
| 40 | 90,000 | 4,988 | 4,990 | 4,952 | 4,768 | 4,990 | 5,001 | 4,501 |
| 41 | 90,000 | 4,991 | 4,949 | 4,952 | 4,996 | 4,900 | 5,011 | 4,501 |
| 42 | 90,000 | 4,991 | 4,949 | 4,952 | 4,996 | 4,900 | 5,011 | 4,501 |
| 43 | 90,000 | 4,898 | 4,899 | 4,764 | 4,999 | 4,999 | 5,012 | 4,511 |
| 44 | 90,000 | 4,999 | 4,961 | 4,748 | 4,997 | 4,997 | 5,010 | 4,507 |
| 45 | 90,000 | 4,999 | 4,962 | 4,997 | 4,999 | 4,999 | 5,001 | 4,511 |
| 46 | 90,000 | 4,999 | 4,965 | 4,900 | 4,999 | 4,877 | 5,110 | 4,508 |
| 47 | 90,000 | 4,987 | 4,990 | 4,988 | 4,888 | 4,766 | 5,002 | 4,518 |
| 48 | 90,000 | 4,998 | 4,981 | 4,990 | 4,966 | 4,999 | 5,007 | 4,511 |
| 49 | 90,000 | 4,999 | 4,766 | 4,999 | 4,888 | 4,999 | 5,005 | 4,503 |
| 50 | 90,000 | 4,888 | 4,999 | 4,987 | 4,966 | 4,987 | 5,010 | 4,509 |

# CHAPTER 6

# ANALYSIS OF BLANKING PROCESS AND MANUFACTURING OF THE BLANKS

In this chapter, finite volume analysis of the blanking process and manufacturing of the blanking dies and manufacturing of blanks on the press will be described.

## 6.1 Simulation Results for Blanking

The design of the modular blanking die set has been given in Chapter 3. For the simulation of the blanking, a cylindrical shaped upper die, a large sheet metal part as workpiece and a hollow cylinder have been used in MSC.SuperForge. The positions of the dies and the workpiece are shown in Figure 6.1. From the material library of the program, CuZn28/CuZn30 is selected as blank material.

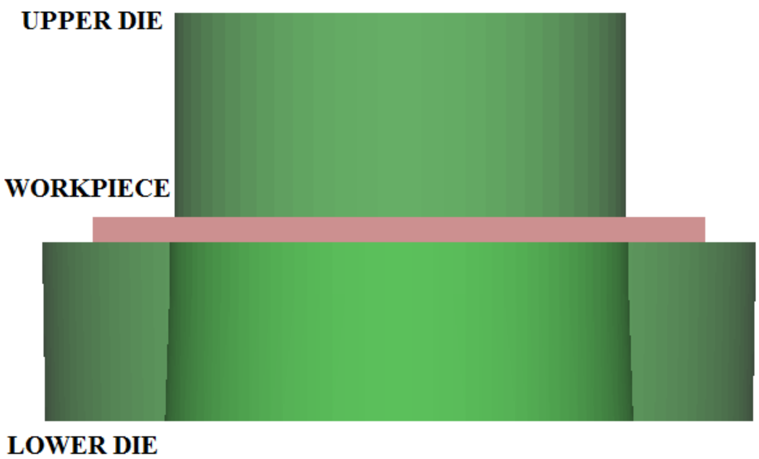



**Figure 6.1 MSC.SuperForge Assembly for Blanking Operation**

In the study, Dirinler 200-ton press which is available in METU-BILTIR Center Forging Research and Application Laboratory is used. the properties of the press is given in Appendix D.

As the result of the finite volume simulation of blanking, the effective stress distributions are illustrated in In Figure 6.2 and Figure 6.3; the effective plastic strain distribution for the blanks is also given in Figure 6.4.

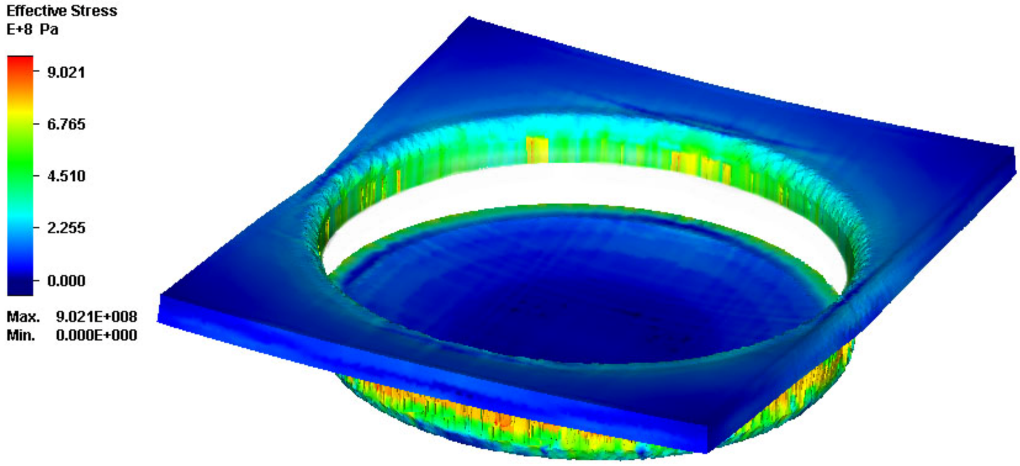



**Figure 6.2 Effective Stress Distribution for Blanks**

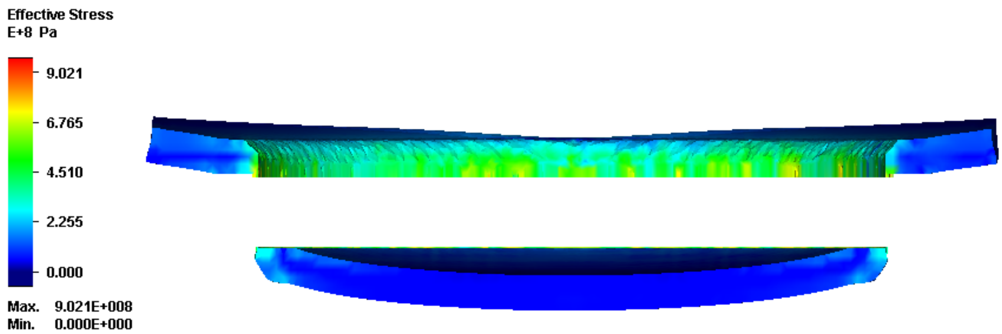



**Figure 6.3 Cross Section of Effective Stress Distribution for Blanks**

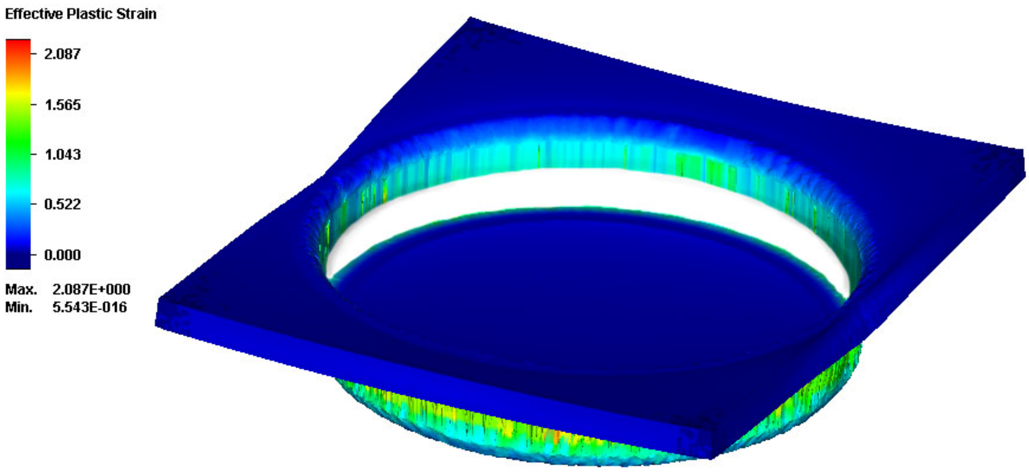



**Figure 6.4 Effective Plastic Strain Distribution for Blanks**

## 6.2 Production of the Blanking Die Set

The components of the blanking die set have been manufactured and assembled in METU-BILTIR Center CAD/CAM Laboratory. The geometry and dimensions of the parts depends on the Dirinler 200-ton eccentric press available in METU-BILTIR Center Forging Research and Application Laboratory (Figure 6.5).


**Figure 6.5 A view of Dirinler 200-ton Eccentric Press in METU-BILTIR Center Forging Research and Application Laboratory [34]**

The Dirinler 200 ton eccentric press, of which the technical data is given in Appendix C, has a ram stroke of 180 mm. The press has a shut height of 200 mm, which is the distance between the ram and the anvil when the ram is at its bottom dead center. When the supporting die is placed, and the ram is at its position of bottom dead center, the distance between the die locating surfaces of the upper and lower die holders is 200 mm. This means that the total allowable height of upper and lower die assembly is equal to the sum of the upper and lower die heights which is 200 mm when dies are fully closed.

The design details of the die set are given in Chapter 3. After the dies are modeled in Pro/Engineer WF 3.0 and simulation of the blanking process in MSC.SuperForge, NC codes of the die sets are prepared using the manufacturing module of Pro/Engineer WF 3.0.

Sleipner, because of its high hardness after high temperature tempering, high compressive stress, high toughness at room temperatures and its good machinability is used, for the upper die only. DIN 1.1730, because of its machinability and cheaper price is selected for the rest of the components. The detailed properties of Sleipner and DIN 1.1730 [33] are given in Appendix A.

Manufacturing of the blanking dies has been performed in METU-BILTIR Center CAD/CAM Laboratory. After turning raw material to the desired diameter value which is slightly more than the exact size, the final size of the dies are given in MAZAK Variaxis 630-5X high-speed vertical milling machine, which is available in METU-BILTIR Center CAD/CAM Laboratory.

The die sets are fastened to the die holders on the press by using T-slots on the die holders. In Figures 6.6- 6.19, the technical drawings of the die set and the manufactured components can be seen.

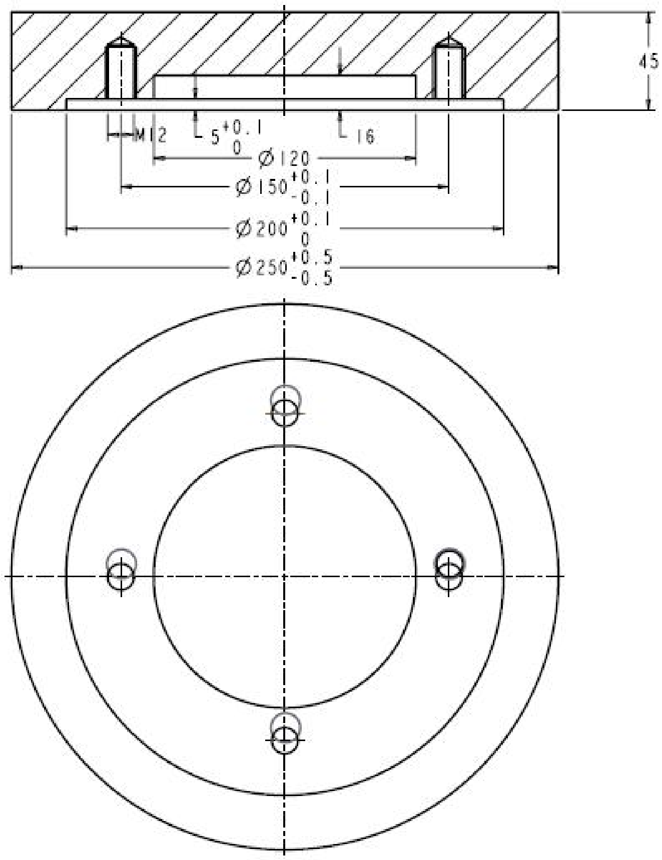



**Figure 6.6 Technical Drawing of the Upper Blanking Supporting Die**

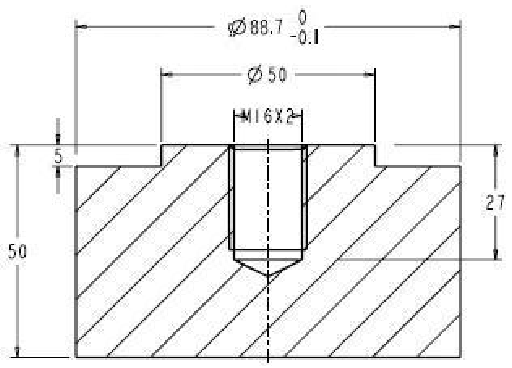



**Figure 6.7 Technical Drawing of the Interchangeable Component of Upper Blanking Die**

**Figure 6.8 A view of Manufactured Upper Blanking Supporting Die**

**Figure 6.9 A view of Manufactured Interchangeable Component of Blanking Upper Die**

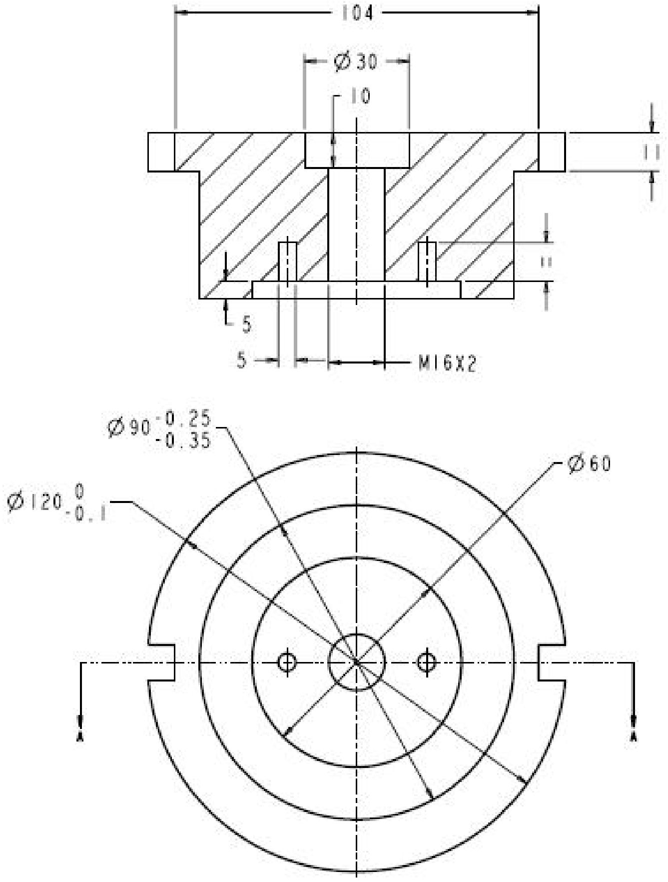



**Figure 6.10 Technical Drawing of the Interchangeable Component of Upper Blanking Die**

**Figure 6.11 A view of Manufactured Fixed Component of Blanking Upper Die**

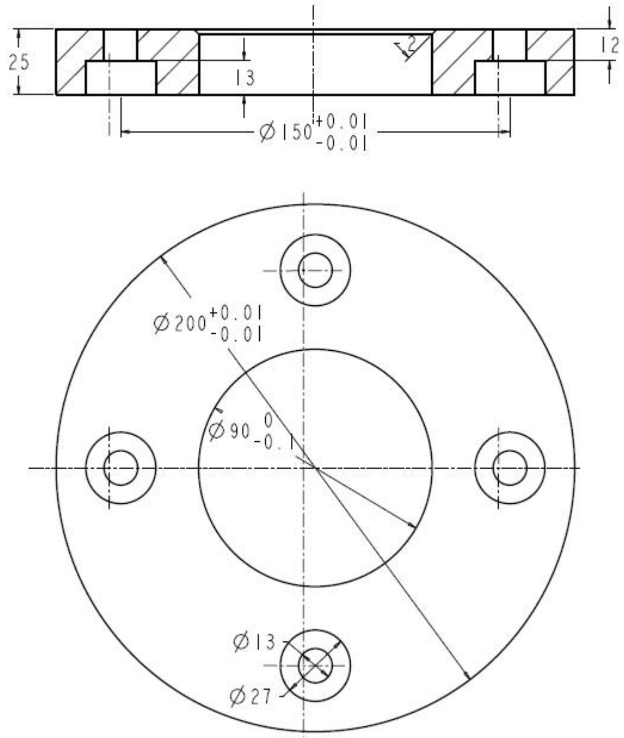



**Figure 6.12 Technical Drawing of the Upper Die Support of Blanking Die Set**

**Figure 6.13 A view of Manufactured Upper Die Support of Blanking Die Set**

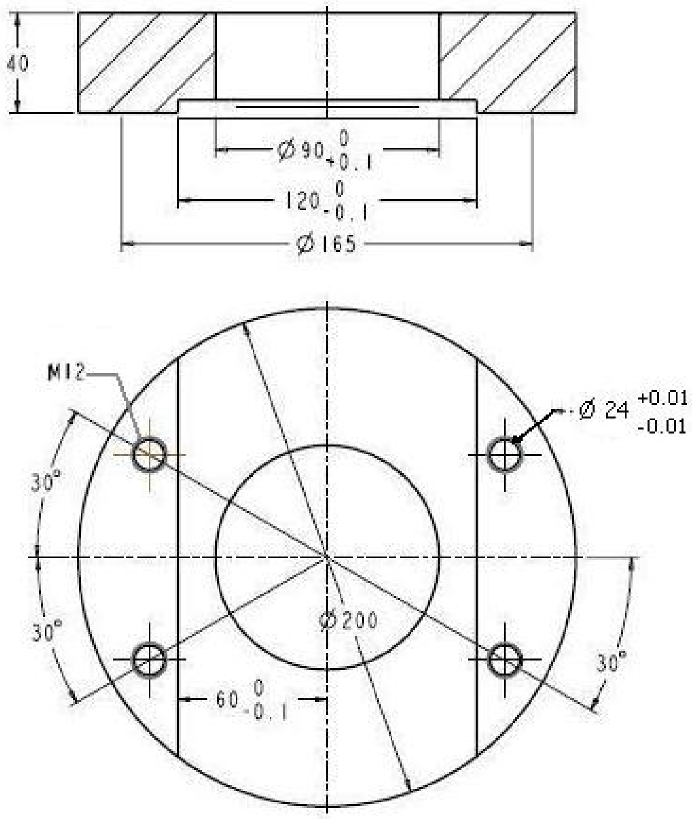



**Figure 6.14 Technical Drawing of the Guide Plate of Blanking Die Set**

**Figure 6.15 A view of Manufactured Guide Plate of Blanking Die Set**

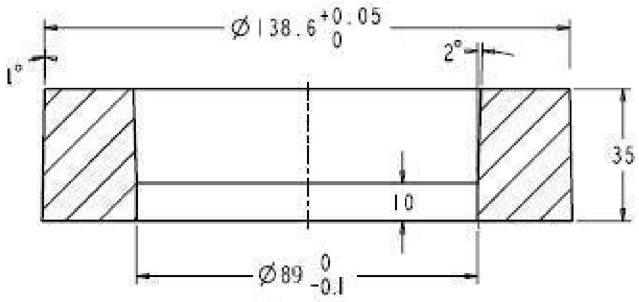



**Figure 6.16 Technical Drawing of the Lower of Blanking Die**

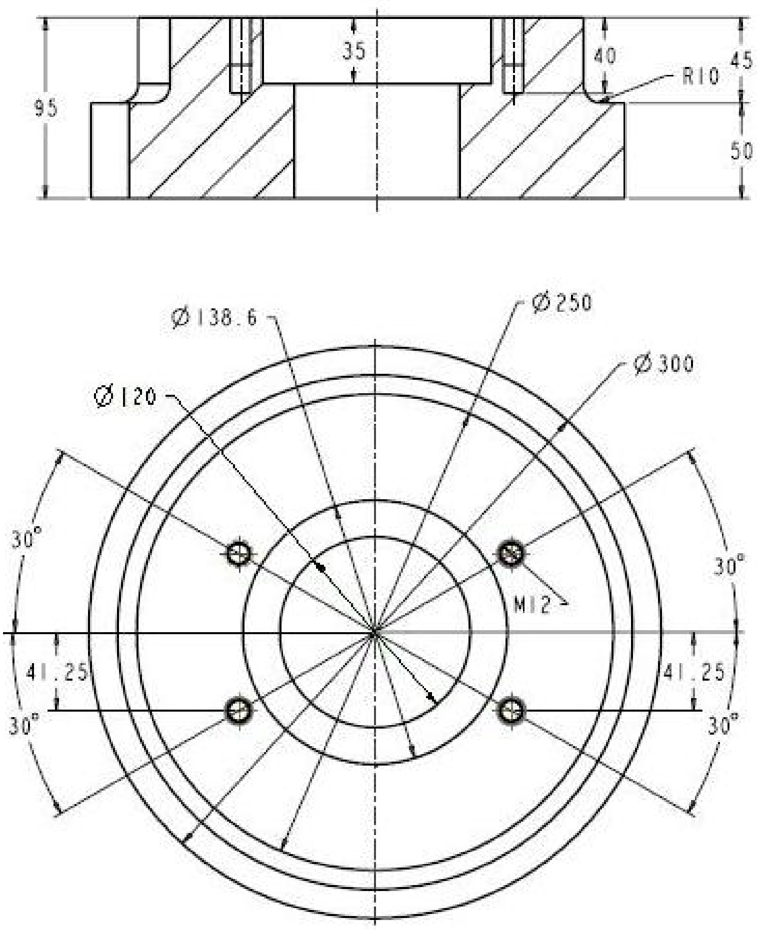



**Figure 6.17 Technical Drawing of the Lower Blanking Supporting Die**

**Figure 6.18 A view of Manufactured Lower Blanking Die**

**Figure 6.19 A view of Manufactured Lower Blanking Supporting Die**

After the production of the die sets for blanking process has been completed, the upper and lower die assemblies that can be seen in Figure 6.20 and Figure 6.21 are assembled and gathered together on the bases of the Dirinler 200-ton press.


**Figure 6.20 A view of Upper Blanking Die Assembly**

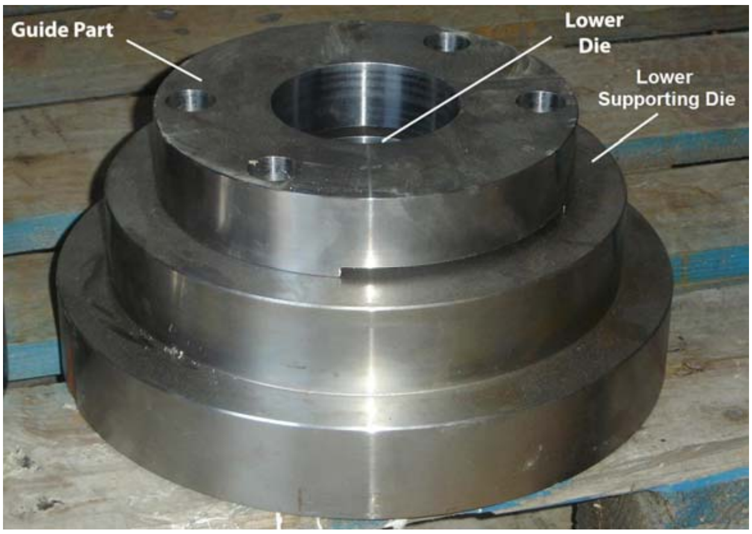



**Figure 6.21 A view of Lower Blanking Die Assembly**

In case of any design of a different coin with the diameter of 90 mm, dies and guide part can be changed easily and the same remaining die set can be used, which gives the design modularity. Then the upper die is attached to the upper supporting die with the help of the flange of the fixed part of the upper die, the upper die support and four die adjustment bolts that fix the die. Then, interchangeable upper die is stabilized and centered to the fixed part by two small pins and a M12 fixing bolt just same as the coining die design. Views of the die components are shown separately in Figure 6.22 and Figure 6.23.

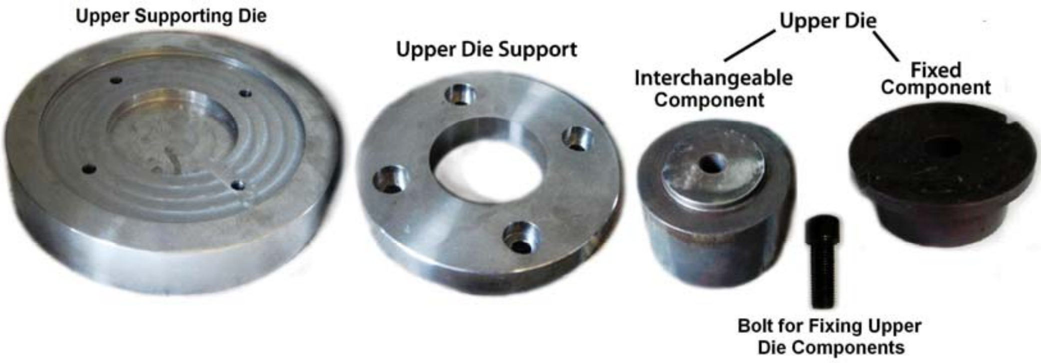



**Figure 6.22 Views of Manufactured Components of the Upper Blanking Die Assembly**

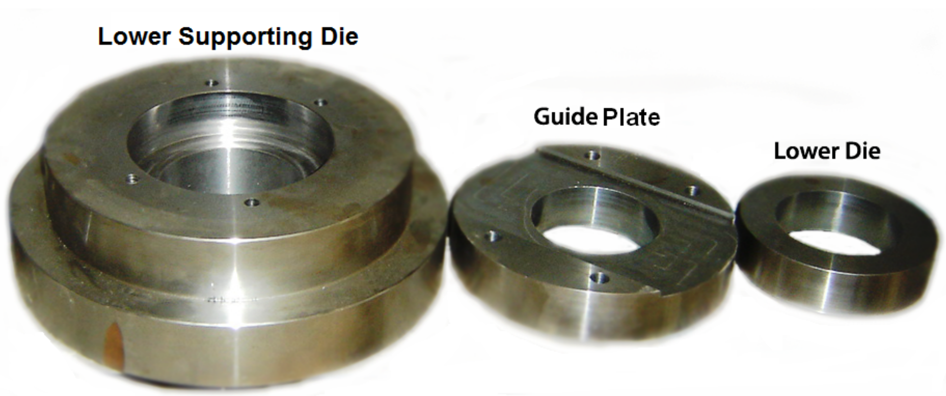



**Figure 6.23 Exploded view of Manufactured Lower Blanking Die Assembly**

During the set up of the upper die set, die assembly is seated onto the base considering the position of the lower supporting die. Then, the supporting die attached to the upper die holder of the press using die clamping elements. After ensuring that clamping elements are placed adequately, die set is fastened with bolts for each clamping elements. Lower die should be centered correctly to prevent the possible damage of dies or inaccurate blank production due to the eccentrically applied shear force. The guide part, finally, placed by the help of four bolts to support the sheet metal and prevent the damage of the strip during blanking. Fixing bolt and die adjustment bolts can be shown in Figure 6.24 and the whole assembly picture of the dies can be seen from Figure 6.25. The die sets can be seen separately in Figures 6.26-6.28.

**Figure 6.24 Bolt for Fixing Interchangeable Upper Die to Fixed Die Upper Die**

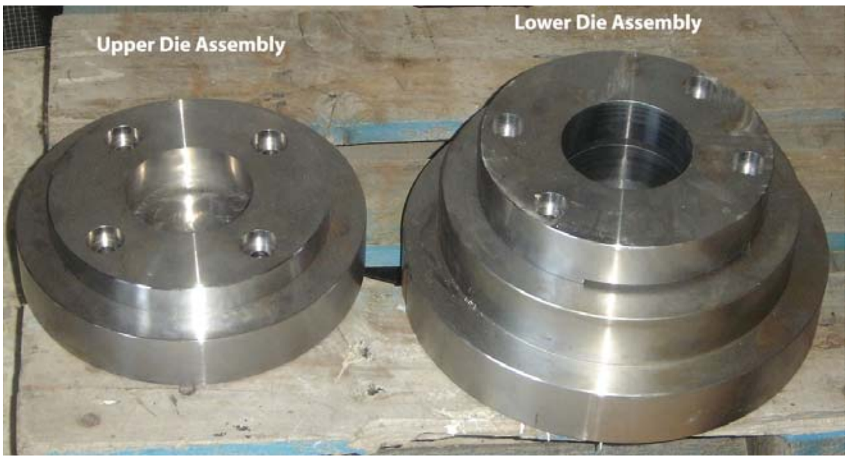



**Figure 6.25 A view of Assembly of the Blanking Die Set**

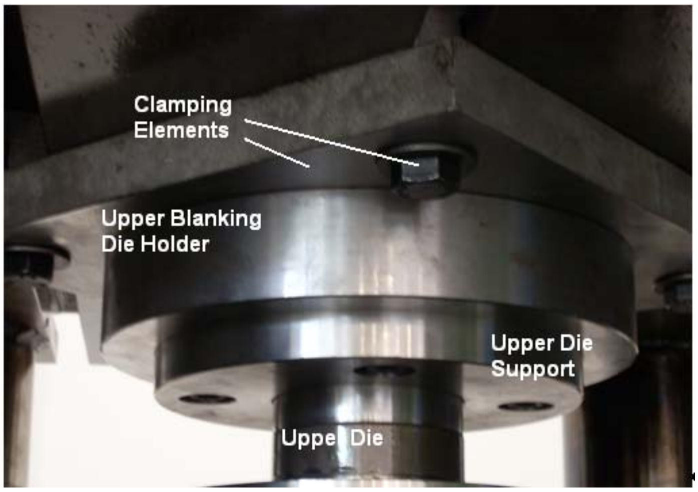



**Figure 6.26 A view of Assembled Upper Die Set**

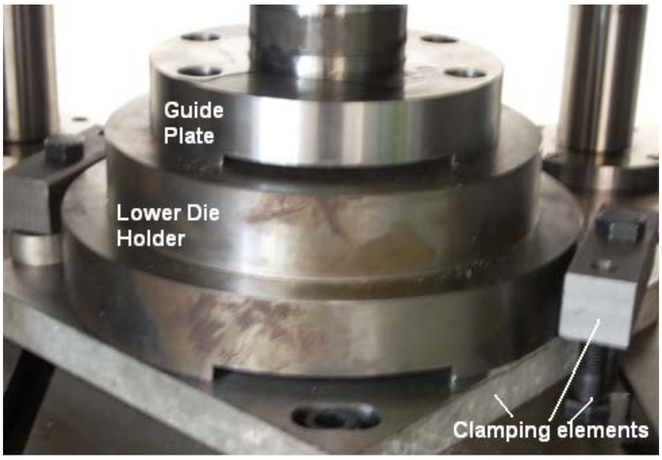



**Figure 6.27 A view of Assembled Lower Die Set**

**Figure 6.28 Modular Blanking Die Set**

## 6.3 Manufacturing of the Blanks by using Blanking Process

As discussed in section 6.1, blank material has been chosen as CuZn30. Blank dimensions and preparation are very important for the quality of coining. Before preparation of the necessary blanks, the dimensions of the workpiece should be determined according to the volume of the finished medallion.

The outer diameter of the medallion was chosen to be 90 mm. The thickness was set as 5 mm and a relief height is set as 0.5 mm considering the esthetical criteria, proportionality of the current medallion geometries and the available sheet material thickness in the market.

In order to fill die cavities the diameter of the blanks should be smaller than the desired medallion diameter. As discussed in Chapter 2, the blanks are cut from the sheet with a width of 100 mm and a pitch of 94 mm which is the sum of the blank diameter (D) and the distance between blanks that will be cut out (b).

Brass tonnage, $P_{BL}$, necessary for the blanking operation can be simply calculated by using the Eq.2.1. The blank diameter, d, is 89 mm, the blank thickness, t, is 5 mm and the shear strength of CuZn30, $S_S$, is 240 MPa as seen in Appendix B. Therefore, necessary tonnage for blanking process is evaluated below.

$$P_{BL} = (\pi \times d) \times t \times S_S \tag{6.1.a}$$

$$P_{BL} = \pi \times 89 \times 5 \times 240 \tag{6.1.b}$$

$$P_{BL} = 335355\mathrm{N} \tag{6.1.c}$$

$$P_{BL} = 34\mathrm{tons} \tag{6.1.d}$$

This result shows that 200 ton Dirinler Eccentric Press available in METU-BILTIR Center is capable for the manufacturing of the blanks for the coining of the medallion.

### 6.4 Real Life Experiments of Blanking

After the modular blank dies were manufactured with desired properties, blanks were sheared from brass sheets by using Dirinler 200 tones trimming press to achieve the desired quality of production.

The sheet metal of brass was bought in the dimension of 2000x680x5 mm. The strips were cut from this sheet to dimensions of 115x680 mm as seen in Figure 6.29.

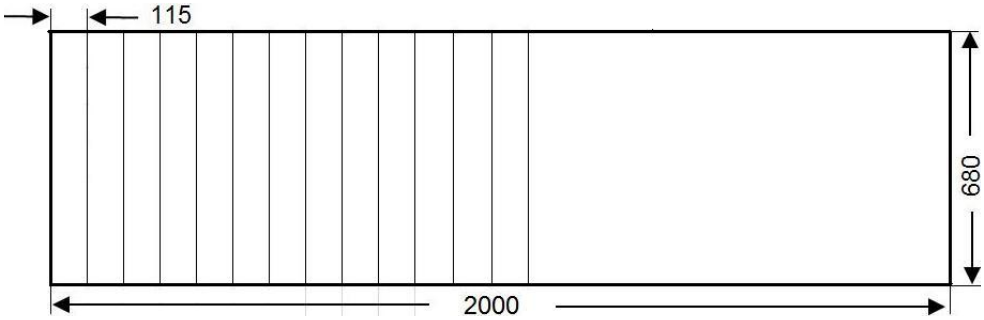



**Figure 6.29 Schematic Illustration of Dimensions of Strips cut from Sheet Metal**

When the press is unloaded, alignment of the dies is controlled by few tests and ensured that it is done appropriately. Then, the upper die is moved down by a distance of 20 mm more. In Figure 6.30, the blanks obtained by blanking process and in Figure 6.31, the sheared blanks for coining can be seen.

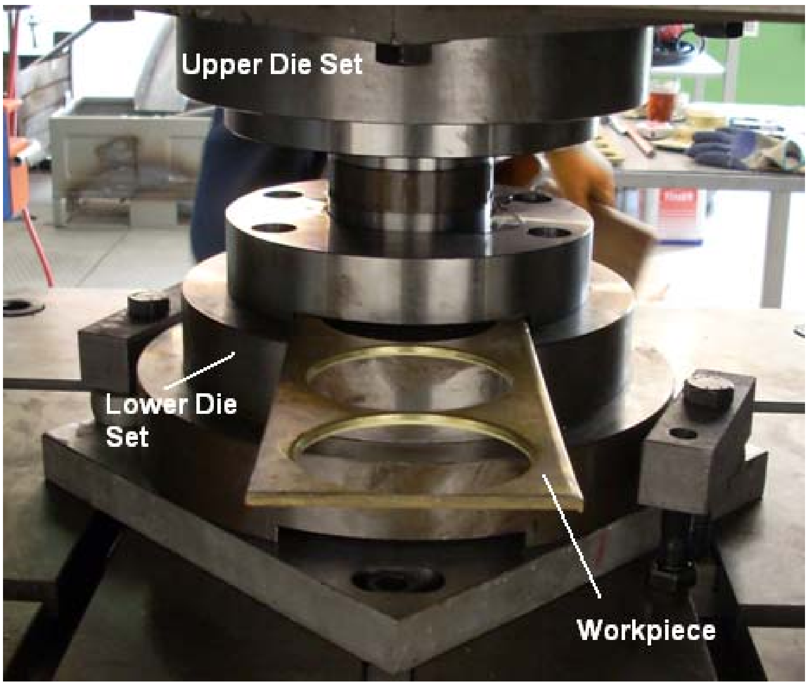



**Figure 6.30 A view of Die Sets during Blanking**

**Figure 6.31 A view of Blank**

After the blanking operation, outer diameters and thicknesses of the blanks were measured from the points that are shown in Figure 6.32. Measured values are given in Table 6.1.


**Figure 6.32 Measurement Points after Blanking**

**Table 6.1 Dimensions of Blanks That are Measured after the Experiment**

| Sample No | Average Diameter | Measurement Point | | | | | Average Thickness |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | |
| 1 | 88,85 | 5,15 | 5,12 | 5,11 | 5,10 | 5,13 | 5,13 |
| 2 | 88,85 | 5,05 | 5,05 | 5,03 | 5,04 | 5,00 | 5,03 |
| 3 | 88,87 | 5,04 | 5,03 | 5,02 | 5,02 | 5,00 | 5,02 |
| 4 | 88,85 | 5,00 | 5,01 | 5,00 | 4,99 | 5,00 | 5,00 |
| 5 | 88,85 | 5,00 | 5,02 | 5,00 | 5,01 | 4,99 | 5,01 |
| 6 | 88,85 | 5,05 | 5,04 | 5,05 | 5,02 | 5,01 | 5,04 |
| 7 | 88,85 | 5,07 | 5,08 | 5,07 | 5,07 | 5,06 | 5,07 |
| 8 | 88,87 | 5,06 | 5,05 | 5,05 | 5,05 | 5,04 | 5,05 |
| 9 | 88,85 | 5,06 | 5,05 | 5,04 | 5,04 | 5,03 | 5,04 |
| 10 | 88,86 | 5,08 | 5,07 | 5,05 | 5,02 | 5,01 | 5,05 |
| 11 | 88,87 | 5,02 | 5,02 | 5,00 | 4,99 | 4,99 | 5,00 |
| 12 | 88,85 | 5,00 | 4,97 | 4,96 | 4,97 | 4,96 | 4,97 |
| 13 | 88,87 | 5,00 | 4,99 | 4,98 | 4,98 | 4,97 | 4,98 |
| 14 | 88,86 | 4,98 | 4,96 | 4,95 | 4,95 | 4,94 | 4,95 |
| 15 | 88,85 | 4,99 | 4,98 | 4,98 | 4,98 | 4,97 | 4,98 |
| 16 | 88,85 | 4,99 | 4,98 | 4,98 | 4,98 | 4,97 | 4,98 |
| 17 | 88,87 | 4,99 | 4,98 | 4,96 | 4,96 | 4,94 | 4,96 |
| 18 | 88,87 | 4,99 | 4,98 | 4,98 | 4,97 | 4,96 | 4,97 |
| 19 | 88,86 | 4,99 | 4,98 | 4,97 | 4,97 | 4,97 | 4,97 |
| 20 | 88,86 | 5,01 | 5,00 | 4,99 | 4,98 | 4,96 | 4,99 |
| 21 | 88,85 | 5,03 | 5,02 | 5,02 | 5,02 | 5,01 | 5,02 |
| 22 | 88,87 | 5,02 | 5,02 | 5,01 | 5,00 | 5,00 | 5,01 |
| 23 | 88,85 | 5,04 | 5,05 | 5,04 | 5,04 | 5,03 | 5,04 |
| 24 | 88,85 | 5,01 | 5,00 | 5,00 | 4,99 | 4,99 | 5,00 |
| 25 | 88,85 | 5,06 | 5,05 | 5,05 | 5,05 | 5,04 | 5,05 |
| 26 | 88,85 | 5,00 | 4,99 | 4,98 | 4,98 | 4,97 | 4,98 |
| 27 | 88,87 | 4,99 | 4,98 | 4,98 | 4,98 | 4,97 | 4,98 |
| 28 | 88,85 | 4,99 | 4,98 | 4,97 | 4,97 | 4,96 | 4,97 |
| 29 | 88,85 | 4,98 | 4,97 | 4,97 | 4,97 | 4,96 | 4,97 |
| 30 | 88,87 | 5,01 | 5,00 | 4,99 | 4,98 | 4,98 | 4,99 |

# CHAPTER 7

# FINITE VOLUME ANALYSIS FOR PARAMETERS IN COINING OPERATION

In coining process, details to be filled are generally very small, however relatively high force is required. Therefore, depth of the cavity for each letter and the position of the letter on the medallion may affect the filling of the coining die. In this chapter, finite volume analysis of the coining process for an experimental medallion will be given to see the effects of these.

## 7.1 Design of the Experimental Medallion

As the commemorative medallion for METU-BILTIR center, the outer diameter of the experimental coin was chosen to be 90 mm and the thickness was set as 5 mm. “R” has been chosen as the character to be examined, since it may represent most of the features of the other characters in the alphabet. It has straight and curved features. The 3-D model of the medallion can be seen in Figure.7.1 and Figure.7.2. As seen in the figure, 17 different “R” characters are located on the medallion.

Die parameters; die radius, r, and depth of die cavity, $h_d$, are shown in Figure 7.3. The character height, S is given in Figure 7.4. Values of these parameters which are considered in the finite volume analysis are presented in Table 7.1.

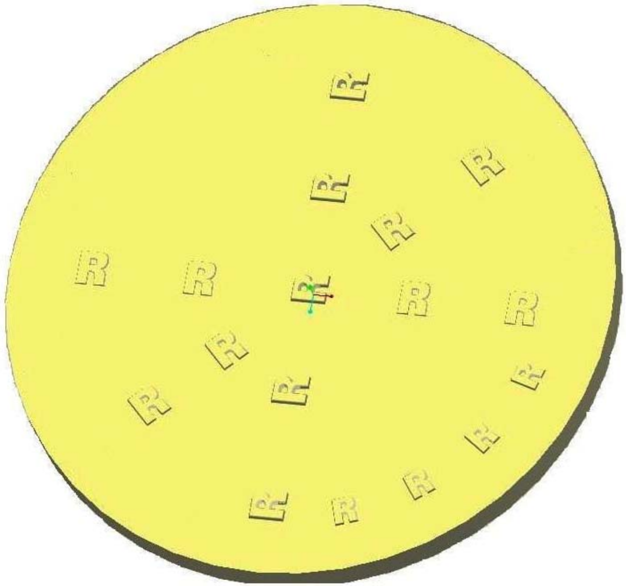


**Figure 7.1 3-D Model of the Medallion**

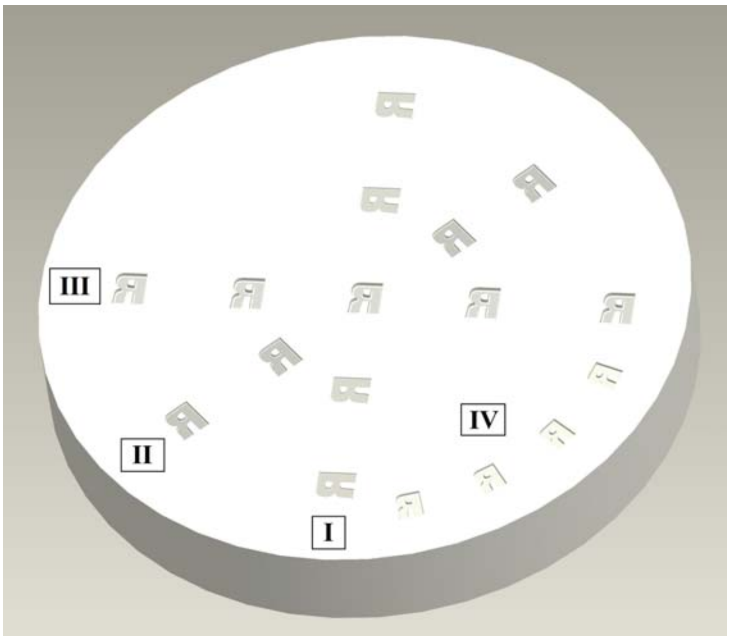



**Figure 7.2 Lines of Relief with Respect to Parameters**

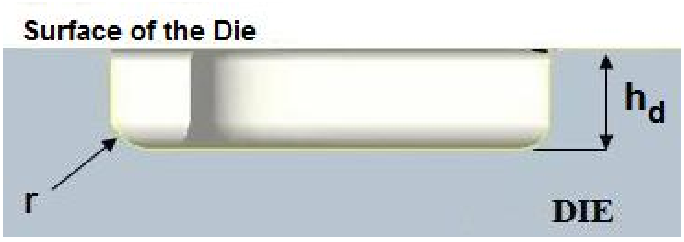



**Figure 7.3 Coining Die Parameters**


**Figure 7.4 The Character Height**

**Table.7.1 Parameters of Character "R" and Coining die**

| Relief Line | Definition of "R" Series | Character height, h | Character size, S | Die radius, r |
|---|---|---|---|---|
| I | Vertical | 0.25 mm | 5.10 mm | 0.10 mm |
| II | with Angle of 45 ° | 0.50 mm | 5.10 mm | 0.10 mm |
| III | Horizontal | 0.75 mm. | 5.10 mm. | 0.10 mm |
| IV | On Curve & Small | 0.50 mm | 4.00 mm | 0.10 mm |

## 7.2 Simulation Results for Experimental Medallion with "R" Characters

During the finite volume simulations, MSC.SuperForge simulation parameters necessary for the analysis are kept the same as that of coining of commemorative medallion. Furthermore, simulations are conducted for the room temperature (20°C), 400°C (temperature below recrystallization zone) and 800°C (temperature for hot working zone). The temperature values are chosen by considering Cu-Zn phase diagram given in Figure 7.5. The results of the simulation of experimental medallion are given in the order of the die filling analysis, effective stress distribution and effective plastic strain distribution in Figures 7.6-7.22.

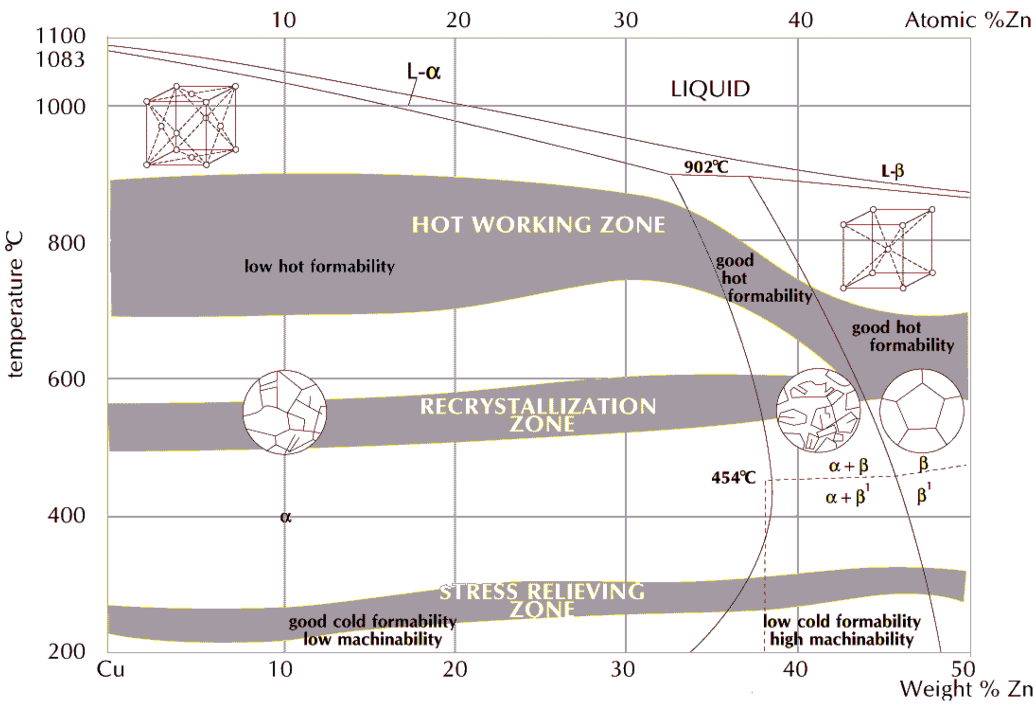



**Figure 7.5 Cu-Zn Phase Diagram [35]**

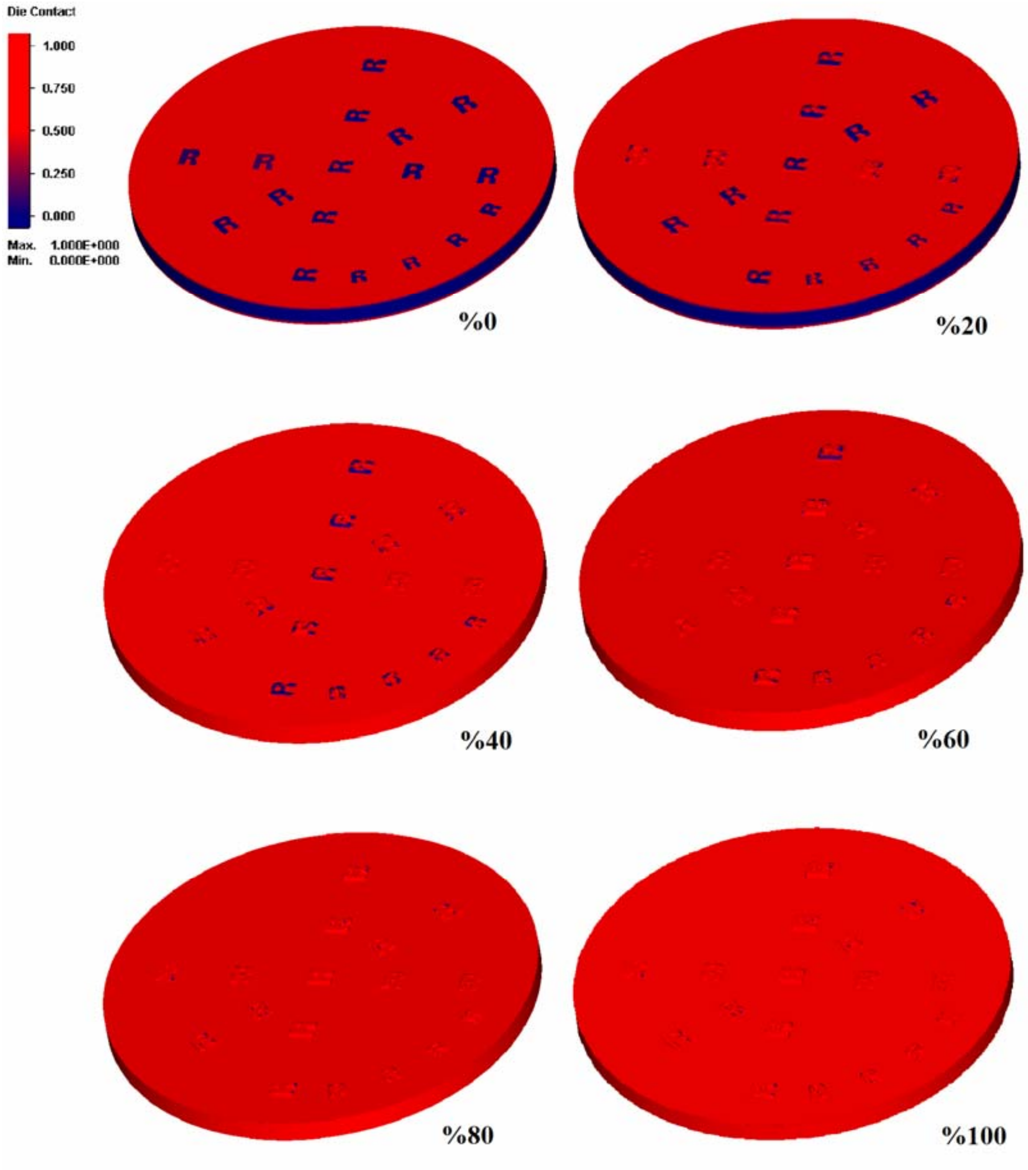



**Figure 7.5 Die Contact (Die Filling) Simulation Steps at 20°C with 0.5 mm Facial Clearance in Cavity Zone**

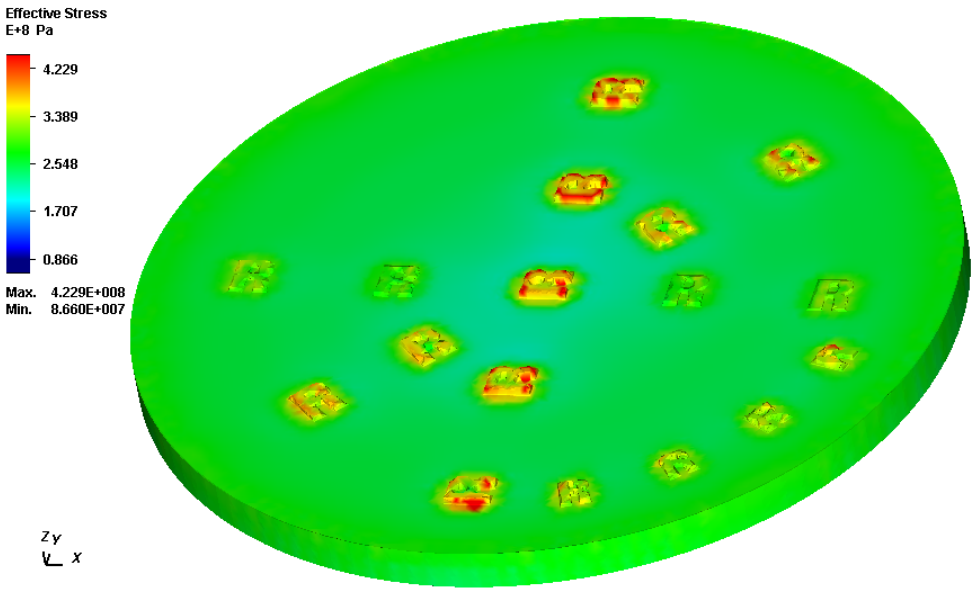



**Figure 7.6 Effective Stress Distribution at 20°C with 0.5 mm Facial Clearance in Cavity Zone**

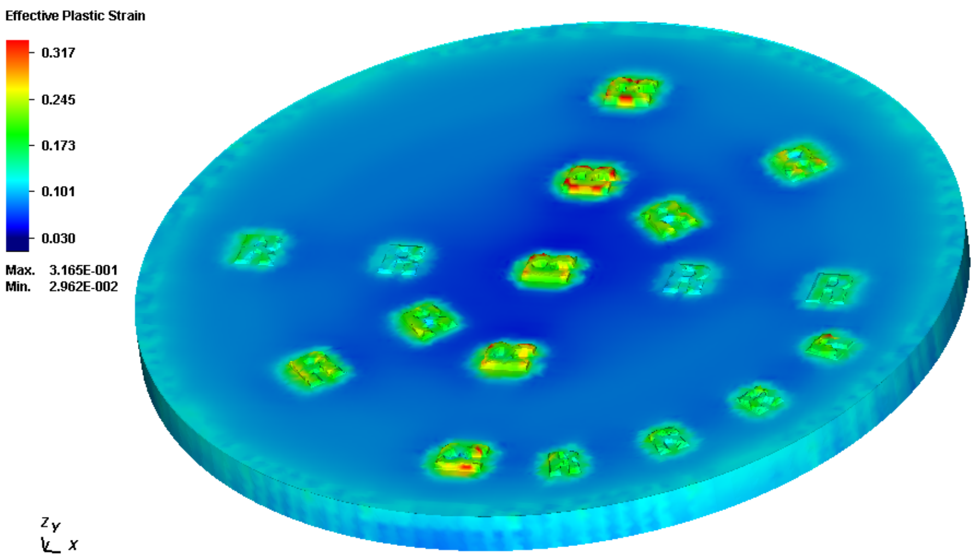



**Figure 7.7 Effective Plastic Strain Distribution at 20°C with 0.5 mm Facial Clearance in Cavity Zone**

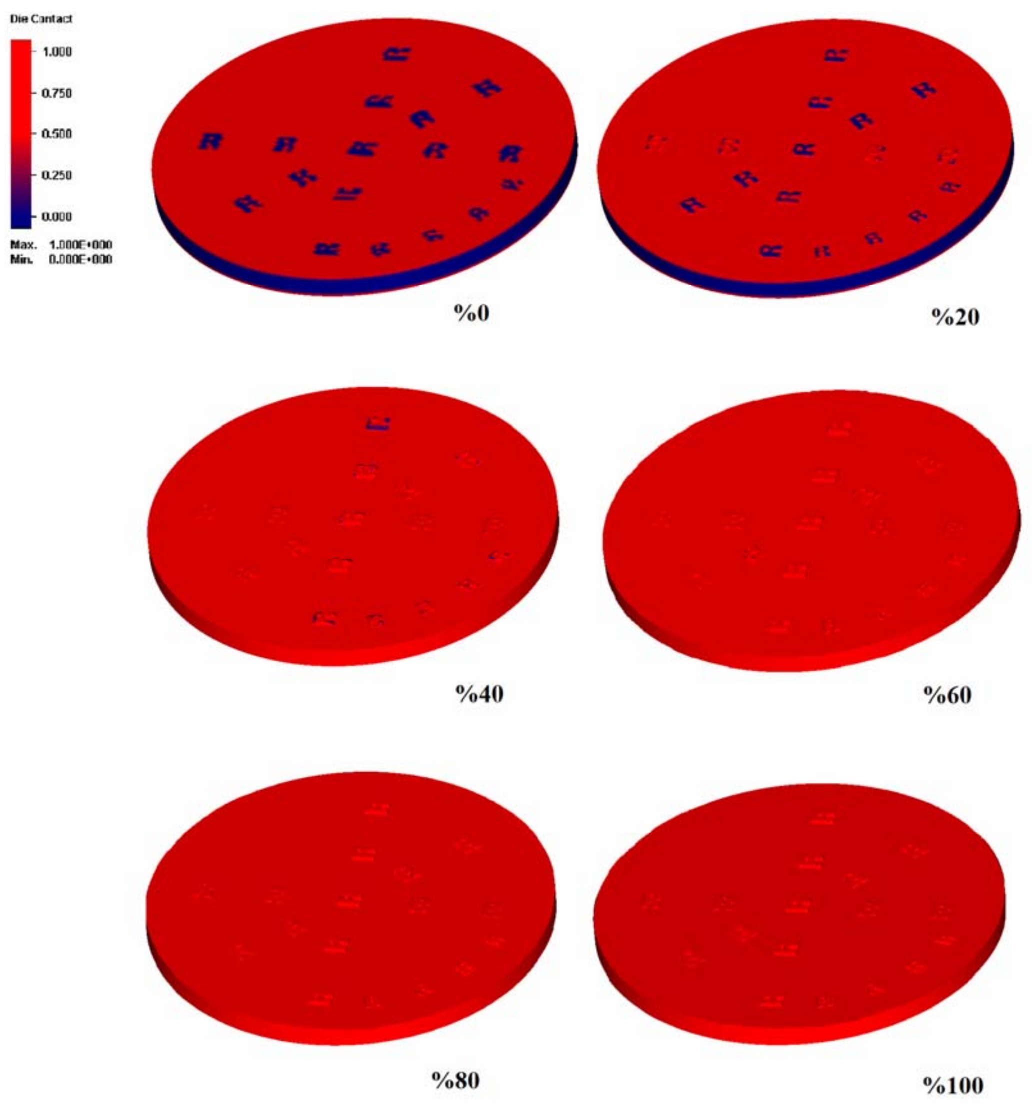



**Figure 7.8 Die Contact (Die Filling) Simulation Steps at 20°C with 1.0 mm Facial Clearance in Cavity Zone**

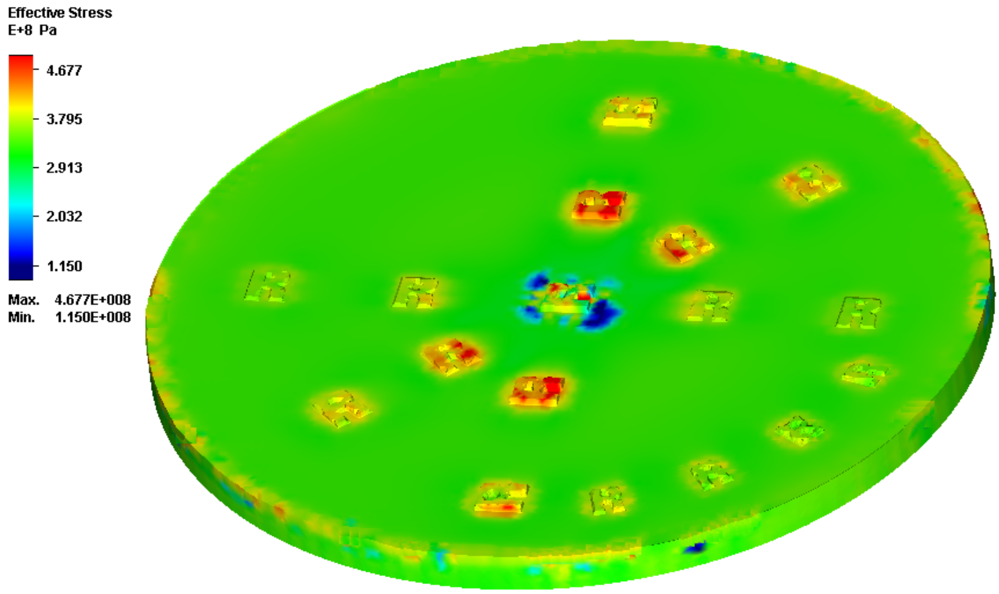



**Figure 7.9 Effective Stress Distribution at 20°C with 1.0 mm Facial Clearance in Cavity Zone**

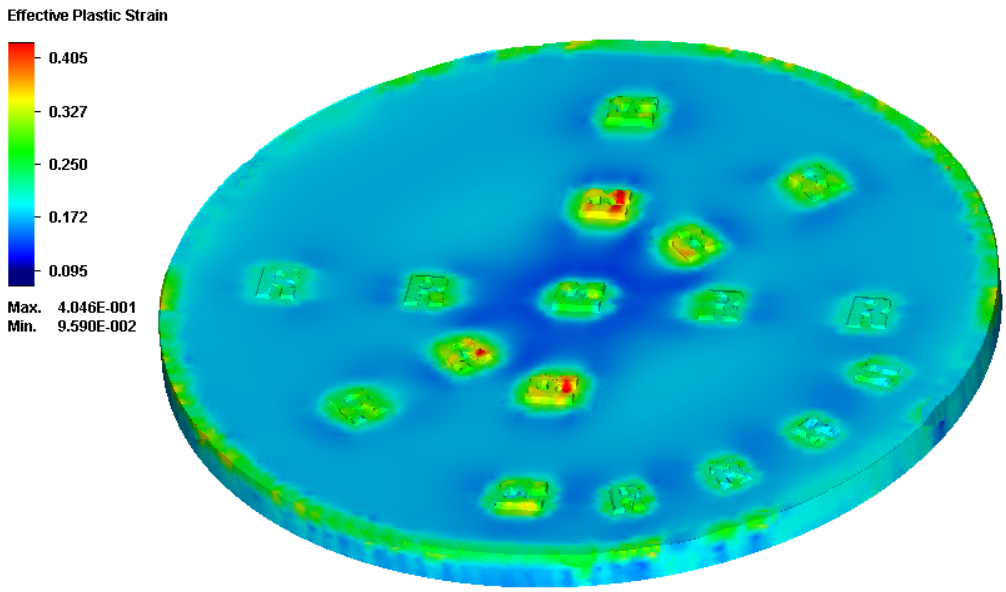



**Figure 7.10 Effective Plastic Strain Distribution at 20°C with 1.0 mm Facial Clearance in Cavity Zone**

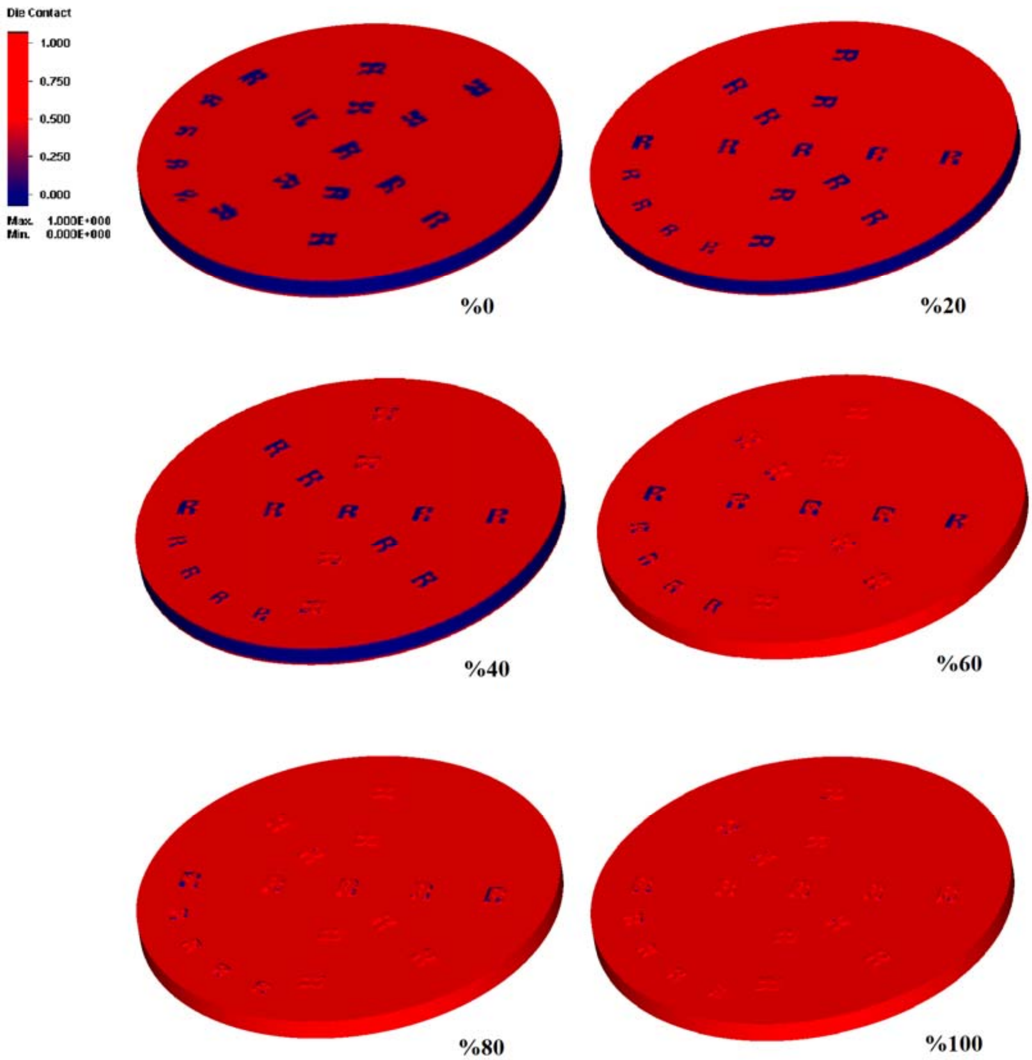



**Figure 7.11 Die Contact (Die Filling) Simulation Steps at 400°C with 0.5 mm Facial Clearance in Cavity Zone**

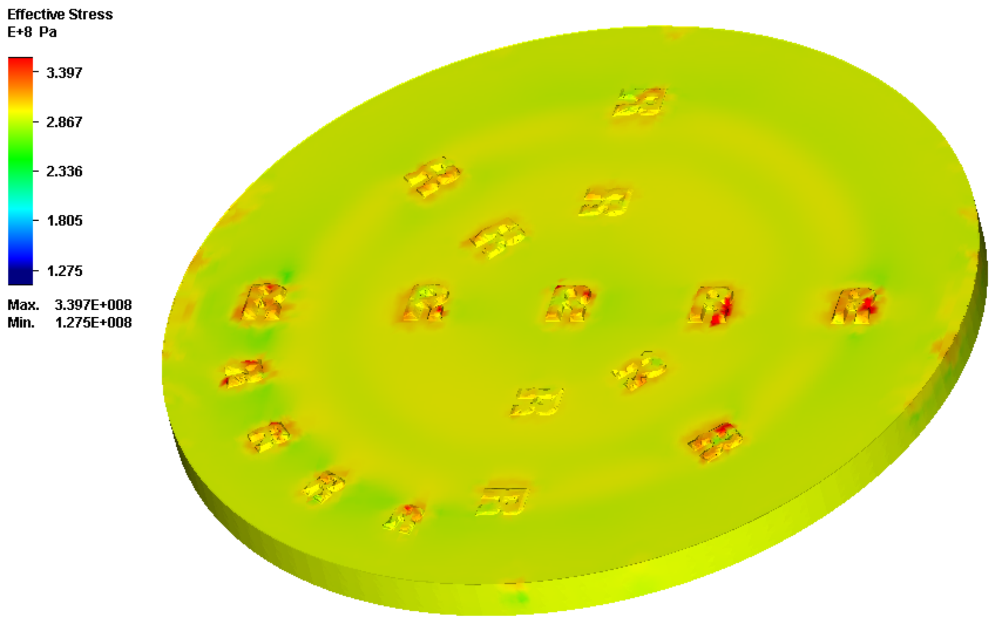



**Figure 7.12 Effective Stress Distribution at 400°C with 0.5 mm Facial Clearance in Cavity Zone**

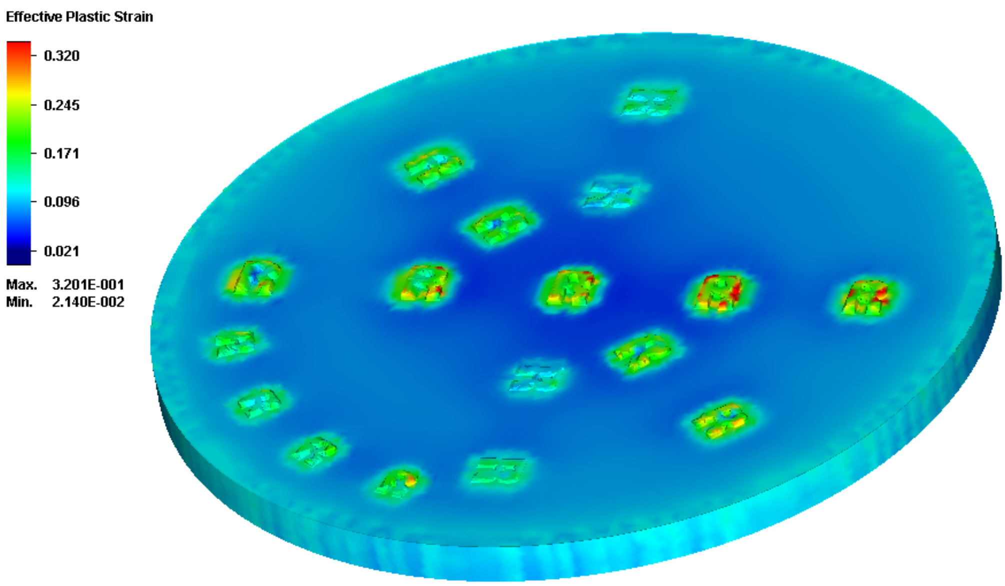



**Figure 7.13 Effective Plastic Strain Distribution at 400°C with 0.50 mm Facial Clearance in Cavity Zone**

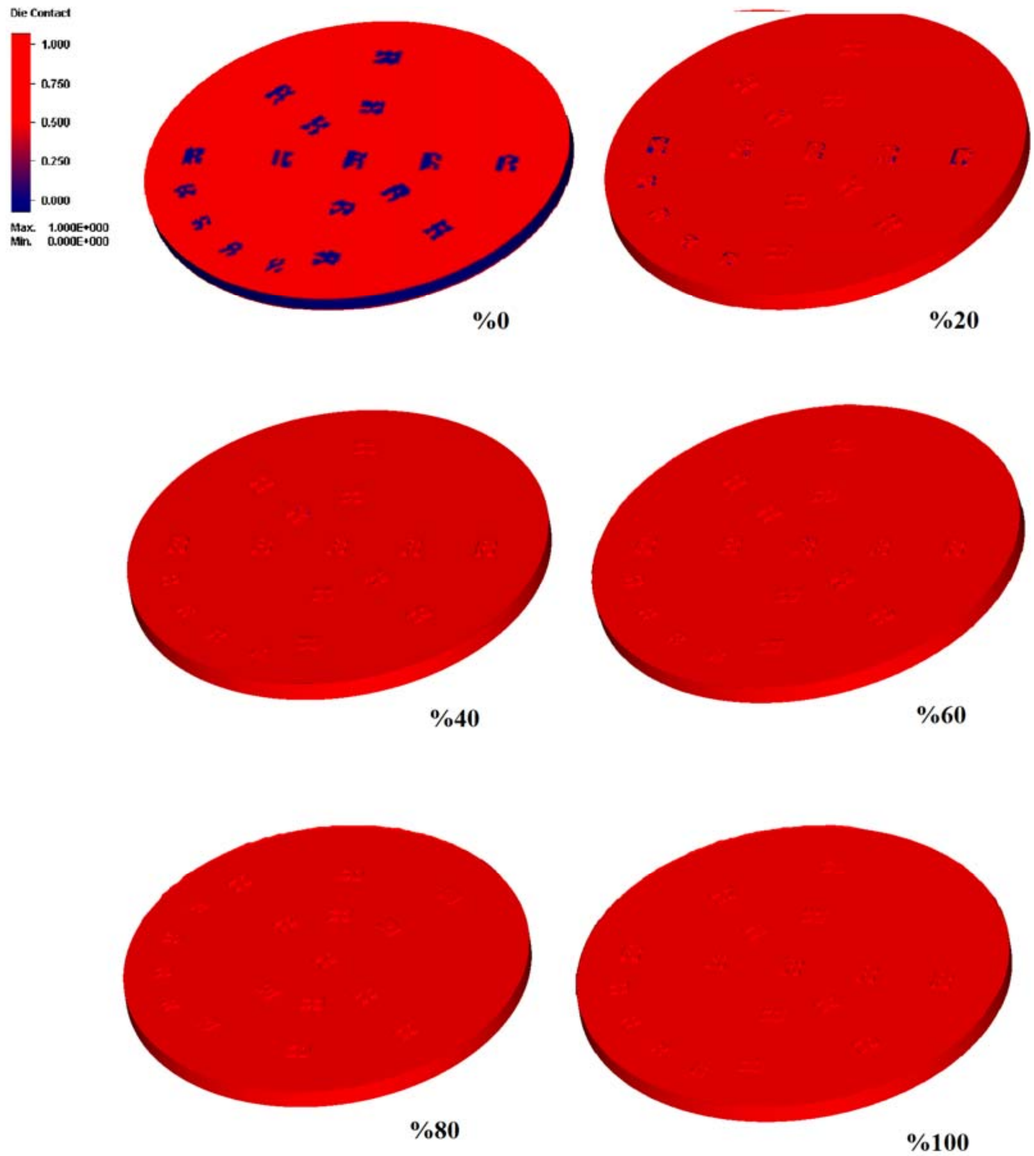



**Figure 7.14 Die Contact (Die Filling) Simulation Steps at 400°C with 1.0 mm Facial Clearance in Cavity Zone**

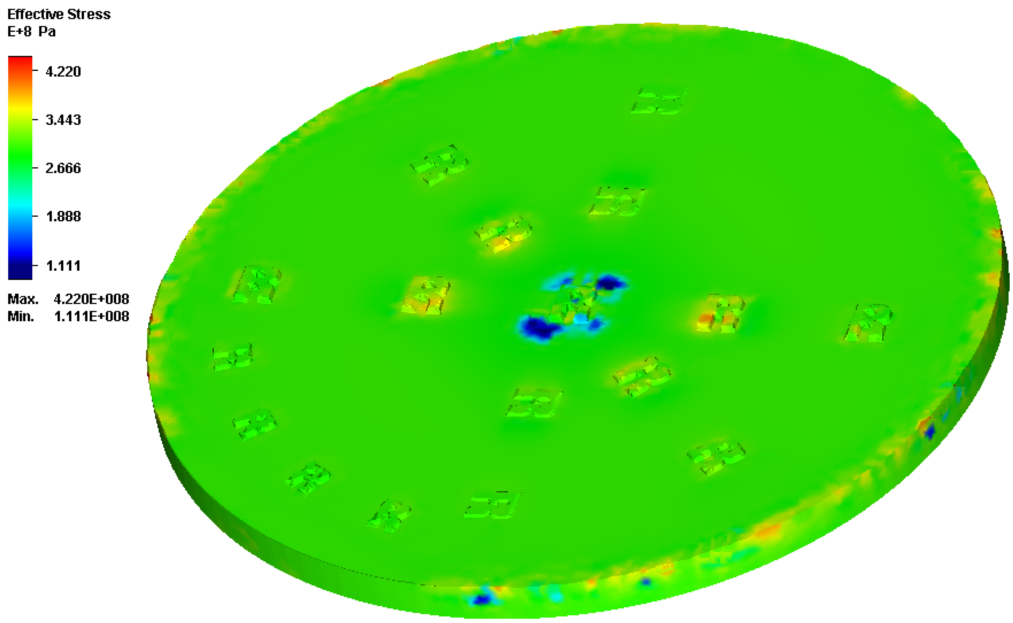



**Figure 7.15 Effective Stress Distribution at 400°C with 1.0 mm Facial Clearance in Cavity Zone**

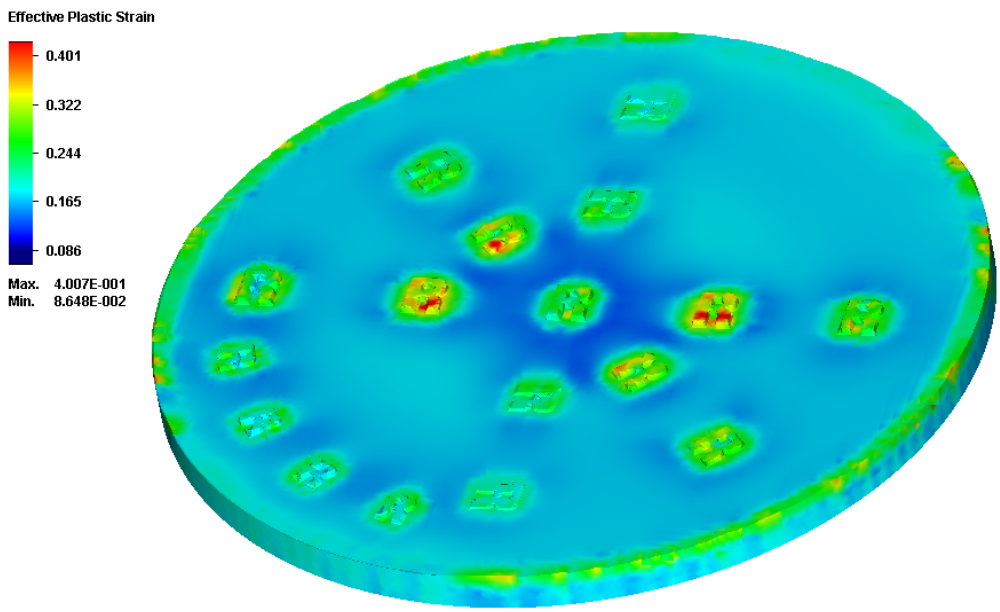



**Figure 7.16 Effective Plastic Strain Distribution at 400°C with 1.0 mm Facial Clearance in Cavity Zone**

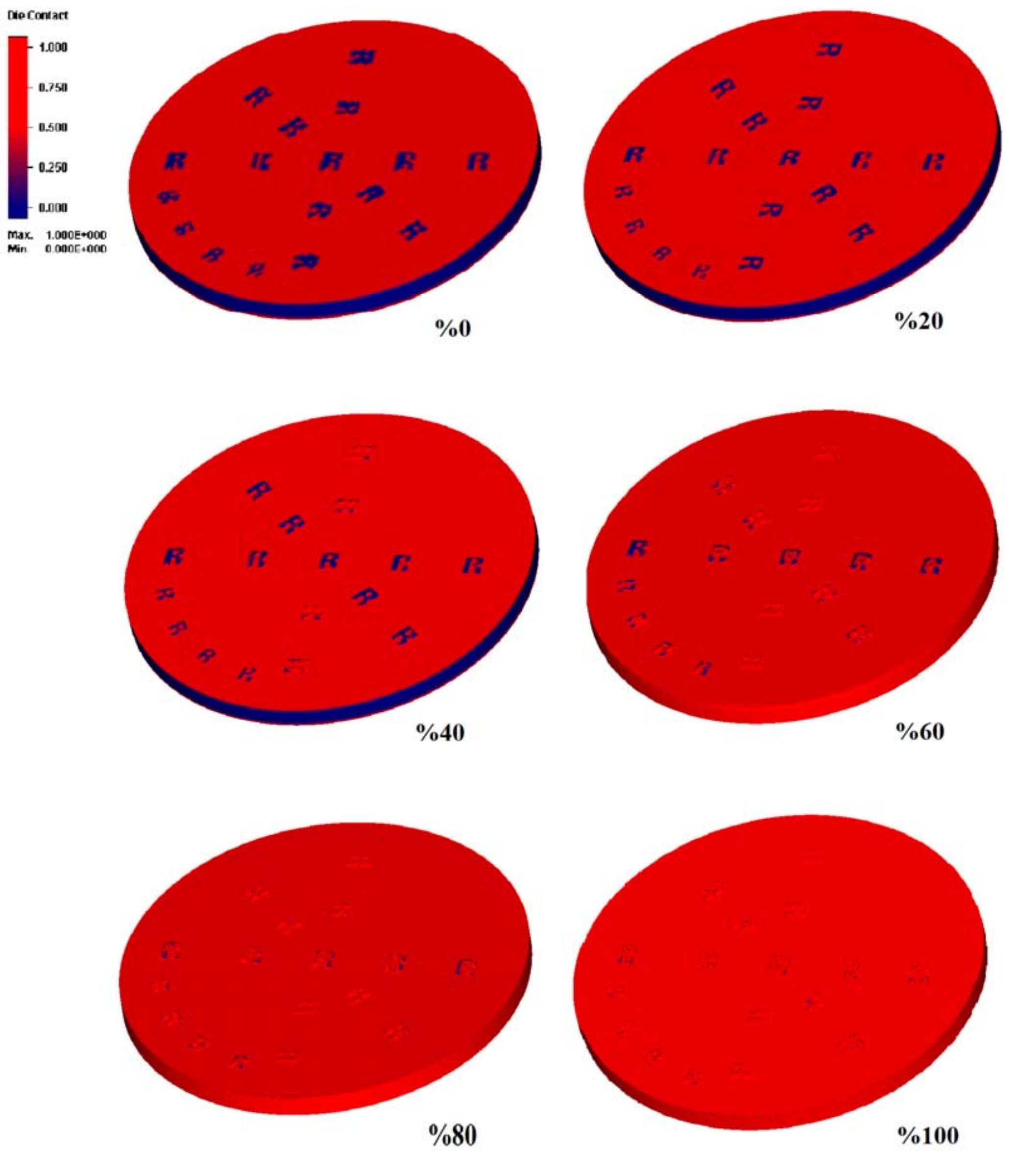



**Figure 7.17 Die Contact (Die Filling) Simulation Steps at 800°C with 0.5 mm Facial Clearance in Cavity Zone**

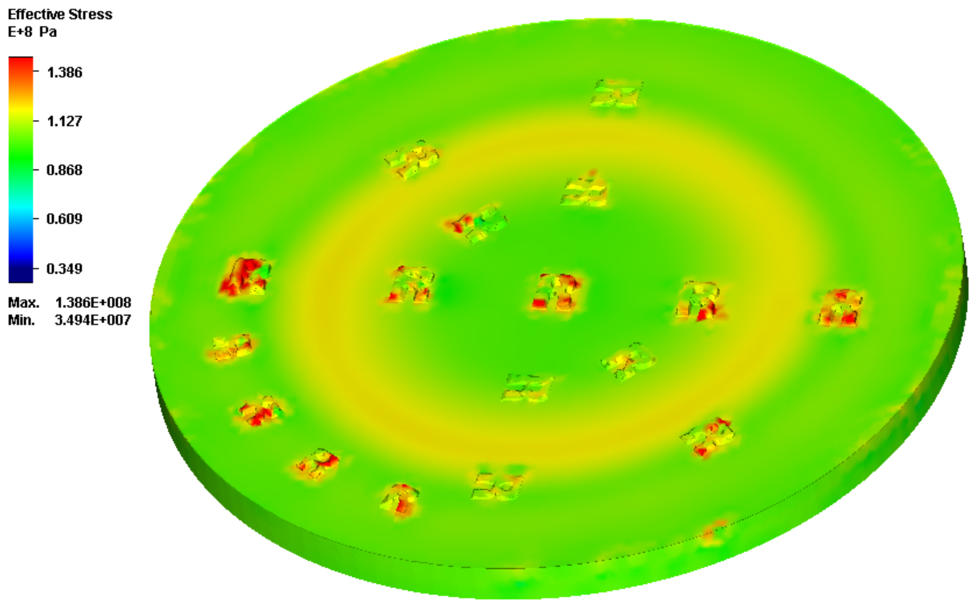



**Figure 7.18 Effective Stress Distribution at 800°C with 0.5 mm Facial Clearance in Cavity Zone**

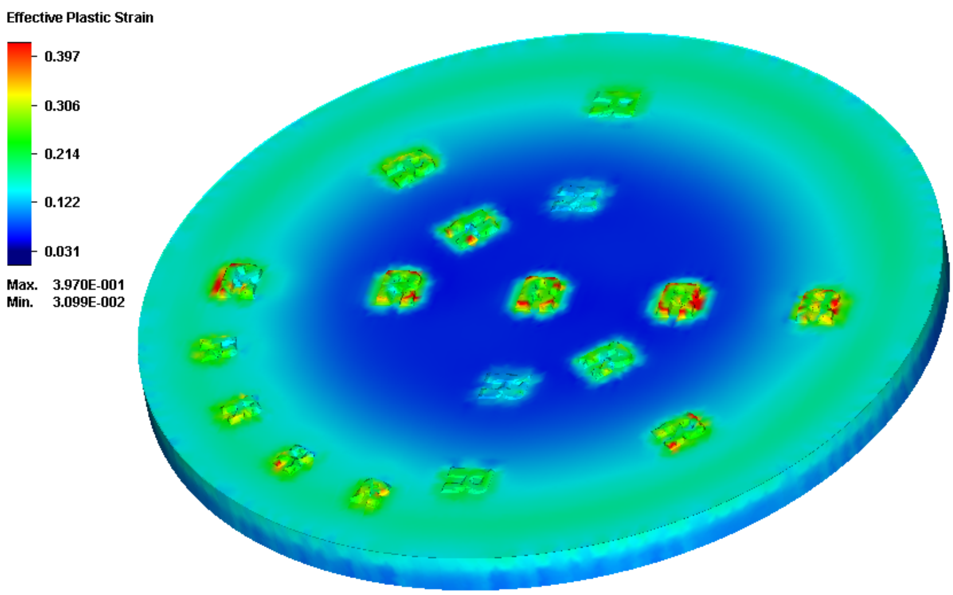



**Figure 7.19 Effective Plastic Strain Distribution at 800°C with 0.5 mm Facial Clearance in Cavity Zone**

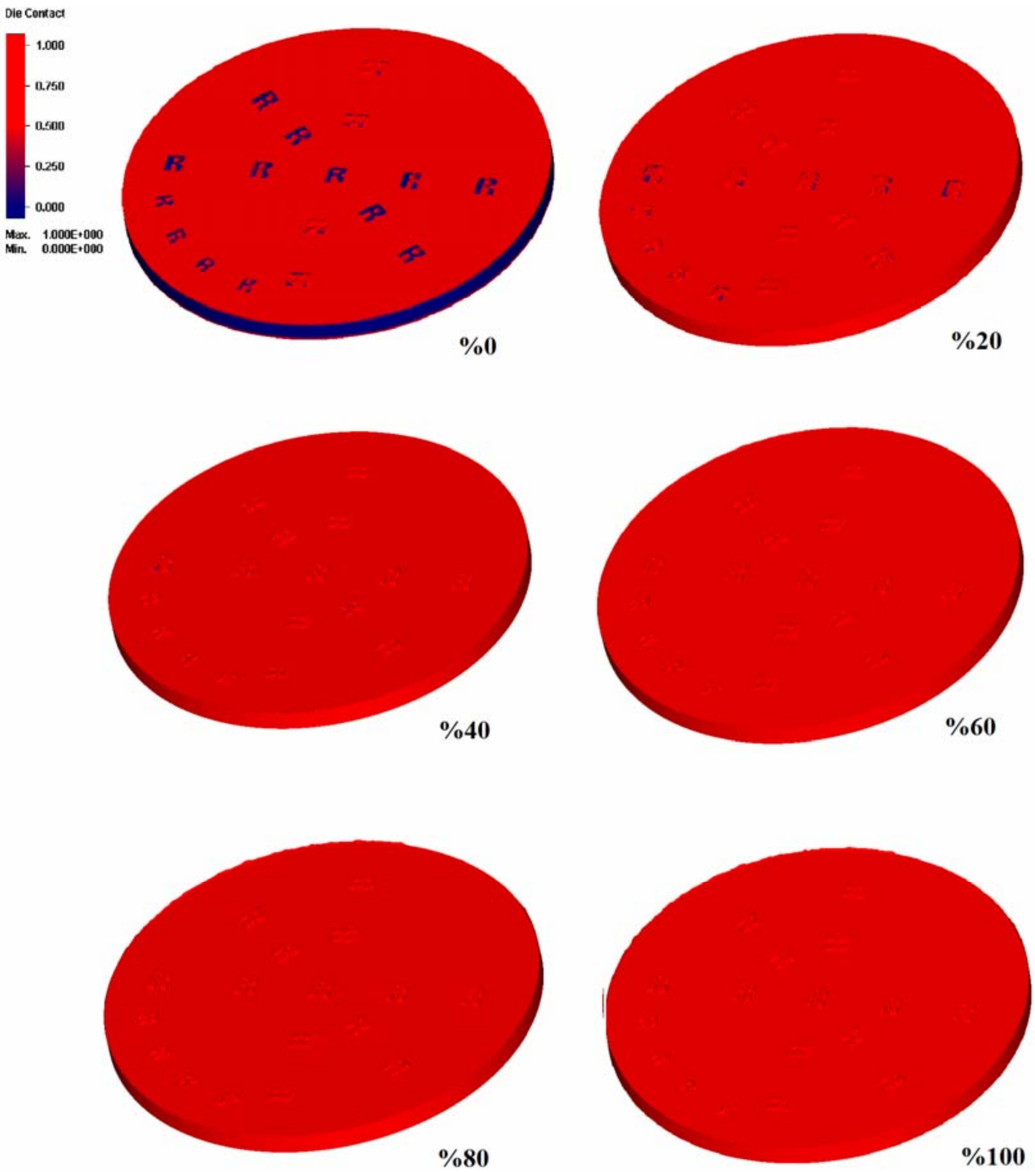



**Figure 7.20 Die Contact (Die Filling) Simulation Steps at 800°C with 1.0 mm Facial Clearance in Cavity Zone**

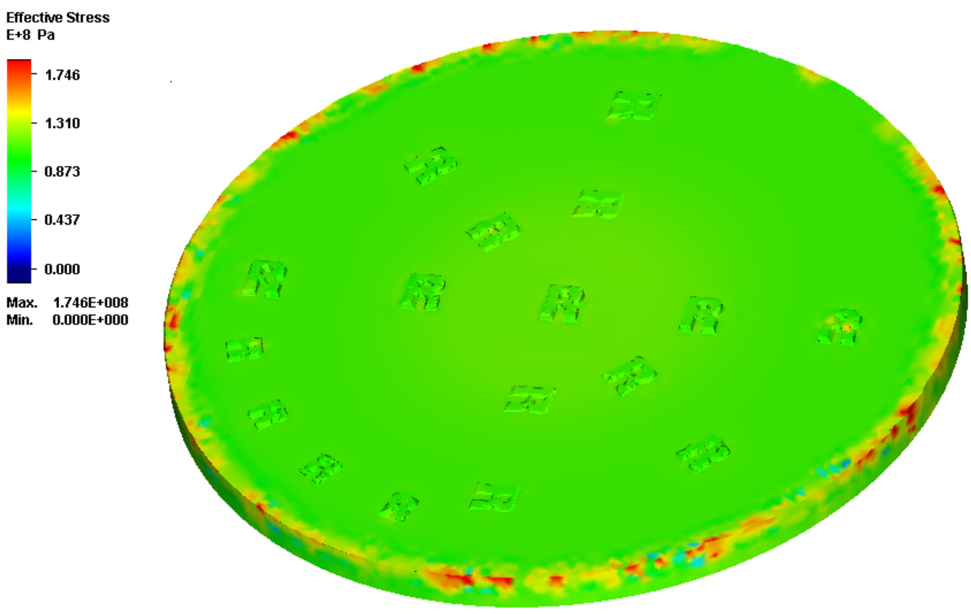



**Figure 7.21 Effective Stress Distribution at 800°C with 1.0 mm Facial Clearance in Cavity Zone**

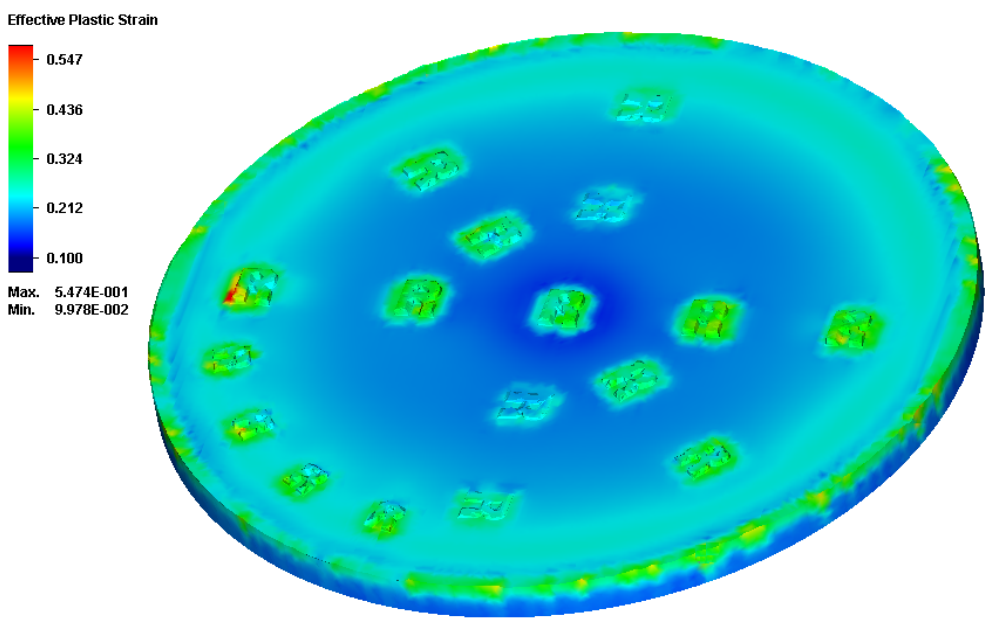



**Figure 7.22 Effective Plastic Strain Distribution at 800°C with 1.0 mm Facial Clearance in Cavity Zone**

## 7.3 Manufacturing of the Experimental Medallion with "R" Characters

After modeling the desired shape of the experimental coin in Pro/Engineer WF 3.0, all of the manufacturing works were accomplished in METU-BILTIR Center CAD/CAM Laboratory. In Figure 7.23 and Figure 7.24 and Figure 7.25, the manufactured interchangeable upper die and the upper die set for experimental coin can be seen.

**Figure 7.23 Manufactured Interchangeable Upper Die for Blanking Die Set**

**Figure 7.24 Manufactured Interchangeable Upper Die Set for Experimental Medallion**

**Figure 7.25 Mounted Coining Die Set for Experimental Medallion on Press**

# CHAPTER 8

# CONCLUSIONS AND FUTURE WORK

## 8.1 General Conclusions

In this study, design and analysis for medallion production for both coining and blanking processes have been realized. Afterwards, real life experiments have been conducted and following conclusions have been reached;

- An alternative methodology for coining operation has been introduced which includes CAD/CAM applications to the design and production phases. The design of medallions and coins are still performed by sketching the paper and transferring to the dies by several intermediate steps in mints. This time consuming procedure results in material waste and time consumption. In this study, instead of preparing molds for the engraving machine and reading details with laser reader of it, the medallion has been designed in CAD environment and NC codes have been prepared by using CAM software and NC codes have been directly transferred to the CNC machine. By this way, significant time can be saved.
- Design of a modular blanking die set for medallion production has been done successfully. The proposed blanking die set consists of two modules which are the upper die set and lower die set. In this modular design, the modules can be easily changed in the case of production of blanks with different diameter values of 30-90 mm.
- Design of a modular coining die set for medallion production has been successfully realized. The coining die set consists of two dies which are the upper die, the lower die and auxiliary elements such as supporting

dies, fixing bolt, ejector pins and keys. The modular components of the die set can be easily changed according to the required diameter and the design of the medallion.

- The finite volume analysis of the particular medallion which has 17 “R” characters at different locations is performed for temperatures of 20°C, 400°C and 800°C by a commercially available finite volume program to see the effects of character height, S, depth of die cavity, $h_d$ and location.
- According to the successful simulation results, the modular die sets for blanking and coining processes for production of medallion have been manufactured in METU-BILTIR Center CAD/CAM Laboratory.
- A commemorative medallion for the Opening Ceremony of METU-BILTIR Center Forging Research and Application Laboratory has been designed. A modular die set for the coining process of this medallion has been designed and the finite volume analysis has been done by using MSC.SuperForge. At the end of the experiments, the medallion is successfully coined with the desired geometry.

### 8.2 Future Work

Suggested future works can be stated as below.

- Experiments for the coining of the experimental medallion with “R” characters should be conducted.
- More experiments should be done to compare the results with CAE results.
- Smeral 1000-ton Mechanical Press which is available in METU-BILTIR Center was designed for hot forging operations. Therefore, the coining process can be further analyzed by using a cold forging press.
- The finite volume simulations could also be conducted by using a Finite Element Simulation program.
- The study may be extended for smaller medallions.

- Coining process may be performed for two-sided medallions.
- Coining with different sizes having ornamented edge and/or coinage with collar may be analyzed.
- Coining for different geometries may be analyzed.
- Coining of medallions with different materials may be studied.
- Tool life and wear analyses may be studied for the dies.

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# APPENDIX A

# HISTORY OF COINING

The invention of coining process, which is an evolution in the development of civilization, is an important milestone in the history of money. Coinage by striking was most possibly first invented in Asia Minor in the first millennium BC when reserves of gold found were melted and turned into pieces of uniform size [14].

Coinage was independently raised from two trajectories in history; in the Lydian Aegean territories in the late seventh century BC and in the China around two centuries later [17].

Aegean type of coinage was characterized by solid, round or rarely rectangular shapes with different visual imagery and manufactured from various metals, mostly gold and silver which are used as aggregate value. The shape of the first Lydian coin can be seen in Figure A.1. Chinese coins, conversely, were cast rather than struck. They were equipped with a usually square hole in the center and not more than a few letters, and were not normally minted from precious metals which are primarily bronze and sometimes iron; whereas gold and silver money circulated in the forms of ingots [17]. The shape of the earlier Chinese coin can be seen in Figure A.2.

**Figure A.1 The Earliest Coins of World Lydia with Lydian Lion [36].**

**a) with round holes** **b) with square holes**

**Figure A.2 The most Common Ancient China coins [37]**

## A.1 Historical Development of Lydian Type of Coinage

After coinage was invented by Lydian people sometime between 650 and 500 BC, Greeks quickly adopted the process. It is known that by the end of the sixth century BC most of the city-states in the Greek world had their own coins. Greeks delivered the process of coinage as soon as they settle to a new place. [14-17]

The earliest coins were made by open-die forging and without sharp details. Western Eurasian or Aegean coinage was based on precious metals, initially electrum which is a naturally yellow gold-silver alloy and then on gold and silver as separately. Silver quickly became the dominant metal of the developing Aegean coinage system. After its adaptation, silver coinage spread along Greek overseas migration, to Black Sea region in the early sixth century BC, to Sicily and southern Italy in the middle of the sixth century BC, and to the coastal settlements in Cyrene, Spain and Provence. For a quarter of a millennium or so, production of Greek-style precious-metal coins was largely confined to Greek populations and those in close contact with them. From the late sixth century the coinage has brought to the northern Aegean in south-western Asia Minor. Although coin use has been relatively rare beyond the western of Mediterranean periphery, the Lydian imitation of Aegean coinage was adopted and modified by the Achaemenid Empire, predecessors of Persians, in the period of war with Greeks in the first half of the fifth century BC. Greek-style coin came to be produced in large quantities all over the former Persian Empire, from Eastern Iran to Mesopotamia, Syria, Egypt and north-western India which had previously begun to produce punch marked silver bars [17].

In the west, the spread of Greek-style coins is difficult to date, although it appears that this process was not developed until the second century BC, resulting in varied output in Spain, Gaul, the Alpine region and the Balkans, as well as in the southern half of Britain [17]. In Italy, Rome was gradually superseded by the introduction of Greek-style silver coins, contrary to tradition of producing heavy metal bars of bronze. Silver increasingly exceeded the bronze money by the second century BC. Roman expansion initiated a protracted process of monetary unification [38].

From the beginning of medieval period to Renaissance, three steps of coinage that are applied today were mainly identical. The first step is bringing the metal into desired shaped sheets; the second one is cutting blanks from these sheets and the last one is striking the coins [39]. The process was based on the striking of the upper die several times with a hammer onto the spike shaped tool placed on a wooden block between the legs of worker. The operation can be seen schematically in Figure A.3. This dies were made locally by the special experienced workers in the mint. The indents of punches are engraved firstly and the dies are used to produce the dies. Each step is necessarily done by experienced workers whose trade is hereditary [39].

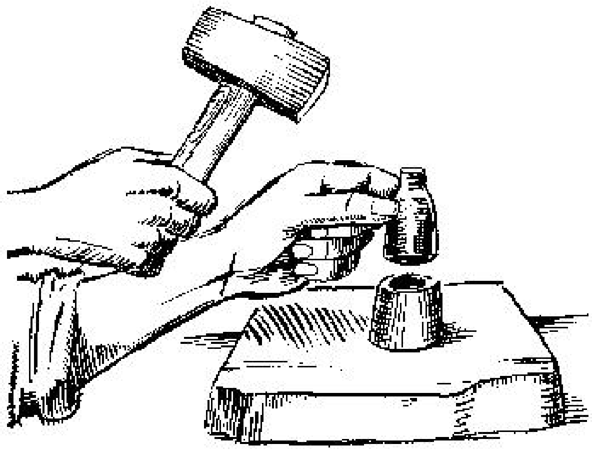

**Figure A.3 Schematic illustration of The Earliest Coining Process [40].**

There are lots of drawbacks when applying this method of striking, some of which are forgery, low quality and not standardized sizes and weight. The production of coins is performed by everyday tools. Therefore, faults of imprint on the coin are common and it is difficult to distinguish the legal patterns from the forged ones. [40].

The minting process was developed mechanically during the Renaissance when the art of medal making began in Italy in the 1430s; same inventions were done to produce the complicated and high-quality medals designs. Medals were usually cast at that time but in the 16th century the demand for strike medals had increased. Some inventions which appear due to the necessity for producing the complicated and high-quality medals designs and striking them with sufficient force and accuracy firstly appeared in Germany and Switzerland in 1550s and spread to the region [41]. The innovations can be considered in two ways of minting which are using a screw-press and using a cylinder press on which the dies were engraved, thus laminating and striking at the same time.

In France and England, the screw press was brought from Germany and adopted. On the other hand, the cylinder-press was used in Austria, Germany, Spain, Italy and Sweden. However, in the 18th century, the screw-press superseded the cylinder press [42]. In France, the mint was set up by an engineer named Aubin Olivier which had added a pieced collar to the screw press powered by water-mills to hold the blank and to avoid striking defects. Because the coin can be removed after each strike with collars, one single process could be mechanized. With the automation of screw press by the late 18$^{th}$ century, the feeding of blanks and the extraction of coins had been made automatic [39].

On the other hand, although the principle was raised from Germany to flatten the metal, Hans Vogler Jr and Rudolf von Rordorf set up the first cylinder-press in Zurich in the early 1550s [43]. The cylinders, which were powered by water-wheels or horses, would be engraved with the coin die so that the coins would be cut out of the stamped strips. On the other hand, the necessity of the use of oval shaped dies with employing removable dies could be considered as the drawback of the machine. Furthermore, generally occurring slightly warped coins prevent the serration of the edges [39].

A different type of cylinder press which was developed in the 17th century necessitated the use of a pair of mushroom shaped pieces which were engraved and inserted in slots of rotating axles. The design, which was known as Taschenwerk, required pre-cut oval shaped blanks whose passage between the dies made them round. Although the cylinder press was very popular initially, the screw press replaced the two cylinder machine because of these disadvantages [39].

Marking the edges of the coin was the most significant development in coining during 18th century. This process was performed by a casting machine which had been invented in England and adopted in France in 1685. Casting machine was employing two steel bars, between which the coin was rolled on a horizontal surface [39].

The portrait lathe (reducing pantograph) which can be seen in Figure A.4 and hubbing invented by the Swiss J-P Droz around 1780 were two of the most important inventions occurred in the late 18th and early 19th century in the area of coining. The major advantage of this innovation was that coins could be identically reproduced. Furthermore, steam-driven machines which were introduced in London mint in 1810 had the ability to produce 70 to 80 coins per minute. However accommodating the rotation and recoil of the screw caused technical problems preventing easy adaption of steam engines to the old screw presses [39].

Lever-press invented in 1817 by D. Uhlhorn, a German engineer in Grevenbroich near Cologne, could more easily be driven by steam compared to screw press. Depending on the size of the coin, 30 to 60 coins per minute could be struck by the lever-press. Uhlhorn' presses were employed by many mints in Germany and Austria. A French inventor Thonnelier used the principle of lever-presses to build Thonnelier press which could strike 40 coins per minute. This machine first came in use in Paris in 1845 and was in use throughout Europe by the end of 19th century striking 60 to 120 coins per minute [39,44].

By the late 19th century, the production of subsidiary coinage was entirely adopted in England. Following England, France (in 1864) and U.S. (in 1850) laid down the first principle of subsidiary coinage.

**Figure A.4 The Portrait Lathe or Pantograph [45]**

## A.2 Historical Development of Chinese Type of Coinage

In the first millennium BC, China had developed a different type of coinage method based on casting of heavy metals with the shape of traditional and distinctive characters. The region contains modern China as well as in the secondary monetary traditions of Korea, Vietnam and Japan.

Earlier round coins cast on similarly shaped disks which were made of valuable stones according to variable regional weight standards with a variety of legends but no pictures. Between the late second century BC and the late second century AD, the concern of the imperial mint was standardizing of the weight and bringing the larger shapes to agreeable values [17]. Between 960 and 1127, bronze coins and the necessary iron equipments for casting were in use until paper money was introduced in 1160. After the withdrawal from circulation in

1430s, silver which was brought in the case of large quantities from the New World and Japan began to use from the mid-sixteenth century. Although Aegean type of silver coins which was accepted by Europe already was used from then on, in the Ming period, China did not start the production of completely solid silver coins until the 1830s. The entire region fully adopted the Aegean type of coinage process with the western influence and the introduction of foreign equipment in Japan in 1867, Korea in the 1880s and in China mostly in the late nineteenth century [14-17].

# APPENDIX B

# PROPERTIES FOR BRASS AND DIE SET MATERIALS

## B.1 Properties of Brass, CuZn30

**Subcategory:** Nonferrous Metal, Copper alloy, Brass

In the cold working operations, the alloys are required high cold ductility which mostly present at brasses given in Table 6.1. The outstanding feature of them is their ductility at room temperature. Therefore, brasses can be easily deformed by forging at the room temperature.

The most ductile one is CuZn30 which contains 30% zinc composed of the highest copper content of the cold working brasses. It has the optimum combination of properties of strength, ductility and minimal directionality. It has also the best corrosion resistance. Medallion has several decorative figures involving delicate geometries. Therefore, the ductility is an essential specification of the material and it can be said that CuZn30 is appropriate for cold forging operations [46].

Cold working brasses of which the properties are given in Table 6.1 are typically used to make semi-finished products. In order to produce simple products with noncomplex forming methods, cheaper alloys with lower copper composition such as CuZn64 or CuZn63 can be used. CuZn10, CuZn15 and CuZn20 can be used for such processes that their excellent ductility, strength and corrosion resistance or decorative color and durability may be important such as decorative architectural applications and costume jewelry [46].

**Table 6.1 Brasses for Cold Working [46]**

| Compositional Designation and EN Number | Relevant Properties |
|---|---|
| CuZn30<br>CW505L | Excellent cold ductility.<br>Can been used for deep drawing.<br>As wire, suitable for the most severe cold deformation.<br>The best corrosion resistance. |
| CuZn37<br>CW508L | Good general purpose alloy suitable for simple forming. |
| CuZn10<br>CW501L | Gilding metal with highest copper content.<br>Very good corrosion resistance.<br>Can be brazed and enameled |
| CuZn15<br>CW502L | Similar to CuZn10 with slightly superior mechanical properties. |
| CuZn20<br>CW503L | Further improvement in mechanical properties.<br>Corrosion resistance not quite as good as CuZn10.<br>Good for deep drawing. |
| CuZn20Al<br>CW703R | Common in tube form.<br>Excellent corrosion resistance.<br>Used particularly for applications in dean seawater. |

Because of the advantages over and the decorative appearance, the brass DIN CuZn30 of which properties are given in Appendix A is chosen as the blank material.

**Table B.1 Chemical Composition (%) of CuZn30**

| Cu | Pb | Fe | Sn | Al | Zn |
|---|---|---|---|---|---|
| 69.2 – 70.0 | max 0.015 | max 0.030 | 0.1 | 0.02 | Rem. |

**Table B.2 Physical Properties of Brass**

| | |
|---|---|
| Density | 8530 kg/$m^3$ |
| Hardness | 78 HRF |

**Table B.3 Mechanical Properties at Room Temperature**

| | |
|---|---|
| Tensile Strength (Ultimate),$R_m$ | 365 MPa |
| Yield Strength, $R_{p0,2}$ | 150 MPa |
| Modulus of Elastisty | 110 Gpa |
| Shear Strength | 240 MPa |
| Elongation, $A_5$ | 54% |
| Poisson's Ratio | 0.375 |

## B.2 Properties of Supporting Die Steel for Blanking Die Set, DIN 1.1730

**Subcategory:** Carbon Steel, Medium Carbon Steel

**Table B.4 Chemical Composition (%) of DIN 1.1730**

| C | Si | Mn | Ni | Cr | Mo | Others |
|---|---|---|---|---|---|---|
| 0.46 | max 0.40 | 0.65 | Max.0.40 | Max.0.40 | Max.0.10 | 0.63 |

**Table B.5 Physical Properties of DIN 1.1730**

| | |
|---|---|
| Density | 7870 $kg/m^3$ |
| Hardness | 170 HB, 84 HRB |

**Table B.6 Mechanical Properties at Room Temperature**

| | |
|---|---|
| Tensile Strength (Ultimate), $R_m$ | 585 MPa |
| Yield Strength, $R_{p0,2}$ | 450 MPa |
| Modulus of Elasticity | 200 GPa |
| Shear Modulus | 80 GPa |
| Elongation, $A_5$ | 12 % |
| Reduction of Area, Z | 35 % |
| Poisson's Ratio | 0.29 |

## B.3 Properties of Supporting Die Steel for Coining Die Set, DIN 1.2714

**Subcategory:** Carbon Steel, Chrome-moly Steel, Hot Work Steel, Tool Steel

**Table B.7 Chemical Composition (%) of DIN 1.2714**

| C | Si | Mn | Ni | Cr | Mo | V |
|---|---|---|---|---|---|---|
| 0.55 | 0,30 | 0,70 | 1,7 | 1,10 | 0.50 | 0, 10 |

**Table B.8 Physical Properties of DIN 1.2714**

| | |
|---|---|
| Density | 7840 $kg/m^3$ |
| Hardness | 38-43 HRc-B |

**Table B.9 Mechanical Properties at Room Temperature of DIN 1.2714**

| | |
|---|---|
| Tensile Strength (Ultimate),$R_m$ | 1174 MPa |
| Yield Strength, $R_{p0,2}$ | 645 MPa |
| Modulus of Elasticity | 215 GPa |
| Elongation, $A_5$ | 25 % |
| Reduction of Area, Z | 55 % |
| Poisson's Ratio | 0.28 |

## B.4 Properties of Modular Die Steel, Sleipner

**Subcategory:** Chrome-moly Steel, Cold Work Steel, Tool Steel

**Table B.10 Chemical Composition (%) of Sleipner Cold Work Tool Steel**

| C | Si | Mn | Cr | Mo | V |
|---|---|---|---|---|---|
| 0,90 | 0,90 | 0,50 | 7.80 | 2.50 | 0.50 |

**Table B.11 Physical Properties of Sleipner Cold Work Tool Steel**

| | |
|---|---|
| Density | 7730 kg/m$^3$ |
| Hardness | 235 HB, 62 HRc-B |

**Table B.12 Mechanical Properties at Room Temperature of Sleipner Cold Work Tool Steel**

| | |
|---|---|
| Compressive Strength | 2350 MPa |
| Yield Strength, $R_{p0,2}$ | 1140 MPa |
| Modulus of Elasticity | 205 GPa |
| Shear Modulus | 205 GPa |
| Poisson’s Ratio | 0.22 |

# APPENDIX C

## HEAT TREATMENT OF SLEIPNER

The expected mechanical properties of a tool steel can only be seen if a proper heat treatment is done after machining. In this study the coining die set is heat treated in the vacuum furnace available at a private company in Izmir [33]. As seen in Figure C.1, the coining die set is heated to the austenitizing temperature which is 1000°C in two sub-stages. When the vacuum furnace is reached to the austenitizing temperature, it is kept in the furnace until all the sections of the dies reach to the same temperature. Afterwards, the dies are cooled rapidly with a cooling rate of 10°C/min. Then the tempering process is applied to the dies. This heat treatment results in higher toughness values, without sacrificing all of the hardness and tensile strength gained from the processes applied previously. The toughness and hardness values are inversely proportional. In this study the toughness, meaning that the impact absorbing ability of steel without fracture is more important than the hardness because of the hitting of the dies one to another. Taking into account to these, the first tempering process is applied about 2 hours at 580°C. The company reported that after the first tempering the hardness values of the dies had been measured as 52 HRC. Then the second tempering process is applied about 2 hours at 610°C and the hardness value had become 60 HRC. Finally, the third tempering process is applied about 3 hours at 580°C and the hardness value had been measured as 62 HRC.

The process can be summarized as;

1000°C Austenitizing (30min) – 36 °C/min rapid cooling rate – 580°C (2hour) first tempering process (52 HRC) - 610°C (2hour) second tempering process (60 Hrc) - 585°C (3hour) third tempering process (62 HRC)

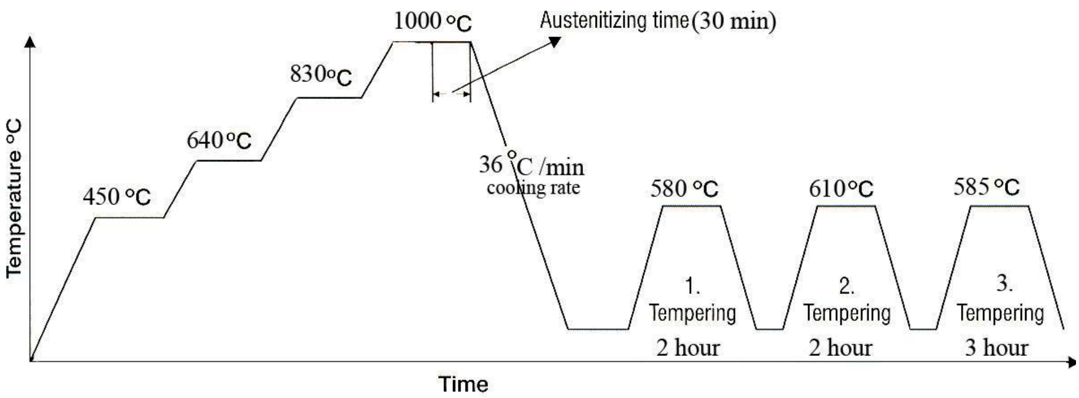


**Figure C.1 Applied Heat Treatment Process**

# APPENDIX D

## TECHNICAL DATA OF AVAILABLE PRESSES IN METU-BILTIR CENTER FORGING RESEARCH AND APPLICATION LABORATORY

**Table D.1 Technical Properties of 1000 Tones Smeral Mechanical Press**

| | |
|---|---|
| Nominal Forming Force | 10 MN |
| Ram Stroke | 220 mm |
| Shut Height | 620 mm |
| Ram Resetting | 10 mm |
| Rod Length | 750 mm |
| Crank Radius | 110 mm |
| Number of Strokes at Continuous Run | 100 $min^{-1}$ |
| Press Height | 4840 mm |
| Press Height above Floor | 4600 mm |
| Press Width | 2540 mm |
| Press Depth | 3240 mm |
| Press Weight | 48000 kg |
| Die Holder Weight | 3000 kg |
| Main Motor Input | 55 kW |
| Max. Stroke of the Upper Ejector (without die holder) | 40mm |
| Max. Stroke of the Lower Ejector (without die holder) | 50 mm |
| Max. Stroke of the Upper Ejector (due to the die holder) | 20 mm |
| Max. Stroke of the Lower Ejector (due to the die holder) | 20 mm |
| Max. Force of the Upper Ejector | 60 kN |
| Max. Force of the Lower Ejector | 150 kN |

**Table D.2 Technical Properties of 200 Tones Dirinler Eccentric Press**

| | |
|---|---|
| Nominal Forming Force | 2 MN |
| Ram Stroke | 180 mm |
| Shut Height | 20 mm |
| Table-Ram Distance | 438 mm |
| Stroke Adjustment | 150 mm |
| Stroke Per Minute | 35 ppm |
| Slide Adjustment | 125 mm |
| Ram Dimension | 1050x750 mm |
| Plate Dimension | 895x750 mm |
| Additional Lower Die Weight (max) | 905 kg |
| Press Height | 4000 mm |
| Press Height above Floor | 4400 mm |
| Press Width | 2400 mm |
| Press Depth | 1650 mm |
| Press Weight | 18500 kg |
| Die Holder Weight | 3000 kg |
| Main Motor Input | 18.5 kW |
| Motor Speed | 1450 rpm |