OPTIMIZATION OF THE FABRICATION PROCESSES OF MICROFLUIDIC CHIPS BY HOT EMBOSSING

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OPTIMIZATION OF THE FABRICATION PROCESSES OF MICROFLUIDIC CHIPS BY HOT EMBOSSING

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Submitted by **Abbas Ali Ibrahim ZIYARA**

Approval of the Graduate School of Natural and Applied Sciences, Çankaya University.

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

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Currently, the advent of microfluidics offers promising tools, especially in life sciences, with applications ranging from biological or chemical sensors to organs on chips. Although, this technology contains various other advantages such as reduction in sample and reagent consumption, decrease in reaction times, and improved accuracy, there are still a few number of commercially available microfluidic devices. One of the reasons hampering commercialization of microfluidics is its fabrication cost. Lithography based techniques are commonly used for microfluidic fabrication owing to the high precision. However in lithography based microfluidic fabrication methods manufacturing lead times are often high. Design-to-device period may reach up to several days. Here, micro scaled conventional methods such as micro milling, micro injection molding, or hot embossing are more prominent. In these methods, the cycle time reduces down to hours or even minutes. This in turn reduces the cost per device considerably.

This thesis aims to design and construct a low cost hot embossing press and optimize the process parameters for fabrication of microfluidic chips. The hot embossing press was designed as a low cost device, having material cost as low as 224 TL. For testing purposes, we fabricated a mold made of brass using micro milling process. We proved that, we can obtain 200 μm wide channels on polymethylmethacrylate (PMMA) substrates, by applying 240 bars or pressure for 6 min. under 180 ^{o}C temperature, total cycle time per one chip is found to be 11 min.

Keywords: Hot Embossing, Microfluidic, Micro Milling.

ÖZ

MİKROAKIŞKAN ÇİPLERİN SICAK BASKI İLE ÜRETİM YÖNTEMİNİN ENİYİLENMESİ

ZIYARA, Abbas Ali Ibrahim
Yüksek Lisans, Makine Mühendisliği Anabilim dalı
Tez Yöneticisi: Yrd. Doç. Dr. Ender YILDIRIM

Şubat 2015, 41 sayfa

Günümüzde, mikro akışkanlardaki gelişmeler özellikle yaşam bilimleri için, biyolojik veya kimyasal algılayıcılardan çip-üstü-organlara kadar farklı uygulamalarda, ümit verici araçların ortaya çıkmasına neden olmaktadır. Bu teknoloji numune ve reaktif miktarının azaltılması, reaksiyon süresinin azaltılması, hassasiyetin arttırılması gibi diğer birçok avantajı içerse de, mikro akışkan tabanlı ticari ürünler halen daha çok az miktardadır. Mikro akışkanların ticarileşmesinin önündeki engellerden birisi üretim maliyetleridir. Mikro akışkan üretimi için, yüksek hassasiyeti sebebiyle sıklıkla litografi tabanlı yöntemler kullanılmaktadır. Ancak, litografi tabanlı mikro akışkan üretim yöntemlerinde imalat süresi genellikle uzundur. Tasarımdan ürüne kadar geçen süreçgünlerce sürebilmektedir. Bu noktada, mikro frezeleme, mikro plastic enjeksiyon ve sıcak baskı gibi mikro ölçekli geleneksel yöntemler öneçıkmaktadır. Bu yöntemlerde imalat döngü süresi birkaç saate ve hatta birkaç dakikaya düşebilmektedir. Bu durum, ürün başına düşen maliyeti önemli miktarda düşürmektedir.

Bu tez düşük maliyetli bir sıcak baskı presinin tasarımı ve üretimini, ve işlem parametrelerinin mikro akışkan çiplerin üretimi için eniyilenmesini amaçlamaktadır. Sıcak baskı presi, malzeme maliyeti 224 TL olacak şekilde, düşük maliyetli bir cihaz olarak tasarlanmıştır. Test amacıyla, pirinç kullanılarak mikro frezeleme yöntemi ile bir kalıp üretilmiştir. Polimetilmetakrilat (PMMA) altlıklar üzerinde 6 dakika boyunca 180^{o}C sıcaklıkta 240 bar basınç uygulanarak 200 µm genişliğinde kanallar elde edilebileceği kanıtlanmıştır. Toplam döngü süresi 11 dakika olarak gözlenmiştir.

Anahtar Kelimeler: Sıcak Baskı, Mikro Akışkan, Mikro Frezeleme.

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LIST OF ABBREVIATIONS

PMMA	Poly Methyl Meth Acrylate
LOC	Lab-On-a-Chip
HPLC	High Pressure Liquid Chromatography
US	Ultra Sonic
PDMS	Poly Di Methyl Siloxane
MEMS	Micro Electromechanical Systems
ICP RIE	Inductively Coupled Plasma Reactive Ion Etching
PC	Poly Carbonate
GPC	Gas-Phase Chromatography
PCB	Printed Circuit Board
PE	Poly Ethylene
CE	Capillary Electrophoresis
UV	Ultra Violet
PS	Plastic Substrate
PEEK	Poly Ether Ether Ketone
LCP	liquid Crystalline Polymer
DSC	Differential Scanning Calorimetry
3D	Three Dimension
CNC	Computer Numerical Control
DOE	Design of Experiment

CHAPTER 1

INTRODUCTION

1.1. Background

Microfluidics is an interdisciplinary field of study that includes physics, biochemistry, engineering, chemistry and biotechnology. Microfluidics deals with small volumes (less than microliters) of fluids mainly in biological or chemical assays. It is considered as an enabling technology to reduce cost and time required in these assays. Scientists are discovering new applications to explore the effectiveness of this technology by applying Lab-on-a-Chip (LOC) to get maximum advantages [1, 2]. LOC means implementation of laboratory routines in a single chip, which is roughly in the size of an envelope or slightly larger than that.

This technology has various advantages, for example, it helps to decrease reaction time, reagent consumption and improved accuracy. Another advantage over conventional laboratory practices is that microfluidic devices reduce consumption of reagents, thus money.

There are various techniques for microfluidic fabrication. Lithography, injection molding and hot embossing are the common microfluidic fabrication methods. Compared to the other micro fabrication techniques, lithography based microfluidic fabrication are less complicated [1, 3]. On the other hand, the cost of lithography based techniques is still not feasible as compared to traditional manufacturing methods like injection molding or hot embossing. Thus, this study aimed to design and construct a low cost hot embossing press and optimize the process parameters for fabrication of microfluidic chips.

The emergence of microfluidics as a field of study came into being because of its contribution in molecular analysis and bio defense [4]. Gas-phase chromatography (GPC), high pressure liquid chromatography (HPLC) and capillary electrophoresis (CE) utilized together to assess minute amount of fluid and results inspired to do further advancement in the field of microfluidics [2]. Microfluidics is playing an important role in cell-based assays by assessing the effect of chemical stimuli on biological cells. It determines the presence or absence of different chemicals in biological cells [3, 4]. Another factor that encouraged the development in the field of microfluidics was the circumstances that arise just after the cold war in the US, and the whole nation was exposed to the threat of biological and chemical weapon, thus in 1990 intending to detect and avoid such threats accelerated the development in this field [1]. Furthermore, in1980 microfluidics played an important role to resolve issues arise after in research in the genome. This problem solving approach inspired a scientist to perform further research in the field of microfluidics.

This chapter begins with a brief background of the importance and application of microfluidics chip followed by explanation of fabrication techniques of microfluidics chips. This explanation will enlighten the resource requirement, advantages and disadvantages of each technique. Among these techniques, we specifically focus on the hot embossing technique.

1.2. Application of Microfluidics

Microfluidic chips contain a network of micro-channel, size ranges roughly from 5 to 500 µm specifically designed to analyze fluid contents [2].

Fig. 1 illustrates one example of microfluidic devices. The device illustrates one of the well known characteristics of micro scale flows; laminar flow. Laminar streams of flow get mixed in a demultiplexer as illustrated in Fig. 1.

These devices are being used for enzyme assays, protein assays, or cell based assays in laboratories for testing purposes or at the point of care for diagnostic purposes.

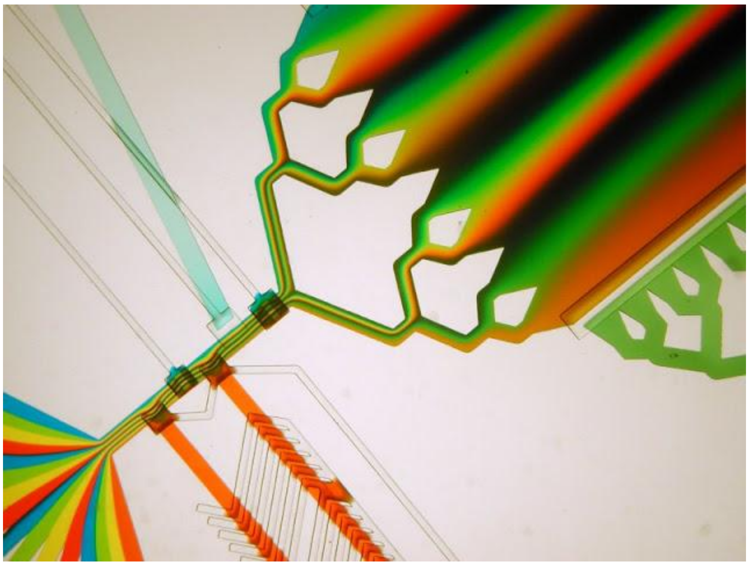


Figure 1: Part of a Microfluidic Chip Illustrating Laminar Flow and a Microfluidic Demultiplexer. Channels widths are in the order of 100 μm (Source: Folch Lab, University of Washington).

1.3. Microfluidic Fabrication Techniques

There are a number of techniques to fabricate microfluidic chips, the most common of which are:

- Soft lithography
- Injection molding
- Hot embossing

These techniques discussed below to evaluate the advantages and disadvantages of each.

1.3.1. Soft lithography

Soft lithography is a technique to fabricate microfluidic chips that involves elastomeric polymer molding in which elastomeric polymer placed on the stamp and rest for a specified period of time [5]. Slightly raised temperature accelerates the process occurring of polymer. Thus, elastomeric polymer leaves an impression on the stamp and it can be used as a mold or die to replicate further chips. Use of metal for the stamp is not necessary because it does not have to be exposed to any pressure or excessive heat, thus the soft material can be employed for stamps. Soft material stamps are also feasible for 3D structures, and multi layers can be fabricated with softer stamps [6]. Process is illustrated in Fig. 2.

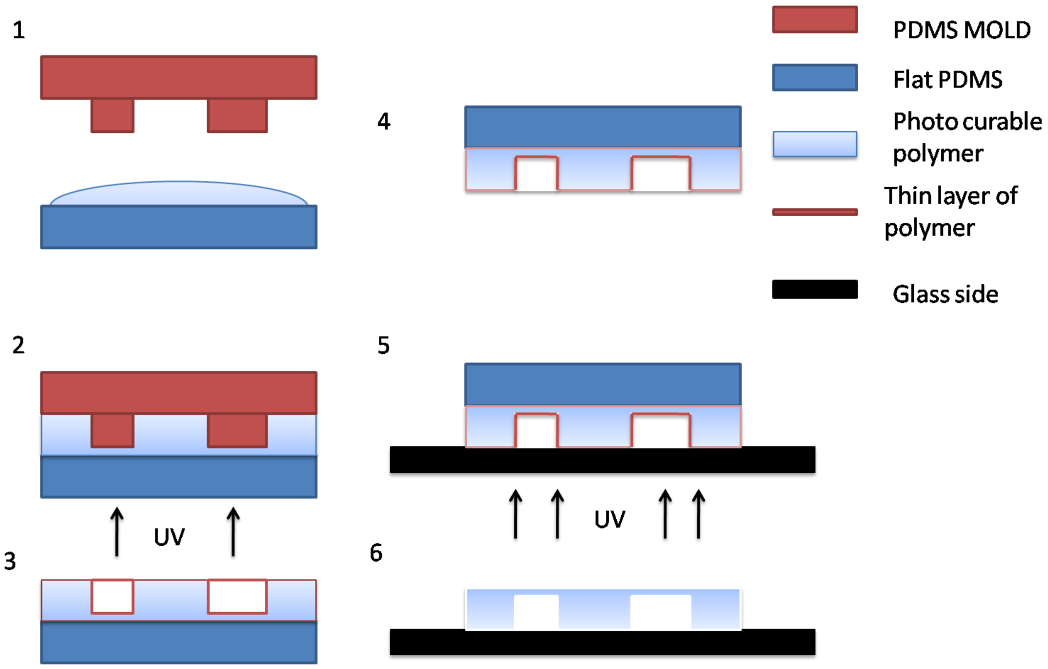


Figure 2: Illustration of Soft Lithography to Fabricate Microfluidic Chip.

(1) The PDMS mould is pressed into a liquid photo curable polymer supported on a flat PDMS substrate. (2) The polymer is partially cured by exposure to UV light. (3) The PDMS mould is peeled off the patterned polymer which still has a thin layer of uncured material at the surface. (4) The patterned polymer surface is pressed onto a thin glass substrate, such as a microscope slide with holes drilled for fluid connections. (5) A further UV exposure completes the polymer curing process. (6) The flat PDMS substrate is peeled off to leave the microchannel device.

1.3.2. Micro-injection molding

Micro injection molding technique is widely applicable in the commercial microfluidic devices since it is considered as cost effective for mass production [7].

In micro injection molding, polymer granules are forced into molds (Fig. 3) in molten state, and then it exposed specified pressure where material adopts the shape and texture of the mold. Temperature of mold freezes the material into mold shape and the product is then ejected [8]

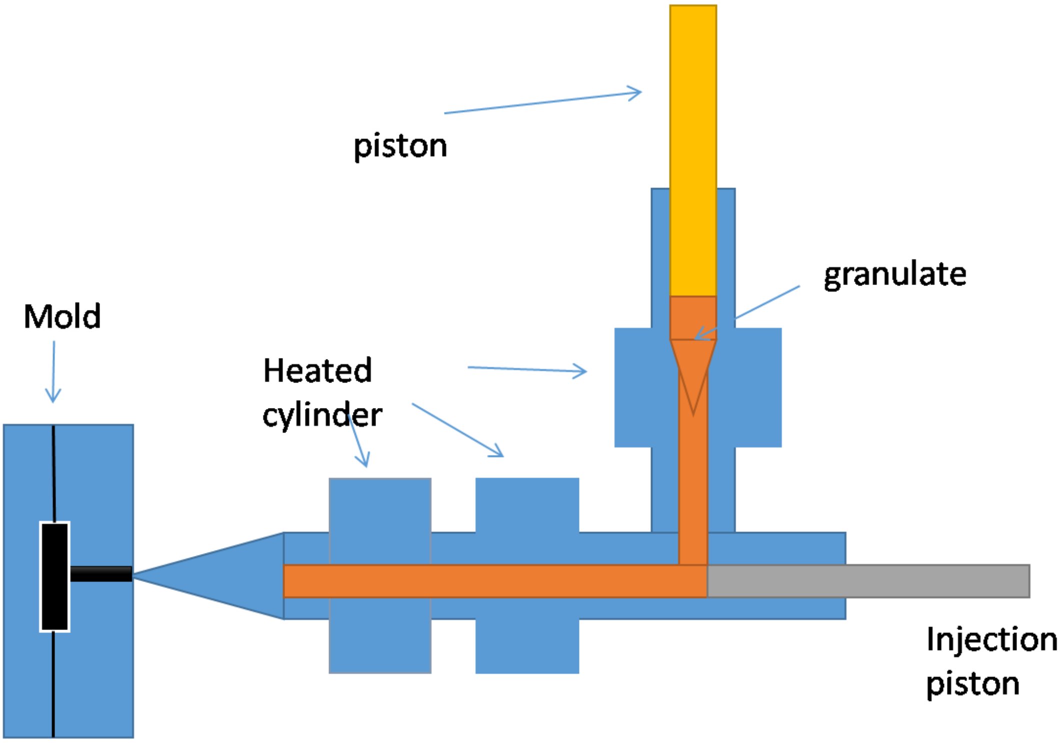


Figure 3: Illustration of Micro-Injection Molding.

1.3.3. Hot embossing

Hot embossing is a versatile technique considered as a simple way to produce low cost plastic microfluidic chips. In contrast to typical means of micro fabrication hot embossing requires simple equipment and less investment. Successful replication by hot embossing depends upon three parameters:

- Embossing temperature
- Embossing time
- Amount of pressure exerted

In hot embossing, of plastic (polymer) substrate and mold are kept in conformal contact and then specific pressure is exerted under particular temperature for a specific period of time [9].The microstructure of die penetrates and embossed onto the plastic substrate by pressing force. Cooling effect with constant pressure stabilize the polymer microstructure. Temperature should be monitored and maintained throughout the cycle.

Conventionally, hot embossing involves the use of programmable hydraulic press or other device to press with heated platens (Fig. 4). In this method the press is heated to a temperature above the glass transition temperature of substrate material. Than the substrate will be set under certain pressure from the top and bottom for a specific period of time. This step is followed by cooling step where a chiller or other cooling equipment lowers the temperature of mold so the sample can be easily removed from mold [10]

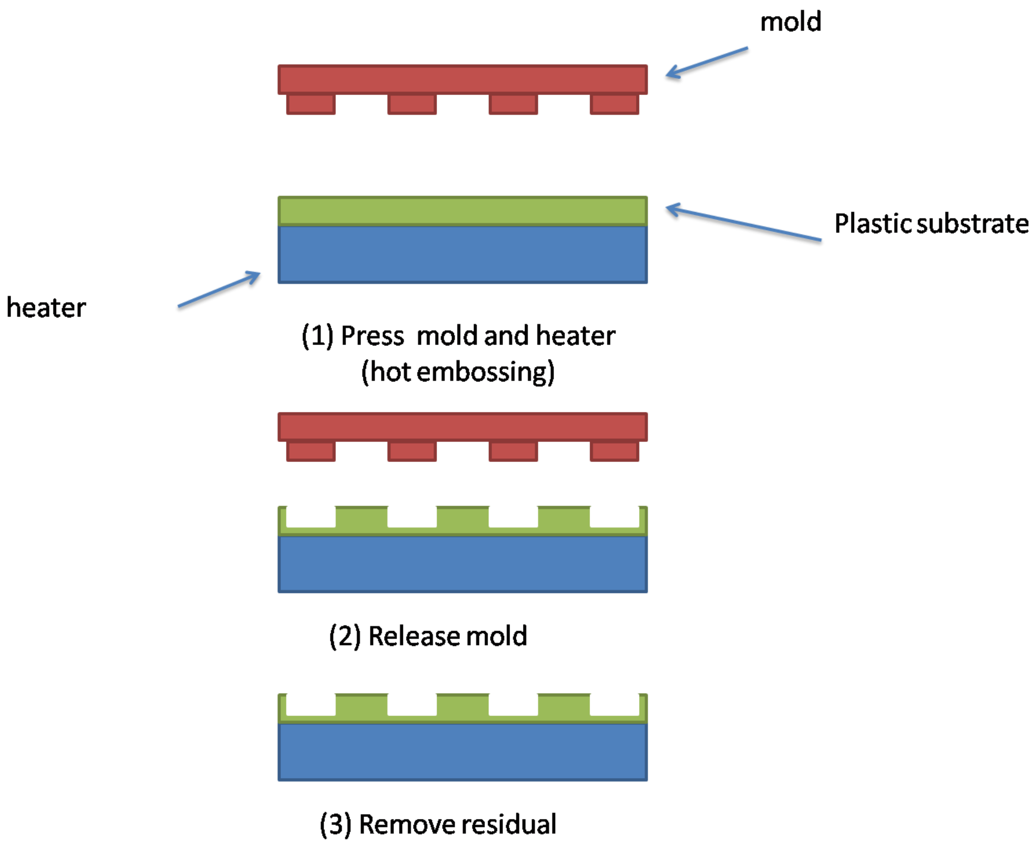


Figure 4: Illustration of Hot Embossing for Microfluidic Fabrication

1.4. Significance of the Study

Hot embossing is considered as feasible especially in moderate volume microfluidic fabrication. The main reason is that hot embossing does not require a costly infrastructure and that both design-to-device time and the manufacturing cycle time are low, especially compared to lithography based methods. Although injection molding allows lower cycle times, since the cost of required infrastructure is considerably higher, the technique is often preferred for high volumes. Table 1 presents a comparison between injection molding and hot embossing. Referring to Table 1, it can be stated that due to its low tooling cost and medium cycle time, hot embossing is a preferable technique for plastic microfluidic device fabrication [11]. It is a cost effective way to produce chips even at small scale, it also preserves time and can replicates 20 to 25 chips in an hour. It also gives fine quality result and produces accurate results on polymer substrate. One other advantage is that this technique does not require large infrastructure [2].

Table 1: Comparison Between Molding Methods [12]

	Injection molding	**Hot embossing**
Mold inserts	Metal molds	Metal and silicon molds
Feature size	Good for small features with low aspect ratio, or large features with high aspect ratio Good for 3D features	Good for small features difficult for high aspect ratio Difficult for multiple depth planar features only
Materials	Mainly low molecular weight thermoplastics	Low and high molecular weight thermoplastics
Processing	Short cycle time (sec-min) closed mold process high automation	Simple medium cycle time (min) potential for continuous production Open mold process
Replication Accuracy	Excellent dimensional control	Less dimensional control
Part quality	High stress on mold insert High mold-in stresses	High mold-in stresses
Cost	High tooling cost for large volume production	Low tooling cost for low medium volume production

1.5. Purpose of the Study

Considering the cost and cycle time, hot embossing process is especially advantageous for fabrication of commercial microfluidic devices. In this study, we aim to construct a low cost hot embossing press for fabrication of microfluidic devices. In addition to this, we also aim to optimize hot embossing process parameters for microfluidic fabrication.

1.6. Thesis Organization

The thesis is organized in five chapters. Chapter 2 presents a literature survey on microfludic fabrication by hot embossing. Chapter 3 explains the design of the hot embossing press. In Chapter 4, we present the experimental analysis to optimize hot embossing process for microfluidic fabrication. Finally in Chapter 5 we discuss the results and present an outlook for future research.

CHAPTER 2

LITERATURE REVIEW FOR HOT EMBOSSING

This chapter consists of a literature review of the hot embossing process for microfluidic fabrication. Specific hot embossing practices are presented in the following sections.

2.1. Hot Embossing of Plastic Microfluidic Devices Using Poly-Molds

In this study [13] authors have talked about the hot embossing of microfluidic devices with poly molds. They presented PDMS based hot embossing process which is less costly and capable to perform rapid prototyping of plastic microfluidic devices. Moreover, without any loss and effects PDMS molds could be reused for various replications. It has various other advantages such as with its low surface energy and PDMS elasticity de-molding could be performed straightly without any mold design. With their design process, they successfully approve that micro-scale features can be replicated in 1.5 mm thick polystyrene slides from various 2 mm thick PDMS molds. For this purpose micro pillars in three different forms rectangle, circle and square been used as a mold. Because of the PDMS thermal stability which is 200°C and elastomeric mechanical characteristics, the PDMS molds remained unaffected after recurrent hot embossing cycles. This process has actually simplified the current by using hot embossing and makes it possible for regular use in laboratories. It comes out with numerous benefits such as structure, replication with lower operational pressure and mold separation without any special model design.

2.2. Micro Hot Embossing For Replication of Micro Structures

In this research [14] authors mention micro structures. They call micro hot process as an ideal and affordable technique for bulk production of micro electromechanical systems (MEMS) parts in plastics. Their basic aim was to introduce hot embossing for high quality pattern transfer from the masters of polymer materials. In order to achieve their goal they design an instrument for hot embossing of nano structures. The material used in this process was polycarbonate (PC), silicon master molds that were anisotropic ally etched or deep inductively coupled plasma reactive ion etched (ICP RIE). Mainly the process is performed with customized process temperature and loading pressure up to 180°C and 500 kg, respectively. With this process micro grooves and micro mirrors' replication for fiber communications achieved.

2.3. Tin Coating/Glass Substrate System Fabricated for Hot-embossing Stamp at Multi-Scale

This article [15] explains about the fabrication of tin coating or glass substrate system for hot-embossing stamp at multi-level scale, in which glass plates being used as substrate and for non-patterns fabrication of hard tin coating has been done. For stamp fabrication, various microns tin coating been put on the glass with the help of the ion beam deposition system and for nano-patterns series ion beam etching system was applied. The driven outcomes of primary hot embossing imprinting showed good results for polymethylmethacrylate (PMMA) that verified conventional hard coating tin for duration enhancement of imprinting stamp. Highly stable chemical, effective thermal conduction performance, high hardness and heat-resistant were the properties of this process that made tin as an excellent choice for stamp material. However, some drawbacks of tin have also discovered: first of all its high chemical stability that reduces the efficiency of tin structure fabrication for both wet and dry etching. Secondly, thermal growth is not feasible in hot embossing. Thus the study shows the use of tin as stamp material is suitable, but for replication purpose for 71μm lines is not an ideal choice.

2.4. Fabrication of Molded Interconnected Devices by Ultrasonic Hot Embossing on Thin Polymer Films

In article [16] an ultrasonic welding machine which works on 35 kHz and capable to generate approximately 900 W with a maximum amplitude and a force of 12 m and 745 N, respectively was utilized. Various other machines are also available with 20 and 70 kHz, as much high the energy would be the frequency will be less. The procedure used here indicates the high efficiency of ultrasonic hot embossing that can generate electrical conductor paths just in few seconds. However, it is an alternative solution of the normal fabrication of printed circuit board PCB in large volume. This kind of method usually has certain limits that indicated in smaller dimensions till now that can only does fabrication process into the tool. The research has shown that the ultrasonic hot embossing is capable to fabricate molds interconnect devices. A metal layer can be cut down and weld onto a polymer substrate just in few seconds. During the experiment a 50m smallest line width was attained. If the pattern is complex and tiny, more efforts will be required. The major benefit of ultrasonic hot embossing is low cost and economic process for small scale production.

2.5. Hot Embossing of Micro Featured Devices

Due to the limitations of Silicon based products we have to look at other alternatives such as micro injection molding, casting and micro hot embossing, etc. The materials which are Polymer-based offer a number of properties and it is suitable for the small scale industries; it is cost effective and provides a number of advantages for the users. An experiment was done in micro hot embossing, by using ultraviolet light on silicon based SU-8 photo resist with a Ni-Co based bio chip. The microchip was having a very minute dimension near about 30µm depth, and the experiment was extremely successful in this dimension. In this study [17], hot embossing was done for micro based devices with Ni-Co stamp and the effect on accuracy was monitored by 3D microscope. The 3D microscope images of the test were observed and the dimensions of the stamp were measured before and after the test, and compared. At the end of this experiment, founding out that the applied force and temperature of embossing affects the imitation accuracy of micro features prominently. The depth of the imprint was increased with the application of applied force until it reached its limit. The researchers also observed that when the temperature was increased, the polymer was easily filling the cavities than the low temperature.

2.6. Polycarbonate as an Elasto-Plastic Material Model for Simulation of the Microstructure Hot Imprint Process

In this study [18] authors have discussed the application of microstructures, which today holds significant importance of multiple printing processes. The hot embossing process is thoroughly discussed being the most widely used process. The scientist have discussed various problems with this process which arise due to insufficient knowledge about polycarbonates, where else the finite element model of mechanical hot prints is explained, in which the entire process is divided into three steps that are heating, printing and demolding. Relevant nonlinear equations of mathematics are derived with the help of COSMOS physics for the accuracy mesh of the model. The scientist concluded that the polycarbonate is elastic which helps with the polymer molding and due its potential it makes the three processes of hot embossing more accurate; highlighting that one from all the most necessary qualitative parameter is filling the ratio of molds micro relief. The finite element model was worked out to maintain the replicas by the assessment of polycarbonates, temperature and compression.

2.7. Low Cost Hot Embossing Process for Plastics Microfluidic Chips Fabrication

Substances like plastic, polymer substrates such as poly, poly methyl, methacrylate (PMMA), Polyethylene (PE), or polycarbonate (PC) are of low cost and greatly fulfill the physical and chemical parameters more micro fluidic chip. For further advancement in productivity, researchers have developed a hot embossing with mold for rapid fabrication of micro fluidic chip. This feature is formed and curved by the UV Light radiations and processed at room temperature the fabrication procedure of metal mold by CNC milling machine with micro fluidic cavity is complicated in this study hot embossing technique is used for PMMA micro structuring because it is a simpler and faster process than others.

The design [19] in this process was made up of computer aid by SolidWorks program and consists of four parts. First was a structural body composed of working stage and another was a mold holder embedded with 250W heater. The compressive system was the third part of two top hydraulic single stage pistons and pole middle pistons. The pressure and depth of pistons were controlled by magnetic switch and micro controller. The fabrication process begins with the aluminum micro mold manufactured by a high precision CNC milling machine with 1μm resolution. The inverted micro channel for this mold is designed to be 200 μm wide and 120 μm high. The 2D profile across micro channel of the aluminum micro mold is measured by contact profiler. Polymethlymethacrylate (PMMA) sheet is then placed for 5 minutes on the micro mold, which is already heated by a hot plate at 200 ^{o}C. Next, the mold and PMMA assembly is then transferred into the hot-embossing machine.

The hot embossing is carried out at different embossing temperatures and embossing time that varies between 2 and 6 seconds while the embossing temperature varies between 60 and 80 ^{o}C. Reported results show that the edges of PMMA micro channel are rounder and the cross sectional dimensions of the micro channel is less than the original mold. Moreover, embossing time and temperature are reported to be two important parameters in hot embossing.

2.8. Production of Micro Configurations through Micro Hot Embossing

In this study Micro hot embossing is a latest method for large scale production of MEMS equipment for optical telecommunications and micro fluids. Through the use of this method [20] different patterns can be transferred from master material to polymer material. Very accurate styles and structures can be produced using this technique. Polycarbonate is used as material, master molds are made up of silicon. To achieve feasible results micro grooves and micro lenses with alignment set as passive were conceded.

The equipment used for this task involves top-bottom heating plates, alignment system along vacuum compartment. The process starts with putting master, polymer materials in vacuum compartment under pressure and then it is heated up to 180°C and cooled little below than 158°C. After this process both materials are detached. As Polycarbonate is used as raw material in this technique, its glass transition (Tg) temperature is found by Differential Scanning Calorimetry (DSC) techniques. A force more than 500kg is required to have a precise reproduction with same features. The grooves used have 50μm width and 35μm depth. Almost exact copy is extracted with few fractures at peak areas of newly formed copy. These newly formed grooves are used for alignment of fiber optics for communication. Silicon master made up of ICP RIE is also produced. This whole process was performed with most suitable temperature about 180°C and optimal force of 500kg. During this micro groove and micro mirrors were reproduced. This technique can be a future for low cost fiber optic equipment for telecommunications and MEMS equipment.

2.9. Hot Embossing of High Performance Polymers

Here researcher has talked about hot embossing of high performance polymers [21]. In this process it is possible to achieve replication of a variety of thermostatic polymers. This process is an innovative and unique embossing process that used for macro replication, as it can be used effectively but with precision, for polyether ether ketone (PEEK) and liquid crystalline polymer (LCP). It follows the principle of one sided hot embossing cycle. Its use in different types of polymers is also possible, such as the amorphous and the semi-crystalline polymers. This method is a bit complicated and has to be maintained with uniformity than other processes. The polymer foil is placed between the micro structured mold insert and the metal plate. The heat is provided till the polymer molding temperature is reached. The method is carried out in 2 steps that make the process effective. Firs the mold insert and substrate are moved towards each other at a distance of 1mm for one min. When the embossing force is constant that is retained for a specific period of time until the process is complete. This is a 2 step compression cycle. The temperature is constant during this process which allows perfect embossing. This method is also effective as it removes any chance of air inclusions in the polymer. For demolding the cooling is continued until the temperature of the molded part drops below the melting point of the plastic, due to this the molded part is demold and gives a perfect replicated high performance polymer.

2.10. Gas Pressurized Hot Embossing for Transcription of Micro-Features

This research [22] presents hot gas as a medium for inserting pressure, which ensures uniform pressure insertion. This is an innovative method that allows perfect fabrication of micro features onto the substrate. The method of using the gas pressure directly to press and mold the substrate is easy and has better results. It offers a parallel replication of the micro-features at a very low cost and a uniform embossing pressure on the substrate while the use of plates does not offer that. The gas pressure in the entire process is uniform. The process at first includes the placement of the plastic films on the stamper so that they can form a perfect mold. This mold is then placed over the cooling or heating plates. Then the mold is heated in a chamber with the gas being blown at a uniform pressure over the film. After that cooling and opening the chamber to get the gas embossed film. This process has various other advantages also such as accuracy that is improved with the use of gas pressure. Because of the use of gas this process can be used for large scale transfer of micro-features 8 or 12 inches for wafers. The wafer tool can be fractured, but the use of gas in this method allows the use of silicon wafer as an embossing tool. The hot gas pressurized embossing allows easy replication of double sided elements. In short, this process has simplified the transcription of micro-features for many substrates.

2.11. Rapid Prototyping of Arrayed Microfluidic Systems in Polystyrene for Cell-Based Assays

The research [10] presents the experiment of the arrayed micro-fluidic system with cell-based assays in polystyrene. Here researcher puts more focus on rapid prototyping of this system. The technique performed here includes mold design to bonding and

Table 2: The Processes of Embossing and Bonding with Different Parameters [11]

Process	Pressure (MPa)	Temperature (^{o}C)	Time (min.)
Embossing	2.3	125	15
Bonding	3.45	90	30

The main purpose was to develop a competitive technique that performs more efficiently than PDMS. In order to achieve this goal, they performed this process in three steps: first traditional lithographic technique used to fabricate mass epoxy molds, then PS layer embossed via hole and lastly thermal bonding has been achieved to gain better bonding over large arrays of microsystems. Overall process has been performed in an organized way that is mentioned in following table.

The table illustrates all one by one used process in terms of performing the steps, , pressure, temperature and time duration. The driven results show that the fabrications of large arrays of Microsystems are possible for long term use in cell studies.

Finally, the range parameters that going to be certified for embossing and bonding presses in any hot embossing considering the literature survey are 70-125^{o}C for temperature[19] and not more than 10 kN for the pressure, and5-30 min duration times[10]

CHAPTER 3

DESIGN OF LOW COST HOT EMBOSSING PRESS

This chapter consists of two sections. The first section presents the conceptual design. The next section presents the calculations related to the structural design.

3.1. Conceptual Design

Chapter 2 presents a review of various studies on hot embossing with numerous devices and techniques, which verify that hot embossing is low cost and an ideal technique for producing microfluidic chips in medium volumes.

Temperature and pressure are two of the most important parameters in hot embossing. Thus, the first thing that we need to address is the devices required to obtain heat and pressure. As mentioned in Chapter 2, hot embossing temperature should be roughly between 70 and 200^{o}C, depending on the material. Also the literature survey showed that the load to create the required pressure should be in the order of 10 kN depending on the pattern being embossed and the material.

To satisfy these specifications we decided to use a ceramic heater, whose temperature can be controlled between 60 and 200^{o}C. To obtain the required pressure, we decided to use a regular bottle type hydraulic jack of 2 tons capacity (equivalent to approximately 20kN load capacity). We also decided to utilize a manometer connected to the jack to monitor the pressure, hence the load that we apply during embossing.

To allow embossing of various sizes of chips, the press should have a large enough service area. In addition to this, in order to reduce the friction during operation use of sliding bearings were preferred.

Constructed hot embossing press is shown in (Fig. 5). Hot embossing press is composed of a steel frame holding the pressure unit and one moveable and one fixed plate holding the heater unit. Engineering drawings of the assembly and the parts are given in Appendix A.

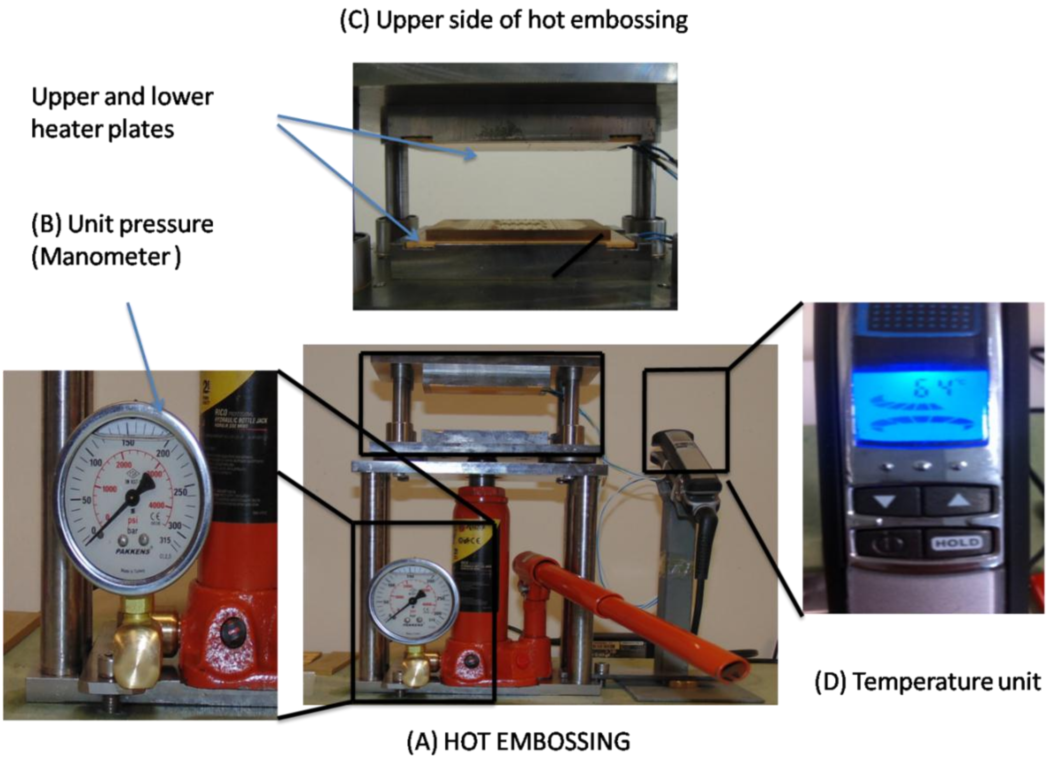


Figure 5: Constructed Hot Embossing Press. (a) Overall view of the press (b) Manometer for monitoring the embossing pressure (c) Heater plates (d) Temperature controller unit.

3.1.1. Heater unit

Fig. 5.b and c shows the heaters and the controller of the heater. This unit is used to heat the mold and the substrate and to control the temperature of them. The unit includes two ceramic heaters; one is for heating the mold, and the other is for heating the substrate. These heaters are embedded under steel plates, which are directing the load on the mold and the substrate. The bottom plate, where the mold is placed, is designed as movable, while the top plate is fixed. In addition to the ceramic heaters, the heater unit involves an external temperature controller, which is used to increase,

decrease, hold and observe the temperature of the heaters. These heaters can provide a temperature for heater between 60 and 200^oC with resolution of 10^oC.

While operating the press, the heaters are heated up to a set temperature and kept there until the pressing is finished. Then the controller is turned off to decrease the temperature of the heaters to room temperature.

3.1.2. Pressure unit

The pressure unit (Fig. 5.a-d) consists of a hydraulic jack with maximum load capacity of 2 tons and a manometer connected to the cylinder of the hydraulic jack. The dial gage manometer with a full range of 315 bars is equipped with scale lines, which allows pressure reading at 10 bars of increments. Considering that the load we need to apply is in the scale of 10 kN, a jack with 2 tons of capacity satisfies the requirement. Knowing the diameter of the piston of the jack, this force can be used to find out the pressure requirement, which comes out to be about 200 bars. This result justifies the selection of the manometer as well. By using the jack, bottom heater plate, where the mold is fixed, is moved up to press the mold on the substrate, which is located on the upper heater plate. During the operation, the pressure, which is set as the process parameter, is continuously monitored by reading the manometer.

The material cost of the hot embossing press is calculated to be 224 TL (Table 3).

Table 3: The Description and the Price of the Hot Embossing Parts

No.	Name or the description of the part	QTY.	The price
1	Hydraulic jack	1	20 TL
2	Manometer and its tubes connector	1	40 TL
3	Heater and control unit	1	80 TL
4	sliding ball bearing	4	60 TL
5	Different kinds of bolts	24	10 TL
6	Steel material to fabricate the structure	2 kg	4 TL
		THE TOTAL PRICE	224 TL

3.2. Structural Calculations

Calculations verifying the design dimensions are provided below. The calculations are based on the worst case scenario, where the hydraulic jack applies 2 tons of load on the plates. The results show that the factor of safety for the load carrying critical components are greater than 1, which proves that the design dimensions satisfy the strength concerns.

3.2.1. The upper plate carrying the heater

The upper plate carrying the heater is prone to bending under distributed load acting on the plate. Therefore, we carried out a bending analysis on the plate. Fig. 6 illustrates the loads on the plate and the free body diagram. For analysis purposes, the plate is simplified as a double clamped beam. The force on the plate is distributed by the heater plate. Therefore, the force is assumed to be distributed all along the upper plate.

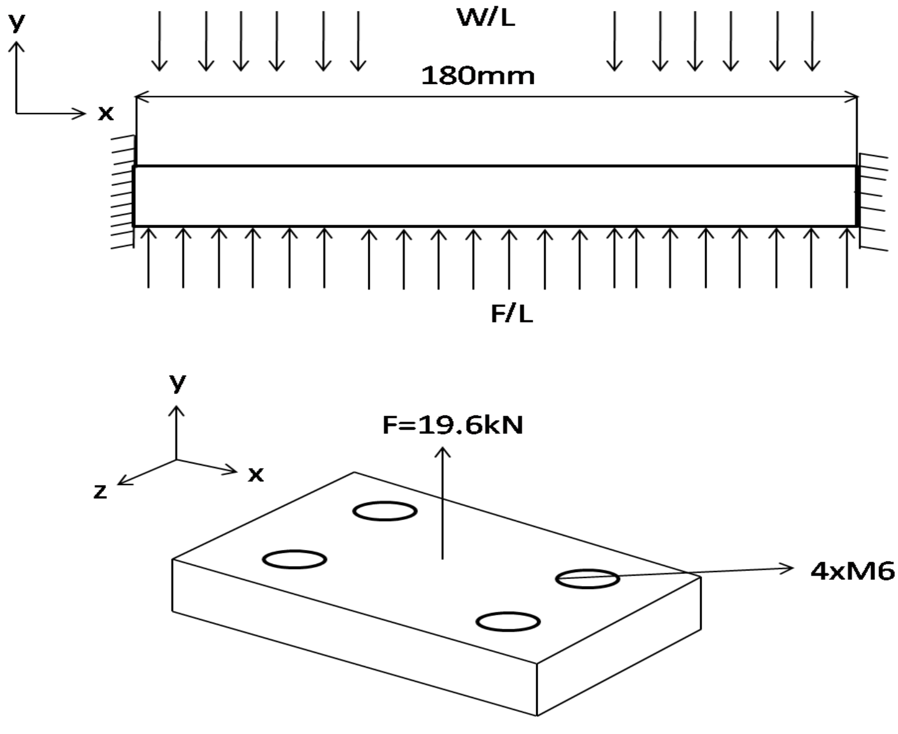


Figure 6: Loading State of the Heater Plate and Free Body Diagram of it.

To find out the weight of the plate, which is acting against the load applied by the jack, we first calculated the volume of the plate. By referring to Fig. 6, we can find the volume of the cylinders as:

$$V_c = 4A_c h = 4(\pi d^2/4)9 = 2827.4\ \text{mm}^3 \qquad (3.1)$$

And the volume of the plate:

$$V_p = (7)(200)(9) = 136800\ \text{mm}^3$$

Then the total volume can be found as:

$$V_T = V_p - V_c = 136800 - 2827.4 = 133972.6\ \text{mm}^3 \qquad (3.2)$$

Assuming that carbon steel is used and unit weight of the carbon steel is $w = 76.5\ \text{kN/m}^3$ weight can be calculated as:

$$\begin{aligned} W &= (76.5\ \text{kN/m}^3)(\ 133972.6\ \text{mm}^3)(10^{-9}\ \text{m}^3/\text{mm}^3) \\ &= 0.01\ \text{kN} \end{aligned} \qquad (3.3)$$

Comparing this load with that created by the jack, which is F = 2000 x 9.81= 19.6N, we conclude that W << F. Therefore, the weight of the plate can be neglected.

The bending moment on the plate can be found referring to the bending moment on a double clamped beam [23]:

$$M = \frac{wl^2}{12} \qquad (3.5)$$

Then, the bending moment becomes

$$M = \frac{Fl}{12} = \frac{19.6\text{x}10^3\text{x}180\text{x}10^{-3}}{12} = 294\ \text{N.m} \qquad (3.6)$$

To find out the normal stress in the beam, we need to find the inertia:

$$I = \frac{1}{12}bh^3 = \frac{1}{12}(180)9^3 = 10935 \text{ mm}^4 \tag{3.7}$$

Then the normal stress in the beam is found as:

$$\sigma = \frac{My}{I} = \frac{(294)10^3(4.5)}{10935} = 127.7 \text{ MPa} \tag{3.8}$$

For the plate material, 1040 HR steel the yield strength is $S_y = 420$MPa. Then,

$$S_{sy} = (0.577)S_y = (0.577)(420) = 242.34 \text{ MPa} \tag{3.9}$$

Then, the factor of safety for the given plate dimension comes to be:

$$n = \frac{S_{sy}}{\sigma_2} = \frac{242.34}{127.7} = 1.9 \tag{3.10}$$

which is greater than 1, showing that the design dimensions satisfy the yield criteria.

Also, calculating normal stress of the each bolt (M6x4 countersunk bolts are used):
Yield strength of the bolts $S_y = 240$ MPa

$$\sigma = \frac{(F/4)10^3}{A} = \frac{(4.9)10^3}{\frac{\pi d^2}{4}} = \frac{(4.9)10^3}{\frac{\pi 6^2}{4}} = 173.3 \text{ MPa} \tag{3.11}$$

$$n = \frac{S_y}{\sigma_2} = \frac{240}{173.3} = 1.38 \tag{3.12}$$

3.2.2. The upper cylinder

To find out the area of the cylinder, which is acting against the load applied by the jack, we first calculated the number of safety. By referring to Fig. 7:

1040 HR Steel $S_y = 290$ MPafrom

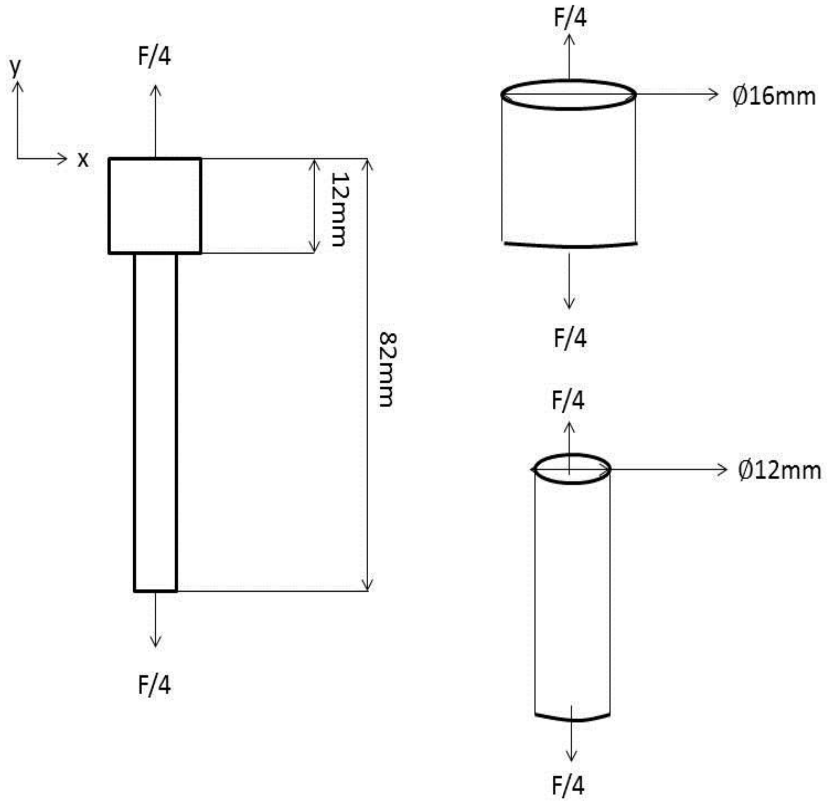


Figure 7: Free Body Diagram and the Dimensions of the Upper Cylinder

$$\sigma_1 = \frac{F/4}{A_1} = \frac{4.9}{\frac{\pi r^2}{4}} = \frac{4.9}{\frac{\pi 16^2}{4}} = 24.4 \text{ MPa} \tag{3.13}$$

$$\sigma_2 = \frac{F/4}{A_1} = \frac{4.9}{\frac{\pi r^2}{4}} = \frac{4.9}{\frac{\pi 12^2}{4}} = 43.3 \text{ MPa} \tag{3.14}$$

$\sigma_2 > \sigma_1$ So, number of safety calculates according to σ_2

$$S_{sy} = (0.577)S_y = (0.577)(290) = 167.33 \text{ MPa} \tag{3.15}$$

$$n = \frac{S_{sy}}{\sigma_2} = \frac{167.33}{43.3} = 3.86 \tag{3.16}$$

3.2.3. The lower cylinder

To find out the area of the cylinder, which is acting against the load applied by the jack. By referring to Fig. 8, we can find the factor of safety as presented below.

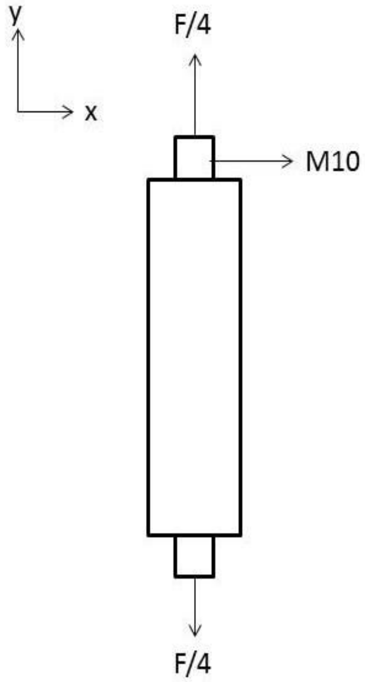


Figure: 8: Free Body Diagram of the Lower Cylinder

The yield strength for the bolts: M10x1.5 ISO 5.8 $S_y = 420$ MPa

$$\sigma = \frac{F/4}{A_1} = \frac{4.9}{\frac{\pi r^2}{4}} = \frac{4.9}{\frac{\pi 10^2}{4}} = 62.39 \text{ MPa} \quad (3.17)$$

$$S_{sy} = (0.577)S_y = (0.577)(420) \quad (3.18)$$

$$S_{sy} = 242.34 \text{ MPa} \quad (3.19)$$

$$n = \frac{S_{sy}}{\sigma_2} = \frac{242.34}{62.39} = 3.88 \quad (3.20)$$

CHAPTER 4

EXPERIMENTAL WORK

This chapter includes four sections. The first section involves the mold design; the second section explains the process of the hot embossing experiment. The third section addresses the experiment's design and the exact chip that the experiment targets. The three sections will explain all the details of the hot embossing experiment design and determine the most effective factors on hot embossing process. Finally, section four presents the results and the feature dimensions obtained best by the hot embossing.

4.1. Mold Design

To begin the experiment, the first requirement was to design the mold. In our experimental design, we aim to optimize the process parameters, which are embossing time, pressure, and temperature for given feature dimensions, which are characterized by channel width and the distance between neighboring channels. We set the height of the channels on the mold to be 100 μm. To determine the effect of the feature size we utilized five straight lines on the mold, which has widths of 100, 200,300,400 and 500 μm respectively. The distances between successive lines are set to 1 mm. In addition to these straight lines, we utilized a simple micro mixer design, which is composed of two inlet ports and one outlet port connected by a serpentine channel. The channel width of the mixer is set to 400 μm. Fig. 9 shows the mold design before and after the fabrication.

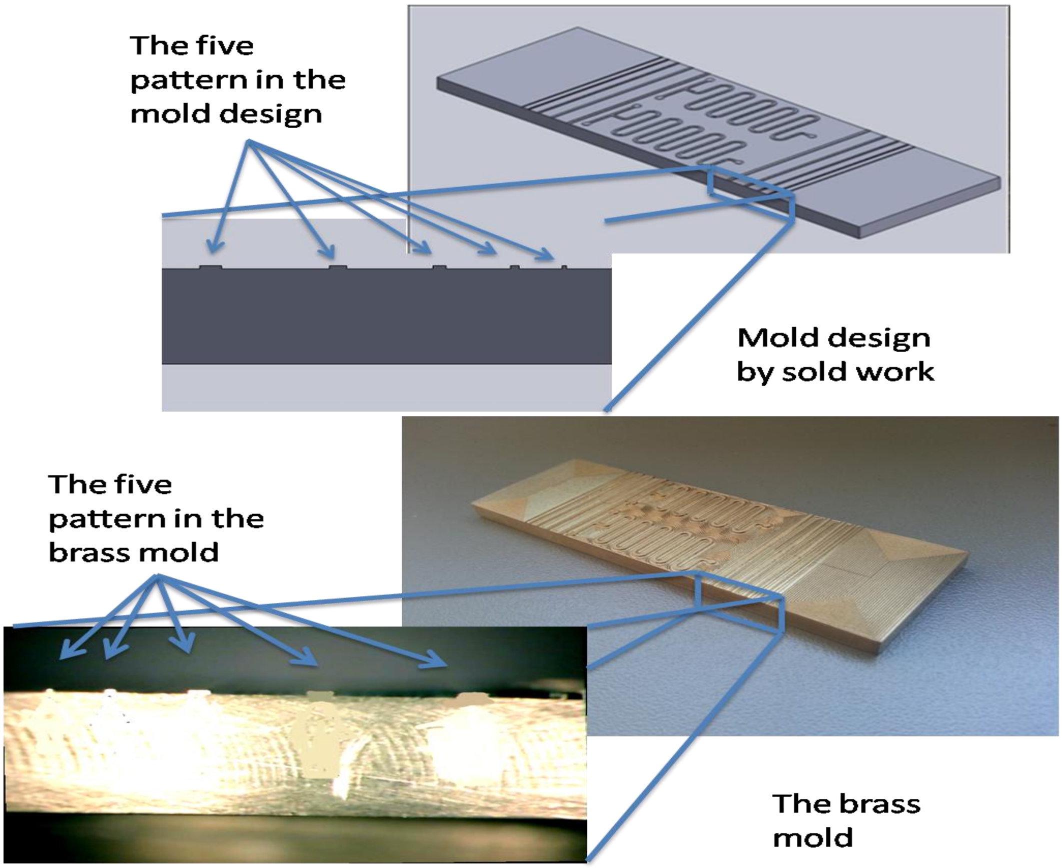


Figure 9: The Mold Before and After the Fabrication Process.

There are many techniques of fabricating a high quality mold. At first, we tried to use the lithography technique using a dry film photoresist. For the mask design, we used the software, CorelDraw. We preferred lithography, since the photoresist used would yield a taper angle which would simplify the removal of the substrate after embossing. However, after conducting the lithography experiment, it was proved to be unproductive because there were no viable results after one month of recurrent trials. The problems that we faced with the lithography can be stated as; the height of the patterns are limited to the photoresist height and cannot be well controlled, the glass substrate used for the lithography sticks on the plastic substrate during embossing process. Therefore we decided to use another technique to fabricate the mold. Secondly, we tried to use precision milling to fabricate the mold. To obtain the mold, we created the solid model of the mold using SolidWorks and then translate it into part program using Solid CAM, which is an add-in to SolidWorks. The part program is run on CNC milling machine (proLIGHT 1000 Machining

Center) using 1 mm end-drill to have the mold on brass block. For milling process, the spindle speed is set to 1000 rpm and the feed rate is set to 100 mm/min.

4.2. Operational Procedure

The operational procedure is explained below.

- Place the mold on the lower plate carrying the heater.
- Connect the heater to a wall plug to provide electricity to the heaters.
- Set the required temperature using the controller.
- Wait for 25 min. until the heaters reach the steady state temperature.
- Place the plastic substrate on the mold. Check the alignment of the substrate with the mold.
- Set the timer to required embossing time.
- Start pressurizing the jack by using the lever.
- Check the pressure using the manometer. Once it reaches up to required pressure start the timer.
- Regularly check the manometer reading to ensure that the required pressure is being applied.
- After the embossing time is over, start cooling down by using air gun (keep pressure while cooling) for five minutes.
- Release the jack.
- Release the substrate.

During the operation, the embossing press should appear as shown in Fig.10. The use of the heaters and the temperature controller are explained in Chapter 3. During operation, since the heaters are not isolated, the operator needs to wait for approximately half an hour after turning on the heaters for the heaters reach the steady state.

It should also be noted that, the temperature reading on the controller of the heater is not the surface temperature of the plates but the temperature of the ceramic heaters. Therefore it is important know the correlation between the set temperature that appears on the monitor of the controller, and the real temperature on the surface of the plate. We relation between the set temperature and the surface temperature is shown on Fig. 11.

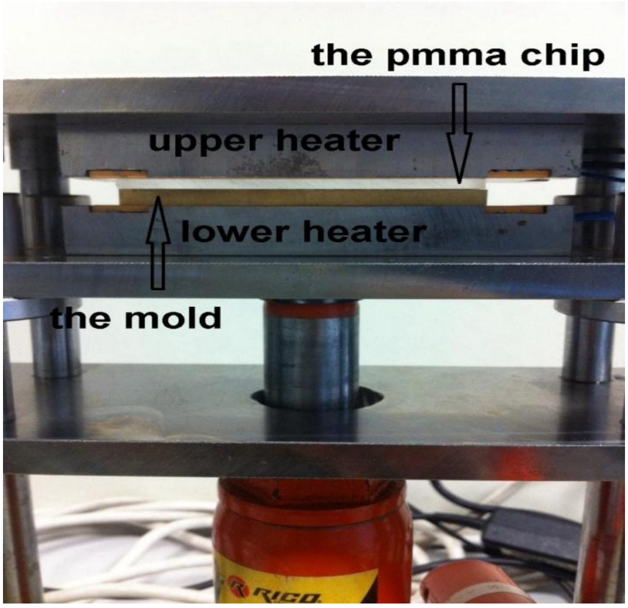
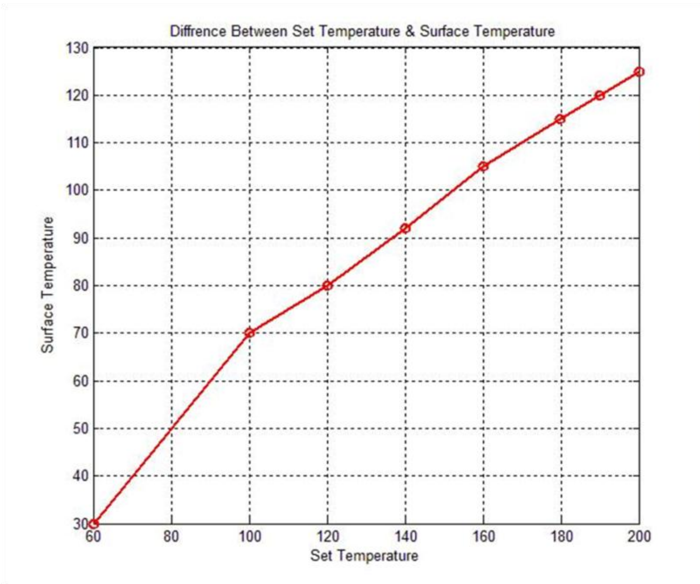


Figure 10: The way that the PMMA Chip and Brass Mold.



Set Temperature (°C)	Temperature on the surface (°C)
60	30
100	70
120	80
140	92
160	105
180	115
190	120
200	125

Figure 11: Surface Temperature Versus the Set Temperature

It is also mentioned that the heater temperature, and thus the surface temperature requires time to settle down. Transient responses of the set temperature and the surface temperature are plotted in Fig. 12.

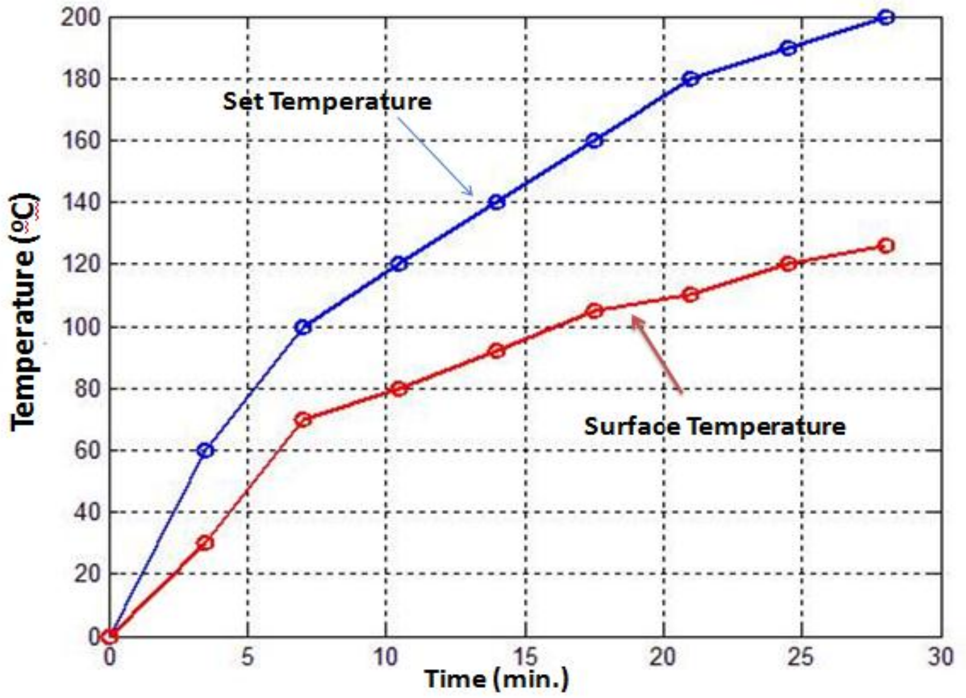


Figure 12: Transient Response of the Surface Temperature and the Heater Temperature. The surface temperature of the heater plate was measured with a UNI-T33C multi timer.UNI-T33C has a K type PT100 thermocouple for measuring temperature, and has a precision of 0.1^{o}C .

4.3. Design of the Experiment

The parameters affecting hot embossing process are pressure, temperature, and time. Experiments should prove which of these parameters is the most effective. To determine the parameter that has the most significant effect, we utilized Taguchi method. Taguchi method is a design of experiments (DOE) methodology, which is used to determine the "best" combination of input parameters in an experiment [24].

In Taguchi method, the first thing is to find out the parameter levels that are likely to produce the best result. This is commonly done by experience. By referring to the literature survey in Chapter 2, and experimental trials. We decided the levels of the parameters as listed in Table 4.

Table 4: The Best Parameters Using in the Design Experiment

Temperature(°C)	115	120	125
Pressure (bar)	220	240	260
Time (min.)	6	7	8

According to the Taguchi method, a 3x3 parameters matrix (Table 3) can be tested in nine experiments. Normally, a combinatorial design requires 27 experiments to test all three sets of parameters. Taguchi method helps us to decrease the number of experiments. The experimental design as proposed by the Taguchi method is shown in Table 5.

Table 5: The Parameters in Each Experiment According to Taguchi Method.

Experiment	**Temperature** (°C)	**Pressure (bar)**	**Time (min.)**
1	180	220	6
2	180	240	7
3	180	260	8
4	190	220	7
5	190	240	8
6	190	260	6
7	200	220	8
8	200	240	6
9	200	260	7

After conducting all nine experiments, the results are analyzed. The analysis is conducting by processing images of the nine chips shot by using a digital microscope (Fig. 13).

The geometers of the chips are analyzed by measuring four independent dimensions; height, width, and right and left angles, measured on the cross-section of the 5 lines shown in Fig. 13. The same dimensions are also measured on the mold for comparison. To get an image showing the cross-section, during embossing the substrate is placed on the mold such that there is an offset as shown in Fig. 14. For image processing, we used a Java based image processing software; ImageJ.

For each experiment, the dimensions measured on the substrate and the dimensions measured on the mold are compared with each other and a similarity index in terms of percentage is calculated for each dimension (Table6). The similarity indices are calculated for each experiment. Table 7 presents the results.

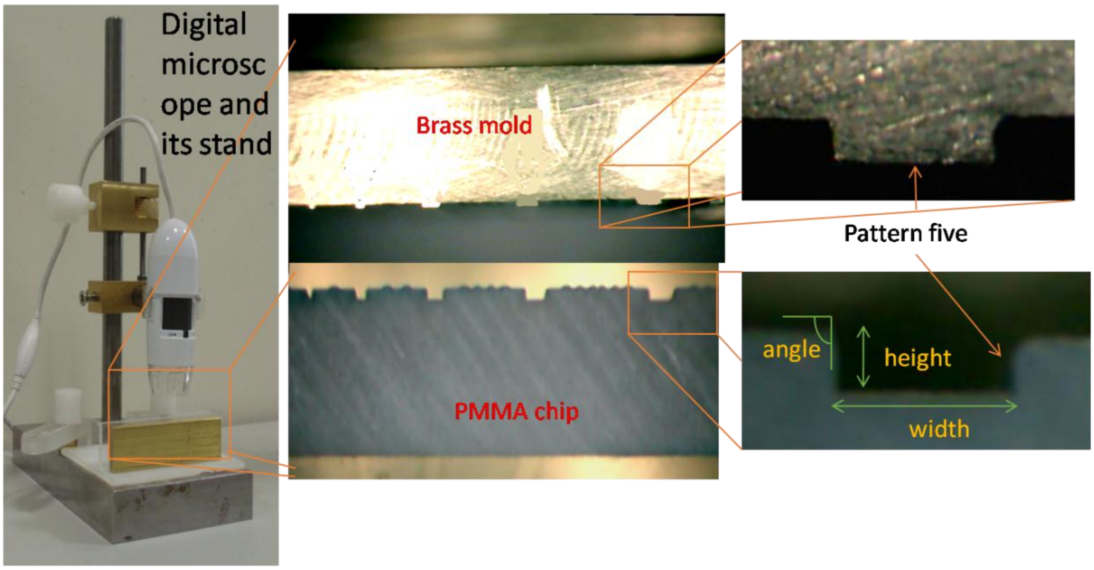


Figure 13: Use of Digital Microscope to Get the Images for the Measurements. The Measurements are Done Using ImageJ.

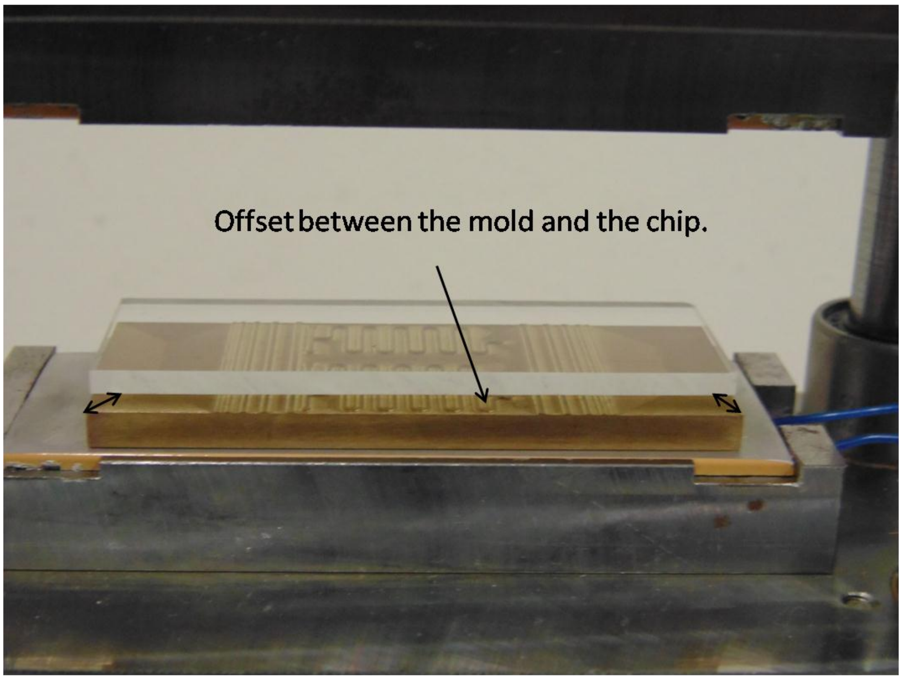


Figure 14: The Offset Between the Chip and Mold Edge

The findings of the experiments are listed below.

- The height of the patterns in the chip is bigger than the height of the patterns in mold at all patterns except the first pattern looks same with the first pattern of the mold.
- The width in the third, fourth and fifth patterns in the chip are bigger than the patterns of the mold in the chip also.
- The best right angle in the fourth pattern of the chip is exactly same with forth pattern of the mold.
- The left angle in the fifth pattern of the chip is about 98 percent comparing with the lift angle of the fifth pattern in mold.

Table 6: Dimensions and Corresponding Similarity Indices Calculated for Each Pattern (embossing parameters: 180^{o}C, pressure 240bars and 6 min).

Pattern no.	Height (μm)			Width (μm)			Right angle (degrees)			Left angle (degrees)		
	Mold	Pattern	Similarity (%)	Mold	Pattern	Similarity (%)	Mold	Pattern	Similarity (%)	Mold	Pattern	Similarity (%)
1	100	99	99	147	165	89	86	74	86	103	90	87
2	135	145	93	267	236	88	82	88	93	99	90	90
3	125	180	69	368	414	88	82	83	98	95	90	94
4	154	180	85	468	528	88	83	83	100	102	95	93
5	149	183	81	624	596	95	87	85	97	97	98	98

Table 7: Shows the Percentage between the Every Chip that Obtain in Every Experiment with the Brass Mold Depending on the Five Pattern in Every Chip

Experiment	Temperature (°C)	Pressure (bar)	Time (min.)	Similarity for Height (%)	Similarity for Width (%)	Similarity for Right Angle (%)	Similarity for Left Angle (%)
1	180	220	6	75.0	76.2	77.8	66.2
2	180	240	7	91.8	82.6	96.0	94.4
3	180	260	8	82.4	86.6	96.0	90.0
4	190	220	7	86.0	85.8	91.6	92.0
5	190	240	8	70.6	87.6	91.2	96.6
6	190	260	6	83.4	86.4	93.8	96.6
7	200	220	8	70.8	91.6	91.6	94.8
8	200	240	6	87.8	77.4	79.8	92.0
9	200	260	7	82.2	92.4	89.0	95.8

The results are then analyzed as proposed by Taguchi method. To determine the parameter that has the highest effect, we used SN ratio for each of the parameters in each experiment.

$$Sm_n = \frac{(length + width + right\,\theta + left\,\theta)^2}{4} \quad (4.1)$$

$$St_n = length^2 + width^2 + right\,\theta^2 + left\,\theta^2 \quad (4.2)$$

$$Ve_n = St_n - Sm_n \quad (4.3)$$

$$SN_n = 10\log\frac{\left(\frac{1}{N}\right)\left(Sm_n - Ve_n\right)}{Ve_1} \quad (4.4)$$

where n is the experiment number, SN is signal to noise (S/N) ratio, St is the summation of the tolerance of vectors, Sm is the summation of the mean value of vectors, Ve is the variance between the summations tolerance and mean value of vectors, and N is the number of vectors. Accordingly, the results tabulated in Table 8 are obtained.

Table 8: The SN Ratio for the Nine Experiments Depending on the Percentage of Height, Width, Right and Left Angle for the Pattern Comparing with Brass Mold.

Experiment	Temperature (°C)	Time (min)	Pressure (bar)	Right angle	Left Angle	Width	height	SN Ratio
1	180	6	220	66.2%	77.8%	76.2%	75%	18.56
2	180	7	240	94.4%	96%	82.6%	91.8%	18.83
3	180	8	260	90%	96%	86.6%	82.4%	19.01
4	190	7	220	92%	91.6%	85.8%	86%	23.52
5	190	8	240	96.6%	91.2%	87.6%	70.6%	12.9
6	190	6	260	96.6%	93.8	86.4%	83.4%	18.48
7	200	8	220	94.8%	91.6%	91.6%	70.8%	13.12
8	200	6	240	92%	79.8%	77.4%	87.8%	17.4
9	200	7	260	95.8%	89%	92.4%	82.2%	17.98

After calculating the SN ratio for each experiment, the average SN value is calculated for each factor and level. This is done as shown below for time parameter (P3) in Table 9.

Table 9: Three Levels of Three Parameters According to Taguchi Method

Experiment No.	Temperature (p1)	Pressure (p2)	Time (p3)	SN Ratio
1	1	1	1	SN1
2	1	2	2	SN2
3	1	3	3	SN3
4	2	1	3	SN4
5	2	2	1	SN5
6	2	3	2	SN6
7	3	1	2	SN7
8	3	2	3	SN8
9	3	3	1	SN9

$$SN_{p3,1} = \frac{SN_1 + SN_6 + SN_8}{3} = \frac{18.56 + 18.48 + 17.4}{3} = 18.14 \quad (4.5)$$

$$SN_{p3,2} = \frac{SN_2 + SN_4 + SN_9}{3} = \frac{18.83 + 23.52 + 17.98}{3} = 20.11 \quad (4.6)$$

$$SN_{p3,3} = \frac{SN_3 + SN_5 + SN_7}{3} = \frac{19.01 + 12.9 + 13.12}{3} = 15.01 \quad (4.7)$$

Equations 4.5, 4.6 and 4.7 are solved for each parameter in accordance with the ANOVA method. A group of statistical models used to examine the distinction among mean and other procedures such as variation between groups which is associated with this group, this group of statistical models actually known as ANOVA (analysis of variance) [25]. The F-test is a most commonly used test to identify the appropriate model for the population against it chosen targeted data sample. The F-test findings are helpful for any sort of statistical analysis, most preferably under null hypothesis where F-distribution is required under test statistics. The F-test results certainly increase when data finds its appropriate model with the use of least square [26].This yields three averages for each parameter. By checking the difference between the maximum and minimum average for each parameter, one can determine the most effective parameter. Accordingly we found that time is the most important parameter in hot embossing process (Table 10).

Table 10: Variation in Each Parameter.
The highest variation is observed for embossing time, which indicates that time parameter, has the highest effect on hot embossing process.

Level	**Pressure (bar)**	**Temperature (°C)**	**Time (min.)**
1	18.4	18.8	18.14
2	16.37	18.3	20.11
3	18.49	16.16	15.01
▲	2.12	2.63	**5.1**
Rank	3	2	1

Similarity percentages tabulated in Table 7 can be used to find an average similarity percentage for each experiment. Tabulating these average similarities show that the best result is obtained for experiment 2, where the temperature is 180^{o}C, pressure is 240 bars, and the time is 7 min (Table 11).

Table 11: Average Similarity Indices for Each Experiment.

Experiment	Temperature (°C)	Pressure (bar)	Time (min.)	Result
1	180	220	6	73.8%
2	**180**	**240**	**7**	**91.1%**
3	180	260	8	88%
4	190	220	7	88.8%
5	190	240	8	86.5%
6	190	260	6	90.25%
7	200	220	8	87.2%
8	200	240	6	84.25
9	200	260	7	90%

4.4. The Final Results

Knowing that, the most important parameter is the time, experiment 2 is repeated for different time durations (6, 7, and 8 min.), while keeping the temperature and the pressure same (temperature at 180^{o}C, pressure at 240 bars). Table11 lists the parameters in these experiments.

Table 12: The Parameters for the Final Experiments

Experiment	Temperature (°C)	Pressure (bar)	Time (min.)
1	180	240	6
2	180	240	7
3	180	240	8

By utilizing the same procedure we calculated average similarity percentages for three experiments. Accordingly we found that the best result is obtained when the temperature, pressure, and time are set to 180°C, 240 bars, and 6 min respectively, with a similarity of 91.1%. However, regarding the temperature we find it useful to mention the surface temperature in addition to the set temperature. It is indeed because the surface temperature that is affecting the process, not the set temperature. Set temperature may change depending on the isolation conditions. Referring to Fig. 11, it can be seen that the surface temperature corresponding to 180°C set temperature is 115°C. Therefore it can be said that the optimum parameters are 115°C for the surface temperature, 240 bars for the pressure, and 6 min. for the embossing time. These process parameters are plotted inFig.15.

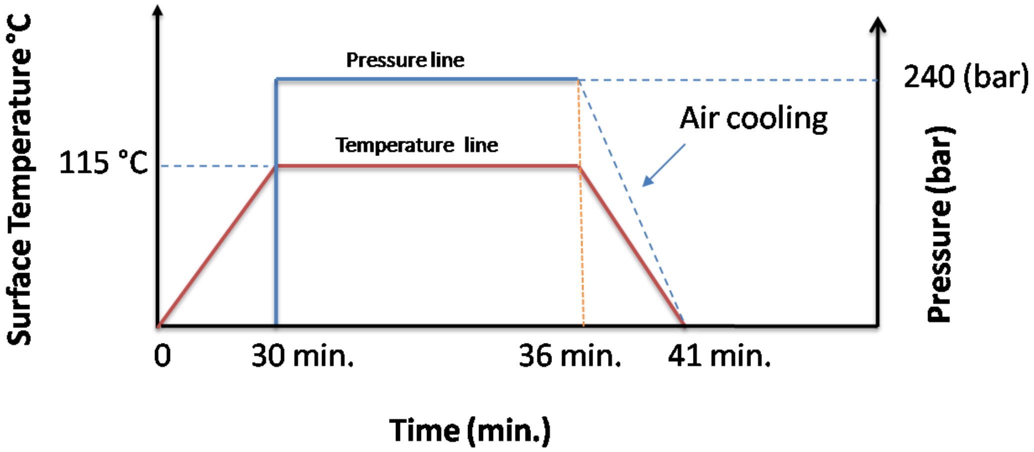


Figure 15: Optimum Parameters Plotted in Time to Explain the Operation.

The optimum pressure is found to be 240 bars. This value represents the pressure applied on the oil enclosed in the cylinder of the hydraulic jack. Considering the diameter of the piston of the hydraulic jack, which is 20 mm, it can be found that this pressure creates a load of 7.5 kN as described in Equations 4.8, 4.9, and 4.10. This value agrees with the embossing loads reported in the literature as described in Chapter 2.

$$240\ bars = 240 \times 10^5\ \mathrm{Pa}\frac{\mathrm{N}}{\mathrm{m}^2} \tag{4.8}$$

$$A = \pi \times r^2 = (0.1)^2 = (3.14)(10^{-4})m^2 \tag{4.9}$$

$$F = P \times A = 240 \times 10^5 \times 3.14 \times 10^{-4} = 7536N \tag{4.10}$$

Considering the patterns on the chip, it is observed that perpendicularity of the side wall gets better as the width of the channel increases. On the other hand, replication of the dimensions (width and the height) gets better as the channel width decreases. Considering the overall average of similarities among four independent dimensions, we find that the best replication is obtained when the width of the channel is 500 µm.

The results per patterns are tabulated in Table 13. Pattern profiles are shown in Fig. 16.

Table 13: Similarity Indices for Each Dimension on Each Pattern.

No of Pattern	Height	width	Right Angle	Left Angle
1	99%	89%	86%	87%
2	93%	88%	93%	99%
3	69%	88%	99%	94%
4	85%	88%	100%	93%
5	81%	95%	99%	99%

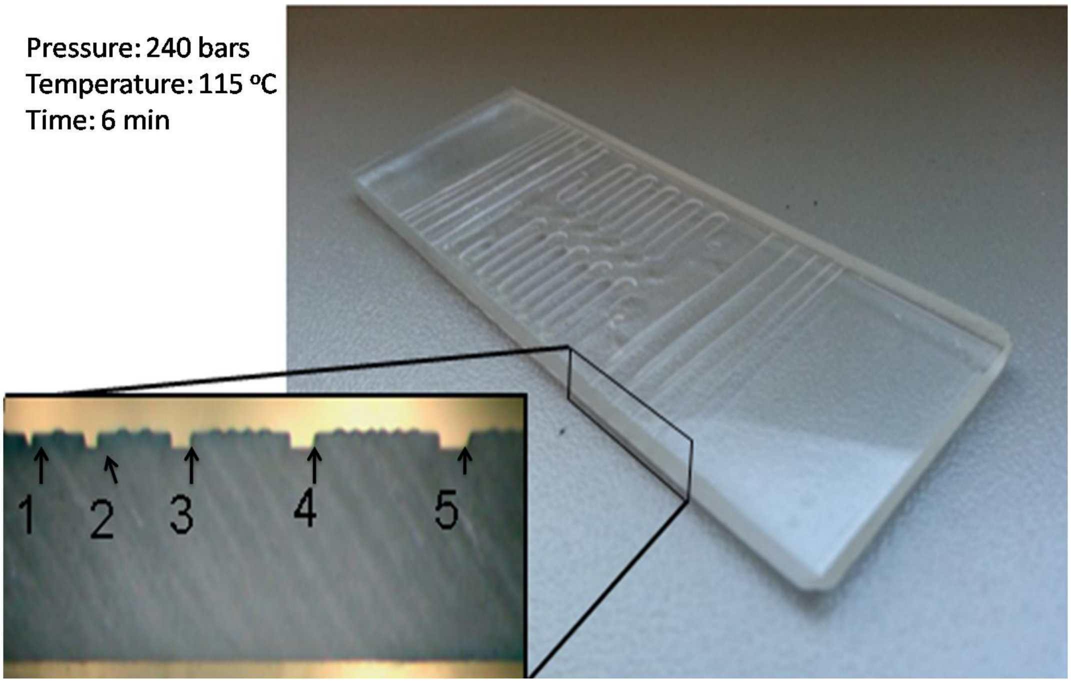


Figure 16: Patterns Obtained by Applying Optimum Process Parameters.

The reader may refer to Appendix B for the detailed results of all experiments.

CHAPTER 5

CONCLUDING REMARKS AND FUTURE WORK

This thesis presents a detailed study of design of allow cost hot embossing press, and optimization of hot embossing process for microfluidic chip fabrication. The motivation is to obtain microfluidic chips with high quality and in relatively short cycle times and lower cost compared to other microfluidic fabrication techniques. The process is optimized for PMMA substrates. However, the process can also be used for other types of biocompatible thermoplastic polymers such as polystyrene or polyethylene.

The results and the achievements of this thesis can be summarized as follows:

1. The micro fluidic chip that we tested has dimensions of 75x25 mm, which are the dimensions of a standard microscope slide. Considering the patterns on the chip, we observed that the best results are obtained with a similarity of more than 90% on 500μm wide channels.

2. After performing the experiments, the following conclusionswere drawn:

   Finding 1:
   If the embossing time is more than eight minutes, thermal stresses start to deform theupper surface of the chip.

   Finding 2:
   It is not possible to get satisfactory results with pressures below 130 bars or temperatures set below 160^{o}C, which corresponds to 105^{o}C of surface temperature. Knowing that glass transition temperature of PMMA is about 110^{o}C it can be concluded that this observation is meaningful since the

embossing temperature should be above the glass transition temperature of the work material.

Finding 3:

After the experiment, optimum embossing time is observed to be between 6-8 minutes. For embossing times less than 6 min., we did not observe any pattern on the chips. On the other hand, for the embossing times higher than 8 min. we observed that the chips start to get distorted due to prolonged heating.

Finding 4:

For embossing pressures less than 200 bars, we did not observe any pattern on the chip. On the other hand, if the embossing pressure is set to a value higher than 260 bars, the optical quality of the chip starts to get distorted and the chip surface starts to look glossy. Therefore, 200 bars and 260 bars can be stated as the lower and upper limits respectively for hot embossing of PMMA by using our hot embossing press.

Finding 6:

The experiment has three essential vectors: temperature, pressure, and time. It is found that time has the highest contribution to the experiment result.

3. The pressure system on the hot embossing press can be improvedby replacing manually operated hydraulic jack with a hydraulic piston controlled through use of a load cell.

4. We selected brass as the material for the fabrication of the moldconsideringits better machinability. However, the surface of the brass mold was observed to be relatively rough. Milling marks created by the tool can even be observed on the mold. Improving the mold surface quality is believed to improve the final chip quality. It is recommended to use steel as the mold material, since steel would yield a better surface. Besides copper can also be used as the mold material, since it has a higher heat conductivity compared to that of brass or steel. Considering that embossing time is the most important parameter, it can be foreseen that changing the mold material will affect the embossing time.

5. After embossing the chip, it is possible to treat it with chloroform vapour to improve the optical quality of the chip by locally melting the surface. This technique can also be preferred to assist bonding of the embossed chip and a cover plate. It is observed that, chloroform treated chips can be bonded to a PMMA cover plate by applying 20 bars at 80^{o}C with 10 min for bonding time.

REFERENCES

1. **Becker H., Locascio L. E., (2002),** "*Polymer Microfluidic Devices*", Talanta, vol. 56, no. 2, pp. 267-287.

2. **Whitesides G. M., (2006),** *"The Origins and the Future of Microfluidics"*. Nature, vol. 442, no.7101, pp. 368-373.

3. **Van den Berg A., Craighead H. G., Yang P., (2010),** *"From Microfluidic Applications to Nanofluidic Phenomena"*. Chemical Society Reviews, vol. 39, no. 3, pp. 899-900.

4. **Hong J., Edel J. B., (2009),** *"Micro-and Nanofluidic Systems for High-Throughput Biological Screening"*. Drug Discovery Today, vol. 14, no. 3, pp. 134-146.

5. **Urbanski J. P., Thies W., Rhodes C., Amarasinghe S., Thorsen T., (2006**), *"Digital Microfluidics Using Soft Lithography"*, Lab on a Chip, vol. 6, no. 1,pp. 96-104.

6. **Whitesides G. M., Ostuni E., Takayama S., Jiang X., Ingber D. E., (2001),** *"Soft Lithography in Biology and Biochemistry"*, Annual Review of Biomedical Engineering, vol. 3, no. 1, pp. 335-373.

7. **Attia U. M., Marson S., Alcock J. R., (2009),** *"Micro-Injection Moulding of Polymer Microfluidic Devices"*, Microfluidics and Nanofluidics, vol. 7, no. 1,pp. 1-28.

8. **Surace R., Trotta G., Fassi I., Bellantone V., (2012),** *"The Micro Injection Moulding Process for Polymeric Components Manufacturing"*, INTECH Open Access Publisher, pp. 66-90.

9. **Becker H., Heim U., (2000),** *"Hot Embossing as a Method for the Fabrication of Polymer High Aspect Ratio Structures", Sensors and Actuators A: Physical*, vol. 83, no. 1, pp. 130-135.

10. **Young E. W., Berthier E., Guckenberger D. J., Sackmann E., Lamers C., Meyvantsson I., Beebe D. J., (2011),** *"Rapid Prototyping of Arrayed Microfluidic Systems in Polystyrene for Cell-Based Assays"*, Analytical Chemistry, vol.83, no.4, pp. 1408-1417.

11. **Nam C., Chang P., Hyun L., Jin P., (2005),** *"Fabrication of a Patterned Replica by Hot Embossing on Various Thicknesses of PMMA"*, Journal of the Korean Physical Society, Vol. 47, pp. 530-534.

12. **Lee G. B., Chen S. H., Huang G. R., Sung W. C., Lin Y. H., (2001),** *"Microfabricated Plastic Chips by Hot Embossing Methods and their Applications for DNA Separation and Detection"*, Sensors and Actuators B: Chemical, vol.75, NO. 1, pp. 142-148.

13. **Goral V. N., Hsieh Y. C., Petzold O. N., Faris R. A., Yuen P. K., (2011).** *"Hot Embossing of Plastic Microfluidic Devices Using Poly (Dimethylsiloxane) Molds"* Journal of Micromechanics and Micro Engineering, vol. 21, no. 1, pp. 160-161.

14. **Shan X. C., Maeda R., Murakoshi Y., (2003),** *"Micro Hot Embossing for Replication of Microstructures"*, Japanese Journal of Applied Physics, vol. 42, no. 6, pp.160-161.

15. **Wang H. R., Zhou Z. T., Jiang Z. D., Sun G. L., Gao X. N., Yang B. S., (2008),** *"TiN Coating/glass Substrate System Fabricated for Hot-Embossing Stamp at Multi-Scale"*, In Nano/Micro Engineered and Molecular Systems, 3rd IEEE International Conference, pp. 1104-1107.

16. **Thomas B., Werner K. S., (2009),** "*Fabrication of Molded Interconnection Devices by Ultrasonic Hot Embossing on Thin Polymer Films"*, Electronics Packaging Manufacturing, IEEE Transactions on, vol. 32, no. 3, pp. 152-156.

17. **Chen S. C., Lin M. C., Chien R. D., Liaw W. L., (2005),** *"Hot Embossing of Micro-Featured Devices"*, In Mechatronics ICM'05, IEEE International Conference, pp. 777-782.

18. **Narijauskaitė B., Palevičius A., Gaidys R., Janušas G., Šakalys R., (2013),** *"Polycarbonate as an Elasto-Plastic Material Model for Simulation of the Microstructure Hot Imprint Process"*, Sensors, vol. 13, no. 9, pp.11229-11242.

19. **Lomas T., Mongpraneet S., Wisitsoraat A., Jaruwongrungsee K., Sappat A., Maturos T., Tuantranont A., (2009),** *"Low Cost Hot Embossing Process for Plastics Microfluidic Chips Fabrication* ", In Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, ECTI-CON 6th International Conference, vol. 1, pp. 462-464.

20. **Peng L., Deng Y., Yi P., Lai X., (2014),** *"Micro hot embossing of thermoplastic polymers: a review"*, Journal of Micromechanics and Microengineering, vol. 24, no. 1, pp. 1-23.

21. **Worgull M., Kolew A., Heilig M., Schneider M., Dinglreiter H., Rapp B., (2011),** *"Hot Embossing of High Performance Polymers"*, Microsystem Technologies, vol. 17, no. 4, pp. 585-592.

22. **Yang S. Y., Chang J.H., (2003)**, *"Gas Pressurized Hot Embossing for Transcription of Mirco Features"*, Microsystem Technologies, vol. 10, no.1, pp. 76-80.

23. **Budynas R. G., Nisbett J. K., (2008),** "*Shirley's Mechanical Engineering Design"*, (9th ed.,).New York: McGraw-Hill, pp. 1007.

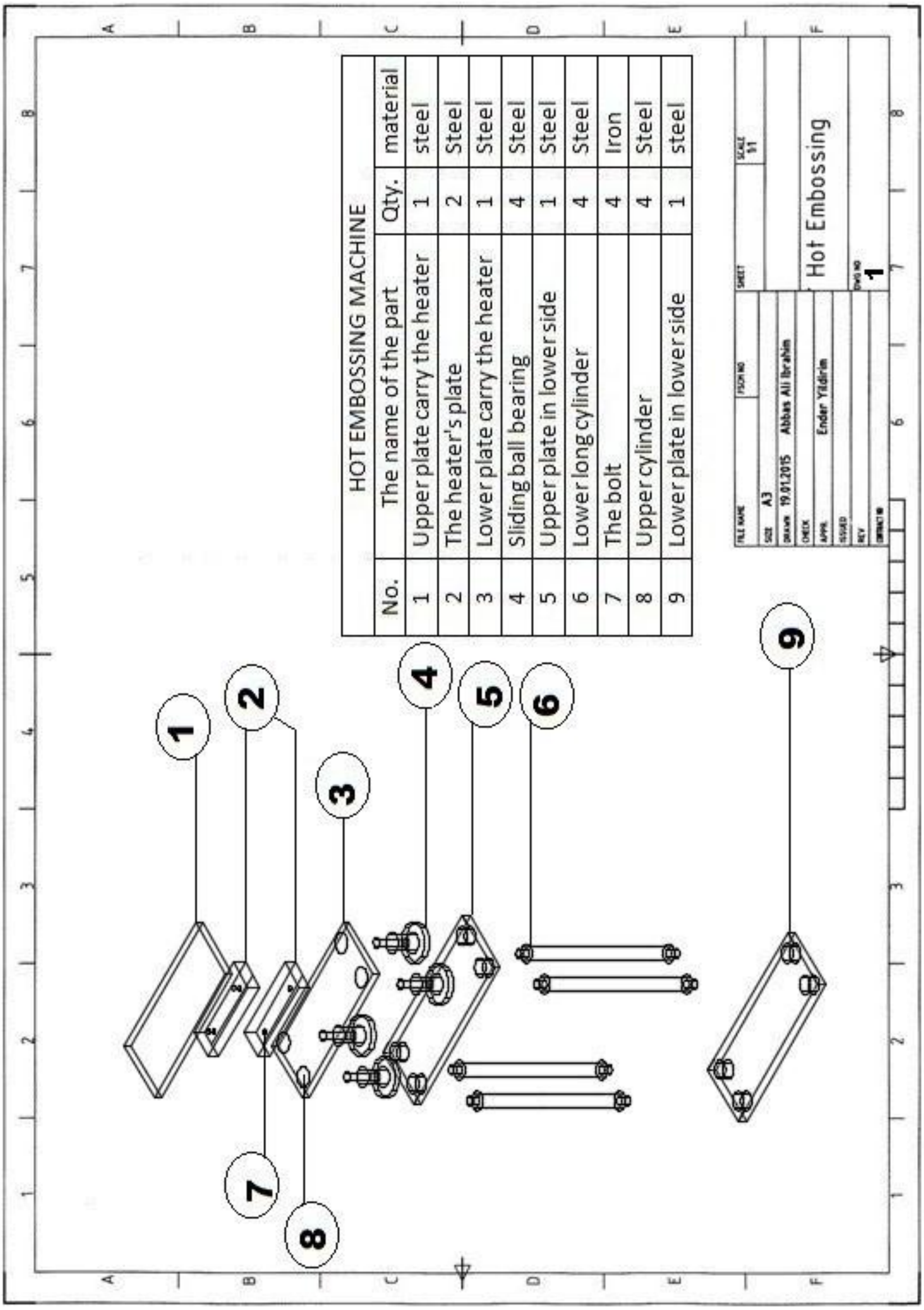
24. **Ravella S. R., Ganesh K., Shetty R., Prakasham Phil J., (2008*).*** *"The Taguchi Methodology as a Statistical Tool for Biotechnological Applications"*, A Critical Appraisal Biotechnology Journal, pp. 3:510–523.

25. **Huairui G.J., (2003)**, *"ANOVA Method for Variance Component Decomposition and Diagnosis in Batch Manufacturing Processes"*, The International Journal of Flexible Manufacturing Systems, pp. 167–186.

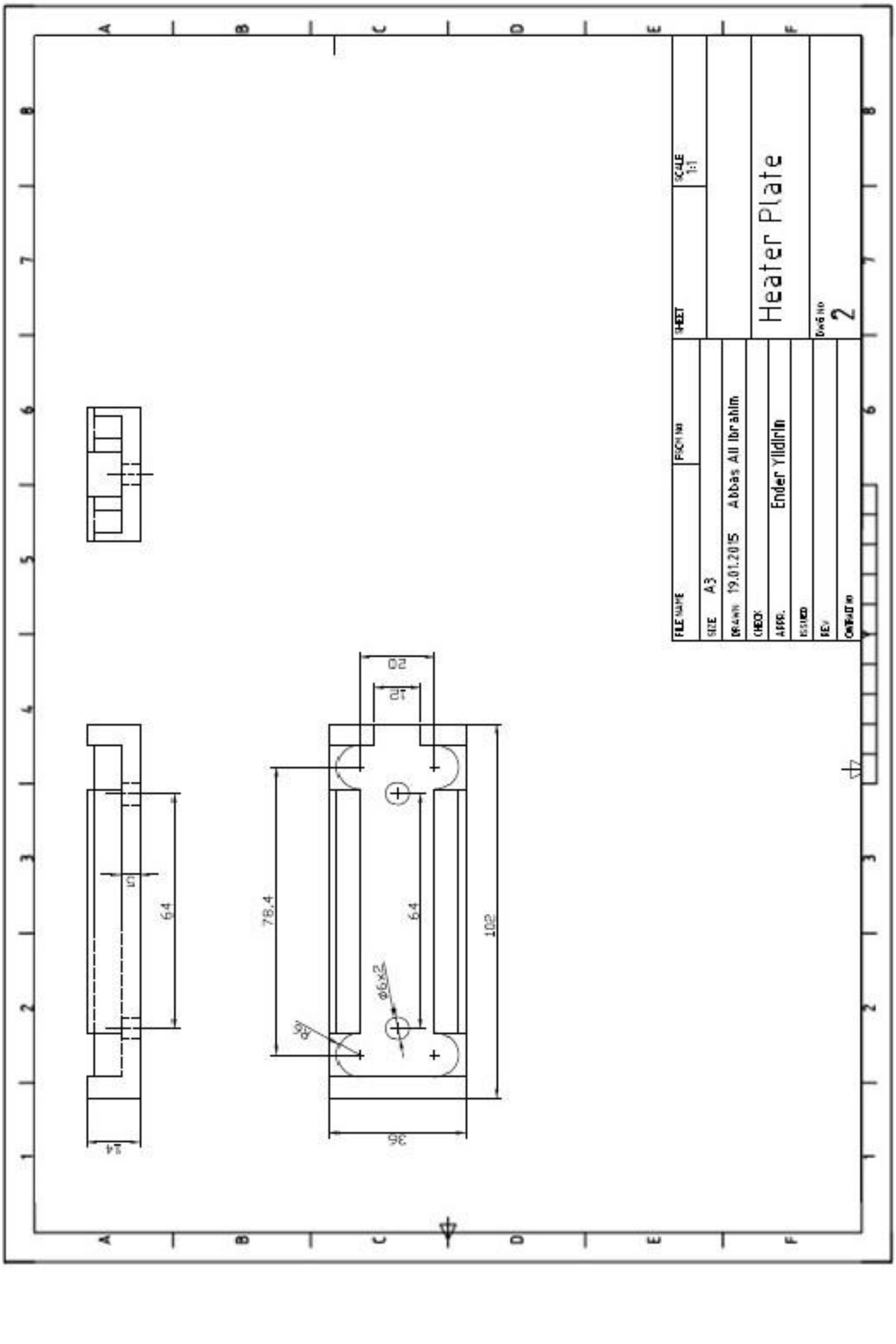
26. **Lomax C., Richard G., (2007),** *"Statistical Concepts: A Second Course"*, ISBN 0-8058-5850-4**,** pp. 10.

APPENDIX A

ENGINEERING DRAWINGS



HOT EMBOSSING MACHINE			
No.	The name of the part	Qty.	material
1	Upper plate carry the heater	1	steel
2	The heater's plate	2	Steel
3	Lower plate carry the heater	1	Steel
4	Sliding ball bearing	4	Steel
5	Upper plate in lower side	1	Steel
6	Lower long cylinder	4	Steel
7	The bolt	4	Iron
8	Upper cylinder	4	Steel
9	Lower plate in lower side	1	steel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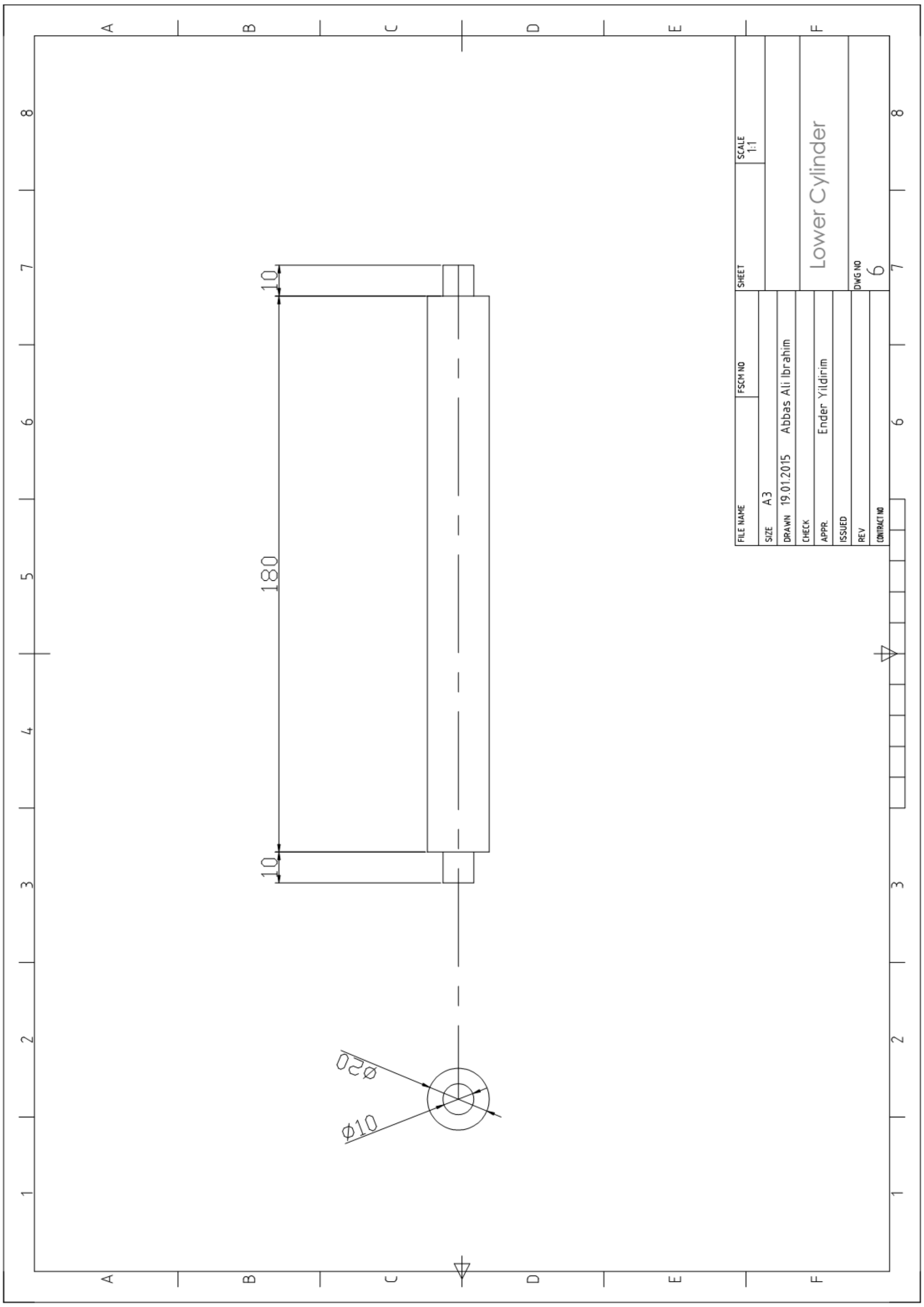
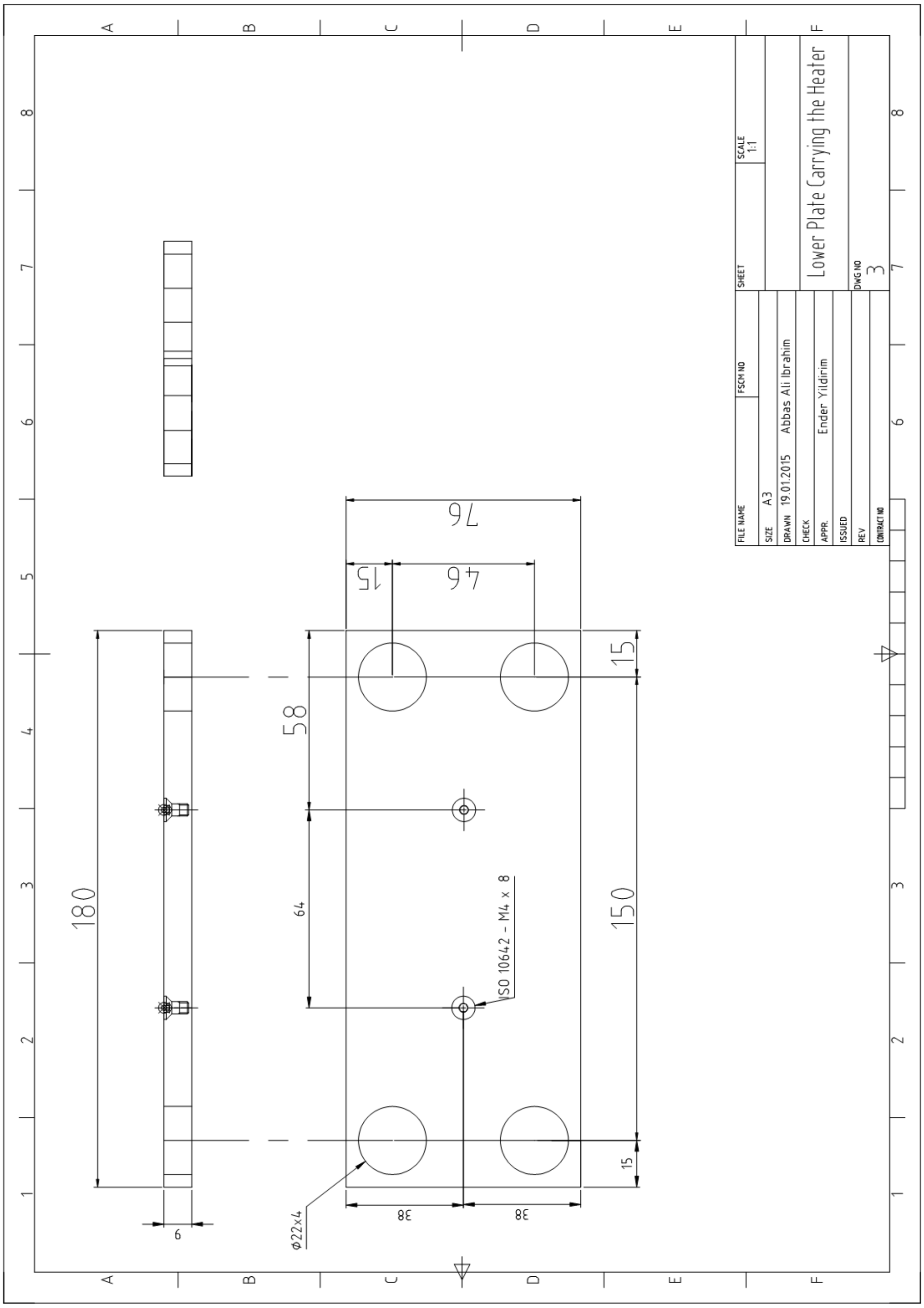
DRAWN 19.01.2015 Abbas Ali Ibrahim
CHECK
APPR. Ender Yildirim
ISSUED
REV
FSCM NO
14
64
36
78.4
64
102
20
12
ø6x2


10
180
10
Ø20
Ø10
FILE NAME
SIZE A3
DRAWN 19.01.2015 Abbas Ali Ibrahim
CHECK
APPR. Ender Yildirim
ISSUED
REV
CONTRACT NO
FSCM NO
SHEET
SCALE 1:1
Lower Cylinder
DWG NO 6

A3



Lower Plate Carrying the Heater
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SHEET
FSCM NO
FILE NAME
SIZE A3
DRAWN 19.01.2015 Abbas Ali Ibrahim
CHECK
APPR. Ender Yildirim
ISSUED
REV
CONTRACT NO
DWG NO 3
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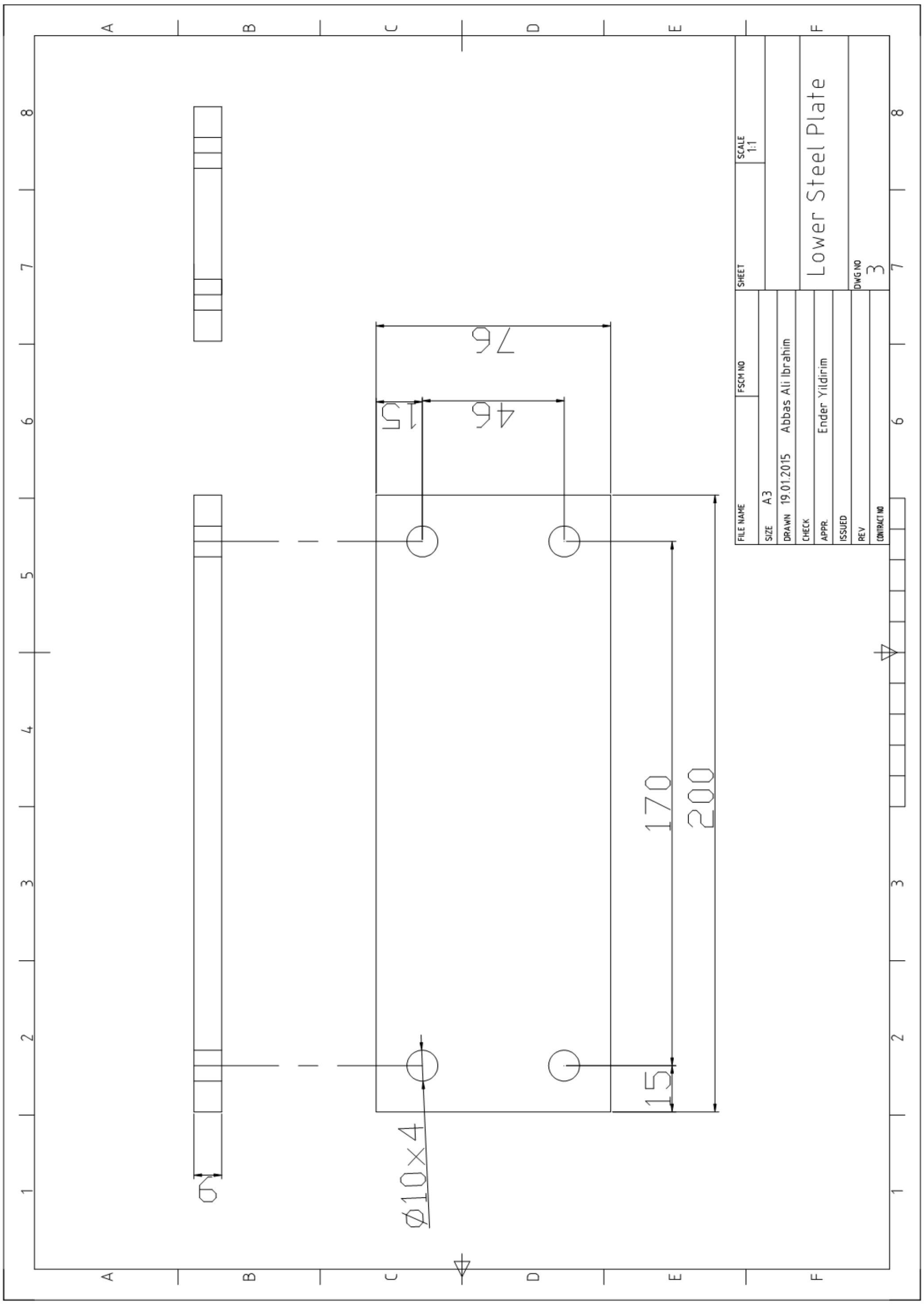
150
76
46
15
58
64
38
6
Ø22x4
ISO 10642 - M4 x 8


Lower Steel Plate
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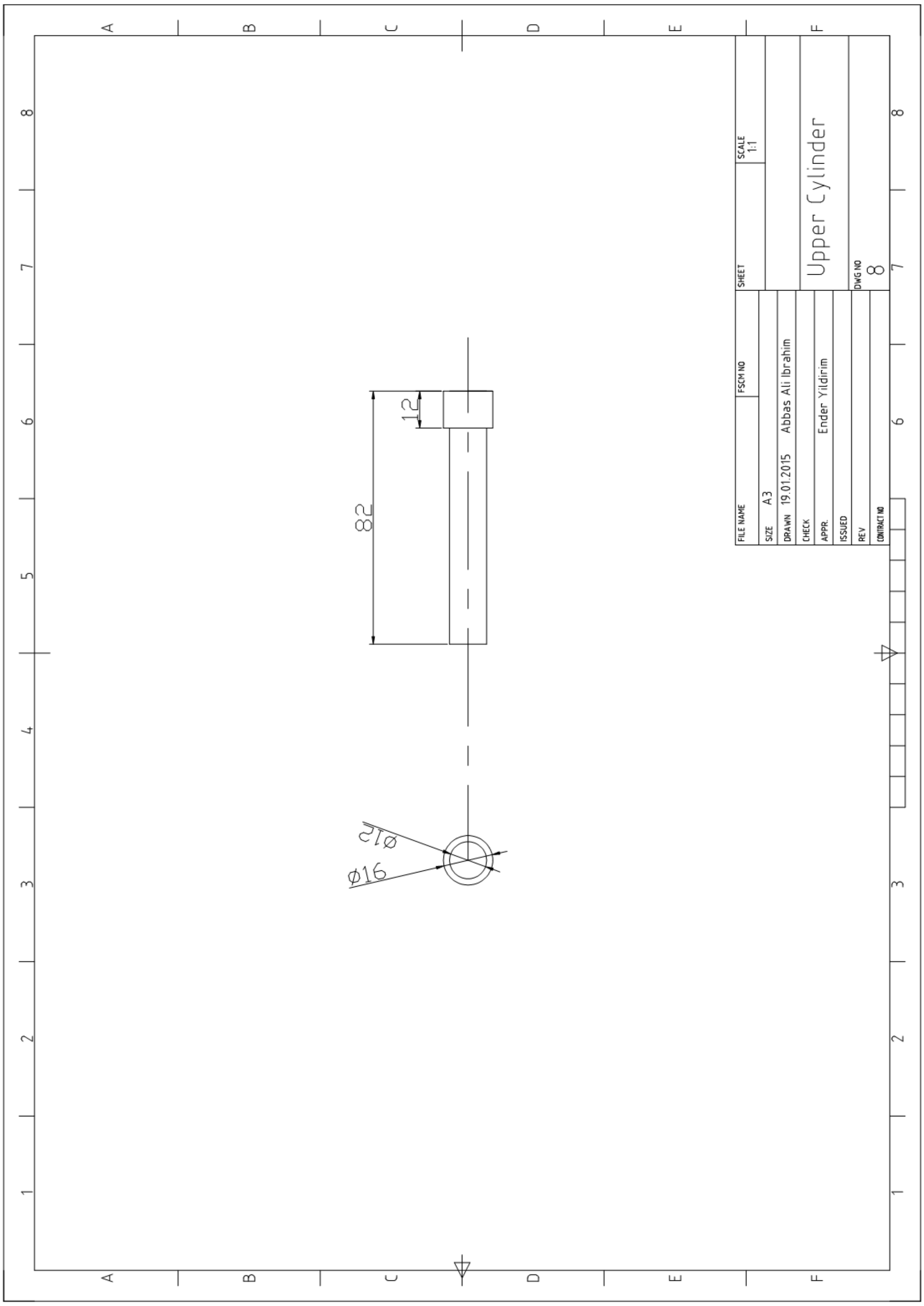
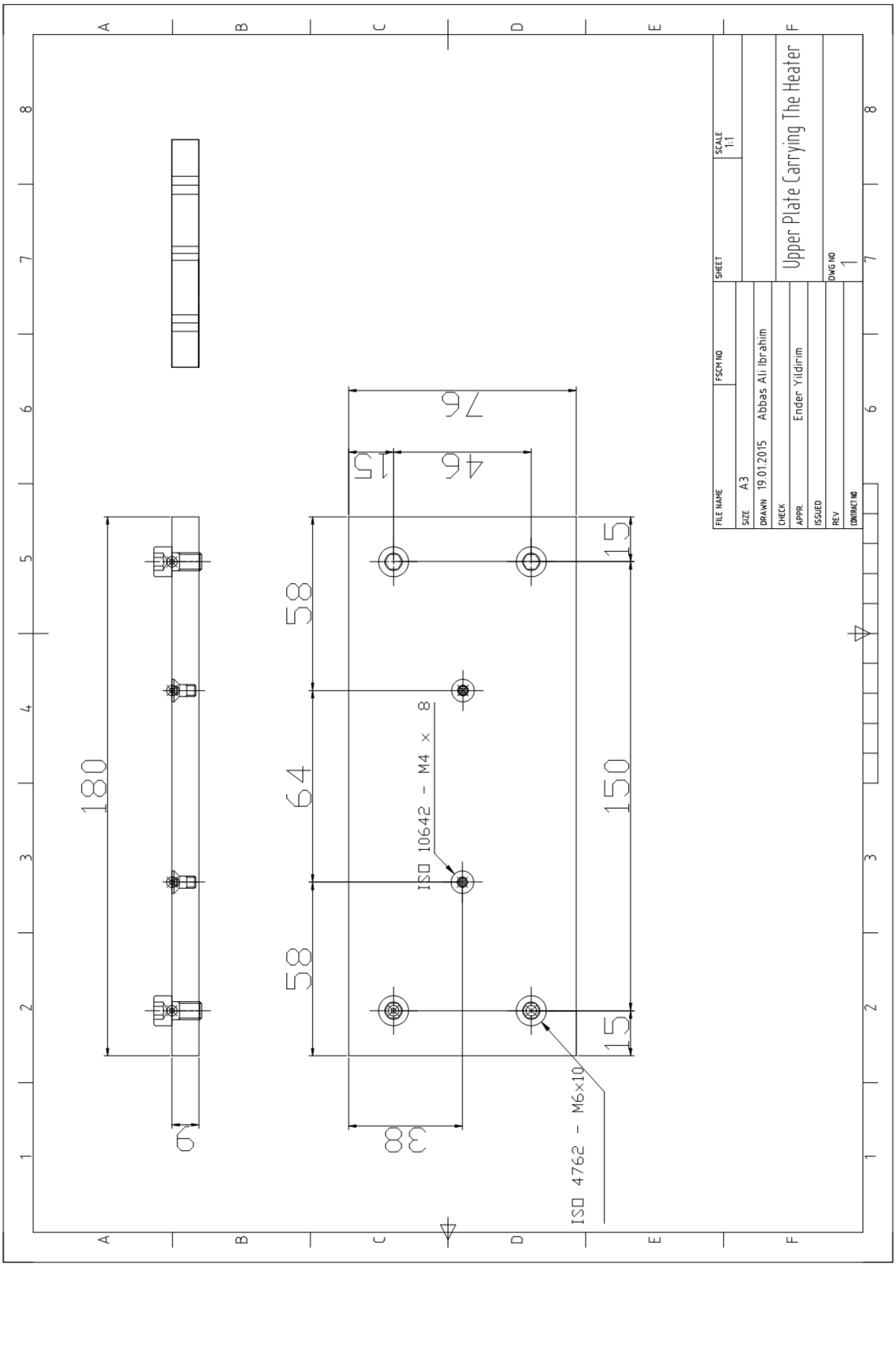
SHEET
FSCM NO
FILE NAME
SIZE A3
DRAWN 19.01.2015 Abbas Ali Ibrahim
CHECK
APPR. Ender Yildirim
ISSUED
REV
CONTRACT NO
DWG NO 3
76
46
15
170
200
15
Ø10×4
5



Upper Cylinder
SCALE 1:1
SHEET
DWG NO 8
FSCM NO
FILE NAME
SIZE A3
DRAWN 19.01.2015 Abbas Ali Ibrahim
CHECK
APPR. Ender Yildirim
ISSUED
REV
CONTRACT NO
82
12
Ø16
Ø12


Upper Plate Carrying The Heater
SCALE 1:1
SHEET
FSCM NO
FILE NAME
SIZE A3
DRAWN 19.01.2015 Abbas Ali Ibrahim
CHECK
APPR. Ender Yildirim
ISSUED
REV
CONTRACT NO
DWG NO 1
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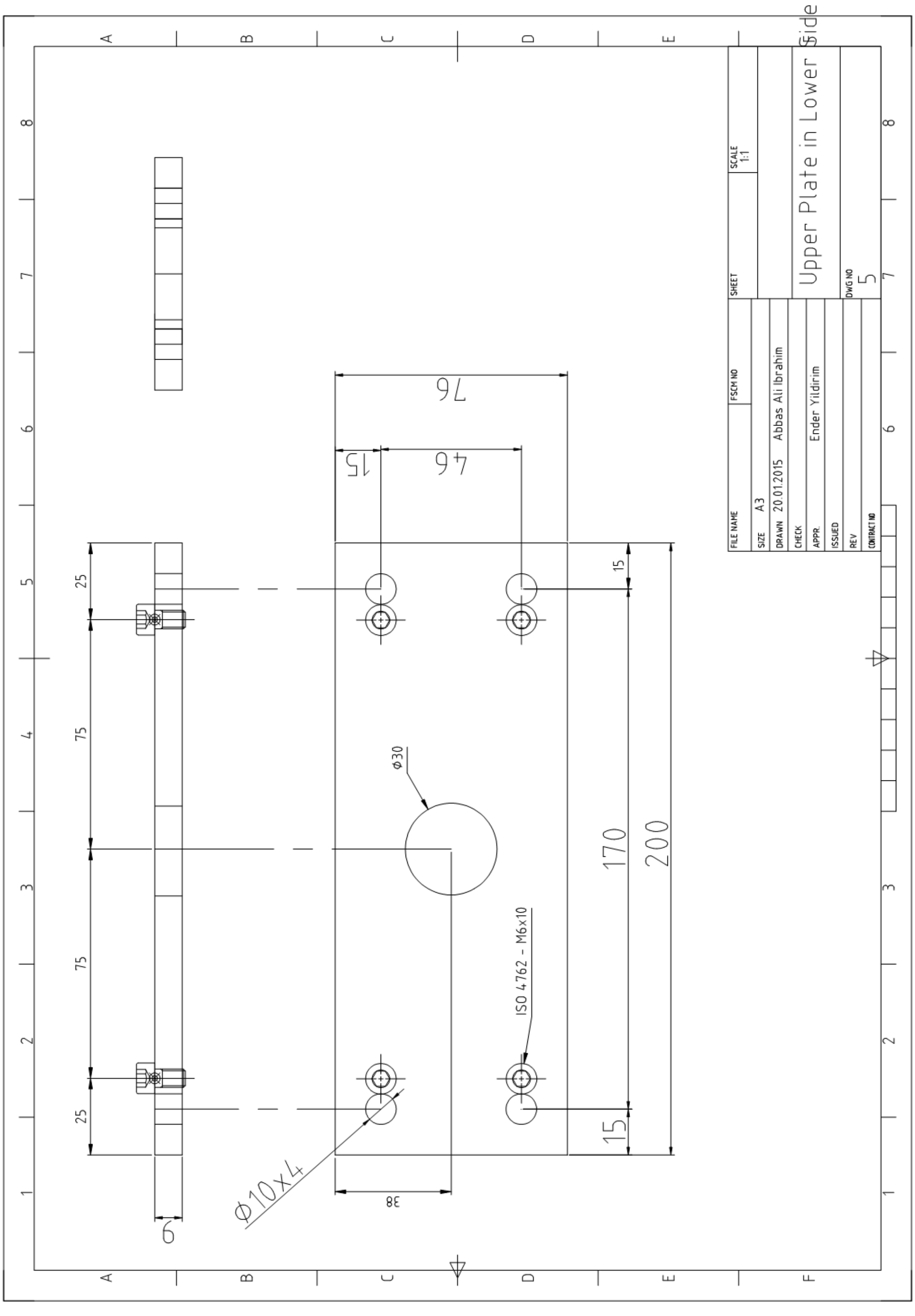
6
76
15
46
58
64
58
38
150
15
15
ISO 10642 - M4 × 8
ISO 4762 - M6×10


Upper Plate in Lower Side
SCALE 1:1
SHEET
FSCM NO
FILE NAME
SIZE A3
DRAWN 20.01.2015 Abbas Ali Ibrahim
CHECK
APPR. Ender Yildirim
ISSUED
REV
CONTRACT NO
DWG NO 5
76
15
46
15
170
200
15
Ø30
ISO 4762 - M6x10
Ø10x4
38
6
25
75
75
25

APPENDIX B

EXPERIMENTAL RESULTS

Dimensions for each pattern on the brass mold

No of Pattern	height(μm)	Width(μm)	Angle right side(^{o})	Angle left side (^{o})
1	100	147	86	103
2	135	267	82	99
3	125	368	82	95
4	154	468	83	102
5	149	624	87	97

Dimensions for each pattern on the chip during the embossing process with parameters 6min, 180^{o}C, 220 bars

No of Pattern	height(μm)	Width(μm)	Angle right side (^{o})	Angle left side(^{o})
1	129	83	100	60
2	165	165	104	63
3	170	321	108	71
4	112	427	109	66
5	206	539	117	72

Dimensions for each pattern on the chip during the embossing process with parameters 6min, 190^{o}C, 260 bars

No of Pattern	height(μm)	Width(μm)	Angle right side (^{o})	Angle left side(^{o})
1	98	98	85	96
2	105	230	90	98
3	109	350	90	99
4	118	457	90	99
5	116	552	89	97

Dimensions for each pattern on the chip during the embossing process with parameters 6min, 200^{o}C, 240bars

No of Pattern	height(μm)	Width(μm)	Angle right side (^{o})	Angle left side(^{o})
1	98	71	71	113
2	119	220	74	98
3	117	288	50	107
4	116	429	72	103
5	128	561	71	115

Dimensions for each pattern on the chip during the embossing process with parameters 7min, 180^{o}C, 240bars

No of Pattern	height(μm)	Width(μm)	Angle right side (^{o})	Angle left side(^{o})
1	114	134	84	107
2	138	184	81	93
3	166	323	84	106
4	158	370	74	98
5	160	550	88	91

Dimensions for each pattern on the chip during the embossing process with parameters 7min, 190^{o}C, 220bars

No of Pattern	height(μm)	Width(μm)	Angle right side (^{o})	Angle left side(^{o})
1	125	129	77	96
2	140	200	81	90
3	145	401	87	93
4	188	454	75	90
5	168	500	99	90

Dimensions for each pattern on the chip during the embossing process with parameters 7min, 200^{o}C, 260bars

No of Pattern	height(μm)	Width(μm)	Angle right side (^{o})	Angle left side(^{o})
1	105	103	50	101
2	115	232	85	98
3	136	370	77	103
4	109	480	74	104
5	106	580	85	104

Dimensions for each pattern on the chip during the embossing process with parameters 8min, 180°C, 260bars

No of Pattern	height(μm)	Width(μm)	Angle right side (°)	Angle left side(°)
1	173	110	87	108
2	176	239	82	81
3	181	390	90	90
4	152	430	80	90
5	144	534	82	91

Dimensions for each pattern on the chip during the embossing process with parameters 8min, 190°C, 240bars

No of Pattern	height(μm)	Width(μm)	Angle right side (°)	Angle left side(°)
1	171	107	82	98
2	170	217	72	98
3	191	388	83	98
4	199	485	87	100
5	200	599	71	92

Dimensions for each pattern on the chip during the embossing process with parameters 8min, 200°C, 220bars

No of Pattern	height(μm)	Width(μm)	Angle right side (°)	Angle left side(°)
1	197	131	90	100
2	181	228	85	90
3	195	380	86	96
4	183	510	85	94
5	189	605	77	101

Similarity indices for each dimension on each pattern during the embossing process with parameters 6min, 180°C, 220bars

No of Pattern	height	width	Angle right side	Angle left side
1	77%	65%	86%	58%
2	81%	61%	78%	63%
3	73%	87%	75%	71%
4	72%	91%	76%	65%
5	72%	86%	74%	74%

Similarity indices for each dimension on each pattern during the embossing process with parameters 6min, 190^{o}C, 260bars

No of Pattern	height	width	Angle right side	Angle left side
1	96%	66%	98%	93%
2	81%	86%	91%	98%
3	87%	95%	91%	95%
4	76%	97%	92%	97%
5	77%	88%	97%	100%

Similarity indices for each dimension on each pattern during the embossing process with parameters 6min, 200^{o}C, 240bars

No of Pattern	height	width	Angle right side	Angle left side
1	98%	47%	82%	91%
2	88%	82%	90%	98%
3	93%	78%	60%	88%
4	75%	91%	86%	99%
5	85%	89%	81%	84%

Similarity indices for each dimension on each pattern during the embossing process with parameters 7min, 180^{o}C, 240bars

No of Pattern	height	width	Angle right side	Angle left side
1	96%	91%	97%	96%
2	97%	68%	98%	93%
3	75%	87%	97%	93%
4	98%	79%	89%	96%
5	93%	88%	98%	93%

Similarity indices for each dimension on each pattern during the embossing process with parameters 7min, 190^{o}C, 220bars

No of Pattern	height	width	Angle right side	Angle left side
1	80%	87%	89%	93%
2	95%	74%	98%	90%
3	86%	91%	94%	97%
4	81%	97%	90%	88%
5	88%	80%	87%	92%

Similarity indices for each dimension on each pattern during the embossing process with parameters 7min, 200^{o}C, 260bars

No of Pattern	height	width	Angle right side	Angle left side
1	95%	88%	70%	98%
2	85%	86%	96%	98%
3	91%	99%	93%	92%
4	70%	97%	89%	98%
5	70%	92%	97%	93%

Similarity indices for each dimension on each pattern during the embossing process with parameters 8min, 180^{o}C, 260bars

No of Pattern	height	width	Angle right side	Angle left side
1	57%	74%	99%	95%
2	76%	89%	100%	81%
3	69%	94%	91%	94%
4	98%	91%	96%	87%
5	95%	85%	94%	93%

Similarity indices for each dimension on each pattern during the embossing process with parameters 8min, 190^{o}C, 240bars

No of Pattern	height	width	Angle right side	Angle left side
1	58%	72%	95%	95%
2	79%	81%	87%	99%
3	65%	94%	98%	97%
4	77%	96%	95%	98%
5	74%	95%	81%	94%

Similarity indices for each dimension on each pattern during the embossing process with parameters 8min, 200^{o}C, 220bars

No of Pattern	height	width	Angle right side	Angle left side
1	53%	89%	95%	97%
2	74%	85%	96%	90%
3	64%	96%	82%	99%
4	84%	91%	97%	92%
5	79%	97%	88%	96%

the percentage of final result for nine experiments according to taguchi method

experiment	Tem.(c)	Pressure(bars)	Time(min)	result
1	180	220	6	73.8%
2	**180**	**240**	**7**	**91.1%**
3	180	260	8	88%
4	190	220	7	88.8%
5	190	240	8	86.5%
6	190	260	6	90.25%
7	200	220	8	87.2%
8	200	240	6	84.25
9	200	260	7	90%

Dimensions for each pattern on the chip during the embossing process with parameters 6min, 240bars, 180°C

No of Pattern	height(μm)	Width(μm)	Angle right side	Angle left side(°)
1	99	165	74	90
2	145	236	88	90
3	180	414	83	90
4	180	528	83	95
5	183	596	85	98

Dimensions for each pattern on the chip during the embossing process with parameters 7min, 240bars, 180°C

No of Pattern	height(μm)	Width(μm)	Angle right side (°)	Angle left side(°)
1	120	127	77	93
2	115	197	74	90
3	123	377	74	90
4	150	462	73	95
5	171	576	82	94

Dimensions for each pattern on the chip during the embossing process with parameters 8min, 240bars, 180°C

No of Pattern	height(μm)	Width(μm)	Angle right side (°)	Angle left side(°)
1	90	126	55	120
2	128	276	55	113
3	190	393	72	111
4	188	528	82	97
5	180	641	83	93

Similarity indices for each dimension on each pattern during the embossing process with parameters 6 min 240 bars 180 ^{o}C

No of Pattern	height	width	Angle right side	Angle left side
1	99%	89%	86%	87%
2	93%	88%	93%	99%
3	69%	88%	99%	94%
4	85%	88%	100%	93%
5	81%	95%	99%	99%

Similarity indices for each dimension on each pattern during the embossing process with parameters 7 min, 240 bars, 180^{o}C

No of Pattern	height	width	Angle right side	Angle left side
1	83%	86%	89%	90%
2	85%	74%	90%	90%
3	98%	97%	90%	94%
4	97%	98%	87%	93%
5	87%	92%	94%	96%

Similarity indices for each dimension on each pattern during the embossing process with parameters 8min, 240bars, 180^{o}C

No of Pattern	height	width	Angle right side	Angle left side
1	90%	85%	63%	85%
2	94%	65%	67%	87%
3	65%	93%	87%	85%
4	81%	88%	99%	95%
5	82%	97%	95%	95%

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name:ZIYARA, Abbas
Date and Place of Birth: 16.03.1989/ IRAQ-NAJAF
Marital Status: Single
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EDUCATION

Degree	**Institution**	**Year of Graduation**
M.Sc.	Cankaya University	2015
B.Sc.	Technical College of Engineering Najaf	2011
High School	Najaf high school	2006

WORK EXPERIENCE

Year	**Place**	**Enrollment**
2011- Present	General Automotive Company	Site Engineer

FOREIN LANGUAGES
Arabic Mother Language, Advanced English, Beginner Turkish.

HOBBIES
Football, Reading books, Traveling.