MINIMIZING WARPAGE USING TAGUCHIAN METHODOLOGY AND ROBUST OPTIMIZATION

A Thesis

By

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Submitted to the
Graduate School of Sciences and Engineering
In Partial Fulfillment of the Requirements for
the Degree of

Master of Science

in the
Department of Industrial Engineering

Özyeğin University
April 2018

To My Parents

ABSTRACT

Injection moulding, which is considered to be one of the most efficient plastic raw material processing methods in plastic industry regarding to its high production rate when manufacturing parts with complex geometries are taken into account. Warpage, shrinkage, flashing and sink marks can be described as quality characteristics for plastic injection moulding products which are greatly depended on injection moulding parameters.

The aim of this study is to investigate the warpage behavior of an injection moulding product made from plastic raw material and improve this quality characteristic by optimizing the injection moulding parameters by using Taguchi methodology and robust optimization approach. For Taguchi methodology, effects of different levels of the selected injection parameters on the warpage behavior is investigated by selecting a suitable orthogonal array, calculating signal to noise ratios and making analysis of variance; 13 different injection parameters with 3 different levels are taken into consideration. By using this information significance and the percentage contribution of each factor is calculated. In order to investigate the parameters' effect more precisely, regression analysis is done and mathematical model for warpage behavior is defined. By using Cplex solver, several different settings are investigated considering the warpage values as well as total cycle time for the process. After determining these settings, several samples are produced in compliance with the results found in this paper in order to observe the improvement in the warpage quality characteristic.

ÖZETÇE

Enjeksiyon kalıplama, karmaşık geometrili parçaların imalatında yüksek üretim oranına sahip olması nedeniyle plastik endüstrisinde en verimli üretim yöntemlerinden biri olarak görülmektedir. Sehim, çekme, çapaklanma ve çöküntü izleri, enjeksiyon makine ayar parametrelerine büyük ölçüde bağlıdır ve plastik enjeksiyon ürünleri için kalite özellikleri olarak tanımlanır [1].

Bu çalışmanın amacı plastik hammadden yapılan bir enjeksiyon kalıplama ürününün sehim davranışını araştırmak ve bu kalite parametresini enjeksiyon makine parametrelerini Taguchi metodolojisini ve gürbüz optimizasyon yaklaşımını kullanarak optimize ederek iyileştirmektir. 3 farklı seviye ile 13 farklı enjeksiyon parametresi göz önüne alınmıştır. Taguchi metodolojisi için; seçilen enjeksiyon parametrelerinin farklı düzeylerinin sehim davranışı üzerindeki etkileri uygun bir dikey sıralama seçilerek, sinyal - gürültü oranları hesaplanarak ve varyans analizi yapılarak incelenmiştir. Bu bilgiler kullanılarak her bir faktörün yüzdesel katkısı ve önemi hesaplanmıştır. İncelenmekte olan parametrelerin etkilerinin daha derinlemesine araştırılması amacı ile regresyon analizi yapılmış ve sonrasında sehim özelliğinin matematiksel modeli bulunmuştur. Cplex programı kullanılarak değişik sehim ve çevrim süresi değerleri için farklı ayarlar bulunmuştur. Bulunan ayarlara göre baskı alınarak bu çalışma sonunda bulunan sonuçlar ile karşılaştırılmış ve sehim özelliğindeki iyileşme gözlenmiştir.

ACKNOWLEDGEMENTS

I would like to offer my sincere gratitude to my advisors İhsan Yanıkoğlu and Erinç Albey. They constantly support me and they had endless patience during my studies. They always helped me with their valuable guidance and suggestions from the beginning of this thesis.

I would like to thank my parents and my brother for their support. They always encouraged me in my whole life. Without their support and encouragement regarding every topic, I would have never completed this study.

TABLE OF CONTENTS

ABSTRACT iv
ÖZETÇE v
ACKNOWLEDGEMENTS vi
I INTRODUCTION 1
1.1 DEFINITION OF THE PROBLEM 1
1.2 INJECTION MOULDING 3
1.3 INJECTION MOULDING MACHINE 4
1.4 INJECTION MOULDING PARAMETERS 5
1.4.1 INJECTION PRESSURE 6
1.4.2 INJECTION SPEED 6
1.4.3 INJECTION TIME 6
1.4.4 HOLDING PRESSURE 7
1.4.5 HOLDING SPEED 7
1.4.6 HOLDING TIME 7
1.4.7 MELTING TEMPERATURE 7
1.4.8 BACK SUCTION OFFSET 8
1.4.9 CAVITY COOLANT TEMPERATURE 8
1.4.10 COOLING TIME 8
1.4.11 REFILL SPEED 9
1.4.12 REFILL PRESSURE 9
1.4.13 HOLDING TRANSACTION 9
1.5 INJECTION MOULD AND ITS PROPERTIES 10
1.6 EXPERIMENTAL SETUP AND COLLECTING THE DATA 10
II TAGUCHI METHODOLOGY 12
2.1 DESIGN OF EXPERIMENT (DOE) 12
2.2 INJECTION MOULDING PARAMETERS' SELECTION AND DETERMINING DIFFERENT LEVELS 13

2.3 DETERMINING ORTHOGONAL ARRAY 14
2.4 CONDUCTING TESTS 15
2.5 ANALYZING AND INTERPRETING THE RESULTS OF EXPERIMENTAL TRIALS 15
2.6 CALCULATING PERCENTAGE CONTRIBUTION 21
III MATHEMATICAL MODEL 24
3.1 REGRESSION ANALYSIS 24
3.2 ROBUST COUNTERPART 29
IV CONCLUSIONS 34
BIBLIOGRAPHY 35
APPENDIX 38
VITA 43

LIST OF FIGURES

3D ASSEMBLY VIEW OF REFRIGERATOR DOOR 2
3D PART VIEW OF REFRIGERATOR DOOR CAP 3
3D CROSS – SECTION OF A REFRIGERATOR DOOR AND ASSEMBLY RELATIONS.. 4
2D REPRESENTATION OF AN INJECTION MOULDING MACHINE .. 5
3D DRAWING OF THE INJECTION MOULD USED FOR THIS RESEARCH 10
REPRESENTATION OF WARPAGE IN A PLASTIC PART................... 11

LIST OF TABLES

THREE DIFFERENT LEVELS OF INJECTION MOULDING PARAMETERS USED IN THIS STUDY.. 14
RESULTS FOUND FOR WARPAGE.. 18
THE RESULTS FOUND FOR SIGNAL TO NOISE RESPONSE 19
GRAPHS FOR S/N RATIO FOR EACH PARAMETER 18
THE S/N RESPONSE TABLE 23
RESULTS OF WARPAGE FOUND FOR DIFFERENT SETTINGS........ 32
TAGUCHI ORTHOGONAL ARRAY L_{27} 42

CHAPTER I

INTRODUCTION

1.1 DEFINITION OF THE PROBLEM

Refrigerator doors consists both plastic and metal parts which are assembled together in mass production and an insulation material which is generally polyurethane is injected in between these components. Polyurethane is a polymer that has very high viscosity until curing is completed so the assembled parts should not have any empty space in between them in order to prevent any polyurethane leakage.

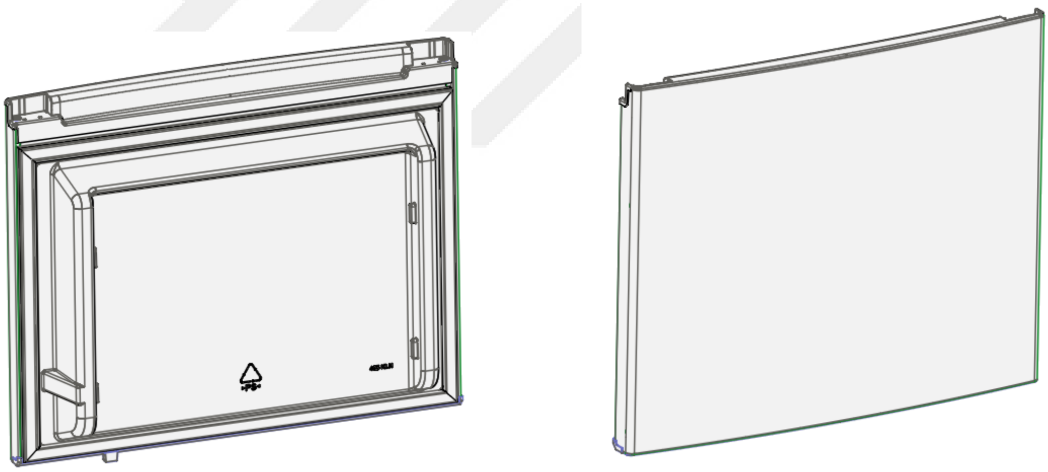


FIGURE 1: 3D ASSEMBLY VIEW OF REFRIGERATOR DOOR

After curing phase is completed it is extremely hard to remove the polyurethane. The refrigerator doors which have polyurethane leakage are separated and have to be reworked again in order to be cleaned and made ready to use in mass production again. Because of this reason, the mass production is disturbed and the process becomes inefficient. The labor costs also increase due to this problem because the cleaning of the polyurethane from the door must be done manually by workers. When the root cause of this polyurethane leakage is investigated, it is found out that door caps and inner door plastics sometimes leave open space when assembled together due to the warpage in door caps. In this paper, warpage of a refrigerator door plastic door cap is investigated and this quality characteristic is tried to be optimized by adjusting injection parameters. 3D assembly of the refrigerator door as well as the door cap is given in the Figures [1-2].

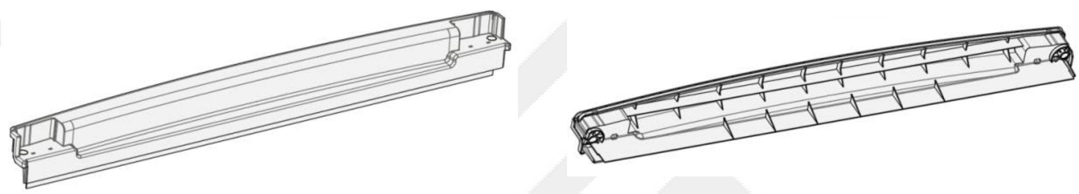


FIGURE 2: 3D PART VIEW OF REFRIGERATOR DOOR CAP

According to the theoretical data, there should not be any empty space between the refrigerator door cap and the door cabinet liner. However, when the mass production conditions are considered it is observed that due to warpage behavior of the door cap, the assembly condition where both components match without any empty space in between them does not always met. While designing such components and adjusting their assembly conditions as well as their assembly restrictions, this kind of events are also taken into consideration. Fortunately, distance mentioned in between the refrigerator door cap and the door cabinet liner must not be exactly zero. There is an assembly tolerance which enables to use the parts with some degree of warpage behavior in mass production. Because of this reason it is not entirely necessary to adjust the warpage to zero but to minimize it as much as it can be in order to increase the mass production efficiency, decrease the rework costs and maintain a stable mass production condition minimizing the warpage of the is very important aspect. Refrigerator door components and their assembly relations are given in Figure [3].

As can be seen from this Figure [3], a sheet metal cover, cabinet liner and a door cap is required in order to assemble a refrigerator door. An insulation material, which is polyurethane in this paper, is used inside the refrigerator door. Polyurethane becomes solid after it is injected inside the door cavity around 1-2 minutes later. During this time it is substantial to maintain the distance between the refrigerator door cap and the door liner minimum. When all above given information is considered refrigerator door cap and the door cabinet liner has a crucial assembly condition.

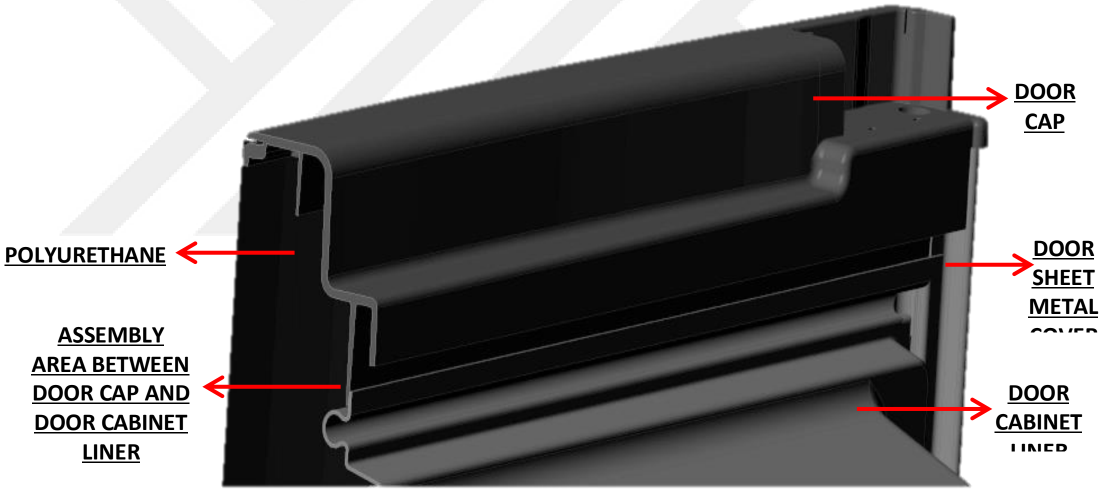


FIGURE 3: 3D CROSS – SECTION OF A REFRIGERATOR DOOR AND ASSEMBLY RELATIONS

1.2 INJECTION MOULDING

Injection moulding is a technique used in the manufacturing of plastic products. This technique consists of inserting melted plastic raw material inside a mould that was tooled into the desired shape [2-3]. Injection moulding is an advance on this process because it allowed plastic raw material to be injected with force into a mould which produced the desired product [4]. After some coloring agents which is called masterbatch are added and the raw material are fed into an injection barrel where they are heated to melting point. The clamping force is then applied to the injection moulding machine so that it can stay close during the injection and cooling phases. The plastic is then allowed to cool inside the mould. After this, the two halves of the mould are opened and separated. Finally, the plastic can be ejected from the mould and can be taken out by the operator.

1.3 INJECTION MOULDING MACHINE

The plastic molding machines are consisting of a heating unit, a screw-type and a material hopper. First, plastic raw material is inserted in the form of grains, which are then heated and injected into a mould. As the granules are slowly pushed forward by a screw, the plastic is forced into a heated chamber called the barrel where it is melted. The mold remains at a set temperature so the plastic can solidify almost as soon as the mold is filled [5].

A representation of an injection moulding machine can be found in Figure [4].

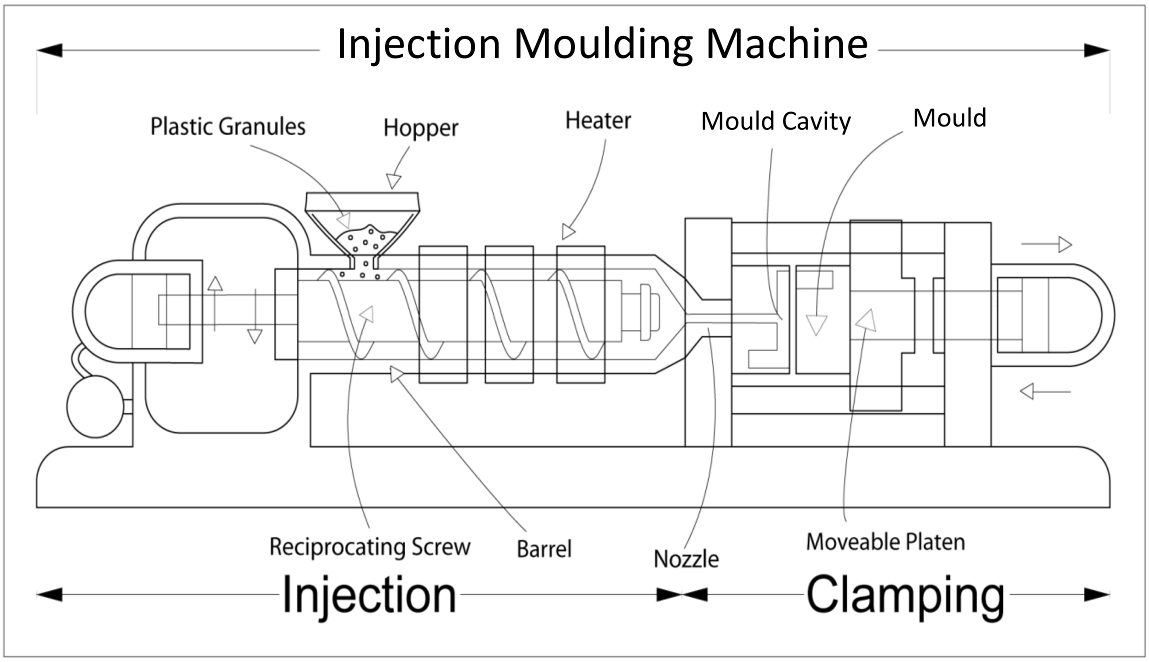


FIGURE 4:2D REPRESENTATION OF AN INJECTION MOULDING MACHINE

1.4 INJECTION MOULDING PARAMETERS

The setting of injection moulding parameters which will be used in mass production and their optimization is considered as a crucial approach in order to improve the quality of the final products. Inconvenient settings for these parameters can lead to production and quality problems [6-7]. The optimization and improvement of these process parameters is a challenging task, because it depends on different independent factors such as the mould design, the material used to manufacture the moulds and the injection moulding machine [8]. According our experience the injection moulding parameters are usually set by an experienced operator. Setting these parameters affect the quality of the moulded parts. Even small adjustments and changes to these parameters can give tremendous outcomes to the final samples acquired from the injection moulding machine [9].

Setting these process parameters require highly skilled workers. However, when the environment in our mass production is considered it can be seen that generally the worker are not educated enough. In addition to this, they usually do not have the theoretical and practical knowledge for these kinds of approaches [10-11].

Setting the injection moulding parameters are also very important because each time the quality of the part is not good enough, they become defects and cannot be used in mass production [12]. In other words, each time an operator adjusts the parameters different from what they are supposed to be companies will lose money. Injection moulding is used in manufacturers with relatively large capacities so setting wrong injection moulding parameters and getting defected samples will be highly time and money consuming [4].

1.4.1 INJECTION PRESSURE

The injection pressure parameter adjusts the pressure of the raw material while filling the cavity [13]. During injection phase the screw movement inside the barrel allows the melted raw material to fill the mold cavity.

1.4.2 INJECTION SPEED

This parameter defines the speed of the molten plastic raw material when it is injected inside the mould. This is also indicated as the injection rate which is the injected volume per considered time. Injection speed parameter adjusts the screw movement inside the barrel and allows regulating how fast the mold cavity can be filled [13].

1.4.3 INJECTION TIME

This parameter adjust how long does it take to allow melted raw material inside the mold cavity. Injection time is highly related with injection speed. After the melt has been plasticized in the barrel, the injection time is the time it takes the screw to move from the injection start position to the transfer position. At the transfer position, which is commonly referred to as the velocity - pressure position, the screw movement is transferred from velocity to pressure control. This is normally considered the cavity fill time. However, the processor has the ability to switch from velocity to pressure control at any time prior to cavity fill. It is common practice that VP switchover occurs when the cavity is about 95% full [4-13].

1.4.4 HOLDING PRESSURE

This is the pressure which occurs and applies when all cavity is filled with the plastic raw material until the openning which is called gate has been frozen and solidifed to that no more plastic raw material can enter inside the mould cavity [13].

1.4.5 HOLDING SPEED

Holding speed parameter adjusts the speed of the raw material when it is injected inside the mould during holding phase. As the material is injected and starts to fill the mould cavity it begins to cool from its initial heated temperature which means that it begins to solidify and then shrink. During holding phase more of the base raw material is added inside the mould cavity in order to compensate for this shrinkage [13 – 14].

1.4.6 HOLDING TIME

The holding time must be set long enough to make sure the gates are frozen when holding pressure is released. The optimal holding time setting is considered to be when the gate area has been solidify and no more raw material can be put inside the injection mould. If the samples weight does not increases when the holding time increases it can be assumed that the gate are is already frozen and any additional raw material cannot be injected inside the mold anymore [13 –15].

1.4.7 MELTING TEMPERATURE

There exist resistances inside the barrel which allow the raw material to melt and make the injection process possible. The raw material is melted with the help of this resistances and the movement of the screw inside the barrel. The resistances inside this barrels are usually for keeping and maintaining the heat inside more stable and uniform [13 – 16].

1.4.8 BACK SUCTION OFFSET

Back suction offset parameter is necessary to ensure uniformity of the polymer melt for maximum part performance. If the back suction offset is too low it can result in inconsistent parts. Increasing the back suction offset will increase the frictional contribution to the melt temperature and decrease the plasticization time [13].

1.4.9 CAVITY COOLANT TEMPERATURE

The cavity coolant temperature is the temperature of the coolant material which runs through the cooling channels on the cavity side. In this study a water temperature regulator is used in order to ensure that the temperature is set accordingly. Primary function of an injection mold is to be a heat exchanger. The heat input is the molten polymer injected at regular intervals. Sufficient heat must be removed from the mold so parts are cooled to a safe ejection temperature. As water flows through a cooling circuit its temperature gradually increases and thus carries away heat from the molded parts [13 – 17].

1.4.10 COOLING TIME

The cooling time in plastic injection moulding is the period of time over which the moulded part is left inside mould to become solid again. The cooling time starts when the holding time ends. If the cooling time is too short, the shrinkage becomes high making the dimensions small, and the moulded part may also get deformed during its ejection from the mould. On the other hand, if the cooling time is too long, the moulding cycle becomes longer reducing the productivity. In other words, the cost of producing moulded parts increases. Cooling lines should be cleaned at least once a year [3-4].

1.4.11 REFILL SPEED

While inside cooling phase the plastic raw material poured inside the barrel for the next moulding cycle. The screw inside the barrel rotates and when its helical structure is considered the raw material is drawn in the center of the barrel from the feeding hopper. The connection in between hopper and the barrel is usually water cooled so that early melting of the raw material is prevented [3].

1.4.12 REFILL PRESSURE

During refilling the raw material is put inside and transferred forward with the help of screws. The raw material is in melted state so when it arrive the forward positon of the screw, it must be fully melted and be homogenize. Then the raw material pushes back the screw back until the desired volume is reached. This is called as refill pressure and helps to maintain a homogenized raw material [13].

1.4.13 HOLDING TRANSACTION

Holding transaction parameter controls the position of the screw which moved to the most forward and backward position during injection phase. Because it defines a position, its unit is mm. This also adjusts the cushion, which can be defined as the remaining raw material inside the barrel on to top of the screw. If the amount of holding transaction is low the holding pressure will not act as it is supposed to be. If the amount is high then the heat defects the raw material and because of this reason it loses its properties [3].

1.5 INJECTION MOULD AND ITS PROPERTIES

The mould refers to the tooling used to produce plastic parts in moulding. Traditionally injection moulds have been expensive to manufacture and were only used in high-volume production applications where thousands of parts were produced [13 - 18].

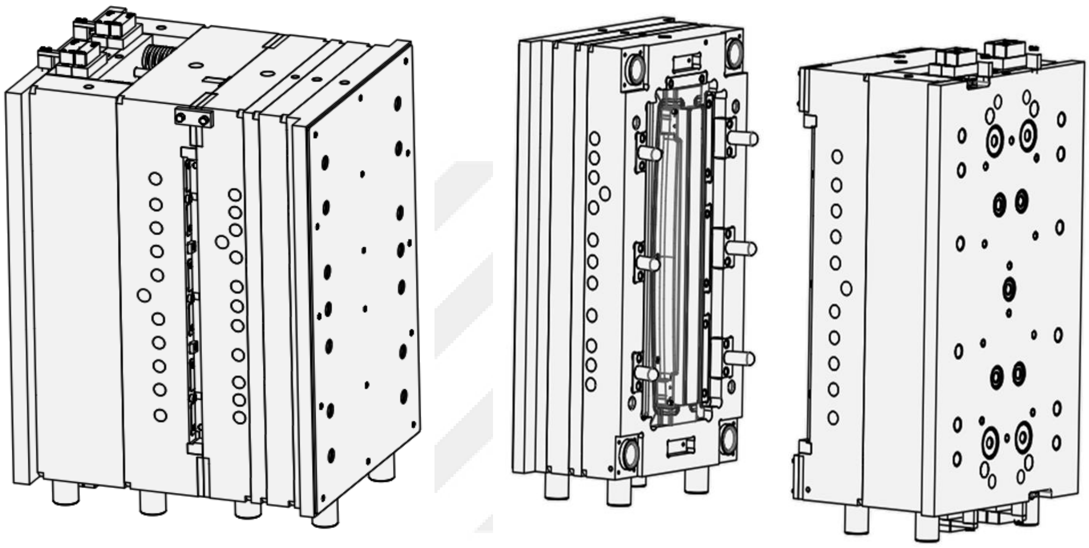


FIGURE 5: 3D DRAWING OF THE INJECTION MOULD USED FOR THIS RESEARCH

1.6 EXPERIMENTAL SETUP AND COLLECTING THE DATA

The injection machine used in order to obtain the samples is Chen Hsong brand which has 470T clamping force. In addition to this, the injection mould that is used to get the samples has two cavities which means from every set of experiment two samples are produced. An expert injection moulding operator set the injection machine and adjusted the right parameter for different set of experiments given in Table [1]. After gathering all 54 samples, the warpage value is measured by placing these samples to a high precision flat surface and using a feeler gauge. All the warpage values are written to the Table [3].

Warpage can be described as the deflection which occurs when the shrinkage in different parts of the injection moulding samples are not uniform. Because of this reason, the samples can be twisted, bend or even cracked [19]. Warpage is usually caused when the cooling of the injection mould is not uniform. When the cooling rates are different inside the injection mould separate areas, there occurs internal stresses within plastic parts. These stresses are then released which leads to warpage [20].

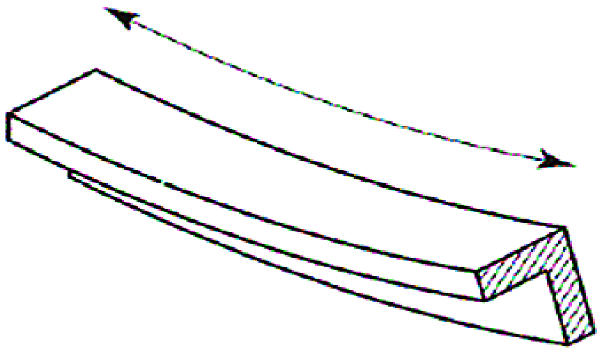


FIGURE 6: REPRESENTATION OF WARPAGE IN A PLASTIC PART

CHAPTER II

TAGUCHI METHODOLOGY

2.1 DESIGN OF EXPERIMENT (DOE)

The design of experiment in Taguchi methodology is selected to investigate the best set of parameters among the effective factors by decreasing number of experiments which ends up just a set of combinations is used instead of full factorial combinations. This method is called Taguchi method or Taguchian approach in quality engineering. Taguchian approach provides a theoretical foresight in which enhanced and formulized in the form of DOE [21]. With the help of his technique, many studies can be carried out which includes many factors and interactions on the quality considerations while saving time and cost.

Taguchi, designed experiments usually using special tables know as orthogonal array. The usage of the orthogonal arrays allows the design of experiments easy. It also requires very limited number of experiments when all parameter space is considered. Because of this reason we can achieve cost, time and work force saving. The experimental results found are then transferred into signal to noise ratio [22]. The usage of signal to noise ratios in order to measure the quality characteristic which deviates from the desired values is recommended by Taguchi. There exist three different approaches of quality properties when the analysis of signal to noise ratios is considered. These approaches are lower the better, higher the better and nominal the better approaches. The signal to noise ratio for each different level of the selected parameter is calculated via signal to noise analysis. The greater signal to noise ratio means better quality property regardless of the approaches mentioned below. Because of this reason, the best levels of the injection moulding parameters are the ones with the greatest signal to noise ratio [23]. In addition to this, further analysis is performed in order to calculate the percentage contribution for each factor [24]. After this analysis, the process parameter which has the highest contribution to our desired quality characteristic is found out. To sum up, with the help of signal to noise ratios and analysis of variance calculations the optimal process parameters can be predicted. After the results are found out, several samples are taken in order to check the results with reality as will be explained in the following chapters.

The main steps in order to achieve an efficient design of experiment is: [25-26]

- Choosing injection moulding parameters with levels
- Selection of orthogonal array
- Conducting experiments using the levels explained in orthogonal arrays
- Analyzing and interpreting the outcomes of experiments

2.2 INJECTION MOULDING PARAMETERS' SELECTION AND DETERMINING DIFFERENT LEVELS

In injection moulding process, there exists possible factors that significantly affects warpage [27]. In this paper, the factors taken into considerations are injection pressure, injection speed, holding pressure, holding speed, holding time, melting temperature, back suction offset, mold cavity coolant temperature, cooling time, refill speed, refill pressure, injection time and holding transition. The injection moulding parameters was defined by varying the injection pressure in between 125 – 145 bar, the injection speed in between 45 – 55 mm/s, the holding pressure in between 55 – 75 bar, the holding speed in between 22 – 28 mm/s, the holding time in between 5 – 7 sec, the melting temperature in between 210 – 230 C^0 , the back suction offset in between 1 – 3 mm, the mold cavity coolant temperature in between 25 – 65 C^0 , the cooling time in between 32 – 38 sec, the refill speed in between 65 – 85 mm/s, the refill pressure in between 80 – 90 bar, the injection time in between 3 – 7 sec and the holding transition in between 10 – 20 mm. These injections moulding parameter levels are selected according to the data found in the literature, technical data sheets, plastic injection moulding handbooks and our personal experience. The selected levels of each injection moulding parameter can be found in Table [1]

INJECTION MOULDING PARAMETERS					
Factor	***Parameter***	***Unit***	***Level 1***	***Level 2***	***Level 3***
A	Injection Pressure	bar	125	135	145
B	Injection Speed	mm/s	45	50	55
C	Holding Pressure	bar	55	65	75
D	Holding Speed	mm/s	22	25	28
E	Holding Time	sec.	5	6	7
F	Melting Temperature	C^o	210	220	230
G	Back Suction Offset	mm	1	2	3
H	Cavity Coolant Temperature	C^o	25	45	65
I	Cooling Time	sec.	32	35	38
J	Refill Speed	mm/s	65	75	85
K	Refill Pressure	bar	80	85	90
L	Injection Time	sec.	3	5	7
M	Holding Transition	mm	10	15	20

TABLE 1: THREE DIFFERENT LEVELS OF INJECTION MOULDING PARAMETERS USED IN THIS STUDY

2.3 DETERMINING ORTHOGONAL ARRAY

The selection of a suitable orthogonal array depends on the total degrees of freedom of the parameters. Degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. In this study, since each parameter has three levels, the number of degrees of freedom for each parameter is equal to 2 and total number of degrees of freedom is equal to 26. Basically, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters [28] Therefore, an L27 (313) orthogonal array with thirteen columns and twenty seven rows is appropriate and used in this study. For the experimental layout of the injection moulding parameters using the L27 orthogonal array, we refer reader to check the tables given in the appendix. Each row of this table represents an experiment with different combination of parameters and their levels. However, the order in which these experiments are carried is randomized

2.4 CONDUCTING TESTS

The tests are conducted on Chen Hsong injection moulding machine. These tests are held out according to the sets of control factors found via orthogonal array. The mold which produces the samples mentioned in this paper has two cavities. For each cavity, the samples are kept in room temperature for 48 hours and then when the samples are considered as stable, warpage of each sample is measured. Result of the warpage values for each cavity is given in the Table [3].

2.5 ANALYZING AND INTERPRETING THE RESULTS OF EXPERIMENTAL TRIALS

The signal to noise ratio is used to evaluate the condition of the quality characteristic warpage in a controlled environment. In Taguchi approach, the statement “signal” represents the desirable effect (mean) for the output characteristic and the term “noise” represents the undesirable effect (signal disturbance) for the output characteristic which effects the outcome due to external factors namely noise factors .

The signal to noise ratio can be defined as [28]:

$$\text{S/N ratio} = \eta = -10 \log (\text{MSD}) \qquad (1)$$

Where, "MSD" represents the mean square deviation of the output characteristic.

The purpose of these experiments is to find out the greatest possible signal to noise ratio as a result. A higher value of signal to noise ratios ensures that the signal is greater than the random environmental effects of the noise or in other words which leads to minimum variance. In order to achieve optimal moulding performance and minimize the warpage behavior the lower the better quality property is used.

The mean square deviation for the lower the better quality property is defined below [28]:

$$\text{MSD} = \frac{1}{n} \sum_{i=1}^{n} y_i^2 \qquad (2)$$

Where, "n" is the number of experiments and yi is the calculated data.

Therefore,

S/N = -10 log (y_i^2) and for experiment #1:

S/N = -10 log (0.8252) , S/N = 1.67

Similarly all S/N ratios are calculated.

Table [3] shows the experimental results for the warpage values of cavity #1, cavity #2, their mean values using equation (1) and (2). Since the experimental design is orthogonal, it is then possible to separate out the effect of each parameter at different levels. For instance, the mean signal to noise ratio for the injection pressure at levels 1, 2 and 3 can be calculated by averaging the signal to noise ratios for the experiments 1-9, 10-18 and 19-27, respectively. In similar manner, the mean signal to noise ratio for each level of the other parameters is computed.

The mean signal to noise ratio for each level of the parameters is summarized and called the signal to noise response table for warpage which is given in Table [4]. From the signal to noise ratio response as shown in Table [4], the best combination of parameters can be identified by selecting the highest difference value from each factor. Graphs [1-13] show the signal to noise response graph for each factor affecting the warpage quality characteristic. As stated in equations (1) and (2), greater the signal to noise ratio, the smaller is the variance of warpage around the desired lower the better value [29].

According to the S/N ratios found, best parameter setup by their levels is given as follows:

A1, B2, C2, D1, E2, F1, G2, H1, I1, J2, K3, L2, M1

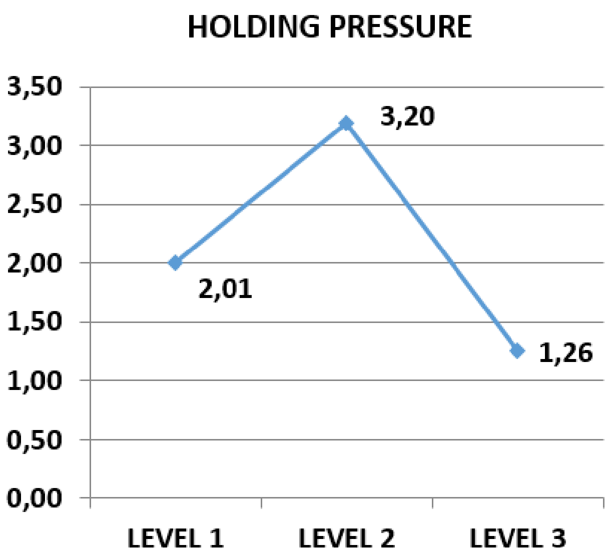
However, the relative importance amongst the parameters for warpage is still need to be investigated further so that contributions of the each parameter can be determined more accurately. This issue will be discussed on next chapter.

Number of Experiments	***Measured Warpage for Cavity #1 (mm)***	***Number of Experiments***	***Measured Warpage for Cavity #2 (mm)***	***Mean Warpage Value (mm)***
1-1	0.75	**1-2**	0.90	0.825
2-1	0.90	**2-2**	0.85	0.875
3-1	0.95	**3-2**	0.85	0.900
4-1	1.05	**4-2**	0.95	1.000
5-1	0.95	**5-2**	0.90	0.925
6-1	0.80	**6-2**	0.95	0.875
7-1	0.95	**7-2**	0.95	0.950
8-1	0.85	**8-2**	0.80	0.825
9-1	1.10	**9-2**	1.00	1.050
10-1	0.75	**10-2**	0.95	0.800
11-1	0.95	**11-2**	0.85	0.900
12-1	0.85	**12-2**	0.90	0.875
13-1	1.05	**13-2**	1.10	1.075
14-1	0.75	**14-2**	0.80	0.750
15-1	0.85	**15-2**	0.80	0.825
16-1	0.95	**16-2**	1.15	1.050
17-1	0.95	**17-2**	0.80	0.875
18-1	0.75	**18-2**	0.45	0.600
19-1	0.85	**19-2**	0.70	0.775
20-1	1.10	**20-2**	1.15	1.125
21-1	0.95	**21-2**	1.05	1.000
22-1	0.85	**22-2**	0.95	0.875
23-1	0.95	**23-2**	0.85	0.900
24-1	1.15	**24-2**	1.20	1.175
25-1	0.95	**25-2**	0.90	0.925
26-1	1.10	**26-2**	1.10	1.100
27-1	0.85	**27-2**	0.80	0.825

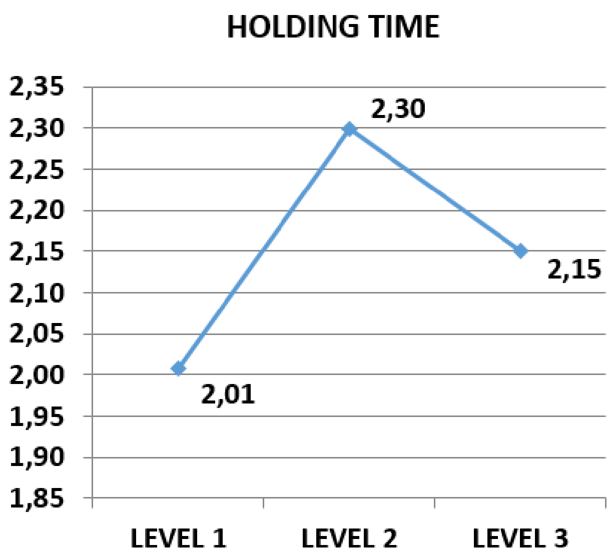
TABLE 3: RESULTS FOUND FOR WARPAGE

Factor	***INJECTION PARAMETERS***	***Mean Signal to Noise Ratio***			***Max. Difference***
		Level 1	***Level 2***	***Level 3***	
A	Injection Pressure	2.69	2.14	1.63	1.06
B	Injection Speed	1.47	2.76	2.23	1.30
C	Holding Pressure	2.01	3.20	1.26	1.94
D	Holding Speed	2.52	2.50	1.43	1.09
E	Holding Time	2.01	2.30	2.15	0.29
F	Melting Temperature	2.87	1.43	2.16	1.44
G	Back Suction Offset	1.91	2.76	1.78	0.98
H	Cavity Coolant Temperature	3.07	2.39	1.00	2.08
I	Cooling Time	2.39	2.20	1.87	0.52
J	Refill Speed	2.16	2.71	1.59	1.12
K	Refill Pressure	1.67	2.16	2.54	0.87
L	Injection Time	0.34	3.28	2.84	2.94
M	Holding Transition	2.31	2.00	2.15	0.31

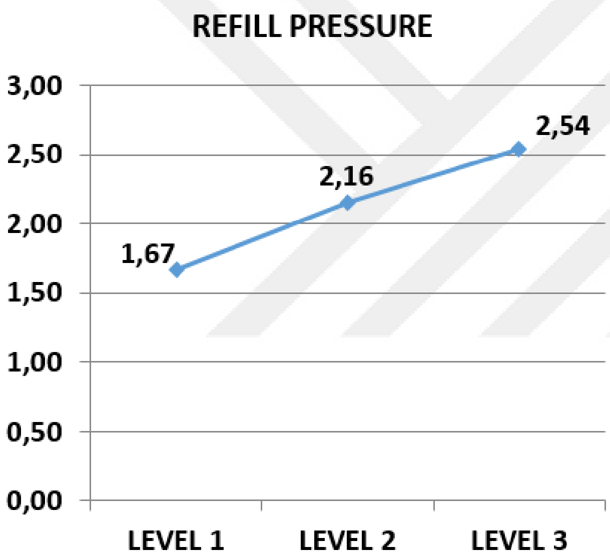
TABLE 4: THE RESULTS FOUND FOR SIGNAL TO NOISE RESPONSE



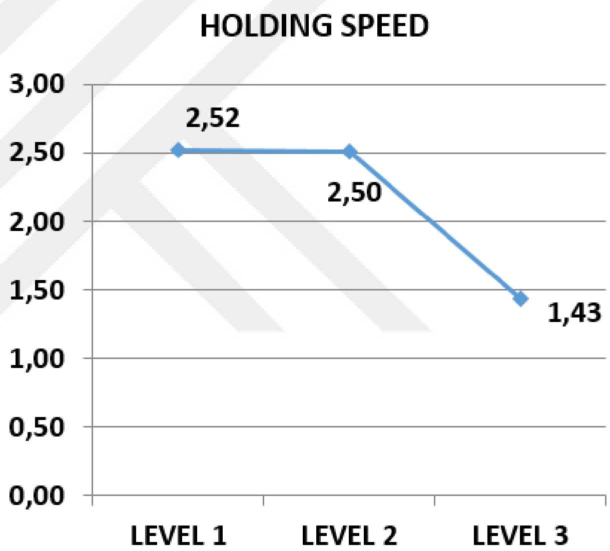
GRAPH 1: S/N GRAPH FOR HOLDING PRESSURE



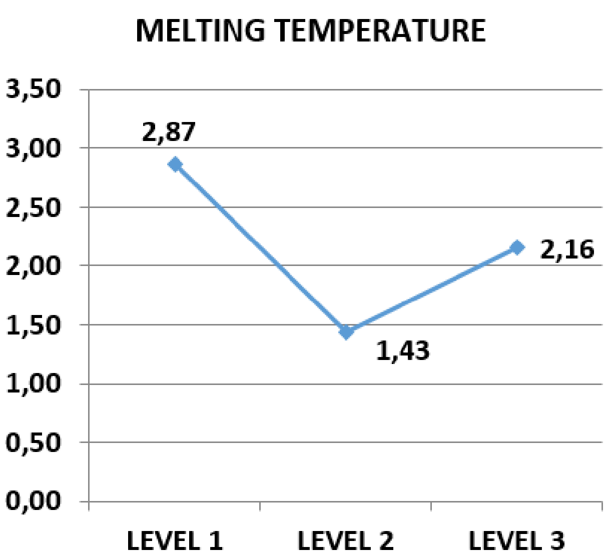
GRAPH 2: S/N GRAPH FOR HOLDING TIME



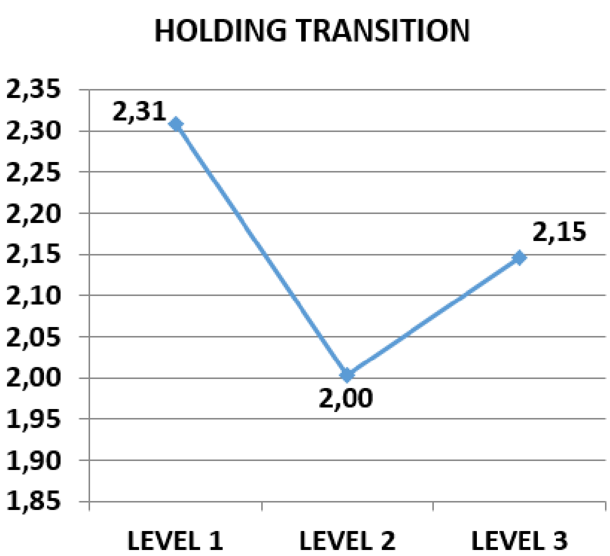
GRAPH 3: S/N GRAPH FOR REFILL PRESSURE



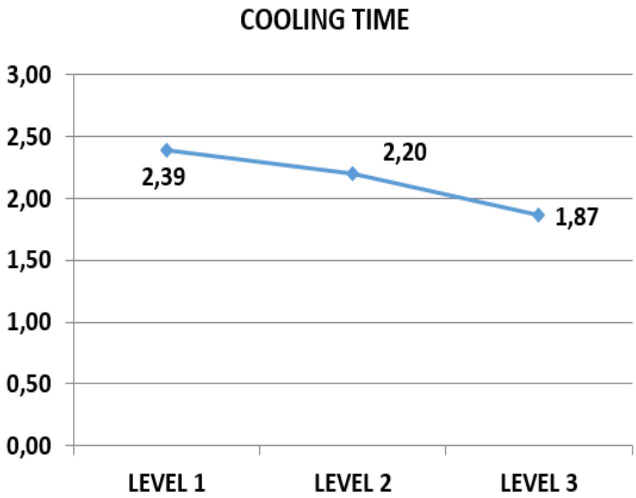
GRAPH 4: S/N GRAPH FOR HOLDING SPEED



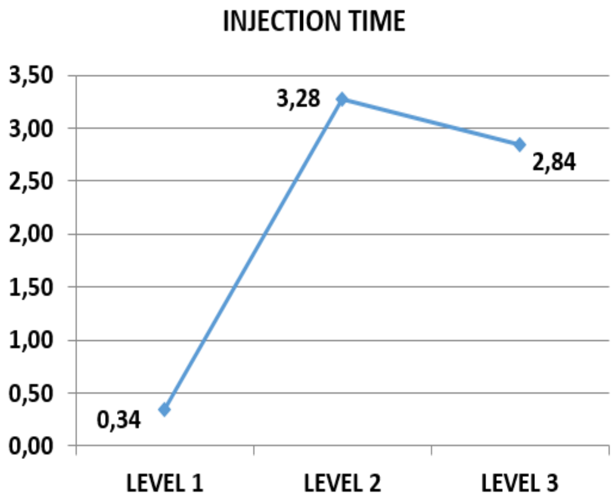
GRAPH 5: S/N GRAPH FOR MELTING TEMPERATURE



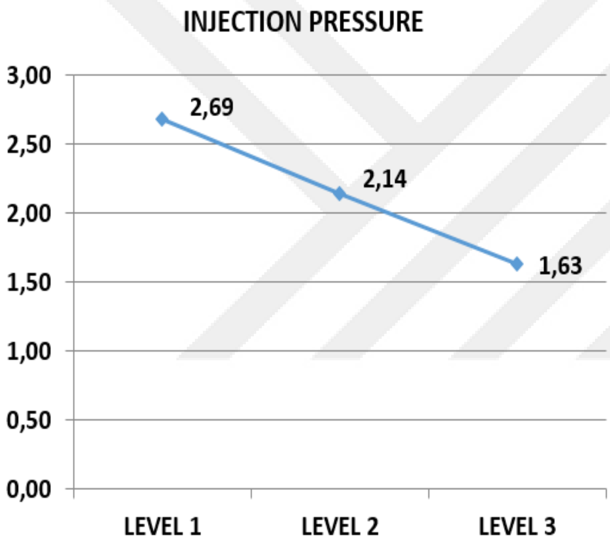
GRAPH 6: S/N GRAPH FOR HOLDING TRANSITION



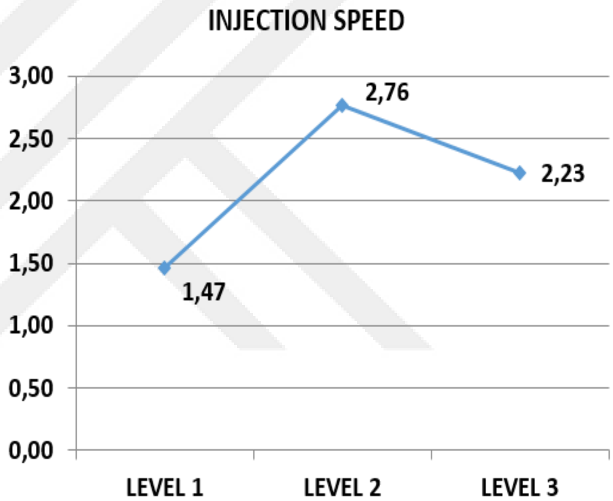
GRAPH 7: S/N GRAPH FOR COOLING TIME



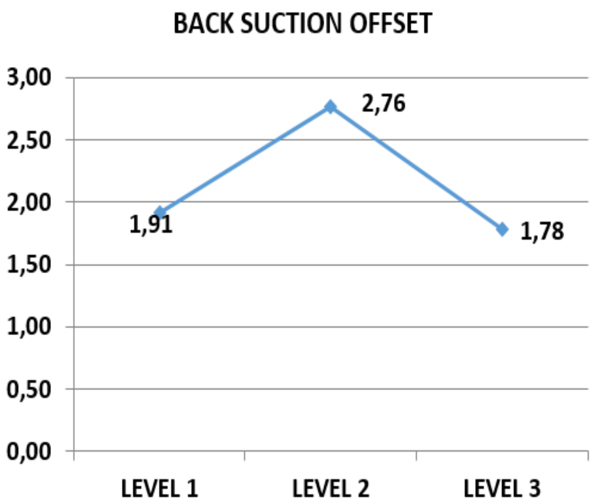
GRAPH 8: S/N GRAPH FOR INJECTION TIME



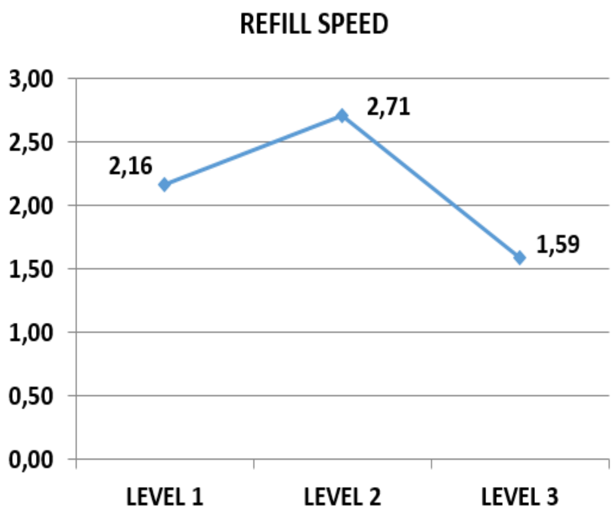
GRAPH 9: S/N GRAPH FOR INJECTION PRESSURE



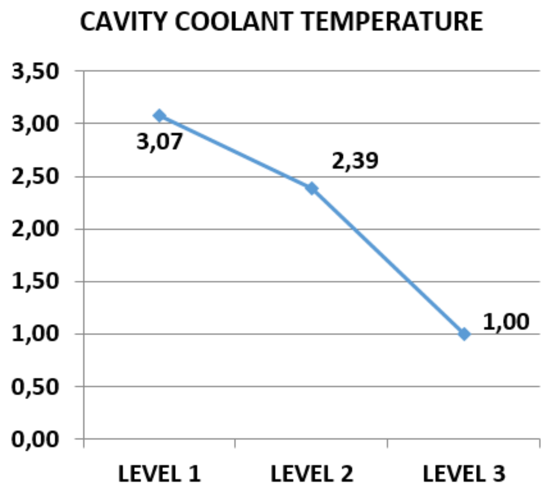
GRAPH 10: S/N GRAPH FOR INJECTION SPEED



GRAPH 11: S/N GRAPH FOR BACK SUCTION OFFSET



GRAPH 12: S/N GRAPH FOR REFILL SPEED



GRAPH 13: S/N GRAPH FOR CAVITY COOLANT TEMPERATURE

2.6 CALCULATING PERCENTAGE CONTRIBUTION

In this chapter analysis will be discussed which its aim is to determine the parameters' effects to the warpage quality characteristic and finding out their percentage contributions.

In order to calculate the percentage contributions, total sum of squares and the sum of squares for each factor must be calculated [28-29].

Sum of squares for all factors as well as the total sum of squares are calculated as given below [28].

Total sum of squares:

$$S_T = (T_{S1}^2 + T_{S2}^2 + ... + T_{SN}^2) - ((T_{S1} + T_{S2} + ... + T_{SN})^2/N)$$

$$S_T = (0.83^2 + 0.63^2 + 0.90^2 + ...0.78^2) - ((0.83 + 0.63 + 0.90 + ... + 0.78)^2/27)$$

$S_T = 0.91$

For factor A:

$$S_A = ((\sum A_1)^2 / N_{A1}) + (\sum A_2)^2 / N_{A2}) + (\sum A_3)^2 / N_{A3})) - ((T_{S1} + T_{S2} + ... + T_{SN})^2/N)$$

Where, "N_{A1}" is the number of experiments done using the A_1 parameter.

$$S_A = ((6.88^2 + 7.15^2 + 7.68^2) / 9) – ((0.83 + 0.63 + 0.90 + ... + 0.78)^2/27)$$

$S_A = 0.03$

Similarly, sum of square values for all factors are calculated and the results are given in Table [5]:

For Error Estimation:

$$S_e = S_T – (S_A + S_B + ... + S_M)$$

$S_e = 0.03$

Similarly, variance values for all factors are calculated and the results are given in Table [5]:

Finally, the percentage contributions for all the factors are calculated as shown below [30]:

For factor A:

$$P_A = (S_A / S_T) \times 100$$

P_A = 3.30 %

Similarly, percentage contributions for all the factors are calculated and the results are given in the Table [5] below:

	Factors	***Sum of Squares***	***Percentage Contribution (%)***
A	Injection Pressure	0.03	3.30
B	Injection Speed	0.04	4.40
C	Holding Pressure	0.11	12.06
D	Holding Speed	0.03	3.30
E	Holding Time	0.01	1.10
F	Melting Temperature	0.04	4.40
G	Back Suction Offset	0.05	5.50
H	Cavity Coolant Temperature	0.13	14.28
I	Cooling Time	0.02	2.20
J	Refill Speed	0.04	4.40
K	Refill Pressure	0.02	2.20
L	Injection Time	0.35	38.46
M	Holding Transition	0.01	1.10
	Error	0.03	3.30
	TOTAL	0.91	100

TABLE 5: THE S/N RESPONSE TABLE

CHAPTER III

MATHEMATICAL MODEL

3.1 REGRESSION ANALYSIS

In classical multiple linear regression, when the number of regressors (i.e., independent variables) is large, it is difficult to assess all possible combinations of regression equations. Therefore, a systematic search mechanism is needed. In the literature, the classical approach is applying a step-wise regression method, where regressors are added and/or removed one at a time [31]. The most commonly used versions of step-wise regression are forward and backward step-wise regressions. In the forward step-wise regression the selected variables set is initially empty and at each step, the most promising variable (i.e., the one with highest p-value) is added to the model; whereas in the backward regression the initial model includes all the variables and at each step the variable with less importance (the variable having a small p-value then the selected critical threshold value) is removed from the set [32]. This removal process is repeated until no further reduction is possible. There is also hybrid versions of the two models, where a variable could be added to or removed from the model.

In this thesis work, we have designed a regression analysis in order to write warpage as a function of injection parameters. There are in total 13 parameters and when first order interactions are taken into account it is computationally challenging to run a regression analysis; we shall delve into details of the stepwise algorithm later in this section.

In order to decrease number of possible combinations in the step-wise algorithm, we use the most significant process parameters found in Chapter II according to Taguchian approach. These parameters are injection time, holding pressure, and cavity coolant temperature. Some additional parameters such as holding time, cooling time and holding speed are also included in the regression analysis because time related parameters are so important in the manufacturing cycle time. For the above listed parameters we run the following regression analysis

input: Set of selected regressors and their interactions, *S*

input: experiment results data matrix, *D*

for $s = 1 \dots S$ **do**

Generate all subsets of *S* that has size *s*, and populate the list *K*

    for $k=1 \dots |K|$ **do**

    Set D_k as the columns of *D*, such that D_k contains the regressors in subset *k*

    Split the rows of D_k into two: D_train_k and D_test_k.

    Fit the linear regression line for D_train_k

    Predict the response variable in D_test_k using the fitted regression model

    Record key KPIs such as R^2, R^2*-adjusted, AIC, f-statistic, p-values, VIF values,*

    testMAPE.

    end for

end for

The regression analysis is executed for all subsets of set S, where S contains the below given six regressors and their two-way interactions:

X1 = Injection Time

X2 = Cavity Coolant Temperature

X3 = Holding Pressure

X4 = Holding Speed

X5 = Holding Time

X6 = Cooling Time

Important key performance indicators (KPIs) are analyzed to select the best performing model. Following is a list for KPI definitions:

R2 is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination.

R2-adjusted is a modified version of R2 that has been adjusted for the number of predictors in the model. The adjusted R2-adjusted increases only if the new term improves the model more than would be expected by chance.

AIC (Akaike information criterion) is an estimator of the relative quality of statistical models for a given set of data. Given a collection of models for the data, AIC estimates the quality of each model, relative to each of the other models.

f-statistic in the context of our analysis refers to the f-statistic value of the ANOVA table, that is the f-statistics value of the null hypothesis whether the regression model is significant or not. In other words, the test shows whether the ratio of the mean variation explained by the model to mean variation not explained by the model is large enough.

p-values show whether the regression coefficients are statistically significant or not

VIF (variance inflation factors) measure how much the variance of the estimated regression coefficients are inflated as compared to when the predictor variables are not linearly related. In other words it is a measure for multi-collinearity, that is linear dependency among regressors (i.e., used to detect whether there exists correlated regressors).

A search needs to be executed to find the “best” multiple linear regression model that has large R2-adjusted value, small AIC value, with all p-vlaues for regressors are significant (i.e., with value smaller than 0.05); VIF values smaller than a threshold and with minimum possible testMAPE. When all KPIs are considered, selecting the best model can also be seen as a multi-criteria optimization problem, where some of these metrics conflict with others. In this thesis work, we prioritize the KPIs (in the following order: R2-adjusted, AIC, p-values, f-statistic, VIF values, testMAPE) and select a model by inspection.

The best regression model found after analysis is given below:

Warpage = 1.2976 – 0.1311*X1 – 0.0122*X2 – 0.1105*X5 + 0.0020*X1*X2 + 0.0016*X3*X5 + 0.0004*X4*X6

The mathematical optimization model to find the best design settings is given below:

$$(\mathbf{M1}) \min_{\boldsymbol{X}} \quad 1.2976 - 0.1311\, X_1 - 0.0122\, X_2 - 0.1105\, X_5 + 0.0020\, X_1\, X_2 + 0.0016\, X_3\, X_5 + 0.0004\, X_4\, X_6$$

Such that;

$X_1 + X_5 + X_6 \leq 46$ (1)

$3 \leq X_1 \leq 7$ (2)

$25 \leq X_2 \leq 65$ (3)

$55 \leq X_3 \leq 75$ (4)

$22 \leq X_4 \leq 28$ (5)

$5 \leq X_5 \leq 7$ (6)

$32 \leq X_6 \leq 38$ (7)

To begin with, our objective is to minimize the warpage. Constraint (1) ensures that total production time per unit cannot exceed 46 seconds. All upper and lower bounds for the selected variables are given in constraints (2) - (7). The mathematical model (M1) is nonlinear and nonconvex in its current form because it contains bilinear terms such as $[0.0020\, X_1\, X_2]$. Next, we shall reformulate these bilinear terms using McCormick inequalities that exactly reformulates bilinear terms using the convex envelops of the associated terms. More precisely, using auxiliary variables, we replace $x_i x_j = w_{ij}$ (given that $0 < x_{i,j}^{L} \leq x_{i,j} \leq x_{i,j}^{U}$) and introduce the following inequalities that yields convex envelops of the associated bilinear term:

$$w_{ij} \geq x_i^L\, x_j + x_i x_j^L - x_i^L\, x_j^L$$

$$w_{ij} \geq x_i^U\, x_j + x_i x_j^U - x_i^U x_j^U$$

$$w_{ij} \leq x_i^U\, x_j + x_i x_j^L - x_i^U x_j^L$$

$$w_{ij} \leq x_j^U\, x_i + x_j x_i^L - x_i^L x_j^U$$

By using these information X_1X_2 is linearized and the associated auxiliary variable is X_7. Similarly, auxiliary variables X_8 and X_9 are associated with X_3X_5 and X_4X_6; respectively.

The mathematical model after linearization is given as below.

(**M2**) $\min_X 1.2976 - 0.1311\, X_1 - 0.0122\, X_2 - 0.1105\, X_5 + 0.0020\, X_7 + 0.0016\, X_8 + 0.0004\, X_9$

Such that; (1) – (7)

$3*X_2 + 25*X_1 - X_7 \leq 75$ (8)

$7*X_2 + 65*X_1 - X_7 \leq 455$ (9)

$7*X_2 + 25*X_1 - X_7 \geq 175$ (10)

$65*X_1 + 3*X_2 - X_7 \geq 195$ (11)

$55*X_5 + 5*X_3 - X_8 \leq 275$ (12)

$75*X_5 + 7*X_3 - X_8 \leq 525$ (13)

$75*X_5 + 5*X_3 - X_8 \geq 375$ (14)

$7*X_3 + 55*X_5 - X_8 \geq 375$ (15)

$22*X_6 + 32*X_4 - X_9 \leq 704$ (16)

$28*X_6 + 38*X_4 - X_9 \leq 1064$ (17)

$28*X_6 + 32*X_4 - X_9 \geq 896$ (18)

$38*X_4 + 22*X_6 - X_9 \geq 836$ (19)

To solve the exact linear reformulation (M2), CPLEX solver version 12.6.1 is used. The optimal setting shall be discussed later in this section.

The total cycle time affects daily production capacity. In the current mass production setup the associated time is 46 seconds.

3.2 ROBUST COUNTERPART

While using Taguchian methodology and orthogonal array approach we have gathered 57 data points and regression analysis is done by using this limited number of data points. Changing setting in order to collect these data during mass production was very time and money consuming. We had to slow or in some cases even stop the mass production. The setup time in between these changes are considered long. When this limited number of data points and the environmental factors are considered, it can be assumed that there might be some uncertainties in the regression coefficients. We are going to use a method which is robust to these uncertainties and which can be used when the distribution of these uncertainties are unknown [33].

In robust optimization approach the probability distributions of uncertain data is assumed to be unknown. Instead it is known that this uncertain data belongs to a so-called uncertainty set [34]. In literature there exists variety of uncertainty sets. The most famous uncertainty sets are box and ellipsoidal. In this study it is preferred to use ellipsoidal uncertainty set.

To begin with, uncertainty in regression coefficients is introduced in the following way:

$$\beta_i = \beta_i + \alpha\beta_i\zeta_i \qquad \forall i \in I$$

Where $\zeta i \in [-1, 1]$ denotes the primitive uncertainty parameter and $\alpha \in [0, 1]$ is the scaling parameter. We assume that the vector of primitive uncertainty parameters resides in the unit ellipsoidal (or ball) uncertainly set:

$$U = \left\{\boldsymbol{\zeta} \in R^{|I|} : \|\boldsymbol{\zeta}\|_2 \leq 1\right\}$$

It is known that the ellipsoidal uncertainty set is less conservative and yields more diversified solutions than box uncertainty set; for more details, we refer reader to Gorissen et. al (2015) [34].

The robust reformulation of (M2) is given below.

$$\min_{\boldsymbol{X}} \max_{\boldsymbol{\beta} \in U} \sum_{i \in I} \beta_i X_i$$

Such that (1) - (19),

where vector β denotes the regression coefficients.

Notice that different than the nominal model (M2), the robust model aims to minimize the worst-case warpage, i.e., it takes the worst-case realizations of the regressions parameters for a given design setting X. The associated robust formulation is a complicated optimization problem because of the nested “minimax” structure of the problem.

To avoid the inner maximization, we maximize the objective function for given X. The resulting robust counterpart for the ellipsoidal uncertainty set is given below.

$$(\boldsymbol{R1}) \qquad \min_{X} \sum_{i=1}^{n} \beta_i X_i + \alpha \sqrt{\sum_{i=0}^{n} \beta_i^2 X_i^2}$$

Such that (1) - (19)

The tractable robust counterpart (R1) is a second–order cone problem (SOCP) that can be efficiently solved by CPLEX.

After running the solver for (M2) and (R1), it is found at that both of these models give the same results which can be concluded as our nominal model is also robust.

This is why we wanted to focus our study on a more interesting robust formulation, i.e., to improve the total cycle time while keeping the worst-case warpage value on acceptable tolerance levels. The resulting robust reformulation is given as follows.

$$(\boldsymbol{R2}) \qquad \min_{\boldsymbol{X}} \; X_1 + X_5 + X_6$$

Such that (1) - (19)

$$\sum_{i=1}^{n} \beta_i X_i + \alpha \sqrt{\sum_{i=0}^{n} \beta_i^2 X_i^2} \leq \tau \qquad (20)$$

The goal of (R2) is to minimize the sum of injection, cooling and holding time. Constraint (20) ensures that the worst-case warpage cannot exceed certain threshold τ. All other constrains are same with previous mathematical models.

The optimal solutions of (M2), (R1) and (R2) as well as the current setting used by the manufacturer are given in Table (6).

X1	X2	X3	X4	X5	X6
INJECTION TIME (sec.)	CAVITY COOLANT TEMPERATURE (C^o)	HOLDING PRESSURE (bar)	HOLDING SPEED (mm\s)	HOLDING TIME (sec.)	COOLING TIME (sec.)

	X1	X2	X3	X4	X5	X6	WARPAGE (mm)
CURRENT MASS PRODUCTION SETTINGS	5	45	65	25	6	35	1.15 – 1.25
TAGUCHIAN METHODOLOGY	5	25	65	22	6	32	0.8 – 0.9
NOMINAL MODEL (M1)	3.2	63	55	22	5	32	0.9 – 1.00
ROBUST MODEL (R2)	3.2	54.96	59.46	23.07	5	32	1.1*

TABLE 6: Results of Warpage found for different settings

*The warpage value for (R2) is on the constraints and limited to 1.1 mm. This value is chosen to ensure that warpage value do not exceed the current mass production settings.

For nominal model (M1) and robust model (R2), all other parameters which are not shown on the Table 6 above are taken from the best option found from Taguchian methodology. Results for both (M1) and (R1) came out same (R1) is not included on Table (6).

The results for the warpage values shown on Table (6) are found out by measuring the average of 6 samples taken with the values given above. Only for model (R2) the values are written from the results found via solver. More samples will be taken in the future in order to check and verify the results found.

As can be seen from Table 6 both for Taguchian methodology and M1 the warpage values are better than our mass production settings. For Taguchian methodology; it is 29% and for (M1) it is 20% better.

For future research samples will be taken for (R2) in order to check and ensure the warpage value given on Table 6. We will also take samples for different values of τ and verify the results found in this study.

CHAPTER IV

CONCLUSIONS

Both Taguchi methodology and robust optimization approach is an efficient way in order to optimize the injection moulding parameters. Taguchi methodology gives an insight about the most important injection moulding parameters and can be used in order to find the percentage contributions. Regression analysis and robust optimization can be used in order to investigate the effects of the decision variables further and make analysis using solver. The data points which can be collected via sampling is limited so the robust optimization approach is an effective method. Samples are taken according to the data found from this study. The samples taken from our current mass production have around 1.10- 1.20 mm warpage. The samples have 0.87 mm warpage value by using the settings found from Taguchi methodology which is calculated by averaging 30 samples. Another 30 samples are also taken by using the settings found for M1 and R2 and their averaging warpage values are 0.89 mm and 0.93 mm respectively. According to the results found through this research both Taguchi method and robust optimization approach improves our mass production conditions. When total cycle time is also considered using the setting found for R2 seems the optimal solution because the warpage value is lower when compared to our existing mass production condition and cycle time is 4 seconds lower which can be also be considered as a huge advantage.

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APPENDIX

CPLEX CODE FOR **(M1)**

```
//variables

 dvar float+ x1; // Injection Time
 dvar float+ x2; // Cavity Coolant Temperature
 dvar float+ x3; // Holding Pressure
 dvar float+ x4; // Holding Speed
 dvar float+ x5; // Holding Time
 dvar float+ x6; // Cooling Time
 dvar float+ x7; // Interaction of x1 and x2
 dvar float+ x8; // Interaction of x3 and x5
 dvar float+ x9; // Interaction of x4 and x6
 dvar float+ x10; // Square Root Operation
 float a = 0.05; //level of robustness

 //expressions

 dexpr float warpage = 1.2976-0.1311*x1-0.0122*x2-
0.1105*x5+0.0020*x7+0.0016*x8+0.0004*x9+a*x10;

 //model

 minimize warpage;
 subject to {

      cons01:
      x1<=7;

      cons02:
      x1>=3;

      cons03:
      x2<=65;

      cons04:
      x2>=25;

      cons05:
      x3<=75;

      cons06:
      x3>=55;

      cons07:
      x4<=28;

      cons08:
      x4>=22;

      cons09:
      x5<=7;

      cons10:
      x5>=5;

      cons11:
      x6<=38;
```

```
        cons12:
        x6>=32;

        cons13:
        x1+x5+x6<=40.2;

        cons13_2:
        (x5 - 5)/2 <= (x1 - 3)/4 - 0.05;

        cons14:
        x7>=3*x2+25*x1-75;

        cons15:
        x7>=7*x2+65*x1-455;

        cons16:
        x7<=7*x2+25*x1-175;

        cons17:
        x7<=65*x1+3*x2-195;

        cons18:
        x8>=55*x5+5*x3-275;

        cons19:
        x8>=75*x5+7*x3-525;

        cons20:
        x8<=75*x5+5*x3-375;

        cons21:
        x8<=7*x3+55*x5-375;

        cons22:
        x9>=22*x6+32*x4-704;

        cons23:
        x9>=28*x6+38*x4-1064;

        cons24:
        x9<=28*x6+32*x4-896;

        cons25:
        x9<=38*x4+22*x6-836;

        cons26:

        x10*x10>=(1.2976*1.2976*a)+(0.1311*0.1311*a*x1*x1)+(0.0122*0.0122*a*x
2*x2)+(0.1105*0.1105*a*x5*x5)+(0.0020*0.0020*a*x7*x7)+(0.0016*0.0016*a*x8*x
8)+(0.0004*0.0004*a*x9*x9);

        cons27:
        x10>=0;

  }
```

CPLEX CODE FOR **(R2)**

```
//variables

 dvar float+ x1; // Injection Time
 dvar float+ x2; // Cavity Coolant Temperature
 dvar float+ x3; // Holding Pressure
 dvar float+ x4; // Holding Speed
 dvar float+ x5; // Holding Time
 dvar float+ x6; // Cooling Time
 dvar float+ x7; // Interaction of x1 and x2
 dvar float+ x8; // Interaction of x3 and x5
 dvar float+ x9; // Interaction of x4 and x6
 dvar float+ x10; // Square Root Operation
 dvar float+ x11; // warpage
 float a = 0.05; //level of robustness

 //expressions

 dexpr float time = x1+x5+x6;

 //model

 minimize time;
 subject to {

      cons01:
      x1<=7;

      cons02:
      x1>=3;

      cons03:
      x2<=65;

      cons04:
      x2>=25;

      cons05:
      x3<=75;

      cons06:
      x3>=55;

      cons07:
      x4<=28;

      cons08:
      x4>=22;

      cons09:
      x5<=7;

      cons10:
      x5>=5;

      cons11:
      x6<=38;

      cons12:
      x6>=32;
```

```
cons13_2:
(x5 - 5)/2 <= (x1 - 3)/4 - 0.05;

cons14:
x7>=3*x2+25*x1-75;

cons15:
x7>=7*x2+65*x1-455;

cons16:
x7<=7*x2+25*x1-175;

cons17:
x7<=65*x1+3*x2-195;

cons18:
x8>=55*x5+5*x3-275;

cons19:
x8>=75*x5+7*x3-525;

cons20:
x8<=75*x5+5*x3-375;

cons21:
x8<=7*x3+55*x5-375;

cons22:
x9>=22*x6+32*x4-704;

cons23:
x9>=28*x6+38*x4-1064;

cons24:
x9<=28*x6+32*x4-896;

cons25:
x9<=38*x4+22*x6-836;

cons26:

x10*x10>=(1.2976*1.2976*a)+(0.1311*0.1311*a*x1*x1)+(0.0122*0.0122*a*x2*x2)+(0.1105*0.1105*a*x5*x5)+(0.0020*0.0020*a*x7*x7)+(0.0016*0.0016*a*x8*x8)+(0.0004*0.0004*a*x9*x9);

cons27:
x10>=0;

cons28:
x11>=1.2976-0.1311*x1-0.0122*x2-0.1105*x5+0.0020*x7+0.0016*x8+0.0004*x9+a*x10;

cons30:
x11<=1.1;

}
```

Taguchi Orthogonal Array L_{27}

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

VITA

Mr. Serkan Okçuoğlu received his bachelor’s degree in mechanical engineering from University of Duisburg-Essen. He started to work in Vestel White Goods – Refrigerator Research and Development Department as a mechanical design engineer in 2013. Since 2016, he has been working as senior plastic injection mould and raw material specialist in the same department. Currently he is a graduate student of Department of Industrial Engineering at Özyeğin University. He conducted his studies under supervision of Assistant Professor İhsan Yanıkoğlu and Assistant Professor Erinç Albey.