OPTIMIZATION OF COOLING CHANNEL PARAMETERS FOR DESIGNING THREE PLATE MOULD OF HEXAGONAL FLOOR TILE USING TAGUCHI METHOD TO REDUCE WARPAGE

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SUPERVISOR’S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing.

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STUDENT’S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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DEDICATION

To my parents and those who made it possible

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ABSTRACT

This project deals with optimization of cooling channel parameters for designing three plate mould of hexagonal floor tile using Taguchi method to reduce warpage. The objective of this project is to analyze the hexagonal floor tile design by simulation with Moldflow Plastic Insight software (MPI) and to optimize the mould design parameter using Taguchi method. The product is designed in hexagonal shape build with interlocking features and will be used for application in indoor sports activities such as futsal, badminton, takraw and other sports. The material used for this design is thermoplastic elastomer (TPE) that increased the slipping resistance due to active and fast movement on it. The design of the product will be analyzed using MoldFlow Plastic Insight software (MPI) to reduce the warpage problem that appears during injecting the product. Warpage is the deflection of the part on the product design from its original shape. Taguchi method is used to optimize the parameter of the mould design for injecting the product with less warpage. In addition, the signal to noise ratio and analysis of variance is utilized to optimize the parameter for the product. The Taguchi method is conducted to minimize the warpage in both +z deflection and -z deflection. The result shown that, the most significance parameter of the mold design that tend to minimized the warpage values are from the cooling channel diameter at cavity half, cooling channel distance at core half and cooling channel diameter at core half. Also, from the result the summarized of the mold design parameter that reduces the warpage problem has been identified for the further process which is fabrication of mold.

ABSTRAK

Projek ini membentangkan tentang kaedah mengoptimumkan parameter sistem penyejukan untuk reka bentuk acuan plastik jenis tiga kepingan bagi produk jubin lantai plastik heksagonal. Objektif tesis ini adalah untuk menganalisa produk jubin lantai plastik heksagonal dengan menggunakan perisian Moldflow Plastic Insight (MPI) dan juga untuk mengoptimumkan parameter reka bentuk acuan plastik dengan menggunakan kaedah pengoptimaan Taguchi. Reka bentuk produk tersebut telah direka dengan sistem 'interlock' pada setiap luaran jubin plastik yang membolehkan pemasangan lebih cepat dan mudah. Produk jubin plastik ini sesuai diaplikasikan pada aktiviti sukan seperti futsal, badminton, takraw dan juga sukan lain. Bahan yang digunakan untuk produk ini adalah daripada thermoplastic elastomer (TPE), bahan ini sesuai digunakan kerana ia mempunyai sifat tahan kepada gerakan yang dapat mengelakkan pengguna daripada tergelincir. Produk ini dianalisa menggunakan perisian MPI untuk mengoptimumkan kadar pengurangan masalah pemeledingan semasa proses pembuatannya. Pemeledingan adalah proses pembengkokan reka bentuk produk daripada bentuk asalnya. Untuk mengatasinya, kaedah Taguchi digunakan untuk mengoptimumkan parameter untuk reka bentuk acuan agar proses pancutan dapat menghasilkan produk yang kurang masalah meleding. Justeru itu, kadar nisbah isyarat dan bunyi serta ANOVA analisis digunakan untuk mengoptimumkan parameter untuk produk tersebut. Kaedah pengoptimaan Taguchi digunakan untuk meminimakan pemeledingan dari arah +Z dan –Z. Hasil analisis itu telah menunjukkan bahawa parameter yang paling mempengaruhi proses meleding adalah garis pusat saluran penyejukan di rongga acuan, jarak saluran penyejukan di teras acuan dan garis pusat saluran penyejukan di teras acuan. Hasil parameter yang mengurangkan proses meleding telah dikenalpasti dan diringkaskan untuk proses akan datang iaitu proses pembuatan acuan.

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LIST OF SYMBOLS

O_1	Start diameter of sprue bush
O_2	End diameter of sprue bush
L	Length of sprue
η	Signal to noise ratio
Y_i	Value of warpage for *i*th test
n	Number of test
f_T	Total degree of freedom
N	Total number of simulation result
f_A	Degree of freedom due to factor A
K_A	Number of level due to factor A
S_T	Total sum of squares
Z	Analysis result value
S	Sum of square
Mq	Mean sum of square
F	F- ratio value
S_e	Sum of square due to error
Sq'	Pure sum of square
Mq_e	Mean sum of square due to error
P	Percentage of contribution

LIST OF ABBREVIATIONS

CAE	Computer aided engineering
MPI	Moldflow Plastic Insight
TPE	Thermoplastic elastomer
ANOVA	Anlaysis of variance
CAD	Computer aided design
S/N	Signal to noise
M.S.D	Mean square deviation

CHAPTER 1

INTRODUCTION

INTRODUCTION

This chapter is arranged in the following manner. Section 1.1 gives an overview of the project background, section 1.2 presents the objectives of the project and section 1.3 presents the scopes of project while section 1.4 describes the problem statement of the project.

1.1 PROJECT BACKGROUND

Nowadays, injection moulding product has been extensively used in the daily application such as for household appliances, industry field and also in the sport equipments. Formerly known, the plastic material has advantages such as lower in cost and light in weight compared to other material which also being used for such applications. In this project, the focus is on the application of sport which is for the sport courts. Plastic material is widely used in the equipment of sport but not in the used for sport courts. Mostly, the sport users want the sport court to give good grips to their movement. The desired to get such function has been developed the idea to introduce the plastic material to be used in the sport court application.

This project is to produce a floor tile which can be used for the indoor sport activity such as futsal, badminton and other sports. The floor tile product will be produce by using the thermoplastic as the material and the product design will be in the hexagonal shape which comes out with the interlocking features for the attaching purpose. In achieving to the goal for creating a plastic floor tile, the processing method will be carried out in the injection mould machine. Therefore, the mould of the product must be design in order to injecting the plastic floor tile.

In order to ensure the mould design will produce a fine injection product, an approach method is undertaken to optimize the mould design parameter that is by using the Taguchi optimization method. The value of parameter used in the optimization method is utilized from the CAE software which is Moldflow Plastic Insight software (MPI).

1.2 OBJECTIVE OF PROJECT

1.2.1 To analyze the hexagonal floor tile design by simulation with Moldflow Plastic Insight Software (MPI).
1.2.2 To optimize the mould design parameter using Taguchi optimization method.

1.3 SCOPE OF PROJECT

The general scopes of this project that need to be focused are:

1.3.1 Determination of the main cause and factors that influence in producing warpage defect
1.3.2 The material used is Thermoplastic elastomer (TPE) which gives desired mechanical properties.
1.3.3 The analysis in Moldflow Plastic Insight software (MPI) is based on 3 plate mould type.
1.3.4 Determination of suitable orthogonal arrays and used smaller the better analysis.
1.3.5 Identified the optimum condition of parameter that minimizes the warpage.

1.4 PROBLEM STATEMENT

In every injection moulding process, the problem after the plastic melt turns to solid is the main undesirable consequence for the product to be made. In fact, the product design for this project is a flat shape design which the product warping is the major problem needs to be concerned. Since the modification for the injection product is irrelevant for reducing the warping problem, the attention should be put before injecting the product that is during the designing and analyzing process for the product design. Also, it is complicated and hard to determine the exact value of the parameter in the injection moulding. It is important to determine one method to get the best result so that for future mould fabrication of this product produce minimize warpage.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

This chapter is arranged in the following manner. Section 2.1 describes about mould components, section 2.2 presents the feed system, section 2.3 describes the thermoplastic material and the last section 2.4 describe about the Taguchi technique.

2.1 MOULD COMPONENTS

The injection moulding is one of the most important methods applied for polymer plastic processing operations in the plastic industry. The injection moulding product has improved the old trend part processing such as die casting since the plastic product gives many advantaged in terms of surface finish, weight and cost reduction.

The process of injection moulding can be described shortly in which the plastic material is heated first in the barrel to its melting temperature. Then, the plastic melt is injected in the cavity of the mould with high pressure. The cavity in the mould has the dimension and shape of the desired product. When filling stage is completed, the cavity is kept under a constant pressure for packing pressure take place.

There are two main type of mould design that is two plates and three plate mould. The different between both type is the two plate mould have only single parting line while the three plate mould have double parting line. The top plate is the part in the mould components that are stationary and this plate will be clamped to the fixed platen of the injection machine. This part consists of locating ring, sprue bush and eye bolt. Locating ring is a component in top plate used to prevent the unmatched nozzle of injection machine. Locating ring is selected by considering the sprue bush design so that the locating ring not smaller than the sprue bush diameter. In designing the sprue bush, the diameter of the ball in the sprue bush must not too smaller than the nozzle diameter to prevent working plastic flash.

There is an addition plate in the three plate mould that is runner stripper plate. This plate used to cut the plastic resin between the sprue bush and the runner. The cavity plate consists of the hollow part which represents the product design to be produced. In three plate mould type, the cavity plate is divided into two that are fixed cavity plate and moving cavity plate. The fixed cavity plate will hold cavity side and the moving cavity plate or male plate used to attach the core side.

Also in this part also hold an important part that is cooling system. Beside the cavity plate is the support plate, this plate used to attach the return pin’s spring. The return’s spring is used to relocate the plate after ejection of the injection product. The bottom plate is used to support the spacer block, hold the cavity and the ejection system like puller and this plate is attached to the movable platen in the injection machine. Shown in Figure 2.1 is the basic construction of three plate mould in which this type of mould will be used in the Moldflow software.

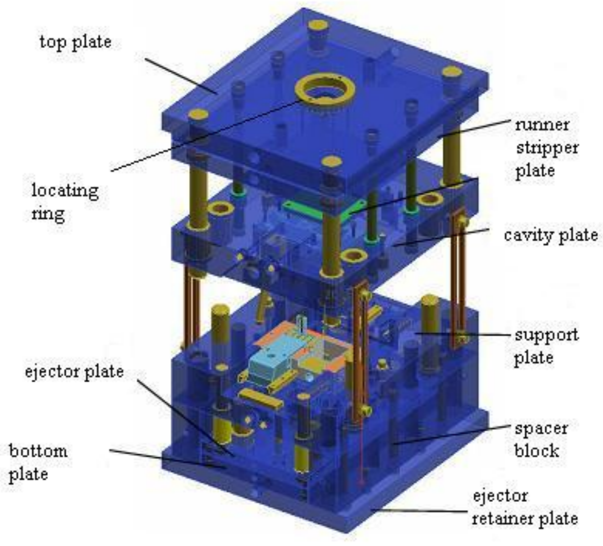

Figure 2.1: Three plate mould components

Source: http://mould-technology.blogspot.com

2.2 FEED SYSTEM

A feed system consists of sprue bush, runner and gating system. The feed system used to deliver the plastic melt into the cavity of the mould. Sprue bush which is locating at top plate of the mould can be design using the design consideration. While runner divided into two types which are hot runner and cold runner. In hot runner mould, the plastic melt stay in liquid forms while the cold runner solidified and need to proceed with the extra process such as cutting. In doing this project, the cold runner system is used since it is less costly for the future mould fabrication.

Mostly, the sprue bush is design from the manufacturer with standard dimension depending on the nozzle type of the injection mould machine. Usually, the sprue bush is design in ½ inch or ¾ inch in radius. It is design in tapered dimension for easily remove of resin from the sprue bush in the ejection stage of injection moulding process. The dimension of the sprue bush is based on the equation 2.1 where start diameter of sprue bush is denoted as O_1 and the end diameter of the sprue bush is denoted as O_2 and length denoted as L. Shown in Figure 2.2 is the figure of the sprue bush.

$$O_2 = O_1 + L\,(\tan 2.386°) \qquad (2.1)$$

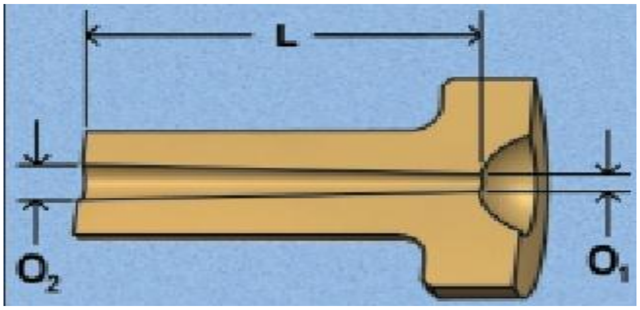

Figure 2.2: Sprue bush illustration

Source: Injection Mould design guideline by Dr. Paul Engelmann and Bob Dealey (1999)

Since the design of hexagonal plastic floor tile is large and for single cavity, the suitable type of gate is the pin point gate. This type of gate is design by locating the gate at the top surface of cavity half. The gate must be design small in shape for ease of cut of the gate. A sprue gate can be used for single cavity but it also must depend on the mould type. In this project, the Moldflow simulation is based on three plate mould and the pin point gate is the best gate type to be applied.

2.3 THERMOPLASTIC MATERIAL

Thermoplastic material is one of material that can be used in the injection moulding process. Thermoplastic elastomer (TPE) is one of the thermoplastic materials that have been extensively used in any plastic industry these days. This type of material has properties such as soften feature, flexible and also stiffness and lower in density. The material properties of the thermoplastic material (TPE) are shown in Table 2.1.

Table 2.1: Material properties of thermoplastic elastomer (TPE)

Material properties	
Melt density	0.76922 g/cm^3
Mould temperature	40 °C
Melt temperature	230 °C
Shear modulus	2.79 MPa
Poisson rate	0.38
Material structure	Crystalline

Source: Moldflow Plastic Insight software (MPI)

Utilizing the packing pressure is needed to fill the remaining volume of the cavity and to reduce shrinkage due to cooling. This shrinkage can be one of the factors for the warpage problem occurred. Warpage can be occurred from the flow orientation when injecting the part in which the orientation of flow leads to directional shrinkage variation.

Differential cooling also contributes in producing warpage by the result in variations in sectional shrinkage. The temperature between core half and cavity half of the mould will cause differential shrinkage which the shrinkage increased the tendency to have bending moment after part is ejected from the cavity. Depending to the mechanical properties of the material selection, this bending moment created warpage or residual stress to the part [1].

A cooling system is used to lowering the temperature of the mould and also help to solidify the plastic melt in the cavity. Given by D.E Dimla et al [2], a better cooling system design must allow the cooling fluid to transfer the heat by circulating action. A new gate can reduce the tendency for part shortage but previous study given by D.E Dimla et al [2], increasing number of gate will not improve the cooling time and tends to make designer to create complex cooling system design.

In the injection process, although the high temperature is considered for the easier flow of the plastic melt into the cavity, the increase in temperature also will bring other consequence as found by A. Demirer et al [3] which state that The increasing temperature will lead to increase warpage generally. Therefore, as the injection pressure increase, the percentage of the shrinkage can be reduced. Also, the residual stress also need to observe since the previous study by C.H Kim [4] found that residual stress can cause warpage to the product due to non-uniform temperature profile.

It is very important to get the desire product with a good quality and in order to get the desired specification, the good cooling channel that provide cooling fluid must be obtained systematically. From the previous study given by D.E Dimla et al [2] state that different cooling channel requirement is needed for different physical effect. The cooling channel must be built in the side of the convex area rather than the concave area because the convex area tends to have concentration of heat.

Also, from this study state that a better cooling system design must allowed the cooling fluid to transfer the heat by circulating action. In our context area, the cooling channel must be balance as the design injection mould product have same thickness and not have either convex or concave properties. Figure 5 shows the example of cooling design in Moldflow Plastic Insight software.

Figure 2.3: Cooling system design in Moldflow software
Source: B. ozcelik et al (2005)

2.4 DESCRIPTION OF TAGUCHI TECHNIQUE

Taguchi technique has been developed by Taguchi and Konishi. This technique is a wide range of range of experimental techniques to dramatically improve process and product characteristic. The principals of Robust Design are based on many ideas from statistical experimental design. They are used to plan experiments for obtaining information about variables involved in making engineering decisions.

The philosophy of Taguchi method is broadly applicable. He proposed that engineering optimization of a process or product should include system design, parameter design and tolerance design [5].

System design requires technical knowledge and extensive experience in area of specialization to initially design or specify the process or product. System design does not utilize design optimization methods such as the design of experiment.

Parameter design provides a means of both reducing cost and improving quality by making effective use of experimental design methods. This involved of determination of parameter values that are least sensitive to noise. Parameter design is most important step when the goal is to design a process or product with high stability and reliability. The objective of the parameter design is to optimize the settings of the process parameter values for improving performance characteristics and to identify the product parameter values under optimal process parameter.

Tolerance design is a means of controlling factors that affect the target value by using higher grade components and inevitably increasing the cost. After the system has been design and the parameter is determined, the next step is to set the tolerance of the parameters. At the tolerance design stage, the noise factors are controlled by keeping them with narrow tolerances.

Some researchers have performed to optimize the optimum levels of parameters based on orthogonal arrays experiments of Taguchi's throughout injection moulding of plastic components. In 1995 [6], Metrol used Taguchi methods together with finite elements method to investigate the optimal dimension for plastic pin ball grid array. Chien and Shiou [7] have studied for determining the optimal process parameter depended on Taguchi orthogonal array in finish operation of a freeform surface plastic injection moulding.

CHAPTER 3

METHODOLOGY

INTRODUCTION

This chapter is divided in several sections that are section 3.1 for product design, section 3.2 describes the pre-analysis of product design .The next sections which are section 3.3 presents the analysis of experimental data and section 3.4 which describes analysis of variance (ANOVA). This chapter shows the sequence of method that has been utilized in doing this project.

3.1 PRODUCT DESIGN

In this project, a product design must be modeled before proceed with performing the Moldflow software and lastly optimizing it using the Taguchi robust design method. The product design in this project is a plastic floor tile used for sport activities purpose. Basically, the product design is in a hexagonal shape and will apply the concept of interlocking plastic tile. The concept of interlocking tile brought by this product will make the tile applying and removing process much ease than conventional tile. Furthermore, this concept will not damage the interface of the basis floor compared to the conventional tile which need permanent joint such as cement.

Since this project is to create a plastic tile for the injection molding product, the product design needs to consider the requirement for the mold design. Even though the mold design must essentially the same as the product shape and dimension, the product design must consider the polymer properties need to be used as well as the possible problem brought by the selected properties such as plastic warping problem. In addition, the shape of the hexagonal tile will be flat which the warping problem is the major attention in injection molding product. The warping problem in the injection product must be avoided since it may alter the specification and dimensional requirements of the product.

Also, the application of this plastic tile is for the sport activities and the plastic tile properties must be design so that the polymer gives the rough properties in the interface of the tile. This property is suitable for the sport application since it exhibits rough surface and give the sport user to grasp tightly with the tiles surface. Shown in Figure 1 is the hexagonal plastic floor tile in isometric view.

The injection product is design that is for the application in the indoor sport activities. The product is in hexagonal shapes builds with interlocking features where this features used to provide easier assembly and hassle when dismantle for maintenance purpose.

The product design begins with designing the floor tile in three dimensional (3D) using Solidworks software. In terms of dimensional specifications, the overall size of the product is in 250mm × 250mm × 15mm. A few ribs are design with the thickness of 3 mm to enhance the product strength and stiffness.

Shown in Figure 3.1, Figure 3.2 and Figure 3.3 are the product design in different views which has been model in CAD software that is Solidworks. The design of the floor tile is also come out with rib design that will be used to strengthen the geometry of the plastic floor shape.

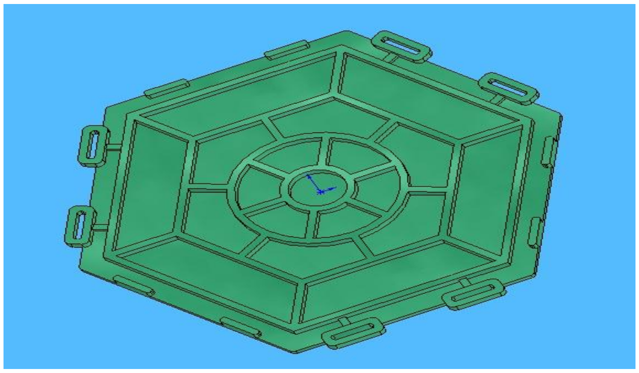

Figure 3.1: Isometric view of product design

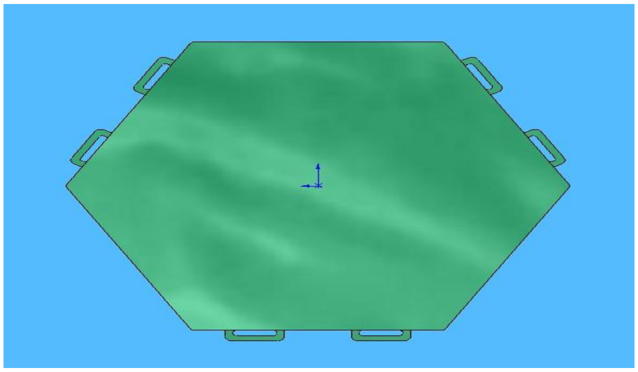

Figure 3.2: Top view of product design

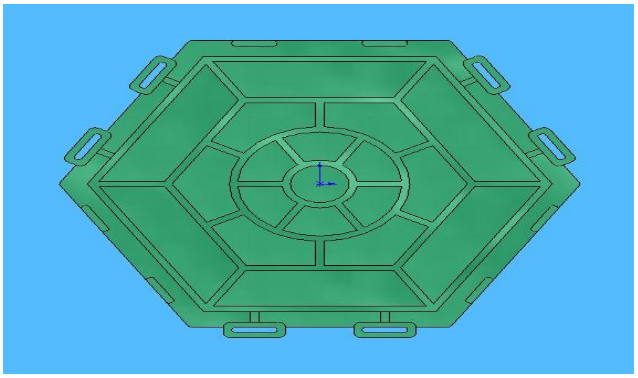

Figure 3.3: Bottom view of product design

3.2 PRE-ANALYSIS OF PRODUCT DESIGN

Since this project is totally for the new design of product and there is no other production that similar for the design, the simulation of plastic flow in the Moldflow software is carried on by using the trial and error analysis. Several simulations are performed in order to find the less value of warpage for the hexagonal plastic floor tile.

In doing so, the first step is to mesh the part so that the analysis can measured the result accurately. The meshing is done by selecting the three dimensional meshing type (3D) as the product design has thick thickness. In addition, after meshing process is the checking and fixing the meshing error. A higher aspect ratio on the product meshing need to be reduced so that the measured of result can be accurate.

For this project, the meshing shows the product has 201195 elements and for the material used in the simulation by Moldflow software is thermoplastic elastomer in which the trade name is Thermolast K HTF9370/30. Shown in Figure 3.4 is the meshing of plastic floor tile in the Moldflow Plastic Insight software (MPI).

Figure 3.4: Meshing of product design in MPI

After the meshing process, the next stage is to set the parameter which including the mold design parameter and injection process parameter. These parameters must be set in the Moldflow Plastic Insight (MPI) software exactly the same with the parameter to be set in the real injection molding process so that the obtaining result could be valid.

In doing so, the parameter of the mold design that has been used in the Moldflow Plastic Insight software (MPI) are consist of diameter of cooling channel in both core and cavity half of the mold, the distance that located the cooling channel for both of half the mold, number of gate used, mold temperature and also the melt temperature of the thermoplastic material. The other parameter such as injection pressure, clamping pressure value is set automatically by the software.

The pre-analysis value is obtained by considering from the literature review that has been made. The researcher found that using multiple of gate will not improve cooling time and will make the cooling design to be complex. Multiple of gating system will complicate the cooling channel and gives the improper heat transfer through the cooling system. A cooling system must be provided properly to reduce the possibility of producing warpage. As for the pre-analysis, several numbers of gates is used to determine the better gate number that will minimize the warpage. The value of sprue used in the Moldflow Plastic Insight software (MPI) is calculating by exploiting the equation 2.1 in chapter 2. The value of the data for the feed system used in the software is tabulated in Table 3.1.

Table 3.1: Value of feed system used in Moldflow Plastic Insight software (MPI)

Feed system used in MPI software		
Type	**Dimension**	**Shape**
Sprue	Start diameter: 7mm End diameter: 4mm Length: 68mm	Tapered by dimension
Runner	Diameter: 5mm	Full round shape
Branch runner	Start diameter: 2mm End diameter: 4mm	Pin point type, tapered by dimension
Gate	Diameter: 1.5mm Length: 2mm	Pin point type

Also, from the literature review state that the cooling designs must be design in the convex area rather than concave area of the part because of different of heat concentration. As for the pre-analysis, the distance of the cooling channel in the core half and cavity half is design differently to determine the best design that minimizes the warpage. Warpage also as there are unbalanced of heat between cavities half and core half. The value of the design parameter used in the Moldflow Plastic Insight (MPI) software is summarized in the Table 3.2

The pre-analysis of the product design are performed for the product design based on two type of top thickness. The first pre-analysis of product is performed for a hexagonal plastic floor tile in which the top thickness of the tile is in 2mm. The other pre-analysis is performed for the hexagonal plastic floor which has the top thickness of 4mm. Shown in Figure 3.5 is the hexagonal tile floor with 2mm of top thickness and the Figure 3.6 shown the hexagonal tile floor with 4mm of top thickness.

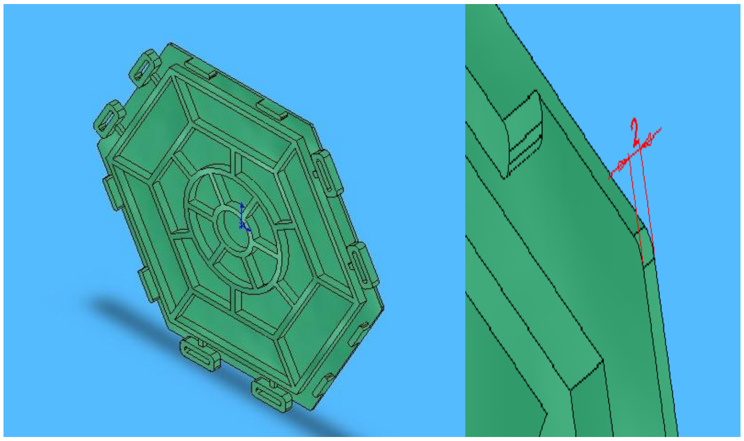

Figure 3.5: Product design with top thickness 2mm

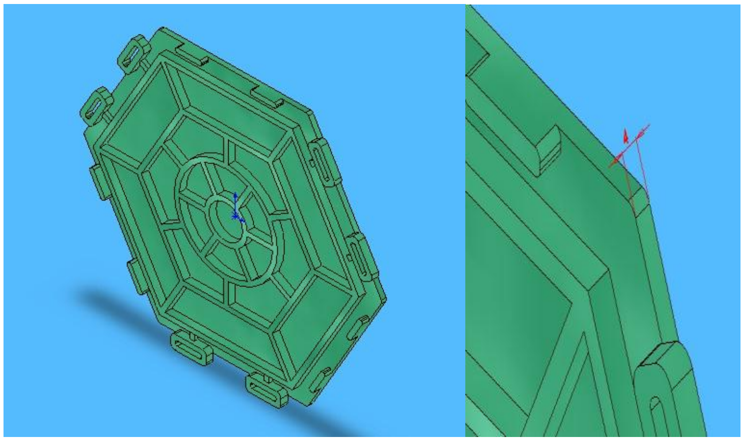

Figure 3.6: Product design with 4mm top thickness

The less value of warpage obtained from the pre-analysis can be optimize by using the Taguchi robust design method to improve the warpage value so that the result of warpage is much smaller from the pre-analysis warpage value.

3.3 ANALYSIS OF EXPERIMENTAL DATA

Taguchi method utilizes the S/N ratio, η approach to measure quality characteristic deviating from the desired value. Usually, there are three categories of the performance characteristics in the analysis of the S/N ratio, that is the smaller the better, the larger the better and the nominal the better. In this project, the calculation of getting the value of the S/N ratio is by utilizing the Stastistica software.

The S/N ratio for each level of process parameter is computed based on the S/N analysis. In this study, the smaller the better analysis is selected since the objective of this study is to minimize the warpage defect through optimum process parameters of mold design. M.S.D is the mean square deviation for the output characteristic. The M.S.D for the smaller the better can be employed as in equation 3.1.

$$M.S.D. = \frac{1}{N}\left(\sum_{i=1}^{n} Y_i^{\,2}\right) \qquad (3.1)$$

The symbol of N refer to total number of data points, the value of warpage is denoted as Y_i which is for the ith test and n symbol referring to the number of test [8].

The S/N ratio is quoted in decibel unit, db and can be expressed as:

$$\eta = -10\log(M.S.D) \qquad (3.2)$$

The –log is a monotone decreasing function, it implies that the S/N ratio value should be maximize [5]. So, the S/N ratio can be calculated by exploiting the equation 3.1 and 3.2.

3.4 ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) is used to find the statistical significance of factors or parameter in simulation. Analysis of variance is a method of partitioning variability into identifiable sources of variation and the associated degree of freedom in an experiment. In determining the ANOVA calculation, the equation is described as:

$$f_T = N - 1 \qquad (3.3)$$

Where f_T is the total degree of freedom and N is the total number of simulation result.

$$f_A = k_A - 1 \qquad (3.4)$$

Where f_A is degree of freedom for factor A and k_A is the number of level for factor A.

Total sum of squares,

$$S_T = (Z_1^2 + Z_2^2 + Z_3^2 + \cdots + Z_7^2 + Z_8^2) - \frac{(Z_1 + Z_2 + Z_3 + \ldots, + Z_7 + Z_8 2)}{N} \qquad (3.5)$$

Where S_T is total sum of square and Z is analysis results from simulation 1 to 8.

$$S_A = \frac{[Total\ of\ A1]^2}{n1} + \frac{[Total\ of\ A2]^2}{n2} - \frac{[Total\ of\ A]^2}{n1+n2} \qquad (3.6)$$

S_A is sum of squares for factor A and n is number of data for level i.

$$Mq_A = S_A/F_A \qquad (3.7)$$

Where F_A is F-ratio for factor A and Mq is mean sum of square.

$$F_A = \frac{Mq_A}{S_e} \quad (3.8)$$

Where symbol S_e is referring to the sum of square due to error.

$$Sq'_A = S_A - f_A\, Mq_e \quad (3.9)$$

Where Sq' is pure sum of square and Mq_e is mean sum of square for error.

$$P\,\% = \frac{Sq'_A}{St} \times 100\% \quad (3.10)$$

Where symbol denoted as P is percentage of contribution for the factors.

CHAPTER 4

RESULT AND DISCUSSION

INTRODUCTION

This chapter is arranged in several sections in the following manner. Section 4.1 describes about pre-analysis results, section 4.2 presents about the Taguchi optimization method and section 4.3 describes about the analysis of variance results. While section 4.4 presents about determination of optimum value of warpage and section 4.5 describes the confirmation test.

4.1 PRE-ANALYSIS RESULTS

4.1.1 Pre-analysis using 2mm top thickness of product design

The pre-analysis is carried on by using product design by which the thickness of the top part is 2mm. From the simulation in the Moldflow software, the result is shown in Table 4.1 and Table 4.2 is tabulated for six gate locations and three gate locations respectively.

Table 4.1: Pre-analysis result for 6 gate locations

Analysis	Cooling diameter (mm)		Distance (mm)		Maximum warpage (mm)
	Above	**Below**	**Above**	**Below**	**Z deflection**
1	6	6	20	15	5.102
2	10	10	20	15	5.279
3	10	6	15	15	5.922
4	10	10	15	15	5.500
5	10	6	10	15	6.488
6	6	6	30	15	5.315

Table 4.2: Pre-analysis result for 3 gate locations

Analysis	Cooling diameter (mm)		Distance (mm)		Maximum warpage (mm)
	Above	**Below**	**Above**	**Below**	**Z deflection**
1	6	6	30	15	4.926
2	6	6	20	15	5.563
3	6	10	20	15	5.564
4	10	10	20	15	5.605
5	10	6	20	15	5.990

In both of the table, the column for cooling diameter and distance have sub-column which are denoted as above and below. This sub-column means that the cooling diameter in cavity half and core half of the mould in which the above of the product is the cavity side and below the product is the core side.

The table 4.1 shows the distance of the cooling channel at core half is set to be fixed into 15mm from the surface of the product. Only the value of cooling channel diameter and distance of cooling channel at cavity half is changing. The analysis 1 shows that when the diameter of cooling channel at both cavity and core half is set to be 6mm while the distance of the cooling channel at cavity half is 20mm, the warpage value is 5.102 mm. While the analysis 2 shown that with the distance of cooling channel similar to analysis 1 and the diameter of cooling channel of 10 mm for both cavity and core half produced the warpage value of 5.279 mm. It shows that as the diameter of cooling channel increased, the value of warpage is not much changing. Analysis 5 gives the highest value of warpage of 6.488 mm in which the cooling channel distance at cavity half of 10 mm, diameter of cooling channel at cavity half of 10 mm and diameter of cooling channel at core half of 6 mm. Then, as the distance of cooling channel at both half of mould is fixed to 15 mm in analysis 3 and analysis 4 also gives the warpage value about 5 mm. In this table, almost all of the value of warpage is analyzed to be in about range of 5 mm to 6 mm. This value is still high for the product which flat surface is needed.

The Table 4.2 shows the pre-analysis of product with 3 gate locations. Also in this table, the distance for cooling channel in core half is fixed to 15 mm. The results show that the lowest value of warpage is in analysis 1 which is 4.926 mm. The analysis 1 used 6 mm of cooling channel diameter at both cavity and core half while the distance of channel in cavity half is set to be 30 mm. As the distance of cooling channel in cavity half is reduced to 20 mm, the warpage is increased to 5.563 mm in analysis 2. Also, as the diameter of cooling channel is increased to 10 mm, the value of warpage also increased to 5.564 in analysis 3. Note that, an increasing of value is produced in analysis 4, 5, and 6 as the distance of cooling channel is design to be near the product surface.

From both results in Table 4.1 and Table 4.2, the value of the warpage is about the same and has no significant in variation of result. These results cannot be used since the warpage can be minimized for smaller values. A much smaller value of warpage is desired for the hexagonal plastic floor tile as it is used for the sport application. Warpage can be considered that the plastic product is altered from its original shape and dimension which tend to produce deflection on the part.

4.1.2 Pre-analysis using 4mm of top thickness of product design

The pre-analysis is conducted and the result is tabulated in Table 4. This analysis is performed after increasing the top thickness of part to 4mm. It is performed in the similar manner as for pre-analysis of 2mm top thickness product which is by using the same design of sprue, runner and gate system.

Table 4.3: Pre-analysis result for 3 gate locations

Analysis	Cooling diameter (mm)		Distance (mm)		Z warpage	
	Above	**Below**	**Above**	**Below**	**Minimum**	**maximum**
1	10	10	30	20	-2.360	2.602
2	10	10	35	20	-2.600	2.843
3	10	10	30	30	-1.469	1.735
4	10	10	30	15	-3.079	3.288
5	10	10	30	20	-2.371	2.608
6	10	10	20	20	-0.900	1.187
7	10	10	40	40	-1.966	2.223

The analysis in the MPI software is conducted with increasing thickness of the product. Table 4.3 shows that highest value of warpage is in analysis 4 which are -3.079 mm for minimum warpage value and 3.288 mm for maximum warpage. It is considered as minimum for –z direction of warpage and maximum for +z direction of warpage. The lowest value of warpage is in analysis 6 which shows the minimum warpage value of -0.900 mm and maximum value of 1.187 mm. The result is produced by designing the distance of the cooling channel in cavity half and core half to be similar which is in 20 mm from the surface of the product while the diameter for both channel is design to 10 mm.

As the distance of the cooling channel for both core and cavity half increased, the value of warpage also increased. The result is shown in analysis 3 in the Table 4.3 which the warpage value is -1.469 mm for minimum and 1.735 mm for maximum. The analysis 7 also shows the increased of warpage as the distance of cooling channel increased with value of warpage -1.966 mm for minimum and 2.223 mm for maximum. In analysis 2, as the diameter of cooling channel for cavity and core half is fixed to 10 mm while the distance of channel in cavity half is 35 mm and distance of channel in core half reduced to 20 mm, the minimum warpage is found to be -2.600 mm and maximum warpage is 2.843 mm.

It is found that, the value of warpage for maximum and minimum is small as the distance of cooling channel in cavity and core half is design to be same. In addition, the increased of warpage value began as the cooling channel for both cavity and core half is design not similar in distance. It happens because as the product is in hexagonal plate shape, the requirement for temperature difference for cavity and core half must balanced. A non balanced temperature difference creates the warpage problem especially for flat plastic product.

From the results shown in Table 4.3, there is a significant in warpage variance among the analysis 1 to analysis 7 in which analysis 6 shows the less warpage value obtained from the simulation in the Moldflow analysis that are -0.900mm for minimum warpage and 1.187mm for maximum warpage. The analysis for 4mm thickness of top part is only carried on by three gate location because this result is enough to show that this result can be improve and optimize using the Taguchi optimization method. Shown in the Figure 4.1 is the result of analysis 6 which gives the less of warpage value.

In the Figure 4.1, the maximum value of warpage is in red color and the minimum value of warpage is in blue color. From the figure, the red color is located at the center of the part which mean that region of product will be warp the most for the positive z direction. The blue color region is located in the edge of the hexagonal tile. It refers that the part will be undergoing warp in negative z direction.

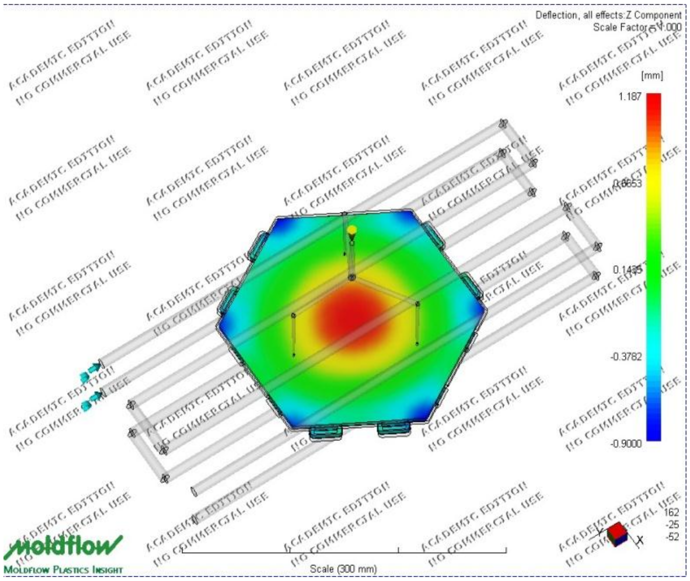

Figure 4.1: The less warpage value from the pre-analysis of 3 gate locations

Warpage problem may appear due to three categories which are flow orientation, area shrinkage and differential of cooling. From the results in the analysis, the problem of the warpage comes from the area shrinkage and differential shrinkage. As the product cooled, it will have volumetric shrinkage because the material structure for the selected material which is thermoplastic elastomer (TPE) will turn to crystalline structure.

The plastic melt which in contact will mould surface will freeze instantly and formed less crystalline structure. So, it will produce the outer part of the tile to have little shrinkage compared to the centre part which is much hotter and cool slowly. Also, the problem comes because of differential shrinkage between the upper and below of the product which is the unbalanced of temperature in cavity half and core half.

4.2 TAGUCHI OPTIMIZATION METHOD

The Taguchi optimization method is carried out by utilizing the value of pre-analysis using the 4mm part top thickness. It conclude that all the analysis for the Taguchi optimization method will use the product design which has being increased its top thickness to be 4mm.

Table 4.4: Factors and levels

	Factor	Level 1	Level 2	Units
A	Cooling diameter at cavity half	6	10	mm
B	Cooling diameter at core half	6	10	mm
C	No. of gate	3	6	units
D	Channel distance at cavity half	15	20	mm
E	Channel distance at core half	15	20	mm
F	Mould temperature	40	50	°C
G	Melt temperature	230	250	°C

Table 4.5: Simulation layout using L8 orthogonal array

Set no.	A	B	C	D	E	F	G
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

Table 4.4 shows the factor of the mould design parameter which are diameter cooling channel at cavity half (A), diameter cooling channel at core half (B), number of gate used (C), cooling distance above the product (D), cooling distance below the product (E), mould temperature (F) and melt temperature (G). Also shown in Table 4.4 is the factor level for each of the parameter that will be used in the Taguchi analysis. Each of parameter is design to be in two level which are level 1 and level 2. Level 1

referred to lowest value of parameter while level 2 referred to the highest value of parameter.

In the Table 4.4, the cooling diameter at cavity half and core half are design to be 6 mm and 10 mm respectively. The number of gate used for the analysis is 3 gates and 6 gates which are for level 1 and level 2 respectively. The distance of cooling channel for cavity and core half is design to 15 mm and 20 mm. This value is utilized from the pre-analysis value of parameter. The mould temperature is set to 40 °C and 50 °C while the melt temperature is set to 230 °C and 250 °C.

Table 4.5 shown the experimental layout proposed by Taguchi method using the L_8 orthogonal array and each factors has two levels of parameters. The Table 4.5 shows that in set number 1 or analysis 1, all parameter will use the level 1 parameters which are 6 mm for cooling channel diameter at cavity half, 6 mm of cooling channel diameter at core half, 3 units of gate locations, 15 mm of cooling channel distance at cavity half, 15 mm of cooling channel distance at core half, 40 °C of mould temperature and 230 °C of melt temperature. The rest of analysis is set in the similar manner according to the Table 4.5 data. The value of parameter is shown in Table 4.6. Each analysis or simulation in the Moldflow Plastic Insight software (MPI) will utilized the combination of factor levels. The Taguchi optimization is carried out using this orthogonal array and the result shown in Table 4.7.

Table 4.6: Simulation layout with value of parameter

Set no.	A	B	C	D	E	F	G
1	6	6	3	15	15	40	230
2	6	6	3	20	20	50	250
3	6	10	6	15	15	50	250
4	6	10	6	20	20	40	230
5	10	6	6	15	20	40	250
6	10	6	6	20	15	50	230
7	10	10	3	15	20	50	230
8	6	6	3	15	15	40	230

Table 4.7: Simulation results of warpage and S/N ratio

Set No.	Warpage + z deflection (mm)	Warpage - z deflection (mm)	S/N ratio + z deflection (dB)	S/N ratio -z deflection (dB)
1	2.257	-1.966	-7.071	-5.872
2	1.329	-1.049	-2.471	-0.416
3	2.440	-2.220	-7.748	-6.927
4	2.239	-1.992	-7.001	-5.986
5	0.734	-0.628	2.686	4.041
6	1.507	-1.274	-3.562	-2.103
7	1.187	-0.881	-1.489	1.100
8	1.940	-1.664	-5.756	-4.423

The values of data obtained in the Table 4.7 are the result from the analysis of Moldflow Plastic Insight software which utilized the combination of factor level of parameter in Table 4.6. The results shown are evaluated in term of warpage at +z deflection and -z deflection which means warpage in direction of +z and direction of -z. Also, the value of warpage produce in the analysis is evaluated in term of signal to noise ratio denoted as S/N ratio. Signal to noise ratio is used to represent the quality of the respective product response to noise factors and signal factors. Noise factor can be defined as the factor that cannot be control in the analysis while the signal is the factor that can be control in the analysis such as the distance of the cooling channel. In Table 4.7, the lowest value of warpage is found in the analysis in set number 5 which are 0.734 mm for +z warpage and -0.628 mm for -z warpage. The value of S/N ratio also evaluated for the analysis 5 by exploting equation 3.1 and equation 3.2 in Chapter 3 with 2.686 dB for +z warpage and 4.041 dB for –z warpage. The highest value of warpage is found in analysis set number 3 with 2.440 mm for +z warpage and -2.220 mm for -z warpage. The S/N ratio also found to be -7.748 dB for +z warpage and -6.927 dB for -z warpage. From the results obtained, the higher the S/N ratio for both +z and -z warpage produced the lower value of warpage in the product.

The response table for both positive z deflection and negative z deflection is created by utilizing the value of mean warpage and S/N ratio in Table 4.7. The value of response is recorded in the Table 4.8 with the mean warpage for factor A at level 1 and 2 can be calculated by averaging the warpage +z deflection for the simulation 1-4 and 5-8 respectively. The other factors such as factor B, C, D, E, F and G can be computed in the similar manner.

Table 4.8: Response table for warpage +z deflection

	A	**B**	**C**	**D**	**E**	**F**	**G**
Level 1	2.066	1.457	1.678	1.655	2.036	1.793	1.798
Level 2	1.342	1.952	1.730	1.754	1.372	1.616	1.611
Difference	0.724	0.495	0.052	0.099	0.664	0.177	0.187
Rank	1	3	7	6	2	5	4
Sig. factors	A	B			E		G
Characteristic type		Smaller the better		Nominal the best		Larger the better	
Optimum	A2	B1	C1	D1	E2	F2	G2

In Table 4.8, all of the mean warpage for the parameter is calculated and recorded according to its level. For the cooling channel diameter at cavity half that denoted as A the mean warpage for level 1 is 2.066 mm and for level 2 is 1.342 mm. For other parameter such as diameter of cooling channel at core half denoted as B, number of gate used denoted as C, distance of cooling channel at cavity half denoted as D, distance of cooling channel at core half denoted as E, mould temperature denoted as F and melt temperature denoted as G is calculated the same way for the mean warpage for each level. Then, the difference between the levels for each parameter is computed to rank it according to the highest the difference value gives the most significance parameter. In Table 4.8, the most significance parameter is parameter A, B, E and G. The optimum values in the Table 4.8 represent the recommended value to be used to get the minimized warpage.

Table 4.9 shows the S/N ratio for warpage +z deflection response values that can be calculated in similar manner as Table 4.8 and the values the S/N ratio graph is plotted in Figure 4.2. The average Eta term is also called S/N ratio. In Table 4.9, the most significance parameter that will maximize the S/N ratio is found from parameter A, B, E and also G. It is required to maximize the S/N ratio since the higher the S/N ratio will minimize the value of warpage.

Table 4.9: Signal to Noise ratio (S/N) response table for warpage +z deflection

	A	**B**	**C**	**D**	**E**	**F**	**G**
Level 1	-6.073	-2.604	-4.197	-4.749	-6.034	-4.286	-4.781
Level 2	-2.030	-5.499	-3.906	-4.697	-2.069	-3.073	-3.322
Difference	4.043	2.895	0.291	0.052	3.965	1.213	1.459
Rank	1	3	6	7	2	5	4
Sig. factors	A	B			E		G
Characteristic type		Smaller the better		Nominal the best		Larger the better	
Optimum	A2	B1	C2	D2	E2	F2	G2

Also, the response table for the mean warpage -z deflection and its response table for S/N ratio are created the same way as for warpage +z deflection. The response table for mean warpage is tabulated in Table 4.10 and according to the data obtained from the Table 4.10, the most significance of parameter that influence the warpage value for -z deflection is from parameter A, B, E and F. It can be defined that most warpage influenced from cooling channel diameter at cavity half, cooling channel diameter at core half, cooling distance at core half and mould temperature.

Table 4.10: Response table for warpage -z deflection

	A	**B**	**C**	**D**	**E**	**F**	**G**
Level 1	-1.807	-1.229	-1.390	-1.424	-1.781	-1.563	-1.528
Level 2	-1.112	-1.672	-1.529	-1.495	-1.138	-1.356	-1.390
Difference	0.695	0.443	0.139	0.071	0.643	0.207	0.138
Rank	1	3	5	7	2	4	6
Sig. factors	A	B			E	F	
Characteristic type		Smaller the better		Nominal the best		Larger the better	
Optimum	A2	B1	C1	D1	E2	F2	G2

Table 4.11: Signal to Noise ratio (S/N) response table for warpage -z deflection

	A	**B**	**C**	**D**	**E**	**F**	**G**
Level 1	-4.800	-1.088	-2.403	-1.915	-4.831	-3.060	-3.215
Level 2	-0.346	-4.059	-2.744	-3.232	-0.315	-2.087	-1.931
Difference	4.454	2.971	0.341	1.317	4.516	0.973	1.284
Rank	2	3	7	4	1	6	5
Sig. factors	A	B		D	E		
Characteristic type		Smaller the better		Nominal the best		Larger the better	
Optimum	A2	B1	C1	D1	E2	F2	G2

The response table for S/N ratio is tabulated in Table 4.11 and the value of the S/N ratio graph is plotted in the Figure 4.3. In Table 4.11, the most significance parameter that influenced the warpage value came from parameter A, B, D, and E. In addition, the Table 4.11 shows the optimum condition of parameter that will maximized the S/N ratio of the -z deflection. From the value in the entire response table for Table 4.8, 4.9, 4.10 and 4.11, the factor level that minimized the warpage result for the hexagonal plastic floor tile can be identified. The difference value for the entire response table can be calculated by taking difference between level 1 and level 2. From the difference values, the ranking from the highest to the lowest difference value can be obtained. Since the degree of freedom for this orthogonal array is 7 which this data can be computed from equation 3.3 in chapter 3, only half of the degree of freedom can be consider as the most significance factor. The rest of factor is not significance in influencing the value of warpage. In doing so, the most significance parameter for +z warpage deflection are factor A, B, E and G while for the –z warpage deflection are factor A, B, E and F.

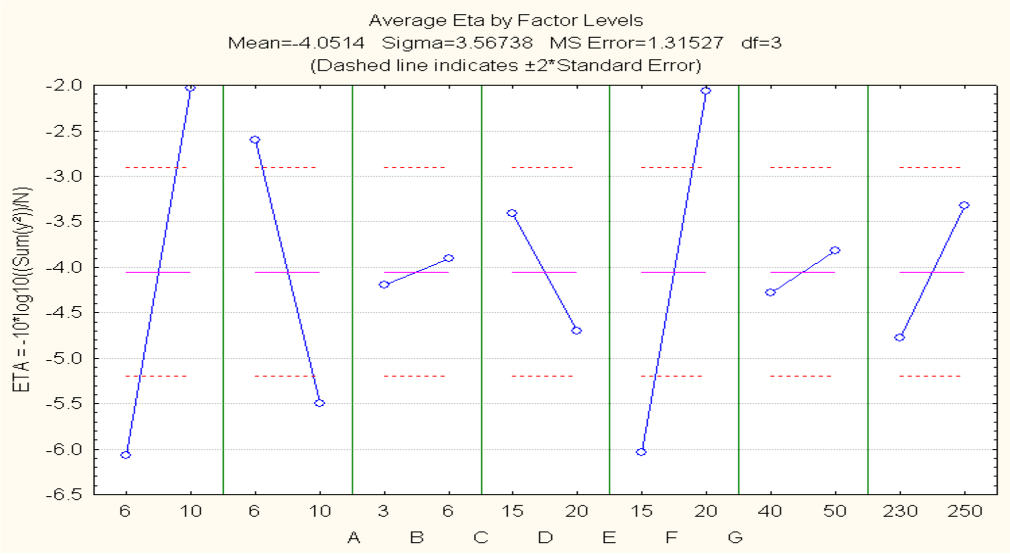

Figure 4.2: Graph of S/N ratio by factor level for +z deflection

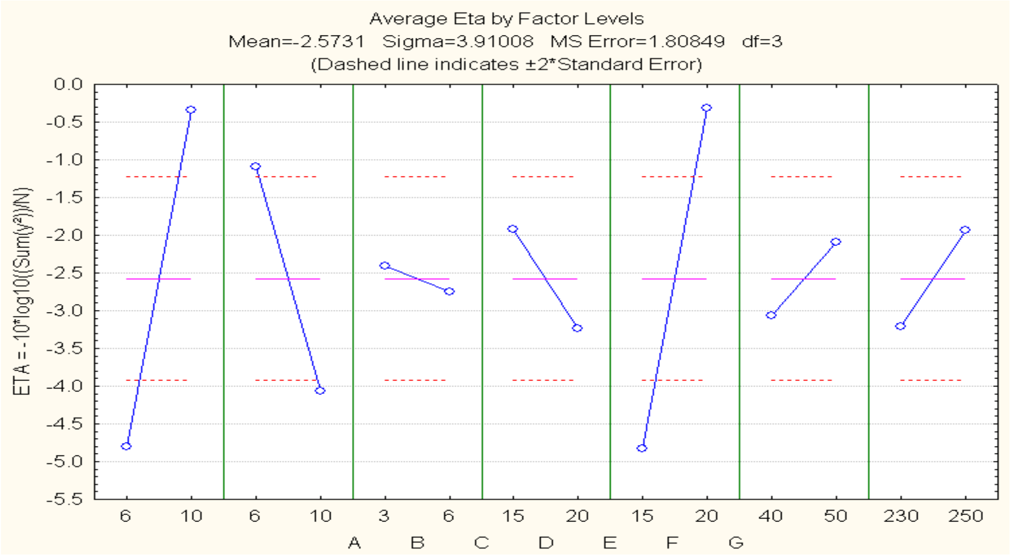

Figure 4.3: Graph of S/N ratio by factor level for –z deflection

The Figure 4.2 and Figure 4.3 is computed by utilizing the value of the signal to noise ratio from the Table 4.7. It represent the visual summary of the simulation of the product design in the Taguchi orthogonal array. From the plotted graph, the optimum setting of parameter for minimizing the warpage is identified. The dash line shows in the above graph indicate the two times standard error limits around the mean S/N ratio or *Eta*. This standard error is computed from the error term. The details of the error term is tabulated in the table in Appendix C1 and Appendix C3 . As the Taguchi optimization is based on the smaller the better type, the analysis must maximizing the signal to noise ratio in order to minimize the warpage values. From the graph, the most factor level that maximized the signal to noise ratio is recognized. In Figure 4.2, the graph shows that the highest S/N ratio is found from the parameter cooling channel diameter at cavity half denoted as A, the second highest S/N ratio is found in parameter cooling channel diameter at core half denoted as B and also from parameter cooling channel distance at core half denoted as E. The graph in Figure 4.3 also shows the same results that are the highest S/N ratio are found in parameter A, B and E.

4.3 ANALYSIS OF VARIANCE RESULTS

The analysis of variance (ANOVA) is analyzed to find the relative percentage contribution among the factors. ANOVA computing the quantities such as degree of freedom (f) sums of squares, variance, F-ratio and percentage contributions. The result from the ANOVA analysis is recorded in Table 4.12 and Table 4.13 for +z deflection and -z deflection respectively. It is required to perform the ANOVA analysis to determine the contribution of warpage from the parameter that has been identified from the previous section 4.2.

Table 4.12: ANOVA table for +z warpage deflection

Source	***S***	***f***	***V***	***F-ratio***	***S'***	***P* (%)**
A	1.04494	1	1.04494	-	1.04494	40.49135
B	0.48956	1	0.48956	-	0.48956	18.97041
C	0.00536	1	0.00536	-	0.00536	0.207700
D	0.01970	1	0.01970	-	0.01970	0.763374
E	0.88113	1	0.88113	-	0.88113	34.14372
F	0.06248	1	0.06248	-	0.06248	2.421095
G	0.06975	1	0.06975	-	0.06975	2.702807
e	0.00773	-	-			
St	2.58065	-	-			
Mean	23.23234	1	-			
Total	25.80939	8	-			100

In Table 4.12 and Table 4.13, the source shows the parameter used in the simulation which are A, B, C, D, E, F and G. The symbol denoted as e referred to sum of squares due to error, St refers to total sum of squares, mean is the sum of square due to mean, *S* is referred as sum of square due to factors, *f* is referred as degree of freedom, *V* is mean sum of square for each factor, *S'* is pure sum of square. All the data is computed by exploiting the equation in section 3.4.

Table 4.13: ANOVA table for -z warpage deflection

Source	***S***	***f***	***V***	***F-ratio***	***S'***	***P* (%)**
A	0.966050	1	0.966050	-	0.966050	40.43313
B	0.423200	1	0.423200	-	0.423200	17.71265
C	0.038364	1	0.038364	-	0.038364	1.605711
D	0.010082	1	0.010082	-	0.010082	0.421973
E	0.828184	1	0.828184	-	0.828184	34.66290
F	0.085285	1	0.085285	-	0.085285	3.569504
G	0.038088	1	0.038088	-	0.038088	1.594138
e	0.000000	-	-			
St	2.389254	-	-			
Mean	17.03528	1	-			
Total	19.42454	8	-			100

The last column in both Table 4.12 and Table 4.13 shows the percentage contribution for each of the mould design parameter. The most significance of parameter has greater percentage and non-significance parameter exhibit less percentage of contribution.

From both of the table, the most significance parameter that influence the warpage problem are from diameter of cooling channel at cavity half (A), cooling channel distance at core half (E) and diameter of cooling channel at core half (B). It can be observed from ANOVA results in Table 4.12 that the factor A, E, B, G, F, D, and C influences the warpage in +z deflection by 40.49%, 34.14%, 18.97%, 2.70%, 2.42%, 0.76% and 0.21% respectively. Also, from Table 4.13 the factor A, E, B, F, C, G, and D give significance contribution to warpage by 40.43%, 34.66%, and 17.71%, 3.57%, 1.61%, 1.59% and 0.42% respectively.

4.4 DETERMINATION OF OPTIMUM VALUES THAT THE MINIMIZED WARPAGE

In determining the optimum values that minimize the warpage for +z deflection and -z deflection, the data from the response table in Table 4.8, Table 4.9, Table 4.10 and Table 4.11 is utilized.

From the data in Table 4.8 the highest difference of warpage for +z deflection according to rank are factor A2, E2, B1, G2, F2, D1 and C1. Also, from data in Table 4.9 which shows the optimum value of factor that maximize the S/N ratio can be utilized to predict the expected value of S/N ratio that minimize the warpage in +z deflection.

According to the ranking for each factor by difference level, the optimum values of factor that give the expected S/N ratio are factor A2, E2, B1, G2, F2, C2 and D2. Note that, only half of the factor that give most significance in influencing the warpage should be used to predict the optimum condition while the other which gives the less significance in influencing the warpage for both direction of deflection can be kept in the recommended values of mould analyser and excluded from utilizing into the prediction model and Taguchi optimization process.

For the prediction of the warpage +z deflection:

$$= \grave{y} + (A2 - \grave{y}) + (E2 - \grave{y}) + (B1 - \grave{y}) + (G2 - \grave{y})$$

$$= 1.704 + (1.342 - 1.704) + (1.372 - 1.704) + (1.457 - 1.704) + (1.611 - 1.704)$$

$$= 0.670 \text{ mm}$$

For the prediction of S/N ratio for warpage +z deflection:

$$= y + (A2-y) + (E2-y) + (B1-y) + (G2-y)$$

$$= -4.051 + (-2.030+4.051) + (-2.069+4.051) + (- 2.604+4.051) + (-3.322+4.051)$$

$$= 2.128 \text{ dB}$$

For the prediction of the warpage -z deflection:

$$= \hat{y} + (A2-\hat{y}) + (E2-\hat{y}) + (B1-\hat{y}) + (F2-\hat{y})$$

$$= -1.459 + (-1.112+1.459) + (-1.138+1.459) + (-1.229+1.459) + (-1.356+1.459)$$

$$= -0.458 \text{ mm}$$

For the prediction of the warpage -z deflection:

$$= \hat{y} + (E2-\hat{y}) + (A2-\hat{y}) + (B1-\hat{y}) + (D1-\hat{y})$$

$$= -2.573 + (-0.315+2.573) + (-0.346+2.573) + (-1.088+2.573) + (-1.915+2.573)$$

$$= 4.055 \text{ dB}$$

From these results, it can be founded that optimum of factor values used to predicted the minimum warpage for both positive and negative z deflection has give the minimum warpage of 0.670mm and -0.458mm for warpage +z deflection and warpage -z deflection respectively. This is the optimum value for both z deflections since 0.734mm and -0.628mm is the smallest value of z deflection among the analysis results.

4.5 CONFIRMATION TEST

Once the optimum level of factor that minimizes the warpage is selected, the confirmation test is performed to increase the efficiency of the applied process within the optimum level of factors. In this study, the confirmation test is carried out by utilizing the optimum level of factor for both type of z deflection; positive and negative.

For the warpage of +z deflection, the parameters used are A2, E2, B1 and G2 while for –z deflection of warpage, the parameters used are A2, E2, B1 and F2. The results of this confirmation test are shown in the Figure 4.4. In addition, by utilizing the Taguchi optimization method, the result from the predicted value in Taguchi optimization method has improved the minimum warpage for both deflections from the result in simulation of Moldflow.

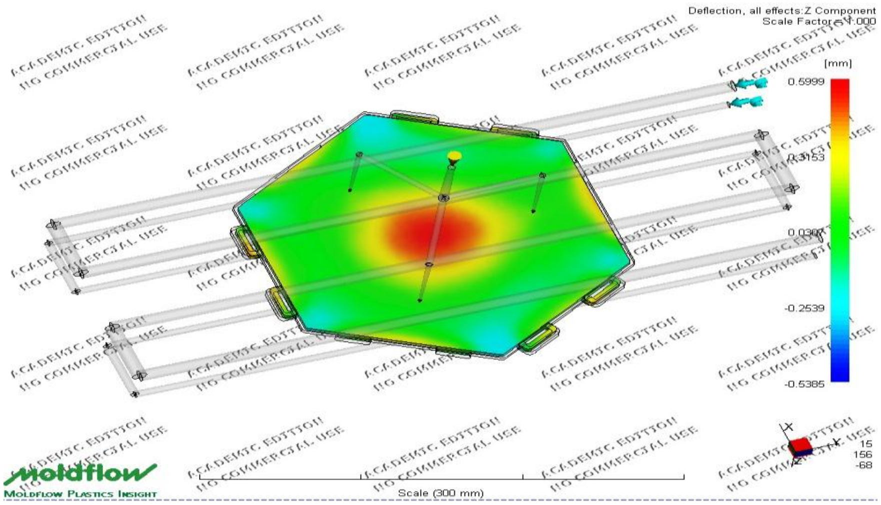

Figure 4.4: Confirmation result by Moldflow analysis

The percentage of improvement is performed as well in order to find by how much the Taguchi method improve the value of warpage to be minimized. The percentage of improvement is calculated for warpage value of +z deflection and -z deflection.

For +z deflection of warpage:

$$+z\ deflection\ improvement = \frac{0.734 - 0.670}{0.734} \times 100$$

= 8.72%

For -z deflection of warpage:

$$-z\ deflection\ improvement = \frac{-0.628 + 0.458}{-0.628} \times 100\%$$

= 27.07%

In addition, the results produced by the confirmation test also being compared with the initial value of the warpage and the values are tabulated in Table 4.14. In Table 4.14, the result shows that for +z deflection, the initial value of warpage has been reduced from 0.730 mm into much smaller value of warpage which is 0.5999 mm. The produced result is found when simulating the confirmation test of the optimal condition of parameter that has been improved using the Taguchi method.

Table 4.14: Comparison after Taguchi optimization

Warpage	**Initial warpage value (mm)**	**Confirmation test value (mm)**
+z deflection	0.7340	0.5999
-z deflection	-0.6280	-0.5385

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This study was focused on the application of Taguchi optimization technique in order to find the optimum levels of mould design parameters used in injection of hexagonal plastic floor tile for indoor sport activities. In doing this, the orthogonal array of $L_{8,}$ S/N ratio, ANOVA were utilized in integrated manner. The result has shown that the value of warpage performed by Moldflow Plastic Insight software (MPI) can be optimize for the more scale of value of warpage.

The project starts with the preparation of the design of the hexagonal plastic floor tile. The design of hexagonal shape is selected and builds with interlocking features on it. The product is design for the sport application purpose with properties of soft but increased resistance due to the fast movement act on it. The product is design with rib features below the product part to increase its stiffness and the CAD software is utilized in modeling the product design. The another method which is analyzing the product in Moldflow Plastic Insight software (MPI) is undertaken with importing the CAD solid design using IGES format and then the meshing of the part is implemented.

Initially, the simulation of the Moldflow Plastic Insight software (MPI) is performed for the hexagonal plastic floor tile which has the top thickness of 2mm but the simulation results produce the high value of warpage for the product. Another initiative is introduced which is by increasing the top thickness of the hexagonal plastic floor tile to be 4mm. In doing so, the simulation of warpage which produce less warpage is obtained.

As the plastic material used for hexagonal plastic floor tile is made from thermoplastic elastomer (TPE) which has soft feature, the thin thickness of product tend to increase the possibility to warp the product from its original shape. Thus, increasing the thickness of the product has increased its stiffness and able to withstand the bending moment created from the differential shrinkage within the cavity half and core half of the mould.

5.1 SUMMARIZED OF OPTIMIZATION VALUE

In getting the optimum condition that minimized the warpage problem, Taguchi approach is undertaken. In doing so, the L8 orthogonal array simulation is selected in order to analyze the warpage of the hexagonal plastic floor tile in the Moldflow Plastic Insight software (MPI). The factor level used in the orthogonal array is two level which represent the lowest and highest value of parameter used in the simulation. In addition, as the objective of the project is to minimize the warpage value of the hexagonal plastic floor, the smaller the better analysis type is chosen. The signal to noise ratio or S/N ratio is utilized as the maximum value of S/N ratio give the minimal warpage value.

The contribution percentage of warpage for the parameter used in Moldflow Plastic Insight software (MPI) is conducted to determine the most parameter that contributes in producing warpage. The percentage contribution is calculated by using the Analysis of variance, ANOVA. From the result, the cooling channel diameter at cavity half is the most parameter that influenced the warpage in +z deflection. It contributes about 40.49%. Similar to warpage in -z deflection, the most parameter that influence the warpage is cooling channel diameter at cavity half with 40.43%.

In this section, the value which has being optimized from the Taguchi optimization method is summarized in the Table 5.1. The value of the mould design parameter including the cooling channel diameter, distance of the channel, number of gate used, mould temperature and also the melt temperature has been optimized to the level that minimized the warpage problem which appear for the flat design of product. The value of from the optimization in this project can be utilized for further process which is the mould design and fabrication process of the hexagonal plastic floor tile. The time consumption in finding the parameter value that minimizing the warpage value is reduced so that the fabrication of the hexagonal plastic floor tile mould will be much easier.

Table 5.1: Optimization value of Mould design

Parameter	Value	Units
Cooling diameter at cavity half	10	mm
Cooling diameter at core half	6	mm
Number of gate	3	-
Channel distance at cavity half	15	mm
Channel distance at core half	20	mm
Mould temperature	50	°C
Melt temperature	250	°C

Based on the Table 5.1, the optimum value produced from the Taguchi method can be implementing to the future mould fabrication of the hexagonal plastic floor tile mould. Shown in the Table 5.1, cooling channel diameter at cavity half of the mould should be design 10 mm from the surface of the product, cooling channel diameter at core half should be design 6 mm from surface of the product while the number of gate used is 3 units. It is also proved that, using multiple numbers of gates is not improving the result of the warpage. In addition, the distance of the cooling channel at cavity half must be design 15 mm from the surface of the product while the distance of the cooling channel at core half should be design in 20 mm from the product surface. Mould temperature is suggested to be 50 °C and melt temperature of 250 °C.

5.2 RECOMMENDATION

As for the recommendation for the future, the parameter used for the simulation process in the Moldflow Plastic Insight software should be increased to get the better result of warpage. The possible parameter that can be included in the future Taguchi method are injection pressure, clamping pressure and position of gate instead using number of gate only. Size of runner used also can be used in the future analysis in the Taguchi method in order to improve the value of warpage.

In addition, the orthogonal array used for the Taguchi optimization method also should be increased including the number of factor level such as lower, medium and higher level instead of using lower and higher level. Since the factor selected in this project is seven parameters, the available factor level in the Taguchi orthogonal layout is two levels. It is recommended as the more variety of factor level will compute the more fine result

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APPENDIXES

APPENDIX A1

FLOWCHART OF THE PROJECT

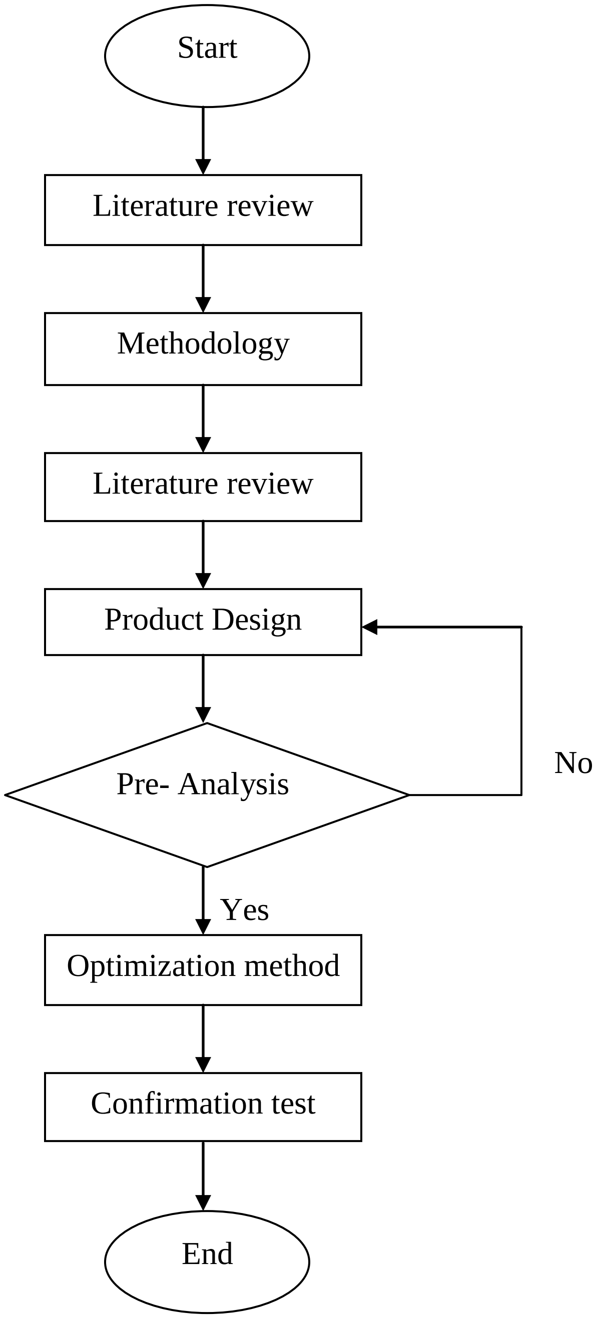
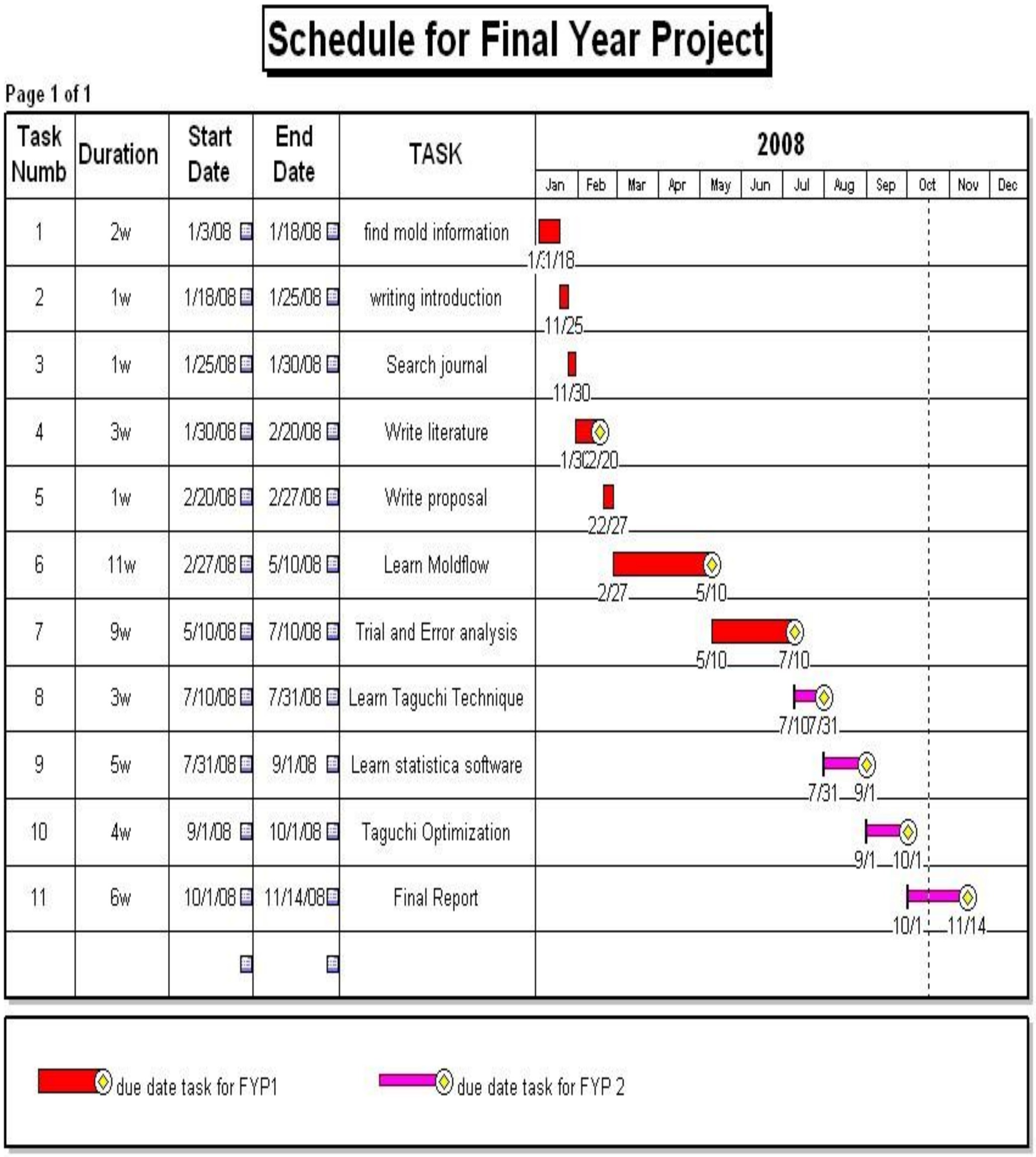


Figure 1: Flow chart of the project

APPENDIX A2

TIMELINE OF THE PROJECT



Schedule for Final Year Project

Page 1 of 1

Task Numb	Duration	Start Date	End Date	TASK
1	2w	1/3/08	1/18/08	find mold information
2	1w	1/18/08	1/25/08	writing introduction
3	1w	1/25/08	1/30/08	Search journal
4	3w	1/30/08	2/20/08	Write literature
5	1w	2/20/08	2/27/08	Write proposal
6	11w	2/27/08	5/10/08	Learn Moldflow
7	9w	5/10/08	7/10/08	Trial and Error analysis
8	3w	7/10/08	7/31/08	Learn Taguchi Technique
9	5w	7/31/08	9/1/08	Learn statistica software
10	4w	9/1/08	10/1/08	Taguchi Optimization
11	6w	10/1/08	11/14/08	Final Report

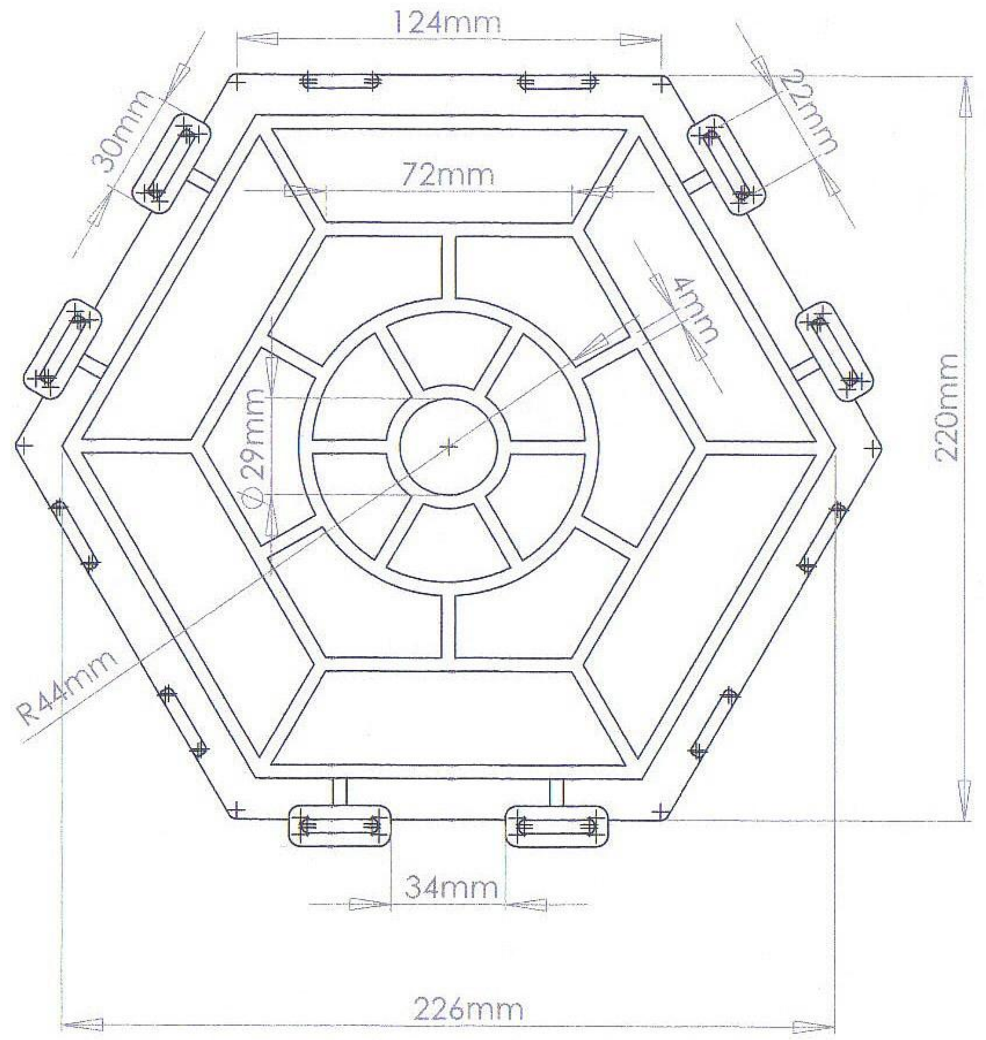
🟥 due date task for FYP1

🟪 due date task for FYP 2

Figure 2: The time line of project

APPENDIX A3

Hexagonal Tile Floor Dimension



APPENDIX B1

TAGUCHI LAYOUT ANALYSIS RESULT

Analysis 1

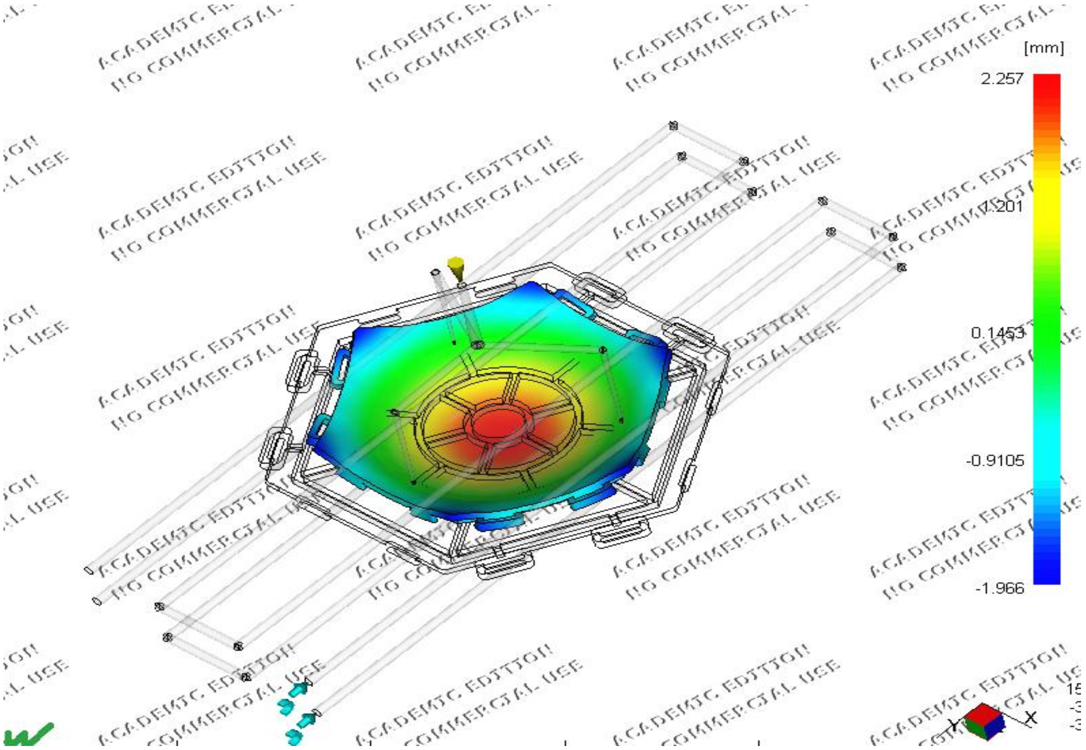


Figure 3: Taguchi analysis 1

APPENDIX B2

TAGUCHI LAYOUT ANALYSIS RESULT
Analysis 3

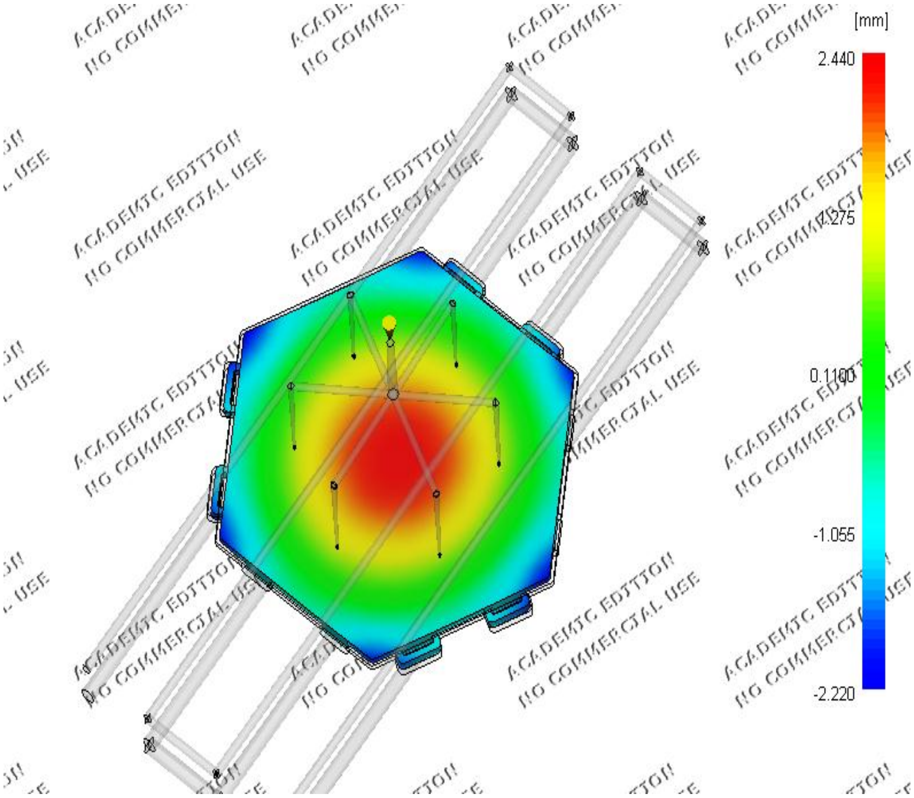


Figure 4: Taguchi analysis 3

APPENDIX B3

TAGUCHI LAYOUT ANALYSIS RESULT
Analysis 7

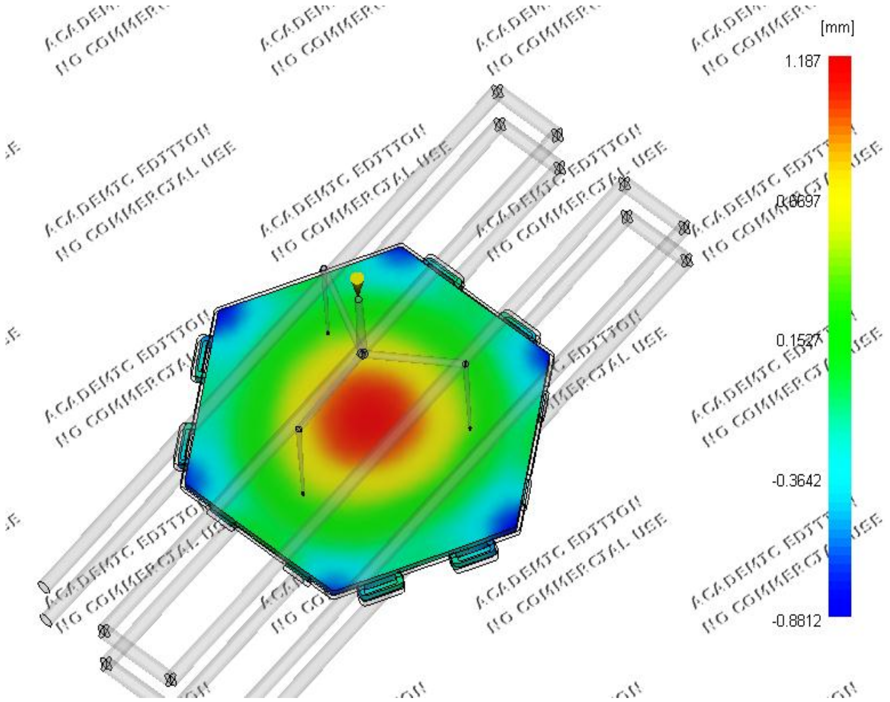


Figure 5: Taguchi Analysis 7

APPENDIX B4

TAGUCHI LAYOUT ANALYSIS RESULT

Analysis 8

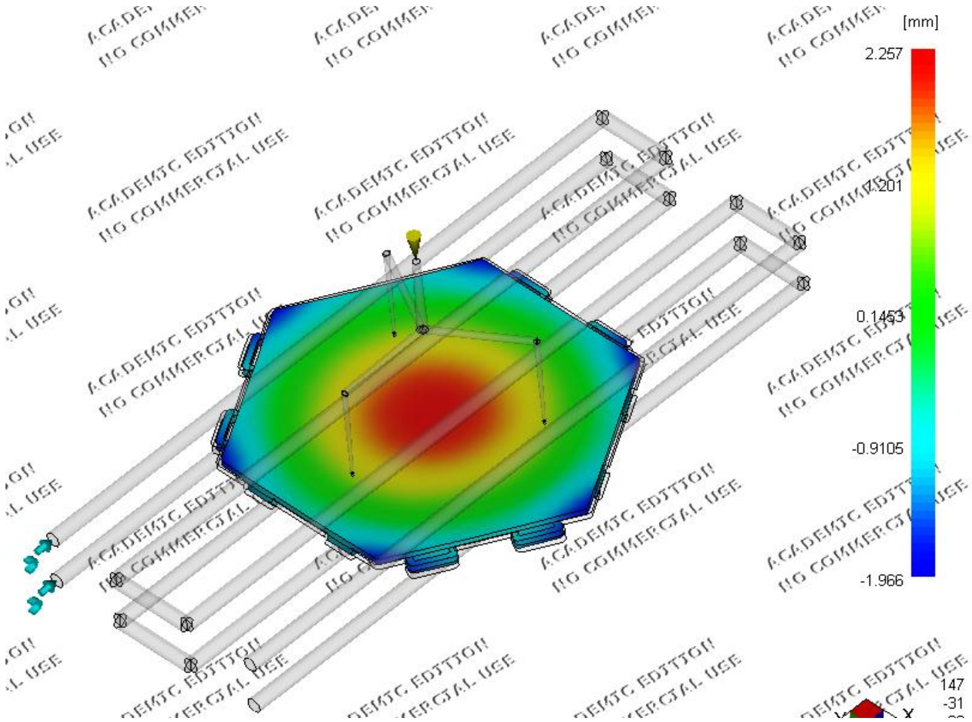
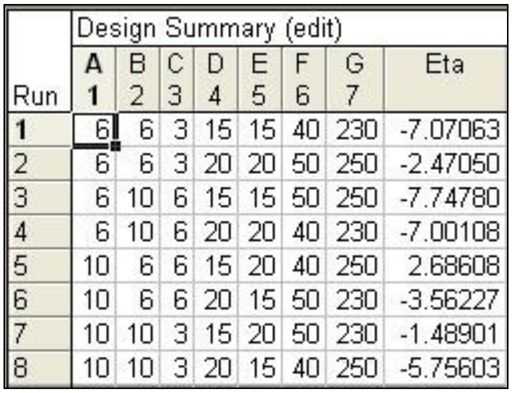


Figure 6: Taguchi Analysis 8

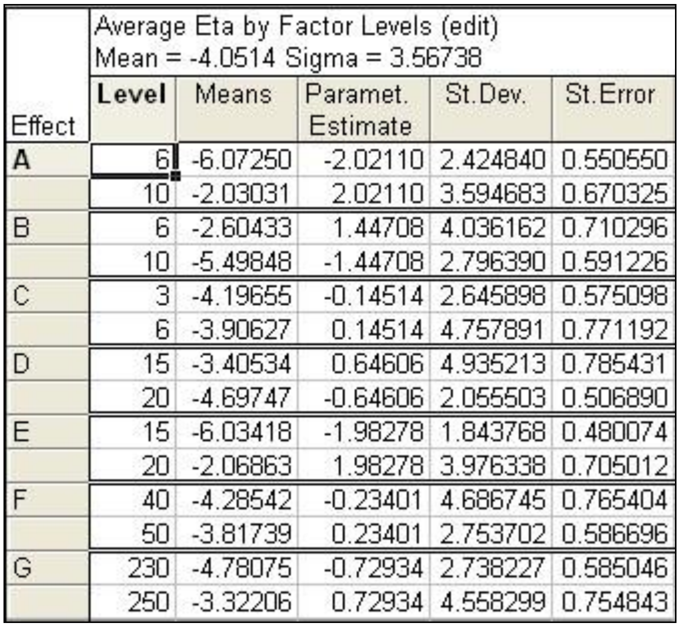
APPENDIX C1

STATISCA SOFTWARE RESULTS



	Design Summary (edit)							
Run	**A** **1**	B 2	C 3	D 4	E 5	F 6	G 7	Eta
1	6	6	3	15	15	40	230	-7.07063
2	6	6	3	20	20	50	250	-2.47050
3	6	10	6	15	15	50	250	-7.74780
4	6	10	6	20	20	40	230	-7.00108
5	10	6	6	15	20	40	250	2.68608
6	10	6	6	20	15	50	230	-3.56227
7	10	10	3	15	20	50	230	-1.48901
8	10	10	3	20	15	40	250	-5.75603

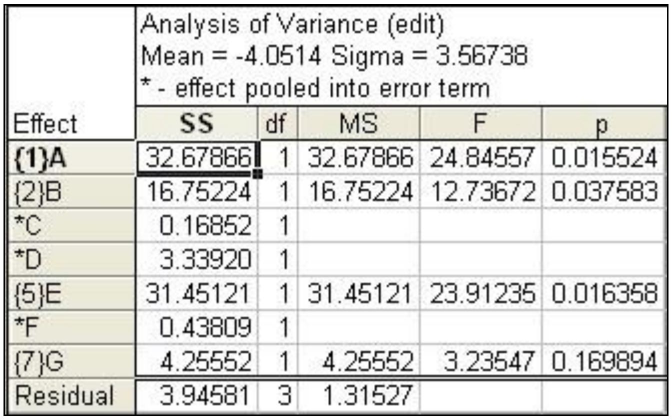
Figure 7: S/N ratio for +z direction



	Average Eta by Factor Levels (edit) Mean = -4.0514 Sigma = 3.56738				
Effect	**Level**	Means	Paramet. Estimate	St.Dev.	St.Error
A	6	-6.07250	-2.02110	2.424840	0.550550
	10	-2.03031	2.02110	3.594683	0.670325
B	6	-2.60433	1.44708	4.036162	0.710296
	10	-5.49848	-1.44708	2.796390	0.591226
C	3	-4.19655	-0.14514	2.645898	0.575098
	6	-3.90627	0.14514	4.757891	0.771192
D	15	-3.40534	0.64606	4.935213	0.785431
	20	-4.69747	-0.64606	2.055503	0.506890
E	15	-6.03418	-1.98278	1.843768	0.480074
	20	-2.06863	1.98278	3.976338	0.705012
F	40	-4.28542	-0.23401	4.686745	0.765404
	50	-3.81739	0.23401	2.753702	0.586696
G	230	-4.78075	-0.72934	2.738227	0.585046
	250	-3.32206	0.72934	4.558299	0.754843

Figure 8: Average Eta by factor level

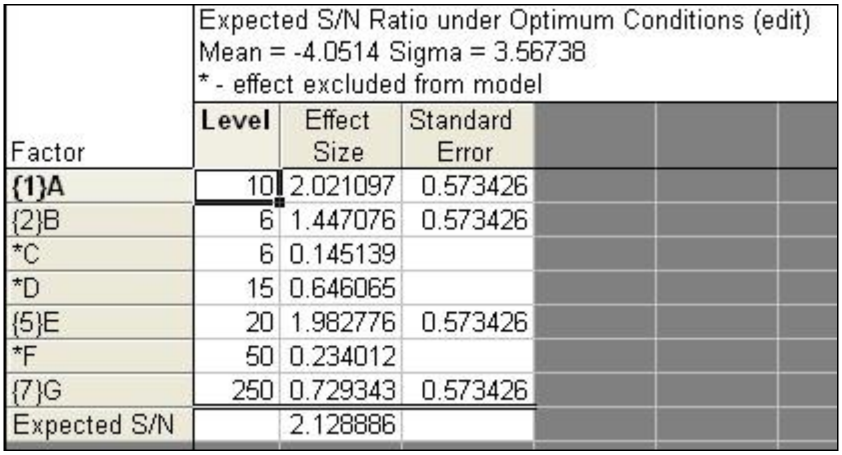
APPENDIX C2



Analysis of Variance (edit)
Mean = -4.0514 Sigma = 3.56738
* - effect pooled into error term

Effect	SS	df	MS	F	p
{1}A	32.67866	1	32.67866	24.84557	0.015524
{2}B	16.75224	1	16.75224	12.73672	0.037583
*C	0.16852	1			
*D	3.33920	1			
{5}E	31.45121	1	31.45121	23.91235	0.016358
*F	0.43809	1			
{7}G	4.25552	1	4.25552	3.23547	0.169894
Residual	3.94581	3	1.31527		

Figure 9: ANOVAs results with pooling effect

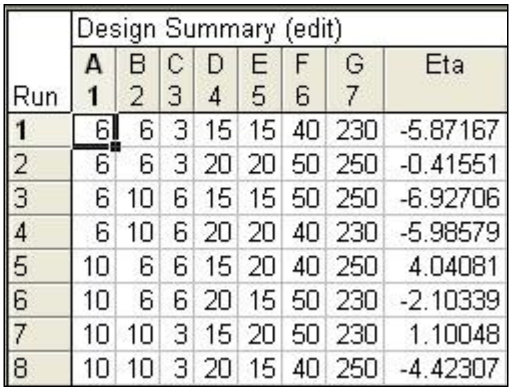


Expected S/N Ratio under Optimum Conditions (edit)
Mean = -4.0514 Sigma = 3.56738
* - effect excluded from model

Factor	Level	Effect Size	Standard Error
{1}A	10	2.021097	0.573426
{2}B	6	1.447076	0.573426
*C	6	0.145139	
*D	15	0.646065	
{5}E	20	1.982776	0.573426
*F	50	0.234012	
{7}G	250	0.729343	0.573426
Expected S/N		2.128886	

Figure 10: Expected S/N ratio under optimum conditions

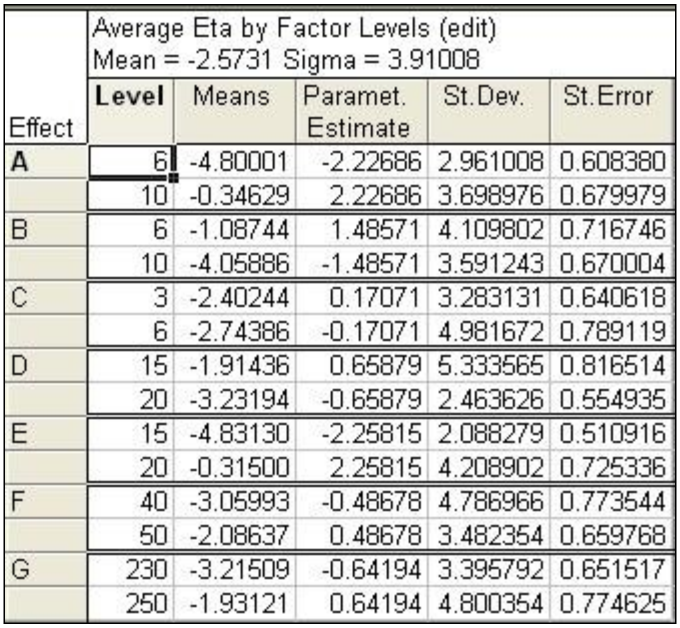
APPENDIX C3



Design Summary (edit)

Run	A 1	B 2	C 3	D 4	E 5	F 6	G 7	Eta
1	6	6	3	15	15	40	230	-5.87167
2	6	6	3	20	20	50	250	-0.41551
3	6	10	6	15	15	50	250	-6.92706
4	6	10	6	20	20	40	230	-5.98579
5	10	6	6	15	20	40	250	4.04081
6	10	6	6	20	15	50	230	-2.10339
7	10	10	3	15	20	50	230	1.10048
8	10	10	3	20	15	40	250	-4.42307

Figure 11: S/N ratio for -z deflection

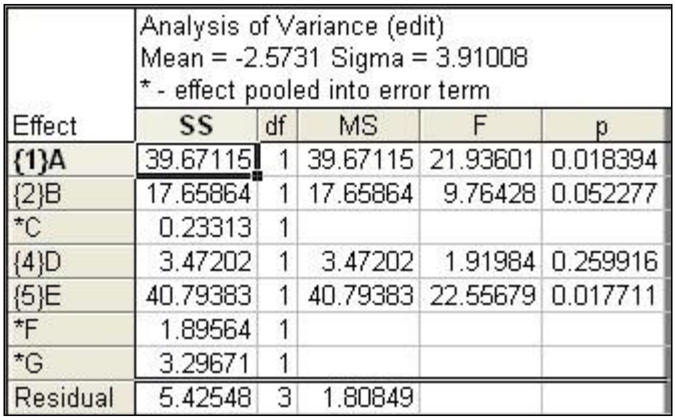


Average Eta by Factor Levels (edit)
Mean = -2.5731 Sigma = 3.91008

Effect	Level	Means	Paramet. Estimate	St.Dev.	St.Error
A	6	-4.80001	-2.22686	2.961008	0.608380
	10	-0.34629	2.22686	3.698976	0.679979
B	6	-1.08744	1.48571	4.109802	0.716746
	10	-4.05886	-1.48571	3.591243	0.670004
C	3	-2.40244	0.17071	3.283131	0.640618
	6	-2.74386	-0.17071	4.981672	0.789119
D	15	-1.91436	0.65879	5.333565	0.816514
	20	-3.23194	-0.65879	2.463626	0.554935
E	15	-4.83130	-2.25815	2.088279	0.510916
	20	-0.31500	2.25815	4.208902	0.725336
F	40	-3.05993	-0.48678	4.786966	0.773544
	50	-2.08637	0.48678	3.482354	0.659768
G	230	-3.21509	-0.64194	3.395792	0.651517
	250	-1.93121	0.64194	4.800354	0.774625

Figure 12: Average Eta by factor level

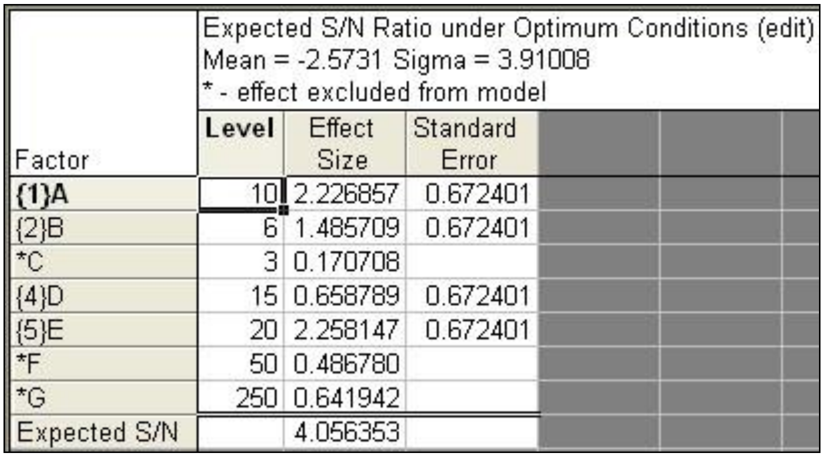
APPENDIX C4



Analysis of Variance (edit)
Mean = -2.5731 Sigma = 3.91008
* - effect pooled into error term

Effect	SS	df	MS	F	p
{1}A	39.67115	1	39.67115	21.93601	0.018394
{2}B	17.65864	1	17.65864	9.76428	0.052277
*C	0.23313	1			
{4}D	3.47202	1	3.47202	1.91984	0.259916
{5}E	40.79383	1	40.79383	22.55679	0.017711
*F	1.89564	1			
*G	3.29671	1			
Residual	5.42548	3	1.80849		

Figure 13: ANOVAs result with pooling effect



Expected S/N Ratio under Optimum Conditions (edit)
Mean = -2.5731 Sigma = 3.91008
* - effect excluded from model

Factor	Level	Effect Size	Standard Error
{1}A	10	2.226857	0.672401
{2}B	6	1.485709	0.672401
*C	3	0.170708	
{4}D	15	0.658789	0.672401
{5}E	20	2.258147	0.672401
*F	50	0.486780	
*G	250	0.641942	
Expected S/N		4.056353	

Figure 14: Expected S/N ratio for -z deflection