Pilot Study on Laminated Tooling with Implementation of Conformal Channel

by

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the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

EE TEIK MUN

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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ABSTRACT

This case study describes implementation of conformal channel in laminated tooling. Laminated tooling is a simple and fast way to make metal tools directly for injection molds in the rapid prototyping field. Injection moulding is the most common mass production process for plastic parts. All thermoplastics and some thermosets can be injection moulded to achieve a wide variety of sizes and intricate shapes. Injection moulded parts can be found from electronics and power tools to appliances. Due to the large impact that injection moulding has on the manufacturing industry, companies constantly strive to shorten both cycle and product development time. Cooling channel design is important in mould designs to achieve shorter cycles and reduced part stresses. Traditionally, cooling channels have been machined into mould components to avoid interference with the ejection system and other mould details. Over the years straight conventional drilled cooling channels have given away to conformal technique.

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First of all, I would like to thank my family for endless support. Without them, I would not be able to complete this project.

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

In the plastic part production, the injection moulding process plays a crucial role for mass production of polymer products. A good injection mould can produce plastic products with desired shape, accuracy and in a short cycle time. In the injection moulding process, cycle time has been prime interest as it determines, to a large extent, the cost of the product produced. The moulding cycle time is made up of the following elements: moulding closing time, mould filling time, melt packing and holding time, part cooling time, mould open time and ejection time. Of these phase, one of the longest and significant time is the part cooling time, which accounts up to 85% of the total cycle time [1}. This cooling time is dependent greatly on the configuration of the cooling channel system that is used to remove heat from the injection mould. Traditionally, this has been achieved by creating several conventional straight drilled holes inside the mould and circulates a cooler liquid to conduct the excess heat away from the part so that the part can be easily ejected. Conventional machining process like drilling will be applied to create these holes. However, this simple technology only creates straight circular holes and not conformals.

1.1 BACKGROUND

The successful development of rapid tooling (RT) will rely on the advantages developed in the RP world, such as sliced CAD data, fast material processing times and innovative joining techniques. The net result will be the production of tools which will be fit for production purposes rather than the typical paper or resin model produced in RP and avoiding the long lead time and expense incurred by using conventional tool making methods.

Laminated tooling involves assembling an array of laminates with each having a uniquely profiled edge and shape. In this project, the linear hack saw machine and milling machine will be used. Layering technique have become a well established way of producing rapid prototypes (RP) such as to cut paper (laminated object manufacturing) or powered laser is used to cure resin (stereolithography).

Even though laminated tooling technique or strategy appears to reduce the cost and time associated with the production of a tool, it sometimes produces an uneven surface finish which, in some situations, must require finishing or rework on the tool as the unevenness of the surface finish portion must be made to be relatively smooth and uniform.

1.2 Problem Statement

Conventional steel tools generally are CNC machined or electrical discharge machined (EDM) from a solid block of tool steel. Consequently, the cooling channels also must be drilled into solid steel. As a result, these channels essentially consist of a series of interconnecting straight segments, each having a circular cross-section. This operation unavoidably results in important limitation.

Since the cooling channels are straight-drilled, they cannot be made to conform to the curved shapes typical of injection molded plastic parts. The result is that some regions of the plastic are better cooled than other regions. The cooler plastic regions reach their solidification point earlier than the hotter regions. When the cooler regions solidify, they shrink. Somewhat later, when the hotter regions finally have cooled sufficiently to solidify, they also shrink. However, the material shrinking last is attached to the plastic that had previously undergone shrinkage. This delayed shrinkage, occurring after attachment, behaves like a bi-metallic strip. The result is significant internal stress and part distortion.

The cooling time is also dependent on several factors, i.e. the quantity of the plastic, component geometry and the efficiency of the cooling channels. Studies have shown that cooling time could be reduced significantly if the cooling channels followed the contours of the tool cavity [2].

1.3 Objectives and Scope of Study

The aim of this study is to investigate, analyze and quantify the effect of straight channel and conformal channel

The objectives of the study:

- To execute the experimental plan
- To design, fabricate & test the tooling

CHAPTER 2

LITERATURE REVIEW

2 Early Development of Laminated Tooling

Research and development in the field of metal sheet lamination technology has been done since the early 1980s by Nakagawa and Suzuki [3]. As a result of the accumulated know-how, it was decided to use a metal sheet lamination technology for Rapid Tooling of large car body parts [2]. For this purpose the Toyota group has launched a project to develop an automated process for the manufacturing of forming tools by Himmer (1998) [4] and Nakagawa (1993) [5]. The main objective is time- and thus cost reduction because the actual manufacturing of forming tools is a time consuming process (Dickens [1]).

In early 1997, a special machining center was installed at the Toyota Technological Institute which has a Nd-YAG laser for cutting or welding and an automated metal sheet loader, consequently the entire build-up can be done automatically. However, the experiments have shown, that the detailed research of various laser technologies is essential to obtain higher part quality and to reduce manufacturing costs.

Development and improvement of new process chains for manufacturing of large tools, is the purpose of research at the Fraunhofer Institute for Material and Beam Technology (Fraunhofer IWS). Different technologies for cutting, assembling and joining of metal sheets by the LOM principle are used so as to reduce the manufacturing time of large tools.

2.1 Profiled Edge Laminate (PEL)

Profiled Edge Laminate (PEL) tooling is a thick-layer rapid tooling (RT) method, developed by Walczyk and Hardt [6], that involves assembling an array of laminates—each having a uniquely profiled and beveled top edge - together in a precise and repeatable manner. The method is illustrated in Fig. 1a. Tooling registration involves forcing each laminate's bottom edge and an adjacent side edge 90° apart against a fixture with precisely machined edges, as shown in Fig. 1b. Profiling and beveling of each laminate's top edge is performed simultaneously using a 'line-of-sight' cutting process such as Abrasive Waterjet (AWJ) cutting, laser cutting, or wire electro-discharge machining. After all the individual laminates are cut, the assembled array of processed PELs can then be clamped, as shown in Fig. 1c, or bonded e.g., applying adhesives, diffusion brazing into a rigid tool.

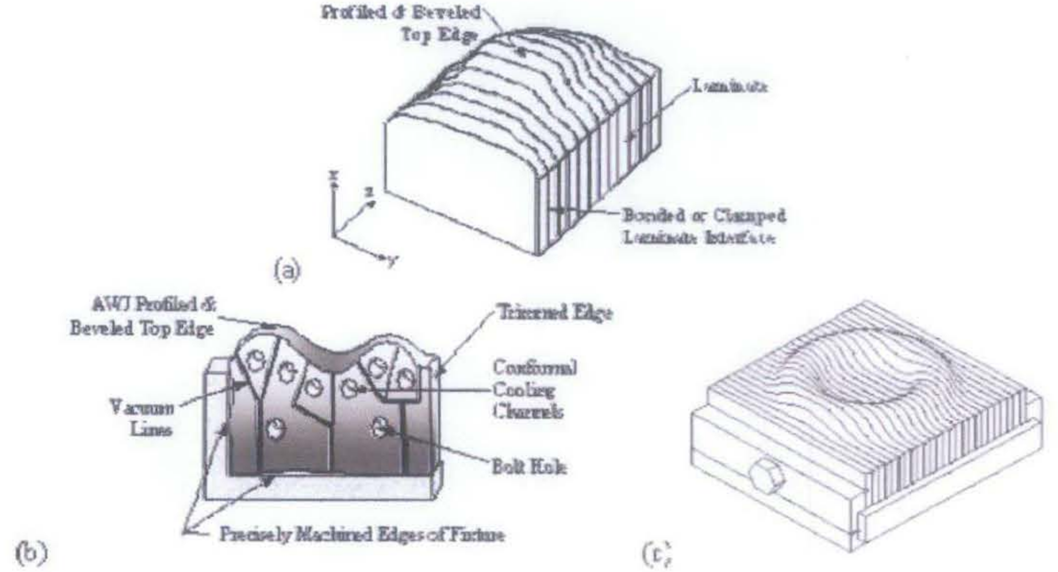


Figure 2.1: Schematics of (a) unclamped PEL tool, (b) possible features of an individual laminate, and (c) a completely clamped PEL tool

2.2 MELATO

Development and improvement of new process chains for manufacturing of large tools, is the purpose of the research at the Fraunhofer Institute for Material and Beam Technology (Fraunhofer IWS). Different technologies for cutting, assembling and joining of metal sheets by the LOM principle are used with regard to reduce the manufacturing time of large tools. Below describes the manufacturing of forming tools using the so called MELATO (Metal Laminated Tooling) -process chains [7].

Firstly, three-dimensional CAD data is modified, sliced and distributed across a sheet panel. The cross-sections are cut out by laser beam and are, subsequently, joined by form closed and force-closed assembly. Strength and life of tools may be additionally improved, for example, by the finishing of critical edges by laser deposition welding. The use of various laser- based methods, such as cutting, welding and deposition welding, will ensure high flexibility of the manufacturing process and convenient geometric modifiability of tools.

Figure 2.2: Sliced Tool Insert

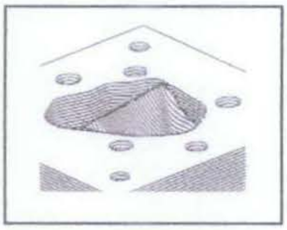


Figure 2.3: Die sliced in 2-D direction

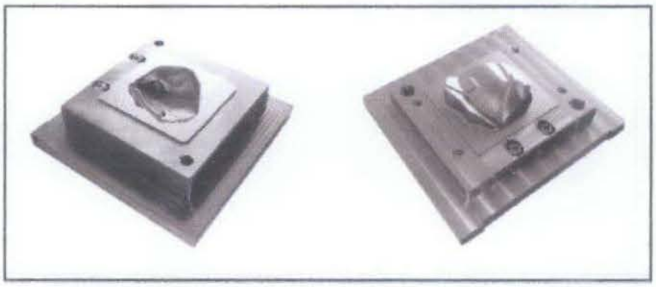


Figure 2.4: Assembled Die and Punch

2.3 Recent Development of Laminated Tooling

Recently, there have been several revelations of laminated tools with conformal channels. Methods used by other researchers for bonding laminate and sealing conformal channels had been vary, mainly with brazing and diffusion bonding.

Bryden [8] discusses the experimental evaluation of laminated tools with conformal cooling/ heating channels through *Lastform* Project in United Kingdom. Carbon steel or stainless-steel laminate are individually contoured using two-dimensional laser cutting and then joined together by high temperature brazing, brazing, adhesive bonding, and simple clamping, depending on the manufacturing process of interest, although there is no mention in the literature of the latter two joining methods being used. All tool surfaces had to be finished by CNC machining or lathing to eliminate the inherent stair-stepped surface. The performance of conformal channels in a laminated tool was first demonstrated using laminated test blocks with holes running through their long axes.

Gibbons [9] created laminated tools with horizontal laminate which similar to PEL tools and conformal cooling channels used for die casting of aluminum parts in short run or prototyping situations. Dies were made by perpendicular laser cutting H13 steel laminate, deburring individual lamina, preparing interlaminar surfaces for brazing, applying brazing paste or powder between these surfaces, fixturing and clamping laminae to prevent movement during brazing, brazing the tool at 1020°C, and finishing the tool using EDM. Use of conformal channel cooling was shown to reduce process cycle time by 11%.

CHAPTER 3

METHODOLOGY/ PROJECT WORK

3.1 Conformal Channel

The standard method of cooling is passing a coolant (usually water) through a series of holes drilled through the mould plates and connected by hoses to form a continuous pathway. The coolant absorbs heat from the mould and keeps the mould at a proper temperature to solidify the plastic at the most efficient rate. Figure 3.1 shows the conceptual view of a cooling system. Due to the nature of the manufacturing methods used, cooling channels typically lay flat in two dimensions. To cover the cavity, baffles have to be inserted to direct the flow in the desired direction and plugs have to be put at the end of bores.

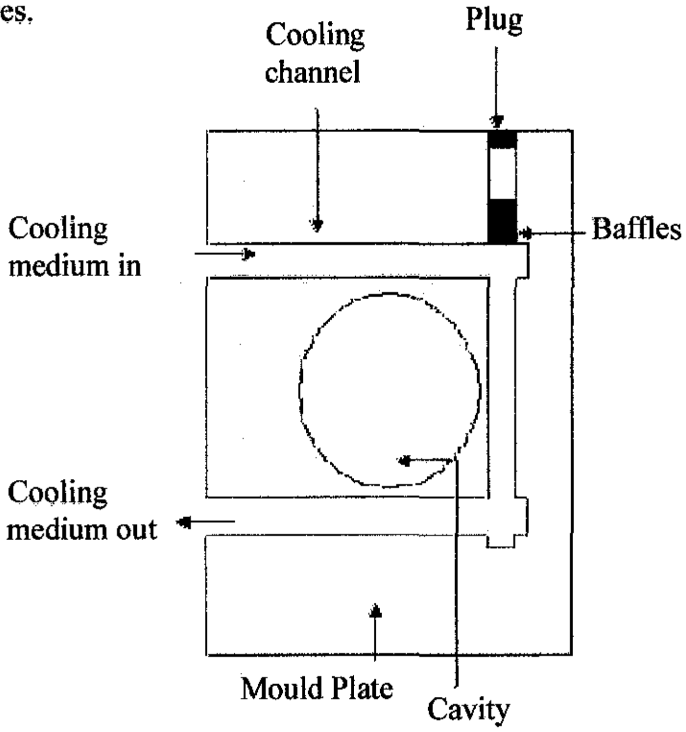


Figure 3.1: Conceptual View of Cooling System

However if the part to be moulded has curvature shape or design, there will be some spots closer to the cooling channels than others. This resulted longer cooling times and defects (shrinkage, warpage). Figure 3.2 shows the example. Section A is closer to the cooling channel comparing to the section B.

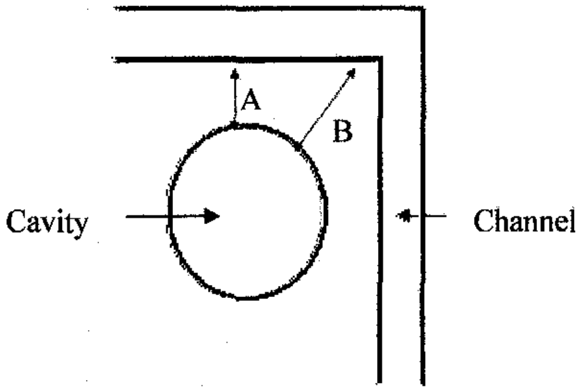


Figure 3.2: Top on a mould with uneven channel

Instead of drilling straight holes into the mould to construct the conventional channel, conformal cooling is a new cooling method where the mould is fabricated with curved channels that follow the contour of the cavity. Figure 3.3 shows an example. This method provides better cooling than conventional methods. The cross-section along the channel is uniform.

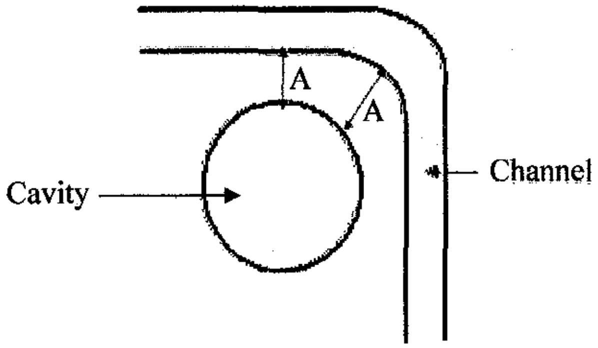


Figure 3.3: Top view of a mould with conformal channel

3.2 Process Flow

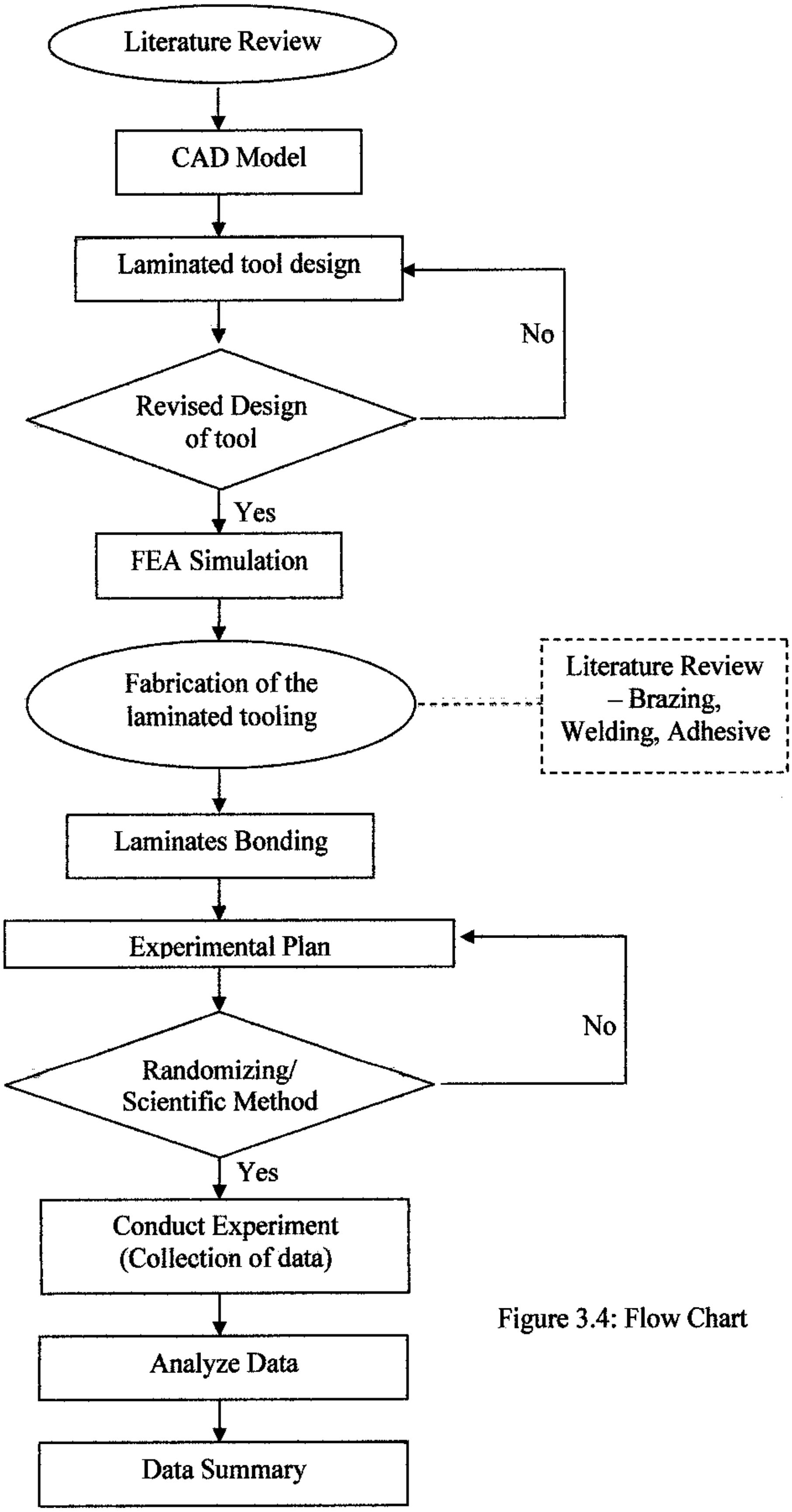
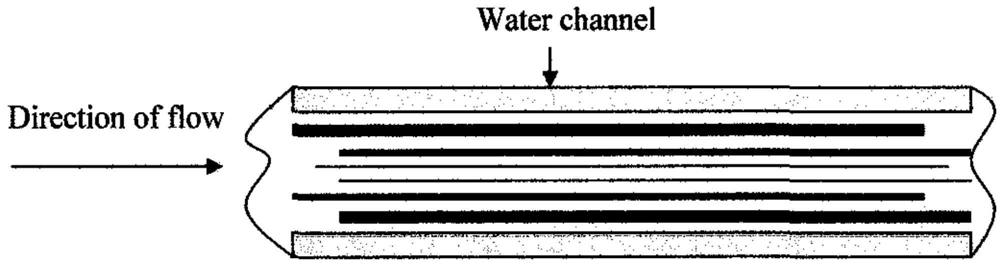


Figure 3.4: Flow Chart

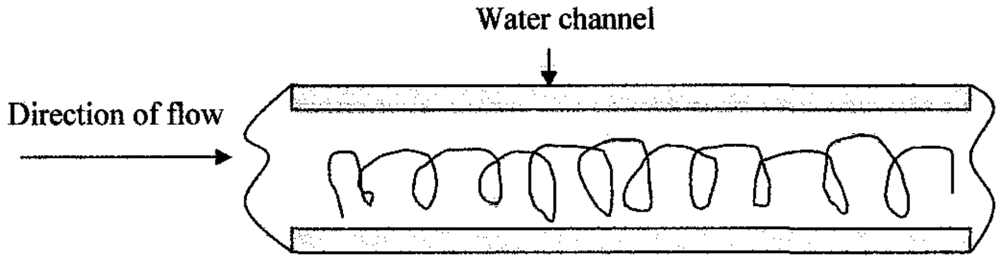
3.3 Turbulent or Laminar

The coolant must flow in a turbulent flow pattern, rather than laminar flow. Turbulence within the flow causes the coolant to swirl around as it flows, thereby continuously bringing fresh, cool liquid in the contact with the hot metal walls of cooling channel and removing more heat. By contrast, laminar flow moves along the channel walls undisturbed, so that the outer layer of the coolant in touch with the metal will heat up, but the center of the coolant flow will remain cold, thus doing little cooling.

There are two different types of flow that water can experience when traveling through a waterline of a mould: laminar or turbulent. Figure 3.5 shows the differences between the two conditions. Both conditions will remove heat from the surrounding mould metal, but the laminar flow is not nearly as effective as the turbulent flow. Note that in the laminar flow diagram, the water travels in separate layers. The layers nearest the outside are next to the mould metal and are in direct contact with the heat that needs to be removed. These layers move slowly (due to friction) and transfer some of that heat to the faster-moving inner layers. However the very center layer, moving fastest of all, receives no heat at all.



Laminar Flow



Turbulent Flow

Figure 3.5: Laminar Flow vs Turbulent Flow

In the turbulent flow model, the water is constantly being tumbled and mixed. All the water is in contact with the mould at one time or another and all of it is used to remove heat from the mould. This is the desired effect.

The creation of the turbulence is a function of flow rate, waterline diameter, water viscosity, water temperature and velocity of the water as it travels through the channels. Whether concerning laminar or turbulent flow, these conditions are characterized by a ratio known as the Reynolds number. Conditions causing a Reynolds number of 4000 or less will result in laminar flow. Reynolds number of 4000 or more will result turbulent flow. The higher is the number, the better cooling efficiency. For better performance, 10000 < RE < 20000, should be attempted. Turbulent flow is defined by the Reynolds number (RE), which is calculated as

$$RE = \frac{(V \mathrm{\ x\ } D)}{v} \qquad \text{with} \qquad v = \mu / \rho$$

where V is the velocity of the coolant (m/s)
D is the diameter of the channel (m)
v is the kinematic viscosity (m^2/s)

μ is absolute viscosity (kg/m.s)
ρ is density of the coolant

*For water at 25°c, $\rho = 9.97 \mathrm{\ x\ } 10^2 \mathrm{\ kg/m^3}$, $\mu = 8.91 \mathrm{\ x\ } 10^{-4} \mathrm{\ kg/m.s}$
and $v = 8.937 \mathrm{\ x\ } 10^{-7} \mathrm{\ m^2/s}$.

**Data from Yunus A Cengel and John M. Cimbala (2006) Fluid Mechanics Fundamentals and Applications*

$$\text{Reynolds no.=} \quad RE = \frac{(V \mathrm{\ x\ } D)}{v}$$

$$= \frac{(1.5\mathrm{m/s} \mathrm{\ x\ } 0.01\mathrm{m})}{(8.937 \mathrm{\ x\ } 10^{-6}\mathrm{m^2/s})}$$

$$= 16785$$

From the calculation above, it is ideal to have D=10 mm (0.01 m) diameter of the conformal channel. The mentioned diameter will be able to generate a high Reynolds number to create turbulent flow in the channels.

3.4 Material

Mild steel is the material used in this project because of the following properties: (Menges et. al, 2001)

- Economical workability (machining, electric discharge machining, polishing)
- Capacity for heat treatment
- Sufficient toughness and strength
- Resistance to heat and wear
- High thermal conductivity

Some non-ferrous metals can be used for the production of injection molds. The most common are copper alloys and zinc alloys. Although these materials offer a much higher thermal conductivity, their mechanical properties are inferior to those of steel. Therefore they are only used as auxiliary materials or to produce prototype molds.

Three-dimensional CAD data of the tool to be manufactured are read into the CAD system, using standard interface formats (STEP, IGES, and STL). Subsequently, the tool is sliced into single cross-sections. In addition, the layer thickness that must be determined before is set, considering metal sheet tolerances or shrinkage of the bonding material (glue, soldering metal). After slicing, the single cross-sections are arranged on a metal sheet panel. The cross-sections are cut out by linear hack saw machine and the conformal channels are drilled by milling machine and subsequently, joined by bonding technologies.

3.4.1 Machines/ Software

Several machines and softwares were used in this study. They included:

- Vertical Turret Milling Machine

Figure 3.6: Vertical Turret Milling Machine

Specification

Model	: 5VM – EATAR Machinery
S/N	: TS- 030552
Voltage	: 415/ 37/ 50 (V/ W/ Hz)

- Water Heater for Measurement of Viscosity (Viscometer)

Figure 3.7: Water Heater

Specification

Model : PHYWE M6 TR 850

S/ N : 850 7231 1406

Voltage : 240/ 1.5k/ 50 (V/ W/ Hz)

Flow rate : 8L/ min

- Linear Hack Saw

Figure 3.8: Linear Hack Saw

Specification

Model : KP-280 – EATAR Machinery

S/ N : TS – 030553

Voltage : 415/ 37/ 50 (V/ W/ Hz)

3.5 Laminated Tool Design

The initial tool design was in SLDPRT format, which is a standard format for Solidworks software. Below show the design of the tool. There are a total of 19 pieces of laminates which will be used to assemble the final tool. Each of the laminate is unique wit its individual dimension, especially on the dimension of the conformal. All units are millimeters (mm).

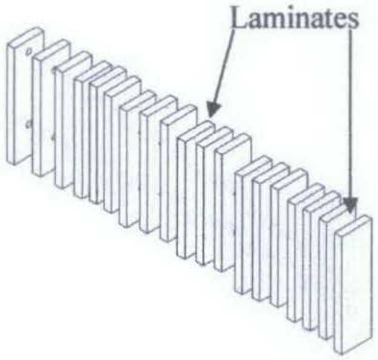


Figure 3.9: Stack of laminates

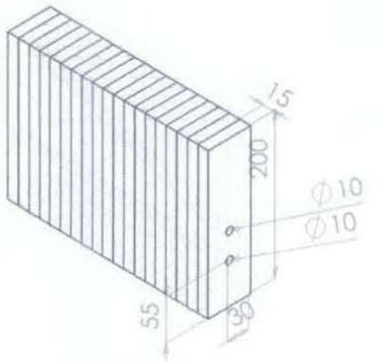


Figure 3.10: Assembled Laminates

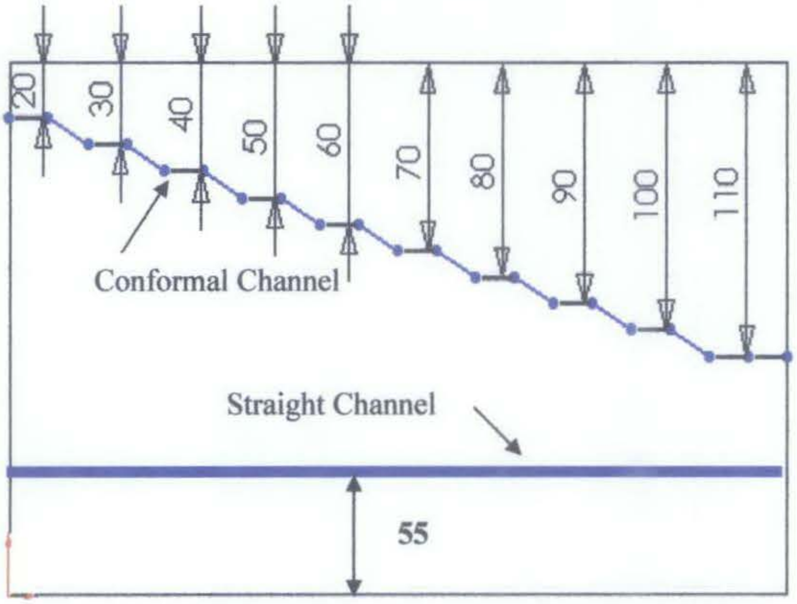


Figure 3.11: Front view of assembled laminates with conformal & conventional channel

3.6 Adhesive Bonding

Like soldering joining process, adhesive must be liquidous at some point of the bonding process to allow molecular intimacy for Van Der Waals[3] attraction forces to take hold. While the adhesive is in its liquidous state, it must be able to wet the parts it is trying to bond together. This wetting phenomenon assures proper molecular intimacy. Wetting by its very nature is a measurement of the compatibility of the adhesive with the adherends. If adhesive in its liquidous state shows inadequate wetting (poor wetting), the joint will then be most likely weak and there could be potential to become unsuccessful.

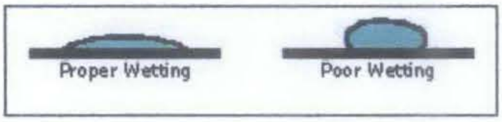


Figure 3.12: Wetting of adhesive on the laminate

3.6.1 Features & Benefits of adhesive bonding

- High strength bonds - Their load-bearing properties are equal to, or exceed, many of the substrates that they bond.
- Excellent environmental and chemical resistance - They resist the effects of dilute acids, alkalies, solvents, greases, oils, moisture, sunlight and weathering.
- Improved aesthetics for bonded assemblies - epoxy adhesives eliminate the distortion, discoloration and surface marring common to mechanical fastening methods such as screw heads, bolts and welds.
- Uniform contact between substrates - They fill irregular contours, ensuring uniform contact where substrate surfaces do not mate critical to many combinations of wood, fiber, rubber, ceramic, glass and foams.
- Flexible cure rates - They cure at room temperature or elevated temperatures (which provides the highest possible bond strength and impact resistance).
- Low shrinkage and good creep properties

---

[3] **van der Waals force** refers to the attractive or repulsive forces between molecules (or between parts of the same molecule)

3.7 Fabrication Process

Fabrications of the laminates were done from the metal block. The slicing process is done by linear hack saw machine. The 2mm blade saw cut through the metal block with approximately 15mm each. Tolerance of 1mm will be imposed.

Figure 3.13: Linear hack saw machining

Figure 3.14: Slicing process

Each of the laminates will takes approximately 20 to 25minutes. The electrical coolant pump will constantly flush out coolant to cool the heat generated from the sawing process.

Figure 3.15: The coolant running through the laminate

Each of the laminates will also be numbered for bonding reference purposes. So far there are 9 pieces of laminate successfully sliced from the initial metal block.

Figure 3.16: The first laminate

Figure 3.17: Laminates

Fabrication of the tool from the metal block already reassembled together and 'became' a metal block again. The assembly process was done by adhesive bonding technique and there will be a gasket paper in between the laminates. The gasket paper functions as insulator which will heat transfer from one laminate to another. The laminates which required drilling were done by two types of machines – the conventional drilling machine and milling machine. The conventional drilling machine is required to drill straight holes while the angle drilling done by milling machine which the spindle head can be tilted to certain angle.

Figure 3.18: Angle drilling by milling machine

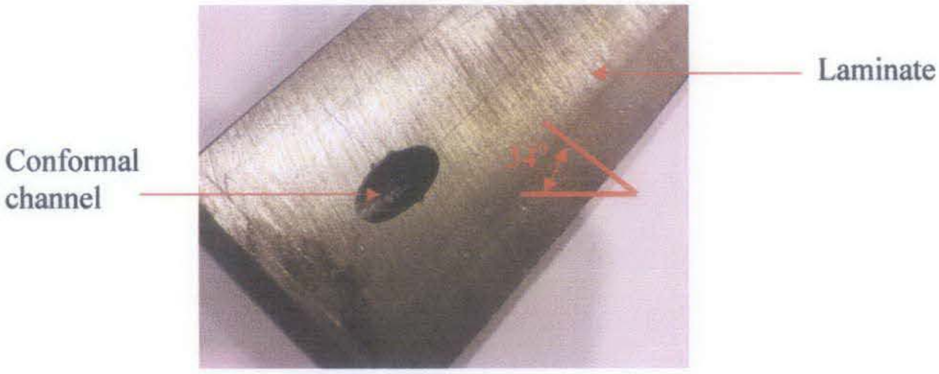


Figure 3.19: Angle drilling on the laminate by milling machine

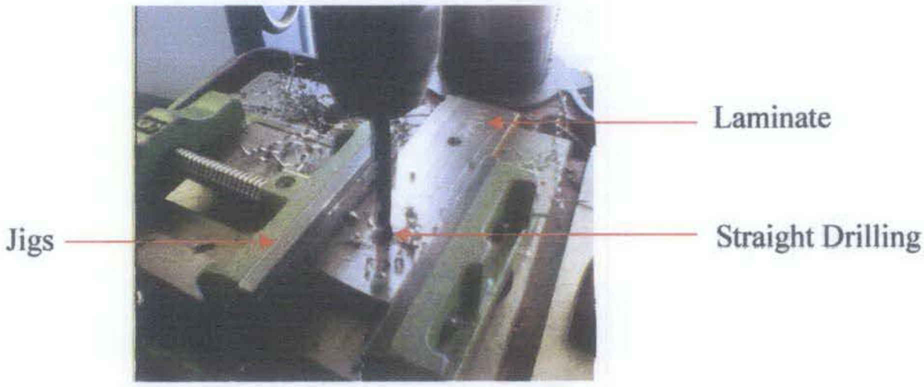


Figure 3.20: Straight drilling by conventional drilling machine

The laminates will be cleaned to make sure no grease or dirty particles that will interrupt the adhesive bonding process in later stage.

Figure 3.21: Adhesive bonding on the laminate

After the bonding process, the assembled laminates will be clamped by G-clamp for at least 24-hours for maximizing the bonding effects earlier on. Later the assembled laminates will be welded to strengthen the bond between the laminates.

Figure 3.22: The assembled laminates with G-clamp on both sides

3.8 Experimental Plan

The experimental process involved in this project follows the model identified within the following stages:

- Conception
- Design
- Preparation
- Execution
- Analysis

The concept is to identify the impact of introducing the idea of the project. The design of the tooling is to enable the data collection in reality approache. Hence the preparation of this project is crucial where the fabrication of the tool and data retrieved from the experiment play important rules directly in the project. Well preparation leads to good execution on the project. Early planning, right tools and suitable software with the time frame and methodology as the main concerns will either make or break this project.

This report is concerned with the Experiment Plan phase for data collection. For this project, a set of data will consist of 9 temperature nodes in a constant temperature (e.g. 50°c). The steps are being repeated, with increment temperature of 10°c (30°c, 40°c, 50°c, 60°c, 70°c).

However, it is recommended that this project will approach the randomizing method. For example, the first set of data is being collected when temperatures hit 50°c, instead of 30°c. The second set of data then being collected at 30°c, the third set at 70°c, the forth 40°c and lastly 60°c before obtained the whole complete set of data from all temperatures.

The reason to approach this method is to minimize the influence of data during the experiment. If the experiment starts at 30°c and ends at 70°c with increment of 10°c in between them, the obtained results will likely not accurate if compare to the randomizing approach. This is because the remaining heat in the laminates will keep on increases when the temperature is being increased. By randomizing approach, we can get the actual temperature form the laminates itself, not the remaining heat transfer from the previous experiment.

3.8.1 Experimental Process

This experiment will be conducted on the straight channel first, followed by conformal channel. First the outlet of water tube from the water heater being inserted into the inlet of the tool, while the inlet of the water tube being inserted in the outlet of the tool. Refer below figure.

Figure 3.23: Water inlet/ outlet

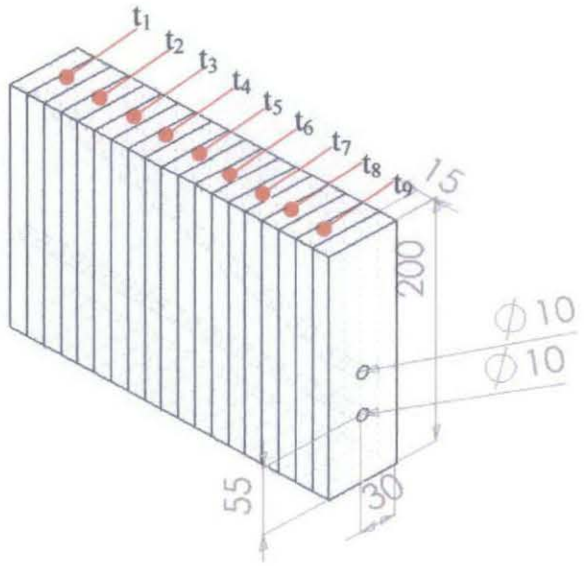


Figure 3.24: Placement of Probes on the Tool

Data logger with wire probes attached at the top of the tooling to detect the temperatures at 9 different points. Water heater will heat up the water supply and at the same time it will flow through the tool, before ending up in the tank again. This creates a continuous cycle of water flow. Temperature of the water can be adjusted from the control panel at the water heater itself. According to experimental plan stated earlier, this experiment started with temperature of 50°c, followed by 30°c, 70°c, 40°c, and finally 60°c. Heat water will be allowed to continuously flow through the tool for 10 minutes. This is to make sure that water temperatures were evenly stable. After that, temperature readings obtained from the display panel of data logger. This process then repeated for other temperatures.

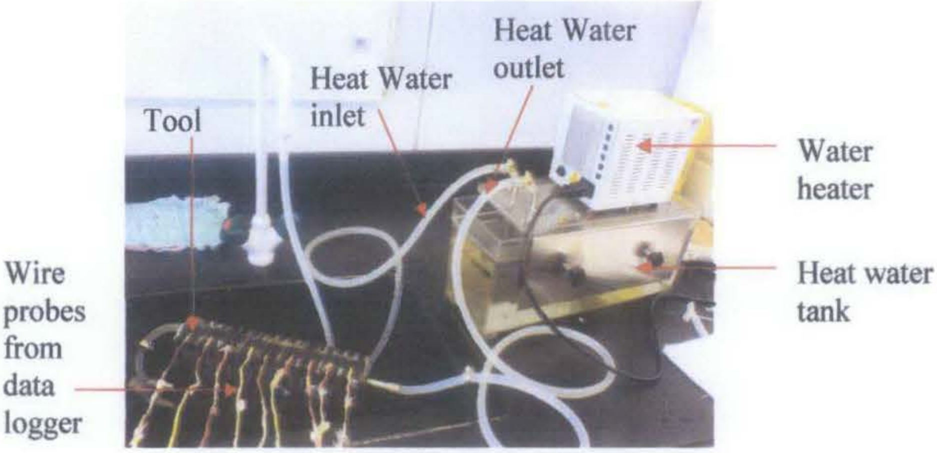


Figure 2.25: Experimental Setup

Figure 3.26: Complete Experimental Setup

3.8.2 Data Analysis Techniques

Data analysis is the process of looking at and summarizing data with the intent to extract useful information and develop conclusions. Formal statistical analysis methods will be applied to the data sets. For comparison of groups of data, graphs will be plotted by using MS Excel with the retrieved data. All these statistics provide significance measures of any relationships between the data and will therefore provide a good indication of the validity of any conclusions.

Before the experiment starts, there are few factors can not be overlooked. One of them is the environment condition. In this project, the experiment will be conducted in the available fluid laboratory. Hence, the surrounding conditions are important elements that can influence the results of the experiment. A lower surrounding temperature/ humidity will gives different results from a condition where higher temperature/ humidity applied. In this study, experiment was conducted in room temperature of 20.7^{o}c with humidity of 67.6 % RH.

CHAPTER 4

RESULT

4.1 Result

The water temperatures (for both straight and conformal channel) at point of different laminates are obtained and recorded as shown in Table 1 until Table 5 respectively.

For 70°c							
Placement	Laminate No.	Straight Channel (°c)			Conformal Channel (°c)		
		1st	2nd	Avg	1st	2nd	Avg
T_1	2	51.3	53.3	52.3	57.9	58.5	58.2
T_2	4	49.7	49.5	49.6	56.1	55.3	55.7
T_3	6	51.3	47.3	49.3	54.6	55.0	54.8
T_4	8	50.5	55.7	53.1	54.0	53.6	53.8
T_5	10	49.8	49.4	49.6	53.0	53.0	53.0
T_6	12	52.1	48.5	50.3	46.9	49.1	48.0
T_7	14	52.3	55.7	54.0	45.3	42.7	44.0
T_8	16	50.2	49.4	49.8	37.2	36.8	37.0
T_9	18	50.6	53.6	52.1	33.9	32.1	33.0

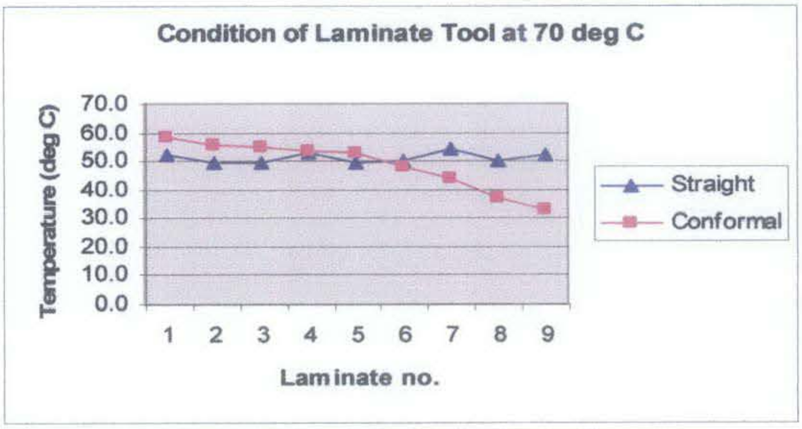


Table 4.1: Water Temperature at 70°c

For 60°c							
Placement	Laminate No.	Straight Channel (°c)			Conformal Channel (°c)		
		1st	2nd	Avg	1st	2nd	Avg
T_1	2	44.0	44.6	44.3	53.1	54.5	53.8
T_2	4	43.1	44.3	43.7	54.0	52.8	53.4
T_3	6	45.1	48.9	47.0	53.3	52.7	53.0
T_4	8	45.6	45.0	45.3	54.7	55.5	55.1
T_5	10	44.0	43.4	43.7	51.9	53.3	52.6
T_6	12	44.7	42.7	43.7	47.2	48.4	47.8
T_7	14	43.2	42.4	42.8	44.0	44.0	44.0
T_8	16	43.9	47.3	45.6	40.5	37.5	39.0
T_9	18	44.0	42.4	43.2	34.7	35.3	35.0

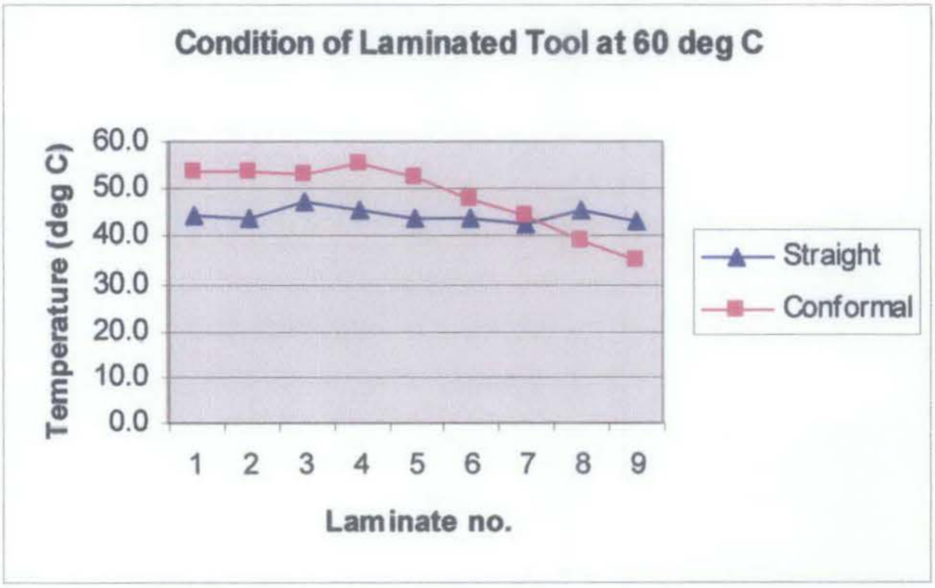


Table 4.2: Water Temperature at 60°c

For 50°c							
Placement	Laminate No.	Straight Channel (°c)			Conformal Channel (°c)		
		1st	2nd	Avg	1st	2nd	Avg
T_1	2	37.4	40.2	38.8	41.2	39.6	40.4
T_2	4	36.7	38.7	37.7	39.1	39.5	39.3
T_3	6	36.0	35.8	35.9	37.0	36.4	36.7
T_4	8	37.1	36.3	36.7	33.9	35.5	34.7
T_5	10	37.4	37.4	37.4	34.1	32.1	33.1
T_6	12	38.1	41.1	39.6	30.5	29.9	30.2
T_7	14	38.5	36.3	37.4	30.0	28.2	29.1
T_8	16	36.3	36.1	36.2	27.1	26.5	26.8
T_9	18	36.7	37.5	37.1	25.9	26.7	26.3

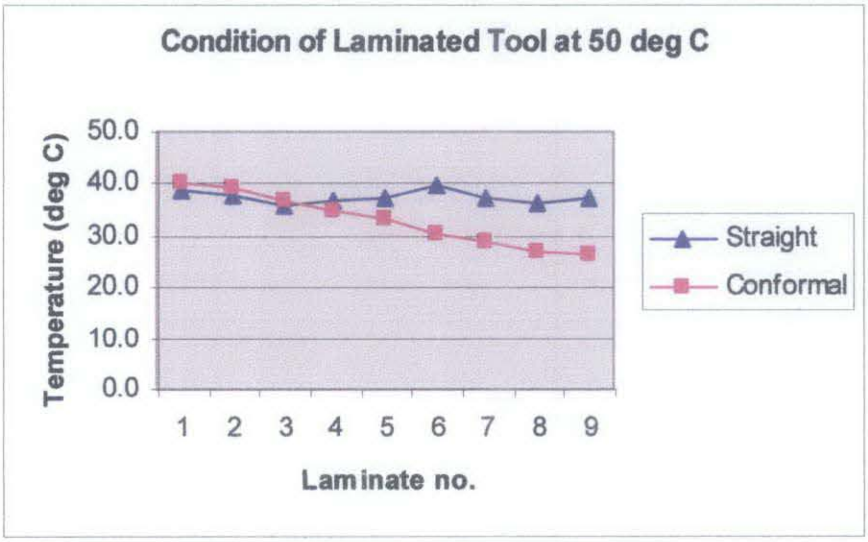


Table 4.3: Water Temperature at 50°c

For 40 deg C							
Placement	Laminate No.	Straight Channel (°c)			Conformal Channel (°c)		
		1st	2nd	Avg	1st	2nd	Avg
T_1	2	30.7	31.9	31.3	35.0	34.0	34.5
T_2	4	31.6	30.0	30.8	33.8	33.6	33.7
T_3	6	33.5	33.1	33.3	32.1	34.1	33.1
T_4	8	28.6	26.6	27.6	32.7	31.9	32.3
T_5	10	27.0	26.0	26.5	27.9	26.9	27.4
T_6	12	24.0	25.8	24.9	25.1	26.1	25.6
T_7	14	25.6	23.4	24.5	24.6	24.6	24.6
T_8	16	24.2	23.2	23.7	23.5	24.3	23.9
T_9	18	23.0	23.0	23.0	23.4	22.8	23.1

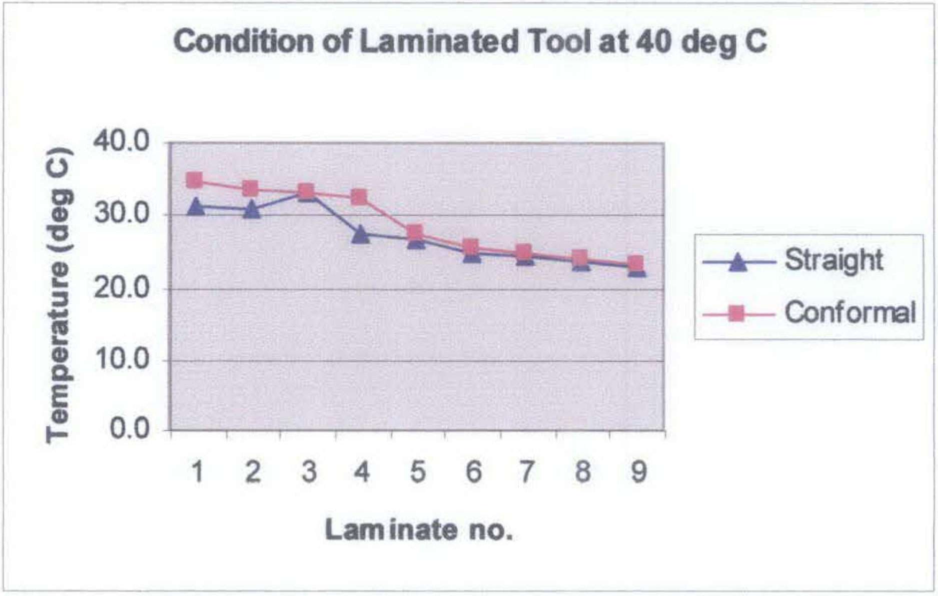


Table 4.4: Water Temperature at 40^{o}c

For 30 deg C							
Placement	Laminate No.	Straight Channel ($^{\circ}$c)			Conformal Channel ($^{\circ}$c)		
		1st	2nd	Avg	1st	2nd	Avg
T_1	2	25.6	26.0	25.8	28.1	28.3	28.2
T_2	4	25.3	25.5	25.4	28.0	26.6	27.3
T_3	6	25.7	27.9	26.8	26.6	27.4	27.0
T_4	8	24.7	23.9	24.3	26.0	24.8	25.4
T_5	10	25.0	24.8	24.9	25.4	24.4	24.9
T_6	12	25.1	26.3	25.7	23.8	23.2	23.5
T_7	14	26.1	26.1	26.1	23.4	23.2	23.3
T_8	16	24.3	24.9	24.6	22.4	22.2	22.3
T_9	18	25.3	25.7	25.5	20.6	21.2	20.9

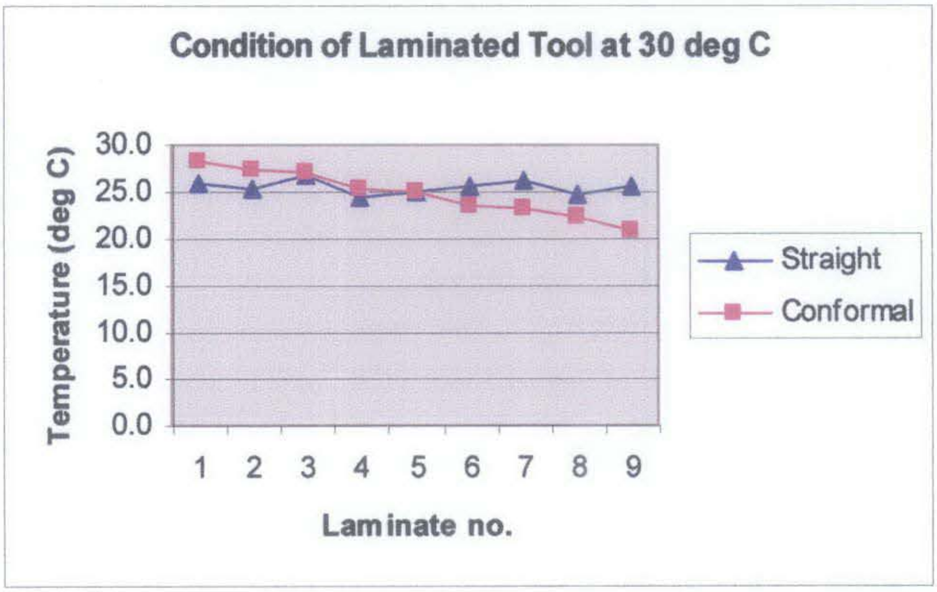


Table 4.5: Water Temperature at 30°c

CHAPTER 5
DISCUSSIONS

5 DISCUSSIONS

It was found that the temperature distribution for conformal is more uniform than temperature distribution for straight channel in same distance from the top location to the channel. This also means that the higher distance of the conformal channel to the cavity will gives lower value of temperature. However, there is a difference in water temperature at point t_3, where it supposes to be theoretically lower than the points before it (mainly t_1 & t_2). These behaviors indicate only either of these two problems: instability of water temperature during experiment session or errors from data-logger.

Based on Table 1, it is concluded that at water temperature of 70°c:

1. The water temperatures are understandably uniform in straight channel.
2. The water temperatures in conformal channel give decreasing readings, due to the design of the conformal.
3. There were no other significant changes of water temperature for T_3, particular on both straight and conformal channel and at any inlet water temperatures

Based on Table 2 (water temperature of 60°c):

1. Water temperatures are quite uniform in straight channel
2. Conformal channel produces lower water temperatures compared to straight channel.
3. Not much temperature differences for straight and conformal channel at T_7.

Based on Table 3 (water temperature of 50°c):

1. Water temperatures are in fluctuation form in straight channel. Average water temperature as high as 39.6°c can be found at T_6 and lowest of 35.9°c at T_3.
2. Water temperatures of the conformal channel are decreased steadily compared to straight channel.

Based on Table 4 (water temperature of 40°c):

1. Temperatures of straight channel are high particular at T_3. This is even higher than the temperature at T_2 or T_4 of the same channel.
2. Temperatures at point T_7, T_8 and T_9 are almost same in both straight and conformal channel.

Based on Table 1 (water temperature of 30°c):

1. Again, temperatures of straight channel are high particular at T_3. This is even higher than the temperature at T_2 or T_4 of the same channel.
2. Conformal channel produced lower water temperatures compared to straight channel.

CHAPTER 6

CONCLUSIONS

6 CONCLUSIONS

This case study concludes that with conformal channel, it can increase heat loss compared with straight channel. Results are presented based on the temperature distributions and the combination of the several machining processes including milling, straight drilling, angle drilling, etc. Based on methodology, this study can be further reliable if Electro Discharge machine is being implemented in fabrication process.

The temperature performance of the straight channel has shown to be a poor cooling/ heating method as compared to conformal channel because of the higher convection heat transfer rate possible.

It is shown through study on water temperature at different points of the laminated tooling; we can analyze the characteristic of different water temperatures from the experiment. It is shown through this study that laminated tooling can deliver convincing result.

6.1 Further Work

Future work in this area should be more focus on the following:

- A real injection mould with conformal cooling channels can be manufactured. The mould could be followed the guidelines provided on this study so far.

- Method of joining the laminate included brazing, welding, adhesive bonding and mechanically clamped can be further studied.

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APPENDICES

APPENDIX 1: Gantt Chart for Final Year Project 1 (Sem July 07)

TASKS	July 07		August 07				Sep 07				Oct 07					Nov 07	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
(1) Selection of Project title	▨☒	▨☒											SEMESTER & HARI RAYA BREAK				
(2) Preliminary Research Work			▨☒	▨☒													
(3) Literature Review																	
• **Laminated Tooling**			▨☒	▨☒	▨☒	▨☒	☒	☒	☒	☒							
• **CNC wire-cut**			▨	▨☒	▨☒	▨☒	☒										
• **Adhesive/ Bonding**				▨☒	▨☒	▨											
(4) Mould Design																	
• **Design with ProE/ Solidworks**				▨☒	▨☒	▨☒	▨☒	▨☒●	☒	☒	☒						
(5) Mould Analysis																	
• **Using Ansys 9.0**								▨	▨	▨	▨●	☒		☒			
(6) Adhesive/ Bonding Analysis												▨		▨☒			

▨ **Process**

▨● **Key milestones**

☒ **Actual Progress up-to-date**

APPENDIX 2: Gantt Chart for Final Year Project 2 (Sem Jan 08)

TASKS	Jan 08		Feb 07				Mar 07				Apr 07					May 07	
Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**		
(1) Literature Review								**SEMESTER BREAK**									
• **Laminated Tooling**	▨☒	▨☒	▨☒	▨☒													
• **Bonding Technique**	▨☒	▨☒	▨☒	▨☒													
(2) Material Selection																	
(3) Fabrication																	
• **Slicing Laminate**			▨☒	▨☒	▨												
• **Drilling**					▨☒	▨☒	☒										
• **Adhesive/ Bonding**						▨	▨☒		☒								
(4) Experimental Setup							▨		▨	☒							
(5) Conduct Experiment																	
• **Experimental Plan**											▨	▨☒	▨☒				
(6) Dissertation											▨	▨	▨☒	▨☒	▨☒●		

▨ **Planned Progress**

● **Key milestones**

☒ **Actual Progress up-to-date**