ANALYSIS AND OPTIMIZATION OF MACHINING PARAMETERS BASED ON DIFFERENT TYPE OF THICKNESS IN INCREMENTAL FORMING PROCESS

ANUARUL IKHWAN B MAT NAZRI

BACHELOR OF ENGINEERING

UNIVERSITI MALAYSIA PAHANG

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ANUARUL IKHWAN B MAT NAZRI

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Especially for

My beloved family

at home

And

All my friends in

UMP

For their support and help

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In the name of Allah, the Most Gracious and Most Compassionate

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ABSTRACT

This research was carried out to develop and analyze the incremental forming machine controlled by a personal computer numerical control (PCNC). The application of this machine is to realize a small production lot with low cost. The process which runs without mould can be used to replace stamping applications which is very costly due to the mould application. Aim of this study is analysis in tool path for new development of incremental forming. The analyses show the implication and justification for forming process. Using FE analysis is to identify the estimations of the formability and the fracture point of the sheet metal.

ABSTRAK

Kajian ini dilakukan untuk memajukan dan melakukan analysis di atas mesin fabrikasi penambahan yang dikawal oleh komputer peribadi kawalan angka (PCNC). Aplikasi mesin ini adalah untuk merealasikan produksi yg kecil dengan kos yang rendah. Proses ini yang berfungsi tanpa acuan boley menggantikan proses pembentukan yang menggunakan kos yang tinggi akibat menggunakan acuan. Tujuan kajian ini adalah mengkaji aliran mata alat untuk perkembangan proses fabrikasi penambahan ini. Kajian ini menunjukkan pelibatan dan pembenaran proses ini. Analisis FE digunakan untuk menganggar pembentukan dan had retakan kepingan logam.

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LIST OF SYMBOLS

σ_y;	Yield Stress
ε_z	Strain
σ_f	Flow Stress
τ	Shear Stress
n	Hardening Coefficient

LIST OF ABBREVIATIONS

ISF	Incremental Single Forming
CMM	Coordinate Measure Machine
DOE	Design of experiment
CAE	Computer Aided Engineering
FYP	Final Year Project

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Incremental forming processes have been introduced in the recent past as an alternative to the money consuming stamping technology, when small batches have to be manufactured. Incremental forming is still a new and not fully assessed process, which is interesting that manufacturing applications start to appear in the world scenario.

Single-point incremental forming (SPIF) is a flexible sheet metal forming process that is economically promising for low production run manufacturing. In this process, a small sized tool moves along a programmed tool path and shapes the part in an incremental fashion. The process is mainly performed by shear deformations.

A particular application has been developed highlighting the point of strength of such a technology. It is, by now, a widely diffused opinion that Incremental forming processes are very suitable when high customized products have to be manufactured. In fact, due to the very low set up cost, the use of this technology may be strategic when industries require small batch or single products.

1.2 PROBLEM STATEMENTS

i. The Incremental forming machine now does not have the proper guide to optimize the machining parameters.
ii. The outcome results of the workpiece after forming is usually not good enough. Some also results by cracking or tearing of the sheet metal.

1.3 OBJECTIVES

The objectives of this project are

i. To study and understand the concept and principle of Single point incremental forming (SPIF).
ii. To investigate the process parameters to obtain a good quality product and the optimization of manufacturing.
iii. To determine the limits of formability by using a scheduled tool path.
iv. To investigate the effect of springback on different types of thickness.

1.4 SCOPE OF STUDY

i. To perform research and to optimize the machining parameters by analysis on ALGOR software.
ii. To have a variable distance of stepdowns to find the most suitable machine parameter on the specific thickness of material.
iii. To analyze the displacement by the springback effect on different thickness of material.

1.5 CONCLUSION

The whole project will be guided by this chapter throughout the whole process. The objectives must be achieved, the scope of study must be completed and the Gantt chart is to be followed to complete the project in the time given.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In a modernization country, there were so many technologies being developed one and another. Day by day almost all of those technologies and inventions being improved for a better performance since there were some problems occurred during their services. Therefore in product development there was an obviously increasing in making product for a complex and higher quality level that has to be achieved especially in product designing and producing a new technology in industry.

For designing in engineering field, there were a widely used of parts made of sheet metal. In sheet metal forming techniques in manufacturing parts such as deep drawing, dedicated tools are needed and this type of forming are highly specialized, expensive and time consuming in producing parts. Therefore there is a new sheet metal forming techniques being introduced, incremental forming rig test, being introduced. It is based on using of simple spherical tool, which is moved along CNC controlled tool path. It is based on deforming the sheet locally layer by layer. The sheet blank is fixed in sheet holder and then the tools will deform the sheet blank drawing a contour on horizontal plane, and makes step downwards and draws next contour and so on until operation is completed.

Even in producing one component by incremental forming the time required is much longer than for ordinary press forming, it is more feasible compared to the traditional sheet metal-forming processes for low volume and prototype production in view of the total process time and costs due to the shorter lead time, faster and less expensive tooling. Incremental sheet forming (ISF) is also an ability to form non-symmetrical geometries with simple or no tooling and low costs. It does not require expensive tools for producing complicated sheet metal parts and the forming equipment is suitable for large variety of products without major changes or expensive investments. In this technique, it may constitute a suitable industrial alternative, especially if one or few parts have to be produced, since it does not require expensive dies.

2.2 INCREMENTAL FORMING RIG TEST THROUGH METHODS

2.2.1 Types of Incremental Sheet Forming Rig Test

There are certain techniques in incremental sheet forming (ISF) that being used nowadays. There are two main techniques for this method which is forming without a support (figure 2.1) and forming with a support (figure 2.2). The other techniques are forming on soft plastic support material (figure 2.3) and forming using multiple set-ups or on multi axis machine tools (figure 2.4).

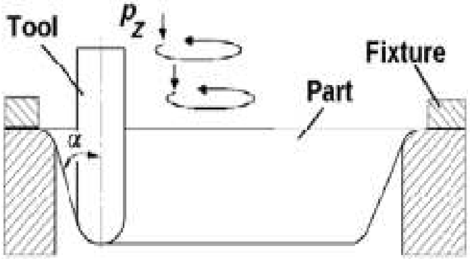


Figure 2.1: Forming Without A Support

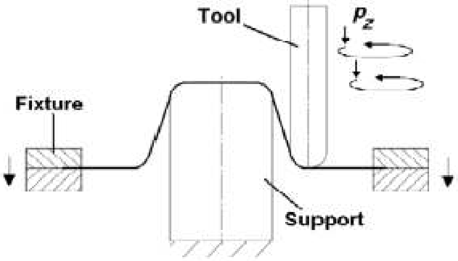


Figure 2.2: Forming With A Support

In this study we are only focusing on forming without support which is using the concept of pressing the sheet metal using centered tools. This technique does not need any support or holding material in the middle of the mold in shaping sheet metal. From the figure above we can see that the fixture is holding the sheet metal in order to hold the force given by the tool on the sheet metal. In Figure 2.7, p_z is the vertical step size and α is the wall draft angle. It is function as the direction of the tool to move and the reference point of the load given on a sheet metal.

Incremental forming without a support is a technique of pressing the tool on the sheet metal whether in the middle or elsewhere and some load given will create a curve and also the wall draft angle, α. While the other forming such as forming with a support need a medium to shape the sheet metal into a new design according to the needs of the industry. Incremental sheet forming without a support and with a support actually using the similar concept but there are several differences between them. In forming with a support, it introduces an extra parameter which is a stretching force. This force is applied to the sheet fixture for pulling the sheet onto the support which is quite similar to stretch forming. When this force is increasing to a certain level it makes a higher accuracy of geometry. Those techniques are also applied on different purposes. Forming without a support is applied to the industry on making prototype which is saving time and cost while the forming with a support involved in making complex products for certain parts such as component of a car.

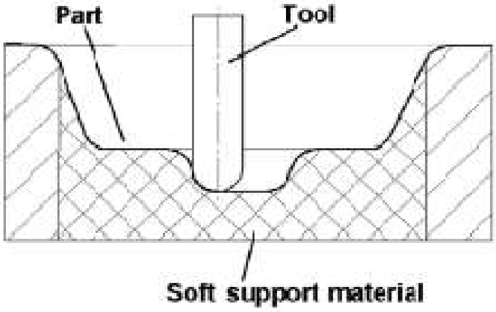


Figure 2.3: Forming On Soft Plastic Support Material

Forming on soft plastic support material is used to achieve better form accuracy Figure 2.3. Support material should be sufficiently plastic to be able to flow away under the tool and have to make sure it is stiff enough to support the sheet blank. The type of the tool is also have to be considered whether it is suitable or not for this type of support material and the sheet metal.

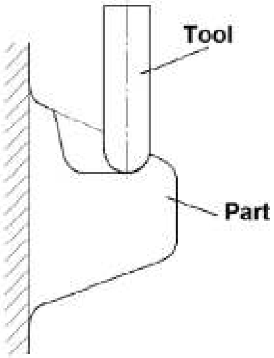


Figure 2.4: Forming Using Multiple Set-Ups Or On Multi Axis Machine Tools

In Figure 2.3 shows the one of the incremental forming techniques that using multi axis machine tools. This kind of technique is use to form for the certain area of the part not possible or hard to form in previous steps. The direction and position of the sheet metal can be changed and modified even in a hard part using the multi axis machine. It just modifying and finishing the part after forming it using different techniques.

2.2.2 Concepts of Incremental Sheet Forming Rig Test

2.2.2.1 Forming By Pushing

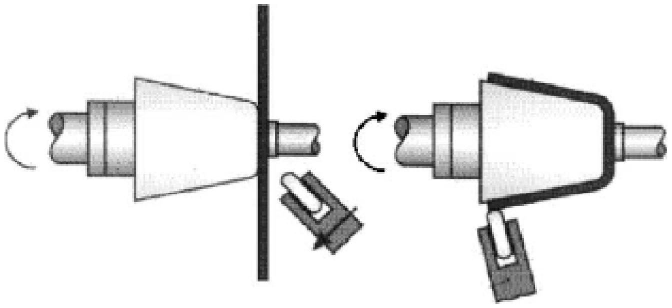


Figure 2.5 Forming With Pushing

It is a process in which the sheet metal rotates together with the spindle (Figure 2.5). The tool which is has a forming disc at its end forms the sheet metal from the centre outwards. This process is appropriate for round products only. It looks like a process forming a vase which is need a tool to form the sheet metal into round shape. This process is rarely used in industry nowadays to produce faster and cheaper in making prototype and others.

2.2.2.2 Forming By Impression

This is a process where the tool is stamped into the sheet metal which is clamped on its circumference. This kind of forming using a tool which is has a simple shape with a ball at its end. The tool travels over a definite distance forming the sheet metal to a final form (Figure 2.6).

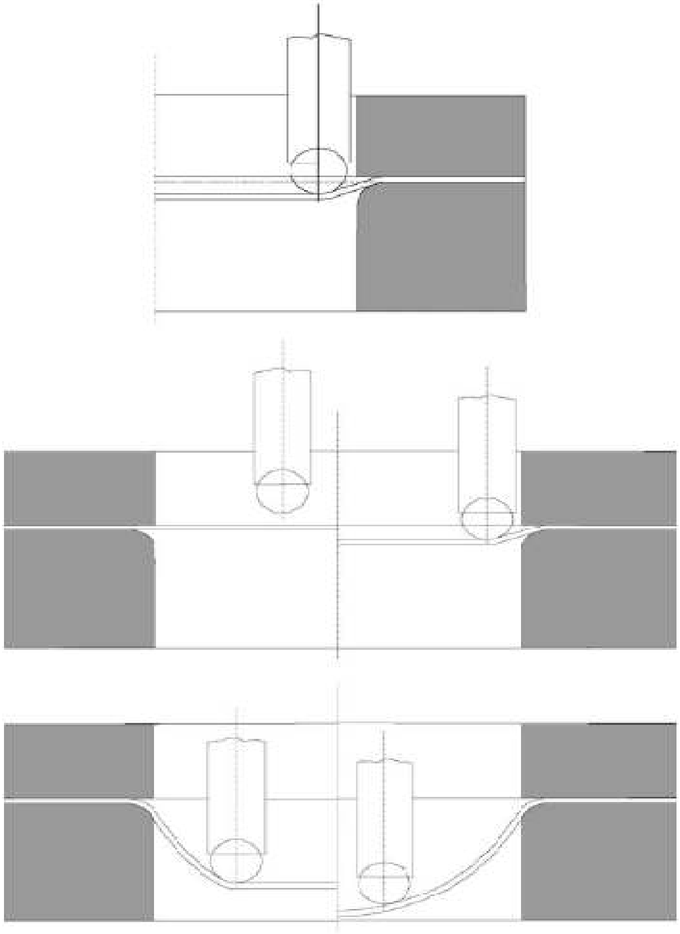


Figure 2.6: Forming With Impression

2.2.2.3 Process Of Incremental Sheet Metal Forming

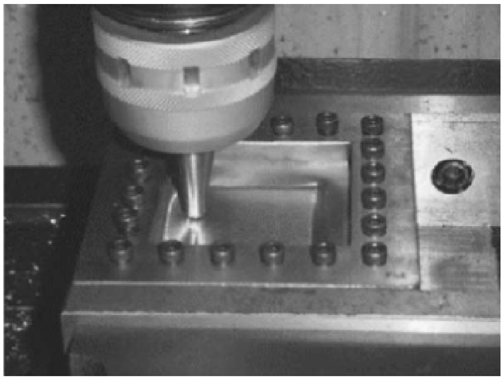


Figure 2.7: Process Of Incremental Forming

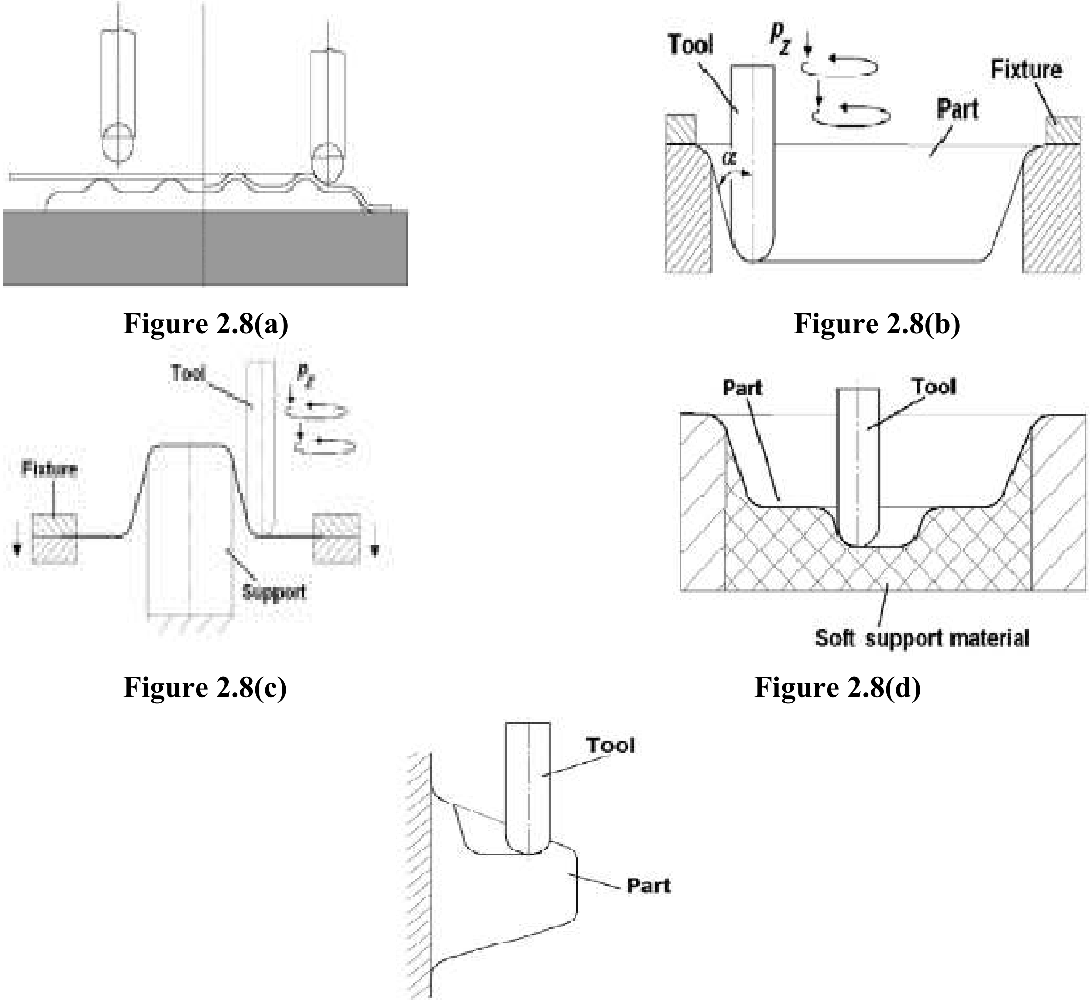


Figure 2.8(a)

Figure 2.8(b)

Figure 2.8(c)

Figure 2.8(d)

Figure 2.8(e)

Figure 2.8: (a)-(e) Process Of Incremental Forming

The incremental forming process is a process where sheet metal is formed with a small force and no press is needed. It is the concept of the technique that being used for in this study. A piece of sheet metal it's chucked all around with a special chuck (Figure 2.7). Using this method, the tool is guided with an NC computer program, which defines the trajectory along which the tool should move. The trajectory along which the tool should move is defined directly from a model made in CAD or Solidworks.

Single Point Incremental Forming (SPIF) is a recently developed **dieless sheet metal part production technique** that is gradually evolving towards industrial applicability. In this process a sheet metal part is formed in a stepwise fashion by a CNC controlled rotating spherical tool without the need for a supporting (partial) die. This technique allows a relatively fast and cheap production of small series of sheet metal parts.

Figure 2.9: NC Milling Machine Configuration Used For Forming A Conical Cup

In the SPIF process generic, freeform shapes can be produced using a standard, spherical, CNC controlled tool. The process starts from a flat sheet metal blank, clamped on a sufficiently stiff rig and mounted on the table of a CNC machine. To form a part, the machine tool follows a pre-programmed contour, similar to a conventional milling operation. The main advantage of this method is that **no die is required**, making this an ideal process for rapid prototyping or small batch production.

Figure 2.10 Sample Of Incremental Forming Products

2.3 INCREMENTAL FORMING ANALYSIS

An approximate deformation analysis for the incremental bulging of sheet metal using a ball has been developed by Iseki. The incremental bulging method has been applied for non-symmetric shallow shells. In the plane-strain deformation model has been proposed. This model makes an approximation that the sheet metal in contact with the ball stretches uniformly. The friction at the interface between tool and sheet, the plane anisotropy and Bausinger effects of the sheet material are neglected. The closed form expressions for the uniform strains εx, εy, and εt of the deformed shell are accentual. The tensile force is determined from the condition that the undeformed part is rigidly moved by the stiffness of the shell. The results are obtained by the approximate deformation analysis, FEM analysis and experiments. Vertical wall surface forming of rectangular shell using multistage incremental forming are studied. A method of calculating for the approximate distribution of thickness strain and the maximum bulging height has been proposed using a plane-strain deformation model with a constant strain gradient. A mapping relationship between the blank and its formed specimen under the condition of even strain is proved.

A simplified calculation model has been developed in assuming that all deformation occurs only by shear deformation. The intermediate shape was determined from the predicted thickness strain so as to distribute the deformation uniformly.

The formability in incremental forming of sheet metal are studied. A forming tool containing a freely rotating ball was developed. The results observed in the tests were examined by grid measurement and finite element analysis. A unique forming limit curve was obtained. The effects of process parameters (tool size, feed rate, plane - anisotropy) on formability are studied.

It is difficult in general to predict the thickness strain distribution of the initial state of a deformation after the accumulation of numerous incremental deformation passes. One option to calculate the thickness strain during the whole deformation process is by using finite element analysis. Nevertheless, it has some difficulties when applied to the incremental sheet metal forming process. The most critical problem is the large number of calculation steps, which means very long time for calculation. Compared with the general sheet metal forming processes, the incremental sheet metal forming process has a simple deformation mechanism but the deformation path of its moving tool in this process is much longer. If the entire process has to be analyzed, too much time is required.

2.4 PLASTIC INSTABILITIES

2.4.1 Forming Limits In Conventional Stamping

Any metal that is continuously being deformed will finally fail. The continuous deformation creates more and more dislocations that move through the material, interact with each other and create voids that finally result in a crack. The limit strain before failure is called the fracture limit and depends on the stress state: a high level of hydrostatic compressive stress squeezes the voids and slows down damage development. This is the reason why forming processes that are largely compressive of nature like rolling and wire drawing can create large levels of strain in the material without causing damage. This is contrary to processes that operate largely in tension. Forming processes operating largely in tension like conventional stamping can also be limited by another phenomenon: instabilities. Instabilities do create a situation that the deformation gets concentrated into a small region (the neck) with the result that the remainder of the product does not deform any further. This limits the amount of deformation that can be generated in a practical forming operation, the limit is conveniently called the necking limit. Because of the small size of the neck, even small extra displacements will generate large additional strains and the material will soon reach the fracture limit and fail. The large deformations in the neck are not practically relevant because they cannot be controlled and, because of the small size of the neck, they do not contribute to the shape of a product.

The best known example of a necking limit is the conventional forming limit curve. Fig. 2.11 schematically presents the relative position of the FLC and also of the fracture limit as for example measured for steel and aluminum. An actual example are the curves measured by Embury and Leroy for Al 5154 that are presented both by Atkins (1996) in his study on fracture in forming, and by Hosford and Duncan (1999) in their review article on sheet metal forming. Fig. 2.11 illustrates the experience that for most ductile metals, the necking limit is much lower than the fracture limit. This leads to an important conclusion: the formability of a material in a forming operation can be increased significantly if one is able to get rid of the instabilities.

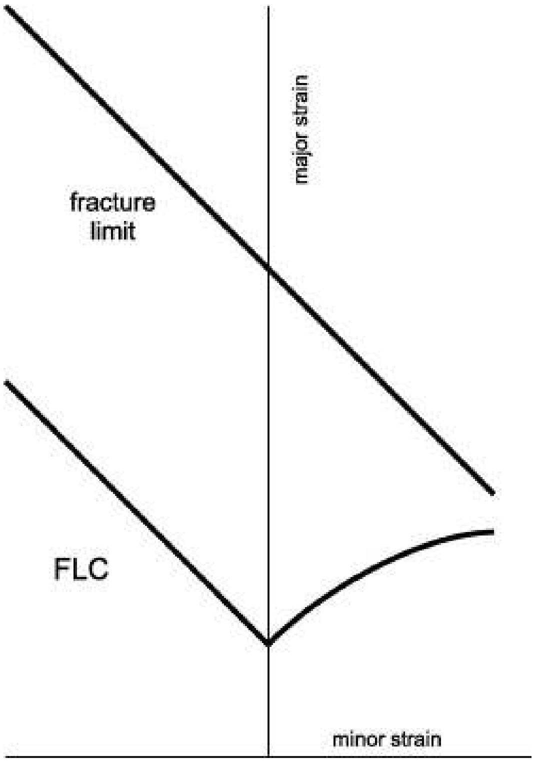


Fig. 2.11: Schematic Presentation Of The Necking Limit (FLC) And The Fracture Limit

It is known that the FLC is only valid under certain restrictions. These are

i. The strain path should be straight (proportional loading),
ii. The deformation is dominantly caused by membrane forces (absence of bending),
iii. Through-thickness shear is negligible, and
iv. A situation of plane stress exists ($\sigma_{33} = 0$).

These conditions look severe, but many practical forming operations operate closely enough to these conditions to justify practical use of the FLC. In Incremental Sheet Forming(ISF), however, all four conditions are violated as will be shown in the following sections.

2.4.2 Stabilization Of Necking In Incremental Sheet Forming

In ductile metals, much 'deformation potential' is available if the necking instability can be avoided or postponed or the growth rate of a neck is reduced. Apparently, at least one of these causes is active in ISF. This means that in the material special situations have to be created.

The observation that at any moment the deformation is localized is by itself no explanation for the enhanced formability in ISF. On the contrary, in classical sheet forming localization is synonymous with necking and instability. This is due to the fact that the necking zone requires the lowest force to elongate. Once a neck is originated it will remain the weakest point.

Another aspect of ISF is that the zone of localized deformation moves with the tool over the sheet. One might argue that high deformations in ISF are obtained because the neck cannot grow into a crack, since the tool is already in another place before the fracture limit is reached. This explanation is not completely satisfying, because it does not explain why a neck once generated will not keep growing, if it is still under tension.

ISF as a practical sheet metal forming process works if the deformation is localized into a small zone, *and* if in that zone a special situation exists that suppresses or retards necking. At the same time, outside that zone the situation must be such that if a neck is generated inside the zone it will not grow. This effect of stabilization can be achieved in two ways: the stress at the location of the neck is reduced to below the level that is required for further growth, or the situation at the originated neck is changed such that the stress needed to develop the neck any further is raised above the level of local stress. The latter phenomenon requires that the effect of the mechanism that causes localized deformation must be reversible.

In literature, a number of mechanisms have been suggested to explain the enhanced formability in ISF, notably the combination of stretching with shear forces, normal forces or bending forces, cyclic or non-proportional deformation paths, too small deformation zones and hydrostatic compressive stresses. Apart from the last two, all suggested explanations indeed violate the conditions for which the standard FLC is supposed to give a valid forming limit.

It will be assumed that if a sheet is deformed in tension mainly, a local reduction of the yield force will also localize the deformation. For all mechanisms their theoretical ability to avoid or postpone necking or reduce the growth rate and their relation with ISF will be assessed.

2.5 EFFECTS OF SHEAR

This section reviews shear as a stabilizing mechanism. It starts with an explanation of the principle of the mechanism, followed by the relation to ISF and a review of testing.

2.5.1 Principle

In terms of stability, simple shear would completely avoid necking, because no tensile force is applied in the plane of the sheet. However of more relevance is shear superposed on stretching of the sheet.

An additional shear stress will lower the yield stress in tension. This follows directly for example from the von Mises yield criterion. If a sheet is stretched to a level just below the flow stress, even a relatively small additional shear stress may be sufficient to start plastic deformation. This shows that an additional shear stress is capable to localize deformation. If the shear stress is caused by a tangential displacement, e.g. by tool movement, the shear stress cannot be sustained if a neck starts to grow. Without a shear stress, the in-plane yield stress increases again and the deformation mechanism is stable until the in-plane stress is high enough to deform the sheet plastically even without additional shear stress.

The result of this stabilizing effect is that it raises the necking limit; the latter defined as the length strain at the onset of necking. This has been shown by Tekkaya in an elaborate analysis, and some results are presented in Fig. 2.12. This figure shows how the yield stress in tension (bottom line) and the necking limit (upper line) are affected by an additional shear stress, the latter expressed as the ratio between shear stress and the material's flow stress.

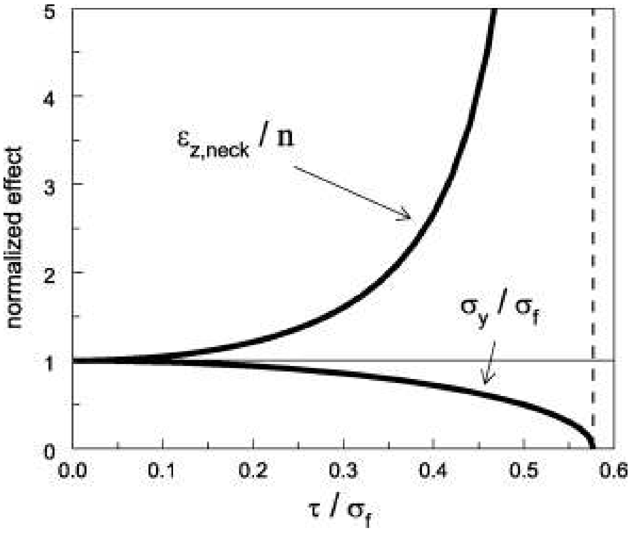


Fig. 2.12: Effects Of Additional Shear Stress On Formability. Bottom Line: Normalized Yield Stress In Tension σ_y; Upper Line: Normalized Length Strain At Onset Of Necking ε_z. σ_f = Flow Stress, τ = Shear Stress, n = Hardening Coefficient.

Eyckens has investigated the effect of through-thickness-shear on the FLC by carrying out an MK-type analysis and found that the presence of shear can raise the FLC significantly, but depending on the orientation of the shear.

In literature the effect of shear on formability in ISF has been described in different ways. Contrary to deep-drawing, in ISF a product is made without the flow of new material from a blank holder area. This means that the product is made by 'stretching' (in a wider sense) and that the material is elongated in at least one direction and thinned. In the early days it has been suggested that this 'stretching' is done mainly by out-of-plane shear (see Fig. 2.13 for definition). This suggestion was not based on experimental evidence, but intuitively by drawing a parallel with shear-spinning. However recent detailed experimental investigation has showed that this suggestion is false.

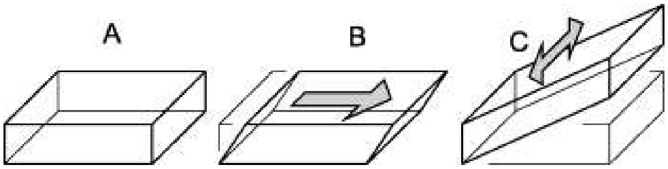


Fig. 2.13: Definitions Of Shear As Occurring In ISF. (A) Undeformed Part Of The Sheet. (B) Through-Thickness Shear As Observed In The Direction Of Punch Movement. (C) Out-Of-Plane Shear As Originally Proposed To Occur In ISF. The Arrows Indicate The Direction Of Punch Movement.

An early mentioning of through-thickness shear in the direction of punch movement (see Fig. 2.13 for definition) was done by Sawada as a conclusion of FEM simulations. In fact this study was one of the first to investigate in detail the forming of the sheet around the punch contact.

Bambach has also noticed the occurrence of shear in his simulation of ISF, and observed that the level of shear depends both on the punch head diameter and the vertical pitch.

Jackson has detected the presence of through-thickness shear in the direction of punch movement experimentally by measuring the relative displacement of both surfaces of a sandwich panel in SPIF, and by a rigorous measurement of a cross section of a 3 mm thick copper plate in both SPIF and TPIF. Some shear was also detected across the direction of punch movement. Eyckens has detected the presence of shear by drilling small holes in the sheet and measuring their orientation after forming. He also observed shear in the direction of punch movement, but little or none in the perpendicular direction.

Besides the shear that can be detected in the finished product, it must be taken into account that shear can also take place during the process in an intermediate stage, without showing up in the finished product.

2.6 FINITE ELEMENT ANALYSIS

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modeling schemes, the programmer can insert numerous algorithms (functions) which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture.

2.6.1 Material Properties

This section refers to material types used to model; there are two types of isotropic material involved in this model: linear elastic-plastic (for sheet metal) and linear elastic (for the punch and die). The basic material properties required for this model are given in Table 1.

Table 2.1: Material Properties Of The Model

Sheet Metal (Aluminum)		
Linear Elastic - Plastic		
Material Property	Symbol	Property Value
Young Modulus	E	78 GPa
Uniaxial yield strength	G_y	550MPa
Poison's Ratio	N	0.3
Material density	P	2700 kg/m^3
Punch and Die (Steel)		
Linear Elastic		
Young Modulus	E	78 Gpa
Uniaxial yield strength	G_y	4000 Mpa
Poison Ratio	v	0.3
Material density	p	7800 kg/m^3

2.6.2 Nonlinear Analysis

Linear finite element analysis assumes that all materials are linear elastic in behavior and that deformations are small enough to not significantly affect the overall behavior of the structure. While nonlinear analysis is much more complicated than simple linear analysis because it is required many variables such as changes in geometry, permanent deformations, structural cracks and buckling. A fundamental difference between geometrically linear and geometrically nonlinear analysis is that in linear analysis equilibrium is satisfied on the initial un-deformed configuration, whereas in nonlinear analysis equilibrium must be satisfied in the deformed configuration. Nonlinear geometric and material effects may be incorporated in this analysis. To achieve final equilibrium in a nonlinear analysis, we solve the model many times, constantly adjusting the applied forces based on the current state of equilibrium, and modifying the geometry based on the current displacements. Convergence nonlinear analyses are generally solved by an iterative procedure and the level of convergence reached tells us the likely error in the solution. Not all nonlinear analysis was guaranteed to converge but often convergence can be helped along by modifying some of the parameters. For nonlinear analysis, since it is no longer possible to directly obtain results according to external loads, a solution procedure is usually adopted in which the total required load is applied in a number of increments. The analysis allows you to set any desired load level for each increment or time step of a nonlinear solution. For the analysis of nonlinear problems, the solution procedure adopted may be of significance to the results obtained. In order to reduce this dependence, wherever possible, nonlinear control properties incorporate a series of generally applicable default settings, and automatically activated facilities.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Before starting the experiments, several things are needed to be done in order to run the experiments smoothly and accurately. Basically, there are four general steps that had been set so that the utilization of Design of Experiment (DOE) tools can be hold efficiently. The four general steps are:

i. Project Flow Diagram
ii. Plan the experiment
iii. Research Procedure
iv. Conducting the experiment

3.2 PROJECT FLOW DIAGRAM

In order to make sure the project could finish on schedule, the project must be planned correctly. This is significant to make sure that the experiment runs smoothly. For more details see Fig. 3.1 and Fig. 3.2.

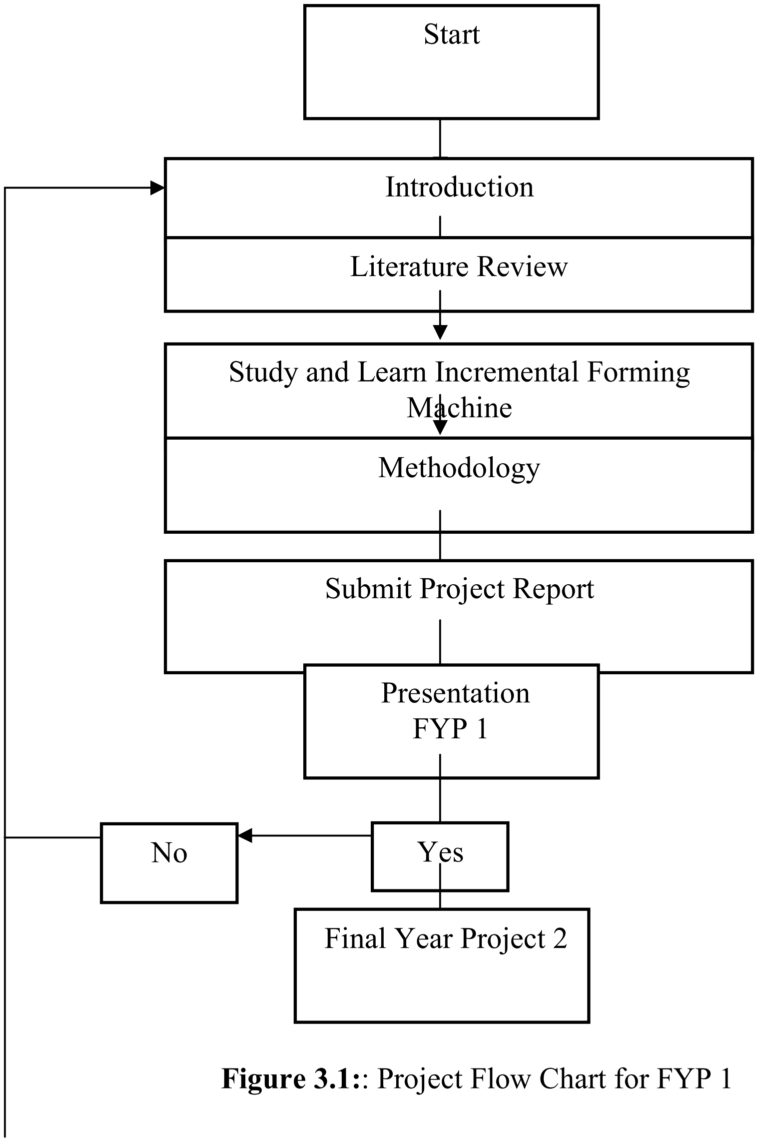


Figure 3.1:: Project Flow Chart for FYP 1

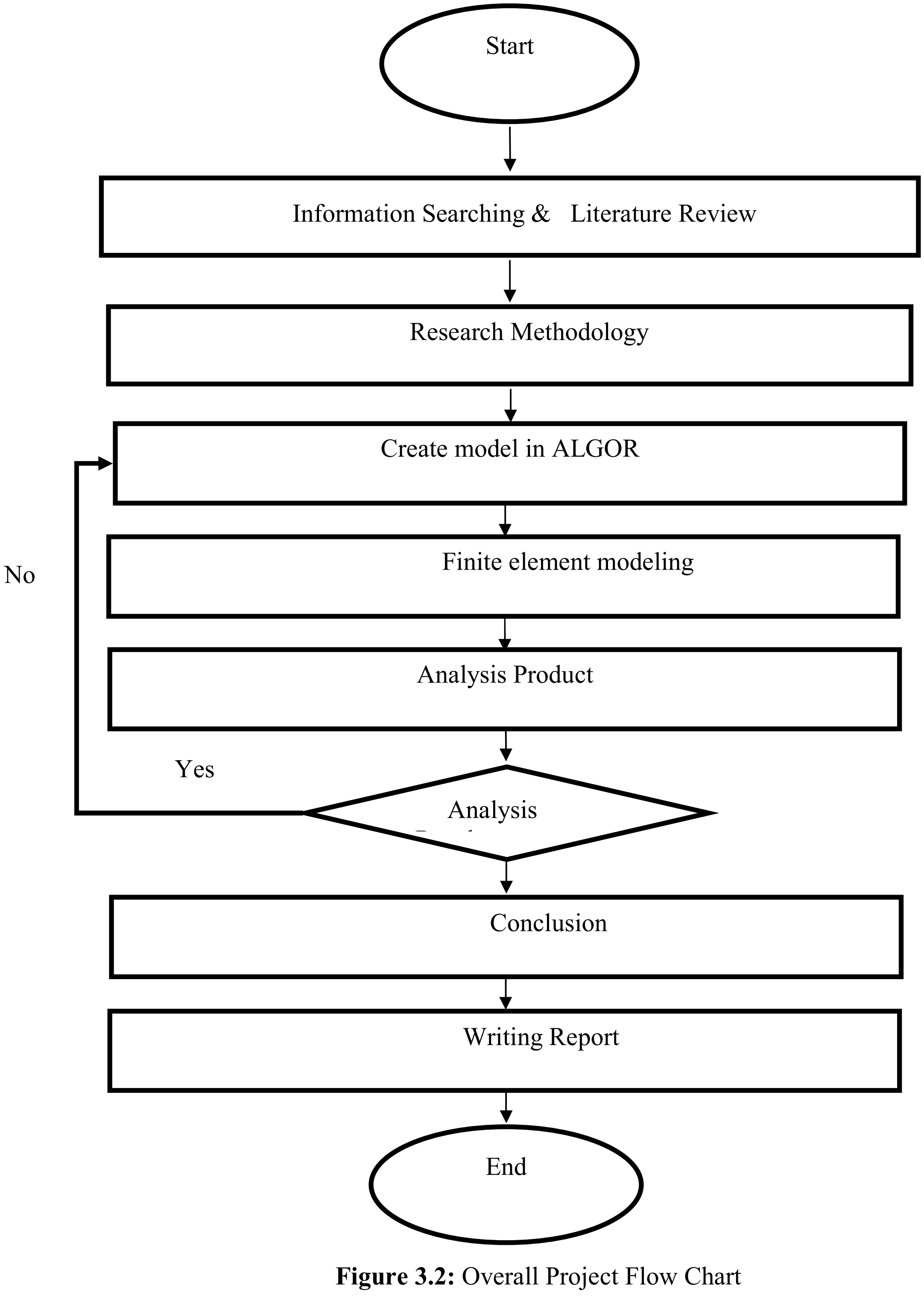


Figure 3.2: Overall Project Flow Chart

In this project includes many processes such as searching information, design, analysis and validation. Those processes will be described in this chapter according to the flow chart. In this part, every data and information were gathered together and being analyzed according to the objectives and scope of this project.

From the information collected and gathered, the project will be continued with the design process. In this stage, ArtCAM Pro software is used to design the model according to the objective. From the design, the numerical control coding is generated. The coding is then transferred to a Borlan Program (C++ programming) in a personal computer – numerical control (PC-NC).

Lastly, the Incremental Forming machine will run using all the necessary settings. After all of this is done, the project will be continued with the design process. In this stage, ALGOR FEMPRO V22 software is used to design the model. The parameter to be verified is the thickness of the material but with a constant material. After the analysis is run through, the product must be compared and analyzed. The analysis is to gather information about the quality of the sheet metal forming.

3.3 PLAN THE EXPERIMENT

In order to achieve the objective of the project the first stage in utilizing the DOE techniques is planning the experiment. There are a few important things that are needed to be considered in order to plan a successful experiment.

3.3.1 Clarify of Project Objectives

The project objectives need to be state clearly to make sure that the experiment can be set up properly and can achieve the project objectives. In order to achieve the project objectives, the methods of how to evaluate those objectives must be taken into account so that no error will compromise the data which can lead to wrong conclusion of experiment. There are two main objectives in this work, which are:

i. Different setting of distance on stepdowns
ii. Analysis of displacement by the springback effect on different thickness of material.

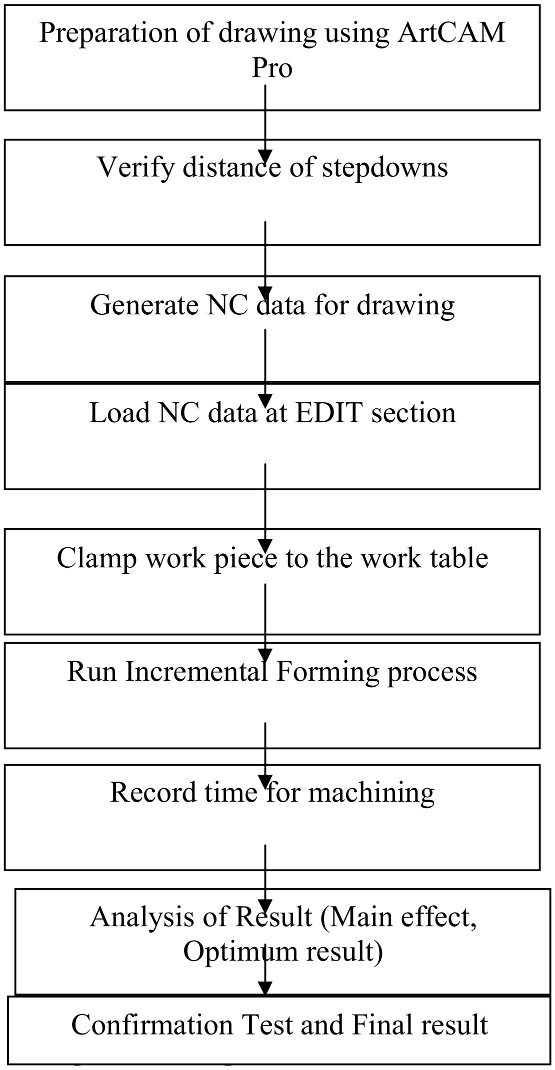
3.3.2 Clarify the Design Factor

The design factor needs to be determined in order to achieve the objective of this project. The machine parameters were decided as the factor that can influence the response of a system. During this project the Incremental Forming machine was used. From the past studies and other researches done by others, it was decided that only two parameters will be taken into consideration. The other parameters will be set as constant values. The two selected design factors are:

i. Distance of stepdowns(mm)
ii. Thickness of material.

3.4 RESEARCH PROCEDURE

Overall research procedure will be explained in this chapter. For clearer and better view of this whole project procedure, step by step procedure will be explained as illustrated in figure 3.3.



3.4.1 Preparation of Drawing

The first walk of these steps is to firstly prepare the drawing. The drawing will be design in the ArtCAM Pro software. A square shape is drawn with a dimension of 100mm x 100mm. A detail explanation will be shown in the subtopic further in this report.

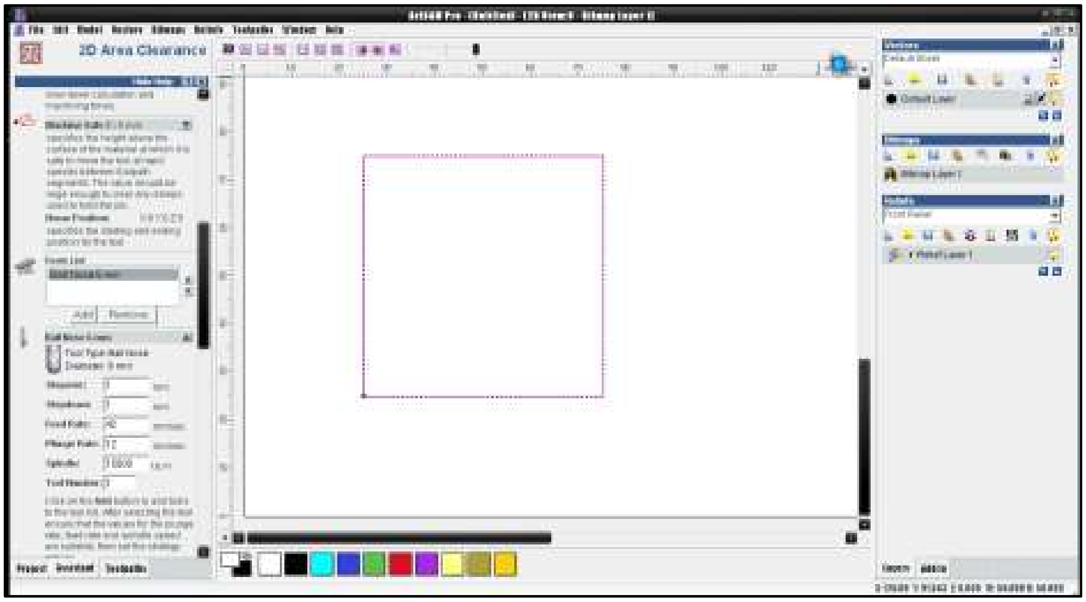


Figure 3.4: Square Drawing Using ArtCAM Pro

3.4.2 Verify Variables

There are three major patterns that are usually used. These patterns are already interpreted in the ArtCAM Pro software. The patterns are consisting of:

i. 0^0 angle Raster pattern
ii. 45^0 angle Raster pattern
iii. Climb Mill Offset pattern

For this project, only the Climb Mill offset pattern with from outside to inside tool path strategy in measured area is used.

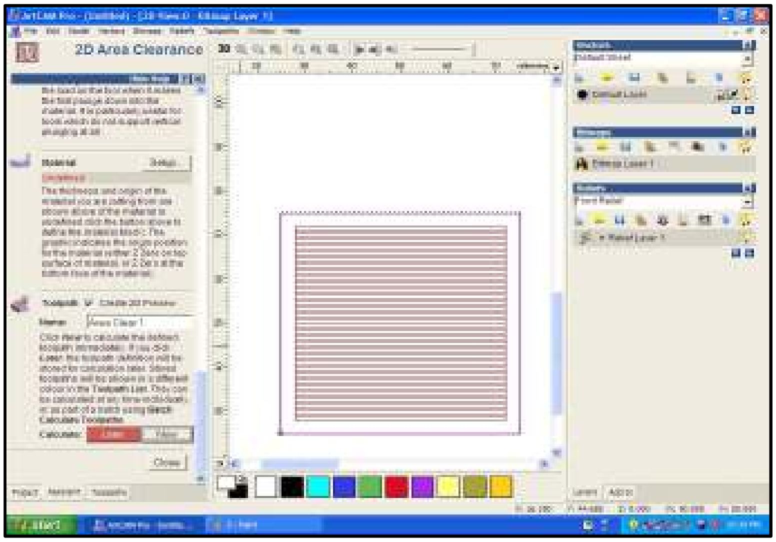


Figure 3.5: 0^0 angle Raster pattern

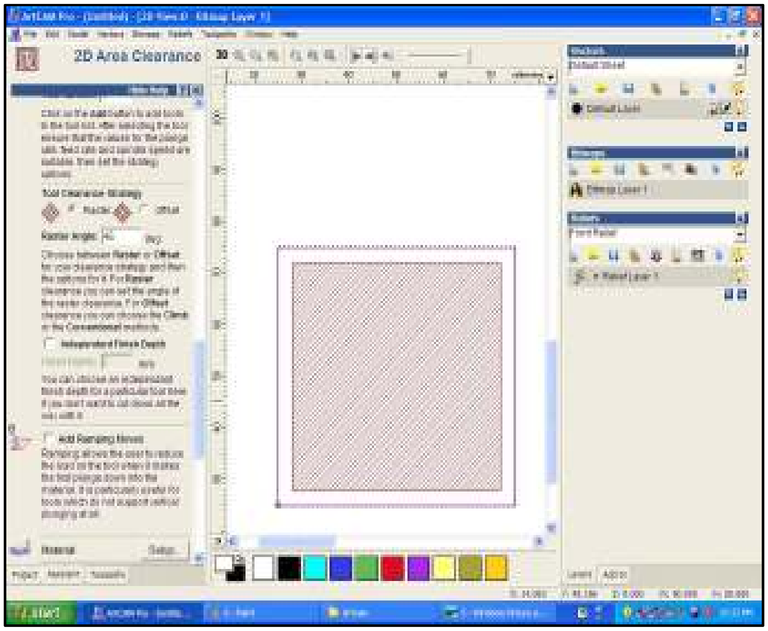


Figure 3.6: 45^0 angle Raster pattern

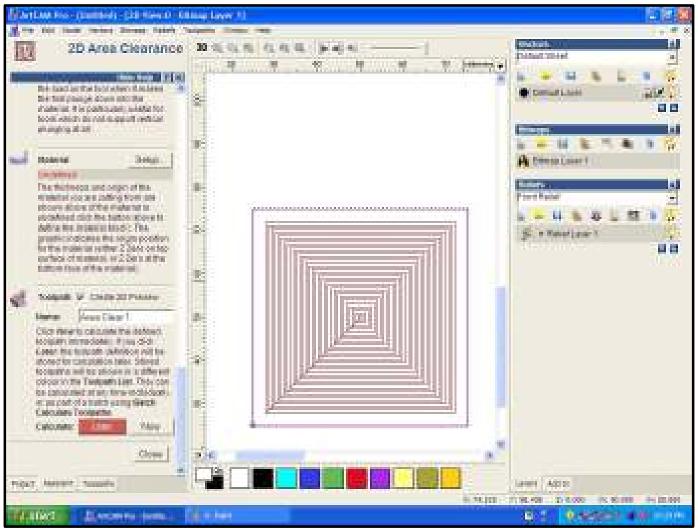


Figure 3.7: Climb Mill Offset Pattern

3.4.3 Generate NC Data

After all the design has been successfully completed, all of these designs are needed to be converted into Numerical Control data to be read by the IF machine. This is done by accessing the options button and save toolpath. By this method the design will be converted successfully.

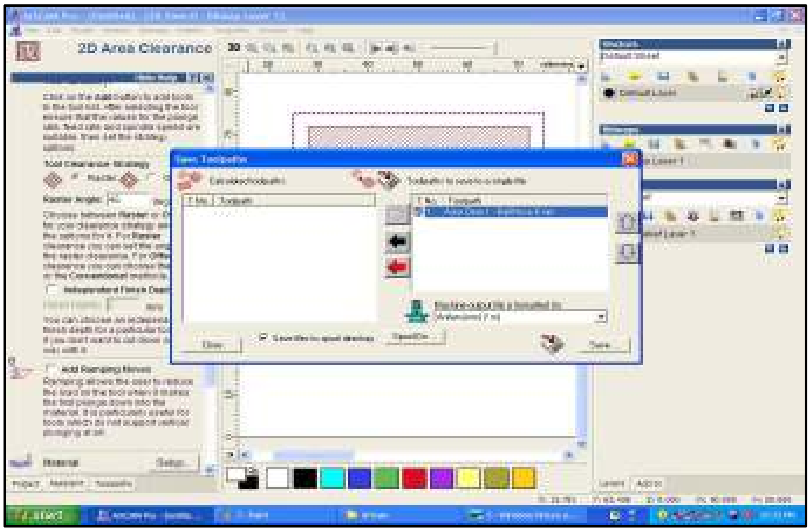


Figure 3.8: Generate Toolpath To NC Data

3.4.4 Prepare Workpiece

For the experimental process, an aluminum sheet metal of 0.5mm thickness is used. The material is cut to a dimension of 250mm x 200mm each to be placed at the clamping area of the IF machine. Each workpiece will be arranged so that 4 experiments can be done on the same material if no tearing is occurred. If this happens it will affect the strain of the load to the material. When this happens another workpiece will be replaced in the clamping area.

Figure 3.9: Incremental Forming Clamping Area

3.4.5 Run Incremental Forming Machine

After all of the above has been set into place, the machine is set to run. The operating time of the machine is recorded to be placed in the data gathered. The machine usually runs about 1 to 4 hours for one pattern to be completed.

Figure 3.10: Incremental Forming Machine

3.5 CONDUCTING THE EXPERIMENT

3.5.1 Design in ArtCAM Pro

Before running the IF machine, a NC code is to be firstly generated by the ArtCAM Pro software. Below are the procedures on how the design is drawn by using this software:

i. The first step is to decide the shape wanted to be drawn.
ii. Create “new model” and click “ok”. Then zoom in until clear.
iii. Click “vector tool” - create the shape wanted. For example: the square. Then move to origin and click “create”, then click “close”.
iv. Next step is to click “2D toolpath” and then go to “area clearance”. Choose the final depth and independent finish. After that, click “add tool” and choose offset pattern (0^0 angle Raster pattern, 45^0 angle Raster pattern, Climb Mill Offset pattern), and the starting point inside or outside. Then click “now”.
v. Click “simulate” and go to the tool icon and choose “toolpath”. Next, click “save toolpath” and press arrow symbol. Then save file, example “name.txt”.

After all of this are done, click generate code icon. Then, click “open” file coding and delete items which will not be used in the program. Below are the steps to be erased:

i. Erase line 1, 2 and 3.
ii. Erase all the word “tool” in the coding.
iii. Lastly erase “endmain”. Then save file.

When running the IF machine, the coding is needed to be transferred to IF programming software which is the Borlan C++ programming. This machine has 3-axis which is the y-axis, x-axis and z-axis.

3.5.2 Design of Incremental Forming Products Analysis in ALGOR Software

Shown below is the table for the constant material properties used for this project analysis. This table is taken from the ALGOR material library.

Table 3.1: Aluminum Alloy 1100 -O

Material Model	**Standard**
Material Source	ALGOR Material Library
Material Source File	C:\Program Files\ALGOR\22.00\matlibs\algormat.mlb
Date Last Updated	2004/09/30-16:00:00
Material Description	None
Mass Density	0.0000000027104 N·s²/mm/mm³
Modulus of Elasticity	68947 N/mm²
Poisson's Ratio	0.33
Yield Stress	34.474 N/mm²
Strain Hardening Modulus	157.817 N/mm²

3.5.2.1 FE Analysis

For every study or research analysis must be carried to be approved as a new invention and to be commercialized. For this project the analysis is done using finite element analysis (FEA) by ALGOR Software.

Different thickness test in ALGOR software

For overall test, the same parameters were chosen:

i. The sheet metal was square-chucked with inner sides of the clamping square 250 mm x 200 mm(See Figure 3.5)

ii. The sheetmetal plate subjected to forming was measured 100 mm × 100 mm

iii. The step-over of tool path strategy was 1.5 mm and step-down was 5.5 mm, 12.5 mm and 25 mm for every sheet metal

iv. Diameter of the hemispherical tool is 6 mm

v. Tool path strategy: from outside to inside in measured area

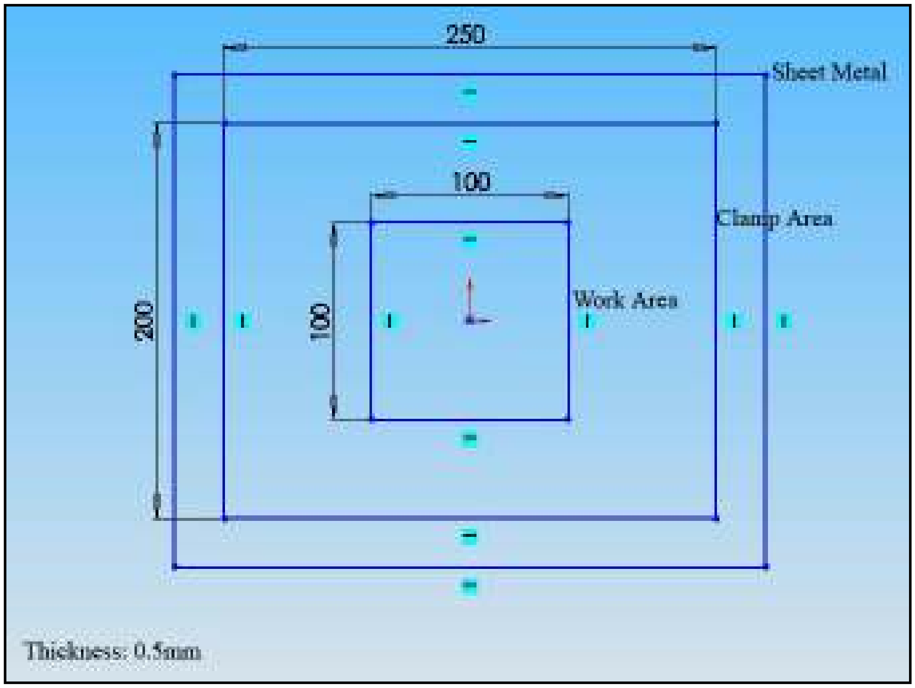


Figure 3.11: Design Of Sheet Metals For Incremental Forming Test

Following are the steps of analysis using finite element analysis methods:

i. Analysis Type

MES with Nonlinear Material Models.

ii. Meshing the model

Click on the Open icon in the “What to do” section on the left side of the New dialog. Select the “IGES Files” option in the “File of type” drop-down box. Then select the Tool.IGS file in the “introduction example/input file” directory. Press the “Open” button and click OK. Press the “Mesh Model” button in the “Mesh Model Settings” dialog. Then access the TOOLS pull-down menu and select the “FEA Editor” command to move to the FEA Editor environment and click OK to accept the default “English(in)” system.

iii. Create Blank (3D)

Click rectangle icon and draw below tool with size 250 mm x 200 mm. Then, mesh 25 x 20.

iv. Defining the material data

Right click on the “Material” heading for Part 1(Tool) Brick and in the tree view and select the “Modify Material” command. Select the “Steel (AISI 4130) ” item in the “Select Material” section of the “Element Material Selection” dialog and click Ok to accept that value.

v. Processor Information

Event Duration 220 s and Capture Rate 1 s/

vi. Nodal Boundary Condition

Tick tz, ty and tx

vii. Nodal Prescribed Displacement

Tick - z(-ve), y(+ve) and x(+ve) such z =-0.5 , y =100 and x =100.

viii. Built curve for Nodal Prescribed Displacement

Table 3.2: Load Curve Information

Load Curve 1 Type	**Time**
Load Curve 1 Index 1 Time	0
Load Curve 1 Index 1 Multiplier	0
Load Curve 1 Index 2 Time	0.5
Load Curve 1 Index 2 Multiplier	0.95
Load Curve 1 Index 3 Time	1.5
Load Curve 1 Index 3 Multiplier	1.05
Load Curve 1 Index 4 Time	2
Load Curve 1 Index 4 Multiplier	5
Load Curve 1 Index 5 Time	40
Load Curve 1 Index 5 Multiplier	5
Load Curve 1 Index 6 Time	41
Load Curve 1 Index 6 Multiplier	9
Load Curve 1 Index 7 Time	80
Load Curve 1 Index 7 Multiplier	9
Load Curve 1 Index 8 Time	81
Load Curve 1 Index 8 Multiplier	13
Load Curve 1 Index 9 Time	120
Load Curve 1 Index 9 Multiplier	13
Load Curve 1 Index 10 Time	121
Load Curve 1 Index 10 Multiplier	17
Load Curve 1 Index 11 Time	160
Load Curve 1 Index 11 Multiplier	17
Load Curve 1 Index 12 Time	161
Load Curve 1 Index 12 Multiplier	21
Load Curve 1 Index 13 Time	200
Load Curve 1 Index 13 Multiplier	21
Load Curve 1 Index 14 Time	201
Load Curve 1 Index 14 Multiplier	25
Load Curve 1 Index 15 Time	210
Load Curve 1 Index 15 Multiplier	25

Load Curve 1 Index 16 Time	220
Load Curve 1 Index 16 Multiplier	0
Load Curve 2 Type	**Time**
Load Curve 2 Index 1 Time	2
Load Curve 2 Index 1 Multiplier	0
Load Curve 2 Index 2 Time	10
Load Curve 2 Index 2 Multiplier	1
Load Curve 2 Index 3 Time	20
Load Curve 2 Index 3 Multiplier	1
Load Curve 2 Index 4 Time	30
Load Curve 2 Index 4 Multiplier	0
Load Curve 2 Index 5 Time	41
Load Curve 2 Index 5 Multiplier	0
Load Curve 2 Index 6 Time	50
Load Curve 2 Index 6 Multiplier	0.9
Load Curve 2 Index 7 Time	60
Load Curve 2 Index 7 Multiplier	0.9
Load Curve 2 Index 8 Time	70
Load Curve 2 Index 8 Multiplier	0.1
Load Curve 2 Index 9 Time	81
Load Curve 2 Index 9 Multiplier	0.1
Load Curve 2 Index 10 Time	90
Load Curve 2 Index 10 Multiplier	0.8
Load Curve 2 Index 11 Time	100
Load Curve 2 Index 11 Multiplier	0.8
Load Curve 2 Index 12 Time	110
Load Curve 2 Index 12 Multiplier	0.2
Load Curve 2 Index 13 Time	121
Load Curve 2 Index 13 Multiplier	0.2
Load Curve 2 Index 14 Time	130
Load Curve 2 Index 14 Multiplier	0.7
Load Curve 2 Index 15 Time	140
Load Curve 2 Index 15 Multiplier	0.7

Load Curve 2 Index 16 Time	150
Load Curve 2 Index 16 Multiplier	0.3
Load Curve 2 Index 17 Time	161
Load Curve 2 Index 17 Multiplier	0.3
Load Curve 2 Index 18 Time	170
Load Curve 2 Index 18 Multiplier	0.6
Load Curve 2 Index 19 Time	180
Load Curve 2 Index 19 Multiplier	0.6
Load Curve 2 Index 20 Time	190
Load Curve 2 Index 20 Multiplier	0.4
Load Curve 2 Index 21 Time	201
Load Curve 2 Index 21 Multiplier	0.4
Load Curve 2 Index 22 Time	210
Load Curve 2 Index 22 Multiplier	0.5
Load Curve 3 Type	**Time**
Load Curve 3 Index 1 Time	10
Load Curve 3 Index 1 Multiplier	0
Load Curve 3 Index 2 Time	20
Load Curve 3 Index 2 Multiplier	1
Load Curve 3 Index 3 Time	30
Load Curve 3 Index 3 Multiplier	1
Load Curve 3 Index 4 Time	40
Load Curve 3 Index 4 Multiplier	0.1
Load Curve 3 Index 5 Time	50
Load Curve 3 Index 5 Multiplier	0.1
Load Curve 3 Index 6 Time	60
Load Curve 3 Index 6 Multiplier	0.9
Load Curve 3 Index 7 Time	70
Load Curve 3 Index 7 Multiplier	0.9
Load Curve 3 Index 8 Time	80
Load Curve 3 Index 8 Multiplier	0.2
Load Curve 3 Index 9 Time	90
Load Curve 3 Index 9 Multiplier	0.2

Load Curve 3 Index 10 Time	100
Load Curve 3 Index 10 Multiplier	0.8
Load Curve 3 Index 11 Time	110
Load Curve 3 Index 11 Multiplier	0.8
Load Curve 3 Index 12 Time	120
Load Curve 3 Index 12 Multiplier	0.3
Load Curve 3 Index 13 Time	130
Load Curve 3 Index 13 Multiplier	0.3
Load Curve 3 Index 14 Time	140
Load Curve 3 Index 14 Multiplier	0.7
Load Curve 3 Index 15 Time	150
Load Curve 3 Index 15 Multiplier	0.7
Load Curve 3 Index 16 Time	160
Load Curve 3 Index 16 Multiplier	0.4
Load Curve 3 Index 17 Time	170
Load Curve 3 Index 17 Multiplier	0.4
Load Curve 3 Index 18 Time	180
Load Curve 3 Index 18 Multiplier	0.6
Load Curve 3 Index 19 Time	190
Load Curve 3 Index 19 Multiplier	0.6
Load Curve 3 Index 20 Time	200
Load Curve 3 Index 20 Multiplier	0.5

ix. Running the analysis

Access the ANALYSIS pull-down menu and select the “Perform Analysis” command to run the analysis.

x. Viewing the results

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter displays all the results obtained from the experiments. Tables of results, graphs, and figures are included. Varying machining parameter has been done in virtual simulation, the result will be displayed and graphs have been interpreted. Detailed explanation of graphs and figures are also provided. The virtual simulation involves in one tool path strategy from outside to inside in measured area of varying machining stepdown parameters. This analysis used four sets of stepdown on four variable of thickness to determine the assume depth after the formation and also the assume point of fracture. The results taken are from the centre node of the sheet metal area. The results from each of stepdown was analyzed and summarized in order to relate between the processes parameters involved.

4.2 DEVELOPMENT OF FE MODEL FOR ISF

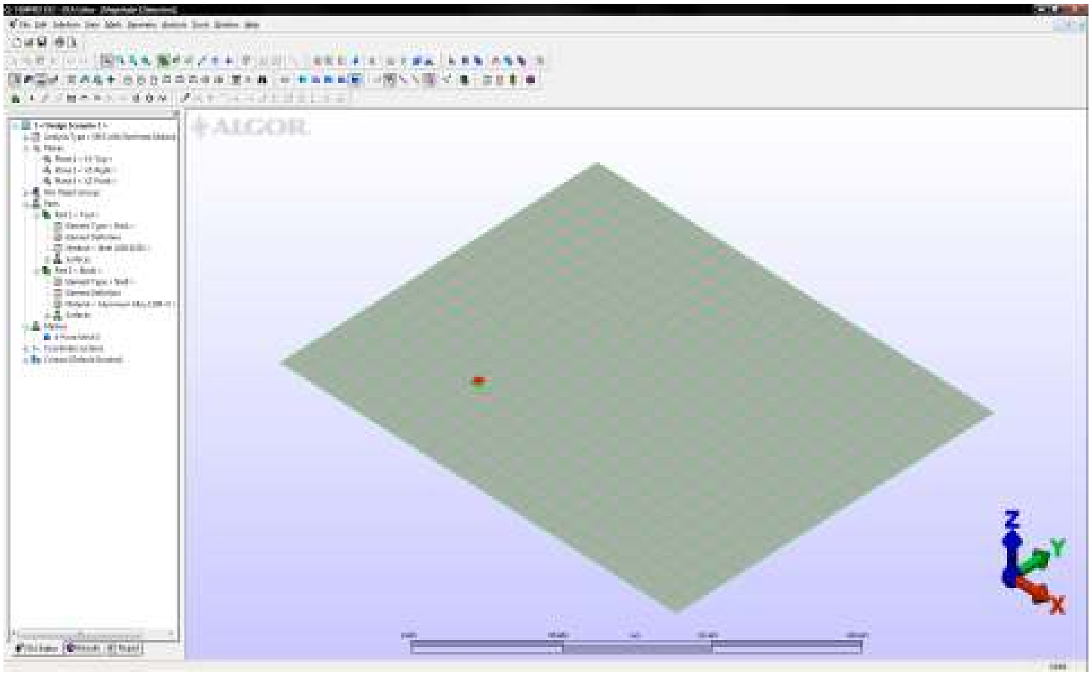


Figure 4.1: Finite Elements Modeling Of ISF

Model Information

Analysis Type - MES with Nonlinear Material Models

Units - Custom - (N, mm, s, deg C, deg C, V, ohm, A, J)

Table 4.1: Part Information

Part ID	Part Name	Element Type	Material Name
1	Tool	Brick	Steel (AISI 4130)
2	Blank	Shell	Aluminum Alloy 1100-O

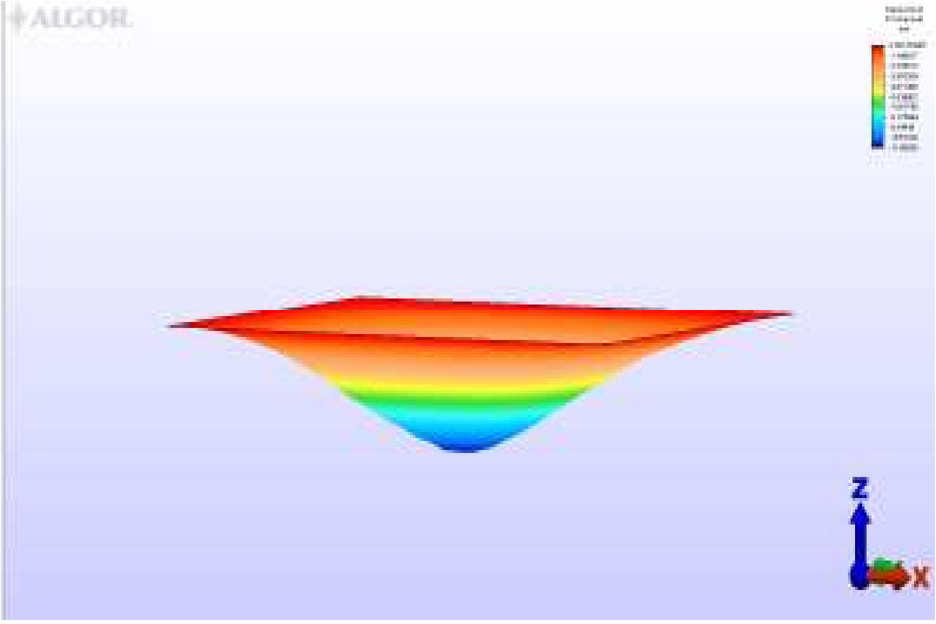


Figure 4.2: Finite Elements Outcome Of ISF

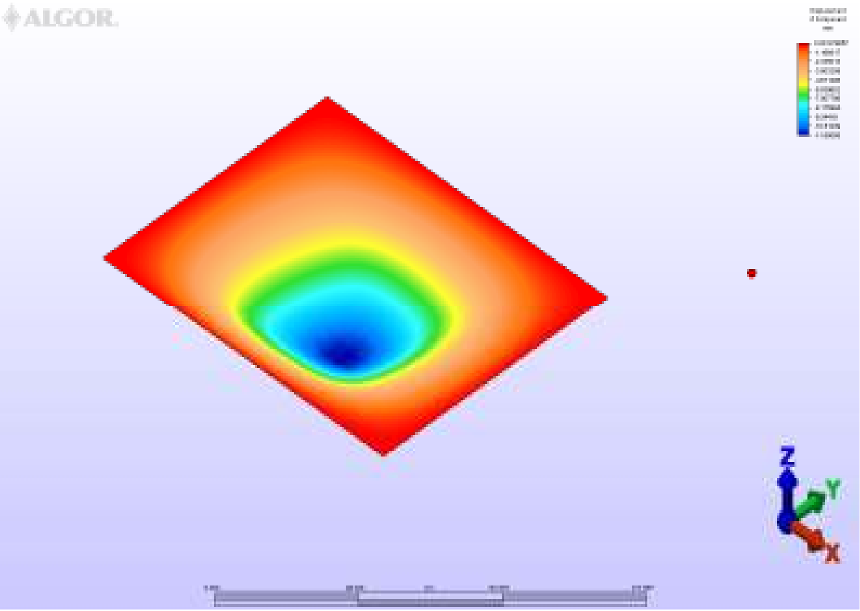


Figure 4.3: Finite Elements Outcome Of ISF

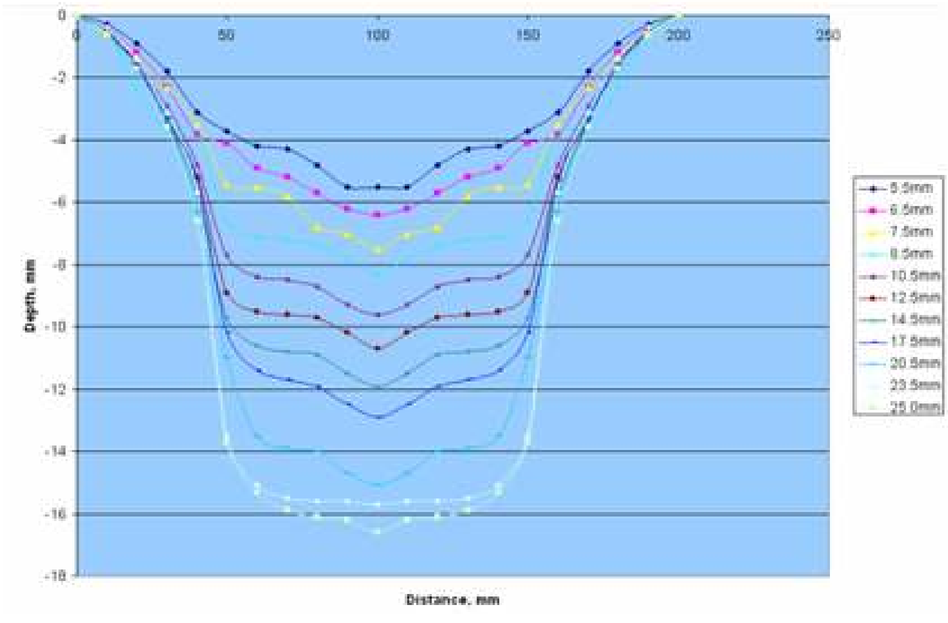
Table 4.2: Instructions For Simulation

Simulation type	Nodal Prescribed Displacement

First Run	Z(-ve) = 5.5 mm
	X(+ve) = 100 mm
	Y(+ve) = 100 mm
Second Run	Z(-ve) = 12.5 mm
	X(+ve) = 100 mm
	Y(+ve) = 100 mm
Third Run	Z(-ve) = 25 mm
	X(+ve) = 100 mm
	Y(+ve) = 100 mm

The analysis is carried out with these parameters on different thickness of the constant material used in this experiment. The thickness of the sheet metal used is 0.5mm, 1.0mm, 1.5mm and 2,0mm respectively.

4.3 EXPERIMENTAL DATA



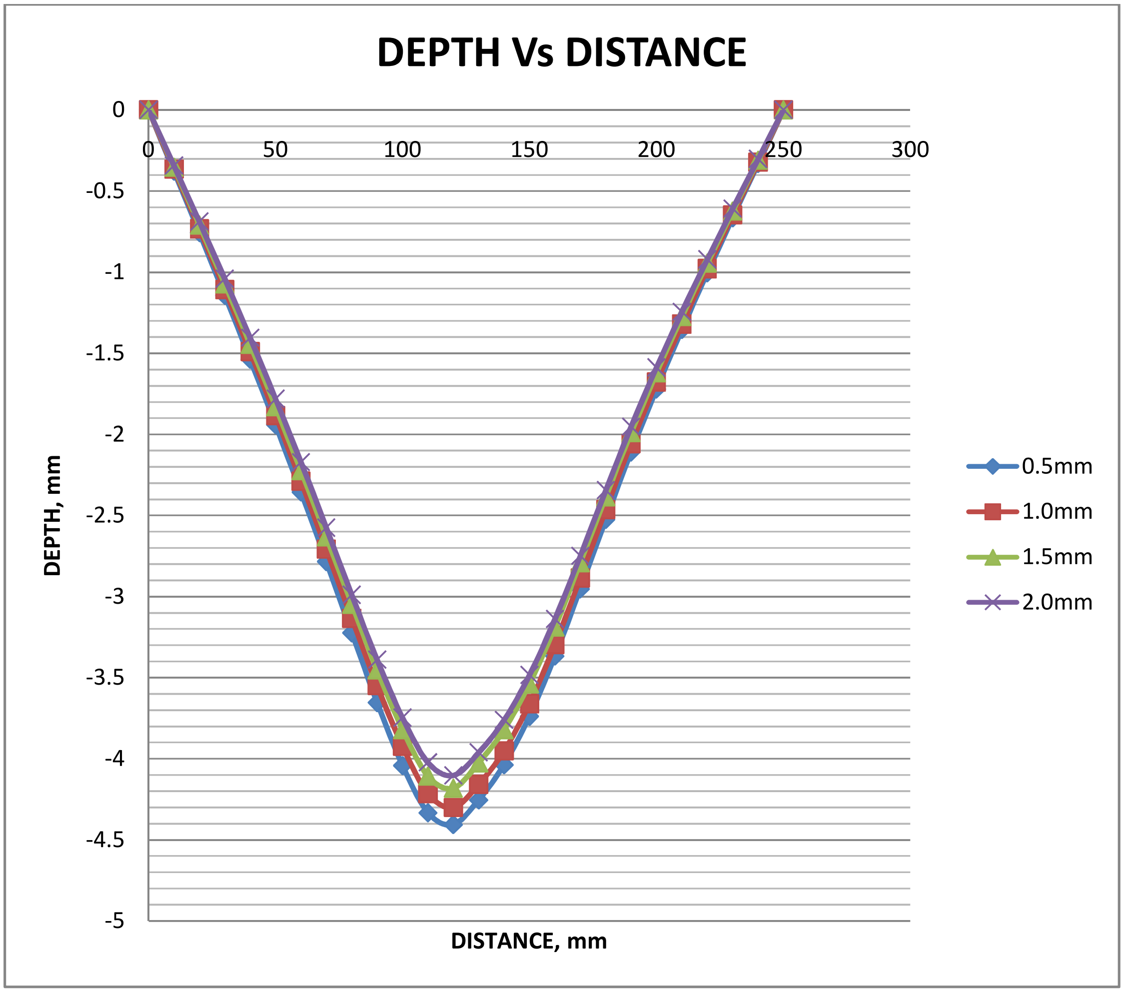
Graph 4.1: Depth Vs Distance For 0.5 mm Sheet Metal Thickness

This graph shows the depth vs distance of a 0.5mm thick sheet metal which is done in an actual experiment on the Incremental Forming Machine. The material used in this experiment is the same as the ALGOR simulation. The results of the FE analysis on the 0.5 mm thick material are compared to the experimental data above.

4.4 OUTPUT DATA

Simulation results on ALGOR

4.4.1 Nodal Prescribed Displacement Z (-ve) = 5.5 mm



Graph 4.2: Depth vs Distance for Nodal Prescribed Displacement Z (-ve) = 5.5 mm

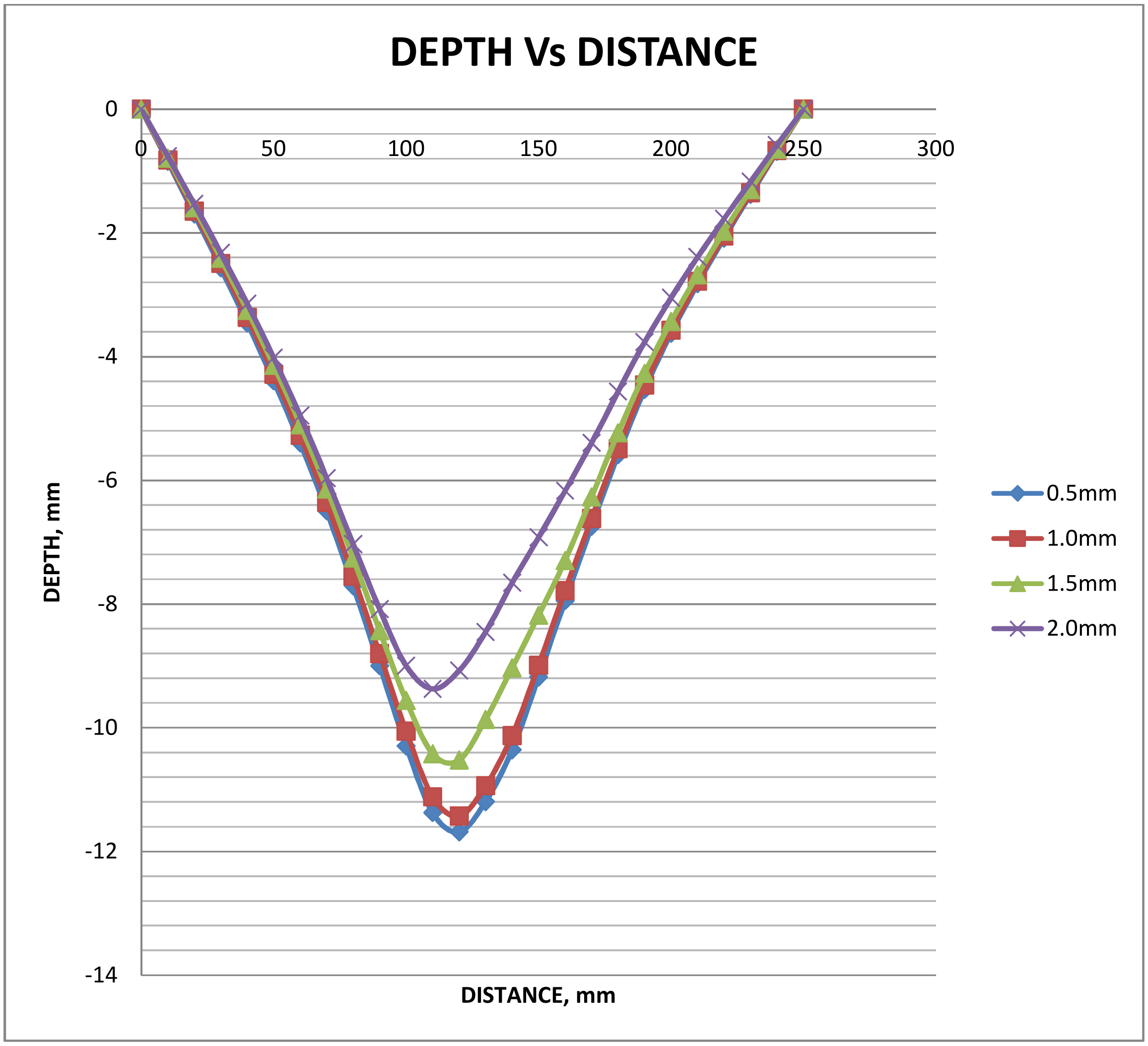
Table 4.3: Comparison Experimental vs ALGOR (z= 5.5 mm)

Material Thickness	**Experimental Displacement (Maximum Depth)**	**ALGOR Displacement (Maximum Depth)**
0.5 mm	4.30 mm	4.426 mm

1.0 mm	4.299 mm
1.5 mm	4.182 mm
2.0 mm	4.102 mm

The results show that the max displacement for the Nodal Prescribed Displacement Z (-ve) = 5.5 mm on a 0.5mm thick sheetmetal for the experimental data is only 4.30 mm while on the ALGOR analysis shows depth of 4.426 mm. The difference value for this depth is 0.126 mm. It shows 2.85% depth was decreased by the springback effect.

4.4.2 Nodal Prescribed Displacement Z (-ve) = 12.5 mm



Graph 4.3: Depth vs Distance for Nodal Prescribed Displacement Z (-ve) = 12.5 mm

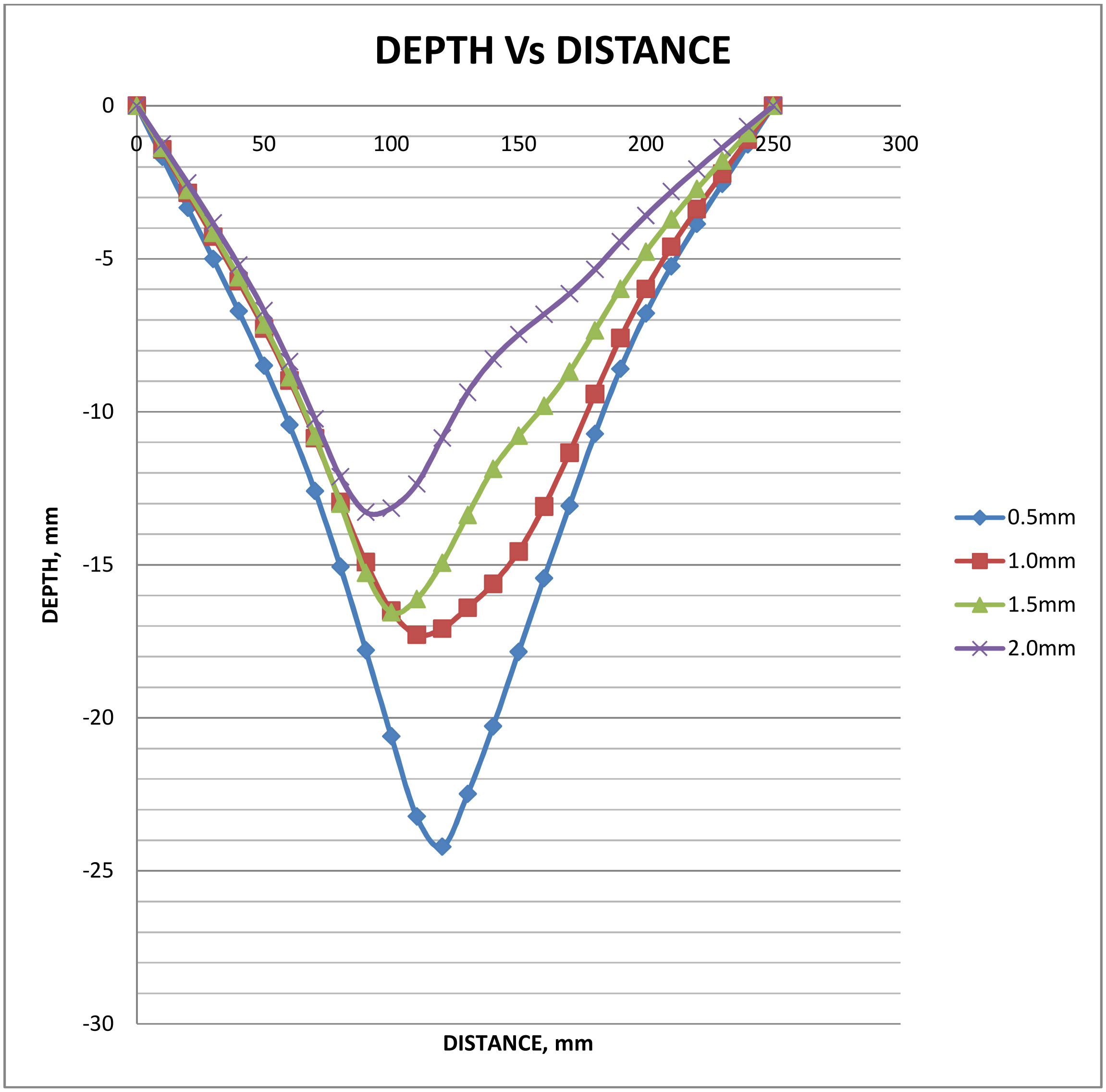
Table 4.4: Comparison Experimental vs ALGOR (z= 12.5 mm)

Material Thickness	**Experimental Displacement (Maximum Depth)**	**ALGOR Displacement (Maximum Depth)**

0.5 mm	10.54 mm	11.681 mm
1.0 mm		11.426 mm
1.5 mm		10.519 mm
2.0 mm		9.369 mm

The results show that the max displacement for the Nodal Prescribed Displacement Z (-ve) = 12.5 mm on a 0.5mm thick sheetmetal for the experimental data is only 10.54 mm while on the ALGOR analysis shows depth of 11.681 mm. The difference value for this depth is 1.139 mm. It shows a more obvious depth was decreased by the springback effect which is 9.75%.

4.4.3 Nodal Prescribed Displacement Z (-ve) = 25 mm



Graph 4.4: Depth vs Distance for Nodal Prescribed Displacement Z (-ve) = 25 mm

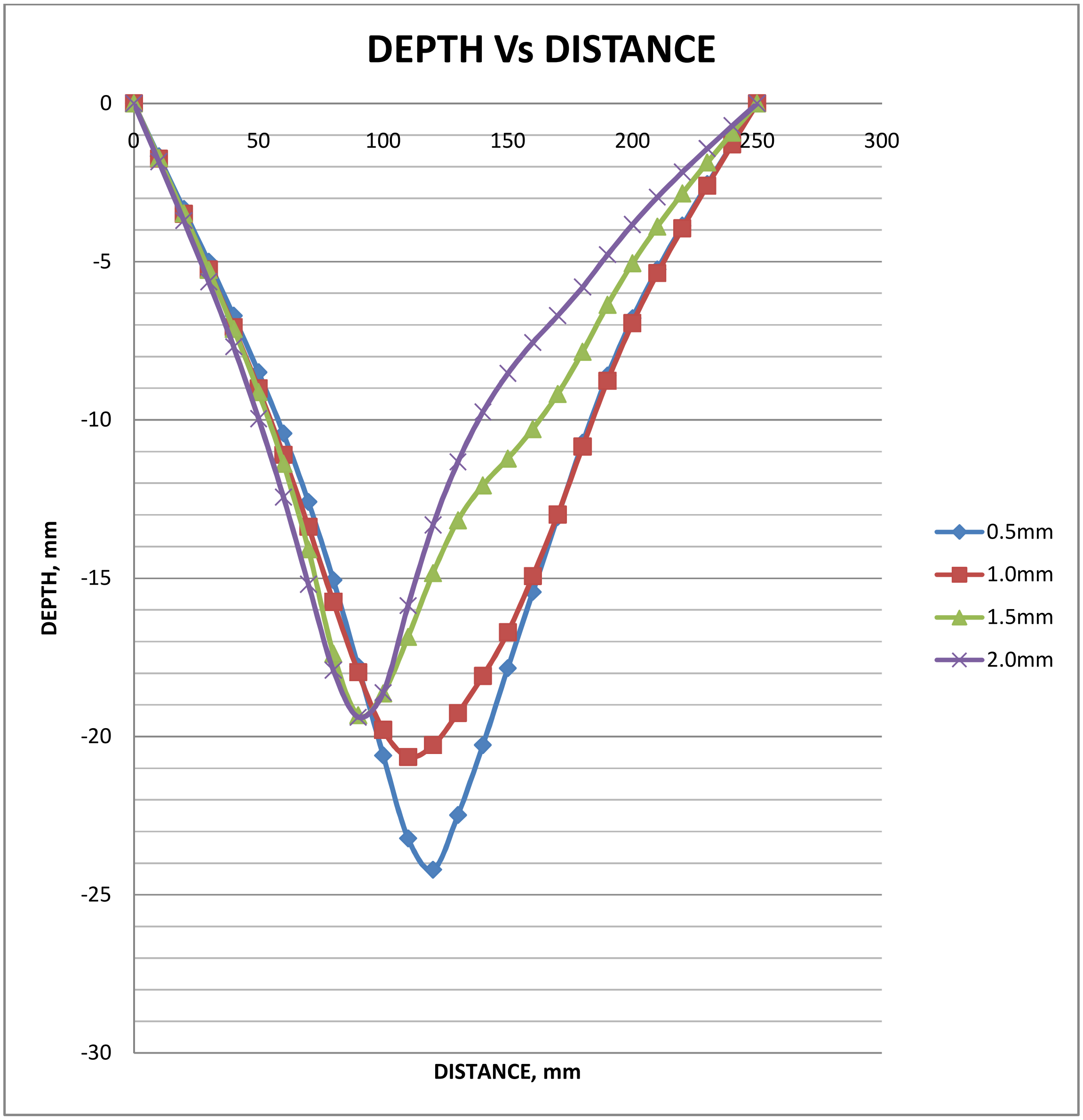
Table 4.5: Comparison Experimental vs ALGOR (z= 25 mm)

Material Thickness	Experimental Displacement (Maximum Depth)	ALGOR Displacement (Maximum Depth)

0.5 mm	16.44 mm	24.213 mm
1.0 mm		17.284 mm
1.5 mm		16.548 mm
2.0 mm		13.145 mm

The results show that the max displacement for the Nodal Prescribed Displacement Z (-ve) = 25 mm on a 0.5mm thick sheetmetal for the experimental data is only 16.44 mm while on the ALGOR analysis shows depth of 24.213 mm. The difference value for this depth is 7.767 mm. It shows a massive 32.08% depth was decreased by the springback effect.

4.4.4 Max Nodal Prescribed Displacement Z (-ve)



Graph 4.5: Depth vs Distance for Max Nodal Prescribed Displacement Z (-ve)

Table 4.6: Comparison Experimental vs ALGOR (z= Max)

Material Thickness	Experimental Displacement (Maximum Depth)	ALGOR Displacement (Maximum Depth)
0.5 mm	16.44 mm	24.213 mm
1.0 mm		20.644 mm
1.5 mm		19.394 mm
2.0 mm		19.394 mm

The experimental result by thickness of Aluminium 0.5 mm shows that 16.44 mm is the point of fracture by a setting of Nodal Prescribed Displacement Z (-ve) of 25 mm. From the ALGOR analysis it is acknowledge that fracture of the sheet material will be caused if the equivalent strain of the material exceeds 20%, so here shows the max displacement of different thickness of sheet metal before the point of fracture.

4.5 CONCLUSION

The FEA result shows that the final depth is more of the final experimental depth. The input depths cannot be reached due to the springback of the aluminum material. Also to take note is that the higher the input of depths, the higher the springback effect to the material.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

The development of simulation model for different thickness of material in terms of stepdowns during virtual incremental forming was successfully achieved. Implementation of the technological process of incremental sheet forming is intended for rationalization of small batch production. These results have proven to assist the fabrication process later on to achieve higher quality products and to avoid waste.

The simulation in ALGOR gave more understanding about the characteristic of the material in terms of formability and depth when different thickness is varied. The material has a tendency to partially return to its original shape because of the elastic recovery of the material or also known as the springback effect. This shows why the analysis in ALGOR has a lower springback effect compared to the experimental data which shows drastic results.

It has been noticed, regarding the simulations results, that it is possible to forecast the failure point of the sheet by the simple comparison between the reached stress value and the material ultimate tensile stress. From the above, it results that by FE analysis it’s possible to determine the limits of formability on the basis of the scheduled tool path. So, this method could be used in order to define the process parameters to obtain a good quality of the product and the optimization of the manufacturing.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations are crucial to improve the incremental sheet metal forming process in both virtual and experimental experiments. These data are analyzed in order to choose more parameters for the optimization of machining and further research of this project thesis. The recommendations for the simulation and modelling improvement are stated as below:

i. To achieve higher product quality, a model can be put under the sheet metal as a supporting tool on the basis of which more demanding shapes can be reached.
ii. Simulation can be carry out in different numbers of finite elements and to be compared with the experimental results.
iii. Vary the material used in this process but before the experimental setup make sure the material is highly deformable and subjected at minimum hardening with respect to previous deformation

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APPENDIX A1

Gantt Chart for FYP 1

TASK	WEEK													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Identify Title	🟥													
Discussion with Supervisor	🟥	🟥				🟥	🟥	🟥			🟥	🟥	🟥	
Introduction, Define Problem Statement, Project Objective, Project scopes			🟥	🟥	🟥	🟥	🟥	🟥						
Literature review	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		
Methodology •Project Flow Diagram •Plan the experiment •Research Procedure •Conducting the experiment				🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Study incremental forming machine.								🟥	🟥	🟥	🟥	🟥	🟥	🟥
Proposal remarks											🟥	🟥	🟥	🟥
Presentation														🟥

APPENDIX A2

Gantt Chart for FYP 2

TASK	WEEK													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Preparation Study and Observation	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
Study ALGOR							🟦	🟦	🟦	🟦				
Run ALGOR										🟦	🟦	🟦	🟦	🟦
Analyze the model/product												🟦	🟦	🟦
Collect and compare the Data													🟦	🟦
Report remarks										🟦	🟦	🟦	🟦	🟦
Final evaluations														🟦