Design of a Heated Blank Holder for a Thermoforming Station

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Background

1.0

1.1.0 Summary

This report consists of the detailed design process of a heated blank holder. After having researched press forming and written literature reviews the problems with press forming became evident. The main design criteria for the blank holder is that the it is heated independently and that several similar blank holders can be stacked upon each other. The design work includes the generation of concepts for:- the modified female tool; the bottom of the blank holder; the distribution plate and eight clips (see fig. 1). The final design consists of hot air being blown into the bottom of the blank holder by two dual temperature heat guns, which is fixed on top of the modified female tool to heat the composite evenly throughout the plate. The composite and pressure distribution plate are placed on top of the bottom of the blank holder. The composite and distribution plate are held securely in place by the eight clips which provide a localised pressure on the composite sheet while it is being press formed. Finite element analysis has been conducted using Abaqus to determine the reaction force at the end of the clips. Finite element analysis was also used to determine the maximum Von Mises stresses and maximum displacement of the modified female tool, to ensure that the female tool does not deform during operation, and to show any effect of tool modification.

Experimentation was conducted to determine the temperature and velocity of air that the heat guns produce, where the air would stagnate and the temperature on the top surface of the bottom of the blank holder. Experiments using the original blank holder and the modified blank holder were conducted to observe how the composite sheet behaved whilst being clamped at different pressures during forming. The results have been analysed and wrinkling, inter-ply slippage, fibre extension and the shear angles have all been quantified using the formed hemispheres.

![Diagram of the modified female tool, clips, bottom of the blank holder, distribution plate and composite.](image-url)

Fig. 1: Final Design of the modified female tool, clips, bottom of the blank holder, distribution plate and composite.
1.1.1 Motivation

Modern manufacturing techniques for objects such as car body panels are made by press forming steel sheets. Manufacturers are now striving to reduce the weight of the vehicles to save on fuel economy and improve the power to weight ratio. Currently, only top of the range cars costing in excess of £100,000 are manufactured using the hand lay-up process involving composite sheet, which contributes to the large price tag. In order to make composite panel cars a more economical alternative, new manufacturing process are now being researched to develop cost effective composites. Another advantage of composite materials is that they can have a much higher aspect ratio.

Composites are currently being researched, as they can have better specific mechanical properties than most metals, although it is difficult to determine how a composite material will behave while it is being formed. Simulation gives the fibre direction which is important for the final mechanical properties.

During press forming of composite materials, fibre-re-orientation and excessive wrinkling can occur. Wrinkling is a major defect in obtaining the optimum textile composite structure. Wrinkling decreases the performance characteristics of the final product and detracts from the surface finish. To be able to simulate the behaviour of the composite material, experimentation on how it forms under differing holding force distribution parameters and temperature has to be conducted. Press forming of hemispheres is used for this process, shown in fig. 2. The composite used to produce the hemispheres is unconsolidated polypropylene supplied by Don & Low Ltd (see fig. 3).

![Fig. 2: Formed hemisphere.](image1)

![Fig. 3: Unconsolidated Polypropylene](image2)
1.1.2 Description and Objectives

Project Description

During the deep-draw forming of metal and composite sheet, a blank holder is essential to control the forming operation. For the process of press forming a composite sheet, the composite has to be held between a blank holder and distribution plate. This enables the controlled of the pressure applied to the sheet. The aim of this project is to design and manufacture a blank holder that can influence the forming process, and to compare the experimental and theoretical results from forming.

Project Objectives

The aim of this project was to re-design a blank holder that can be heated independently from the tooling and control the draw of several individual layers of composite sheet at the one time. By conducting experiments and using computer simulations, it is be possible to quantify the wrinkling, inter-ply slippage, fibre extension and the shear angles of the composite sheet once it has been formed.

Objectives

- Research and understand the thermoforming process and the behaviour of the composite using a heated blank holder.
- To design a heated blank holder which can be heated independently from the tooling.
- The blank holder has to be able to stack several similar blank holders upon each other to hold several layers of composite at the one time.
- Conduct finite element analysis to calculate the stresses and forces on the components in the thermoforming station.
- To produce CAD drawings of the design.
- To supervise of the manufacture of the heated blank holder.
- Assemble the completed components of the heated blank holder.
- Order the required materials.
- To complete experiments using the original blank holder and the heated blank holder.
- Analysis the formed hemispheres using MatLab, to quantify the wrinkling, inter-ply slippage, shear angle and fibre extension.
Background

1.1.3 Progress

A Gantt chart (see Appendix A) is used plan and to outline the tasks that have to be completed within a allocated time. A Gantt chart allows anyone to follow the progress of the project easily. The chart has been modified throughout the project, as some of the tasks required longer than previously thought due to unforeseen circumstances. The final Gantt chart ensured the completion of the project within the time scale given.

Previous students work

The design of the heated blank holder is part of a larger project, the design of a thermoforming station. This is a continuation of two previous student projects, whose contributions are outlined below:

- Laurent Maurel (French exchange student, Leonardo da Vinci programme), designed and manufactured the electrically heated and water cooled tooling (Maurel. 2005).
- Gordon Pettigrew (BEng), designed and manufactured the pre-heating system. (Pettigrew. 2006)

Objectives for previous student projects

The main objectives for Laurent’s project:
- To design and manufacture male and female tools,
- Ensure the male and female tool increase and decreased in temperature, from 20°C to 200°C quickly,
- To maintain the position of the composite sheet while it is being formed,
- To allow the composite sheet to slip into the tooling while it is being pressed,
- To remove the composite sheet from the tooling easily after it has been formed,

The main objectives for Gordon’s project:
- Finalise, assemble, install and test the existing tooling in the press,
- Design a pre-heating addition to improve the operation of the thermoforming machine,
- Carry out and report on various experiments and forming tests,

All of the previous and current work has been completed in conjunction with the project supervisor, Dr Philip Harrison.
Background

1.1.4 Composites

Composite materials have superior specific properties when compared to conventional materials. Composite materials are made from a matrix and reinforcement material. The matrix material surrounds and supports the reinforcement material, and the reinforcement material imparts its mechanical and physical properties to enhance the matrix properties.

This project is concerned with a particular class of composites, textile composites, in particular self reinforced composites (SRC).

During forming, the composite sheet has to be partially consolidated to prevent the composite from relaxing (See fig. 4). To consolidate the composite sheet (See fig. 5) the tooling has to be heated to just below the melting temperature of the pre-consolidated sheet. Once the material has been formed the tooling is rapidly cooled, to set the composite in place.

Fig. 4: Relaxed Composite

Fig. 5: Consolidated Composite

The aspect ratio of composites is far superior to that of metals. This allows composites to produce more exotic shapes, as it can be drawn deeper.

Unconsolidated Polypropylene

The melting temperature of unconsolidated polypropylene is 147.5°C. It has a density of 905kg/m³. Unconsolidated polypropylene has a tensile strength between 250 and 350MPa (Houshayar, S and Shanks, R.A, 2004).
1.1.5 Thermoforming Process

Press forming of composites is very similar to the deep drawing process for metal sheets. Deep drawing is a metal forming process in which sheet metal, called blanks are rapidly drawn into a forming die by a mechanical punch to create geometrical shapes.

Press forming of a composite material is where a composite sheet is held between two parts of a blank holder, which applies a distributed pressure on the composite sheet. This is then heated in an oven until the composite is just below its melting temperature. The blank holder and composite are then placed inside a forming press with a shaped male and female tool, which can be either hot or cold. The male tool is then pressed into the female tool through the composite. The composite then takes the shape of the tooling, and is then either force cooled, or left to cool naturally before being removed from the press.

Studies have been carried out to test the press forming of composite materials. When pressing, the composite can warp, rip and wrinkle. This may be due to the pressure being applied to the composite from the blank holder; whether the tools were hot or cold; how quickly the tooling was cooled or the amount if heat that was lost when transferring the blank holder and composite from the oven to the forming press.
1.1.6 Hand Lay-up Forming

There are many different types of composite forming processes. The process is determined by the component size, required material properties, shape, quantity and cost.

The hand lay-up process is a simple and versatile method of manufacturing composite materials. This process consists of layers of reinforcement being manually applied to an open mould and then impregnated with resin via the use of a brush. A roller is run over the wet surface to remove any trapped air pockets within the laminate structure (See fig. 6). The assembly is then heated in an oven to cure the resin. The composite is then removed from the mould and trimmed to size. The disadvantages to the hand lay-up process are:- it can be slow, messy, very labour intensive and produces toxic fumes which makes the open process less popular due to safety. However, any size and complexity of composite can be produced.

![Fig. 6: Lay-Up Process](image)

Press forming can produce composites similar to that of the hand lay-up process. Press forming is a much quicker, easier and tidier method than hand lay-up. There is no need for skilled labour during press forming as the tooling forms the composite. Repeatability is a major advantage of press forming, and more reliable shapes can be formed without voids or defects.
1.1.7 Literature Review

Title: An Overview of the Technology of Fibre-Reinforced Plastics for Design Purposes.

Summary:
This journal paper is an overview of fibre-reinforced plastics to obtain within the reader, a reasonable understanding and sufficient knowledge to be able to pursue relevant topics. The article provides a simplified introduction to fibre-reinforced thermosetting plastics, defining descriptions of commonly used material types, properties and manufacturing process.

The paper goes into great detail on types of composite material, their properties and various manufacturing techniques. The most relevant areas are illustrated below.

Reinforcement materials: There is a vast amount of reinforcing agents, such as fibres and flakes. The reinforcement materials are most commonly used in long, continuous forms to provide the stiffest and strongest materials. Introducing fibres into the matrix produces directionality or anisotropy in the material, therefore fibre reinforced plastics are highly dependent on the alignment of the fibres.

Glass Fibres: Glass fibre is a mixture of oxides. There are several grades of glass fibres the most widely used grade is E-glass which is a good electrical insulator and has high strength.

Carbon Fibre: Carbon fibre is produced by the controlled pyrolysis of a precursor. By differing the process temperature it is possible to produce carbon fibres with different mechanical properties. There is three main types of carbon fibres, high modulus, high strength and general purpose.

Fibre properties: A material drawn into fibre form is stronger in the direction it has been drawn in than its original form. By drawing the different fibres, different structures are formed. The fibres have different properties in the longitudinal and transverse direction. All of the fibres, when in tension show elastic behaviour up to the point of failure. There is no yield point and very low strain to failure.
Matrix materials: A matrix is used to maintain the structural integrity by bonding the reinforcement together and also provides environmental protection to the reinforcement material.

Epoxies: Epoxies are formed by condensation of epichlorhydrin and polyhydroxy compounds. Epoxies are normally supplied as a single constituent, the resin, with a second constituent, the hardener or cross-linking agent, has to be added. Epoxies have higher strength and adhesion to fibres than polyesters.

Pre-preg: Pre-preg is a thin sheet of partially cured resin containing reinforced fibres. The fibres can be woven or unidirectional. The parameters that are usually specified are fibre type, grade and whether the surface can be treated or resin type, content and cured ply thickness.

Hand lay-up or contact moulding (see fig.. 6): The process consists of applying layers of reinforcing material against a singled sided mould and working resin into the material with a brush or roller. The process is slow and highly labour intensive although the size and complexity of the mouldings that can be produced are limitless.

Vacuum-bag and autoclave moulding: With the use of a male and female mould for large or complex mouldings. The technique is used with pre-preg resin systems and consolidation is achieved by covering the moulding with an airtight bag with the air being removed by vacuum pump. If pressures over 1 atmosphere are required the whole assembly is placed in an autoclave.

The journal provides a condensed source of information about fibre reinforced plastics by providing an insight for exploring design possibilities of these materials.
Background

1.1.7 Literature review

Title: Predictive FE Modelling of Prepreg Forming to Determine Optimum Processing Conditions.
Authors: Hua Lin, Andrew Long, Mike Clifford, Jin Wang and Philip Harrison

Summary:
This journal investigates the numerical and experimental studies of forming a carbon/epoxy prepreg into a hemisphere and helmet shape. By changing the parameters such as the forming rate; forming temperature; blank size and holding pressure. The journal explains the consequences of varying each of the forming conditions. By using case studies of press forming, it is shown that the experimental and numerical values have good correlation, to show that the forming process is optimised by increasing the holding force around the edges of the composite sheet and with increasing the forming temperature and the forming rate.

Results:
Optimisation of forming rate shows that when decreasing the forming rate of the composite at room temperature, a reduced compressive stress results in less wrinkling.
Optimisation of forming temperature shows that wrinkling is reduced when the temperature is increased from room temperature to 80°C. When increasing the temperature an increase in shear deformation and a decrease in compressive stress also occur.
Optimisation of the size of the blank shows that the smaller the blank, the larger increase in wrinkling occurs. The maximum shear increases and the compressive stress decreases when the blank increases in size.

To conclude, when varying the forming rate; forming temperature; blank size and holding force; the wrinkling, shear deformation and compressive stresses also vary. This highlights the importance of the correct forming parameters.
This report constitutes the design and manufacture of a thermoforming station which is used to press composite materials.

The final solution consists of a rounded male and female tool being heated by cartridge heaters and then cooled rapidly with tap water. It is therefore easy to control the temperature. The composite sheet was held by a simple blank holder which was heated in an oven before pressing.

The male and female tools that were produced are electrically heated and water cooled. The spherical shape of the tooling was determined by the hemispheres that had to be produced. This was to easily simulate the behaviour of the composite sheet while it is being formed.

The blank holder is made from two aluminium plates. The thicknesses of the upper plate and lower plates are 10mm and 20mm respectively. The composite sheet is placed between the plates, with the clamping pressure being applied by four compression springs and bolts, which maintains a uniform pressure (see fig. 7). The blank holder is then heated to approximately 80°C, and is then placed on top of the female tool before forming.

Future Work

- Re-designing the blank holder.
This report consists of the design and manufacture of a mobile, radiant heating system for the thermoforming station.

A pre-heating solution was necessary as the blank holder complete with composite sheet had to be heated in an oven, and then manually transported to the forming press. This resulted in a large heat loss, and therefore the results were inaccurate.

The final solution was a pneumatically controlled radiant heater (see fig.8). The radiant heater can be heated up to 540°C. The radiant heater is used to heat the centre of the composite, as the blank holder would not be heated to the correct temperature, by conduction via the female tool. The heater is attached to the forming press but can be removed manually. It is moved rotated to the correct position by using a small lever on the base of the heater.

When the blank holder complete with composite sheet is positioned on top of the female tool, the radiant heater can be moved between the male tool and the blank holder, to heat the centre of the composite sheet. The pneumatics system provides enough force to move the heater smoothly, with the aid of a small portable compressor that has a maximum pressure of 10 bar. The piston velocity is controlled by a flow control valve.
2.1.0 Morphological Chart

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<td>Steel</td>
<td>Brass</td>
<td>Titanium</td>
</tr>
</tbody>
</table>

Fig. 9: Morphological Chart

The first stage of the design process was to create a morphological chart. From this chart, (see fig. 9) the design concepts were generated. A morphological chart provides a well structured approach to concept generation. The chart increases the design possibilities available to a defined design problem.

The chart is used to provide a visual aspect of the design solutions, by defining the main design problems based on the products function, and by obtaining a number of possible solutions, the overall solution can be determined.

To solve the problem of re-designing the original blank holder, the optimum design was obtained using the morphological chart. Hot air guns are used to heat the aluminium bottom of the blank holder. A clamping mechanism involving a clip, nut and bolt, controlled by a spring, is used to apply a localised pressure to the composite in the blank holder.
2.1.1 Modifications to the Original Blank Holder

See Appendix B for dimensions of the original blank holder.

The original blank holder was designed by Laurent Maurel (Maurel, 2005). The blank holder consists of two aluminium plates with four compression springs and bolts. The lower plate is 20mm thick. When the original blank holder is placed on top of the original female tool, the blank holder is held in the linear and transverse directions (see fig. 10). The upper plate is 10mm thick and held securely on top of the lower plate by four bolts (see fig. 11). The composite sheet is held tightly between both plates with a uniform pressure being applied. The applied load is controlled by the four compression springs.

Before experimenting with the original blank holder, the plates had to be skimmed until completely flat. Due to time constraints, an aluminium ring was bonded to the internal surface of the under side of the blank holder (see fig. 12) rather than skimming the surface. This was completed to ensure that the pressure being applied would be constant across the composite sheet. The outer dimensions of the plates were reduced, to minimise the weight of the blank holder. Subsequently, the bolt holes had to be relocated (see fig. 13). The holes were placed in symmetrical positions to ensure the pressure from the bolts was evenly distributed.
2.1.2 Distribution Plate

Fig. 14: 1mm thick distribution plate

The purpose of the distribution plate is to separate the composite sheet from the clips. It is used to distribute the load from the clips onto the composite. Without the distribution plate, the composite would tear at the jaws of the clips. The distribution plate is machined from 1mm thick aluminium, which was supplied by Aalco.

See Appendix C for dimensions of the distribution plate.

The distribution plate is made from 1mm thick aluminium plate (See Fig. 14), to reduce the height of the complete blank holder assembly, so that four layers of composite can be fit between the tooling at the same time.

The distribution plates have to be stacked to be able to press more than one layer of composite at a time. To be able to stack the distribution plates, pegs are attached to the top distribution plate and then placed in the holes on the bottom distribution plate (see fig. 15). This also ensures the plates are aligned and will not move out of place when the press is in motion.

The surface of the distribution plates has to be polished so that they are smooth to ensure a low drag coefficient on the composite. This is to minimise the risk of the composite sheet ripping during forming.

Fig. 15: Exploded view showing how the layers of distribution plates would be stacked on top of one another.
2.1.3 Concepts for the Bottom of the Blank Holder

The original concept for the bottom of the blank holder was a simple circular, 1mm thick aluminium plate with a lip on the underside to locate the plate on top of the female tool (see fig. 16). The plate would have been heated via conduction from the female tool. Although this concept would have been acceptable the bottom of the blank holder has to be heated independently from the female tool so that experiments can be carried out with different heating conditions. For this the plate has to be hollow.

The bottom of the blank holder has to be heated to a constant temperature so that the composite sheet will be heated evenly. This area of the design has changed significantly from the original blank. (Maurel, 2005). The original blank holder comprised of two aluminium plates with four compression springs and bolts. The compression springs applied a constant pressure across the composite sheet.

The second concept consists of the hollow bottom of the blank holder, being heated independently by hot air. The air is being blown in from both sides using two dual temperature heat guns, which produce a constant temperature across the plate. The maximum rated temperature of the heat guns is 650°C, although a lot of heat will be lost through convection.

After experimentation this concept has been modified, as the inlet and outlet pipes are round and need to be tapered to allow a larger air flow into the bottom of the blank holder, as it was not reaching the required temperature. The internal walls are too long, as the air is not circulating properly and producing localised heat areas (see fig. 17).
2.1.4 Final Design of the Bottom of the Blank Holder

The bottom of the blank holder is machined from 6mm thick aluminium sheet. The internal supports provide rigidity to prevent the bottom of the blank holder deforming under the pressure of the clips, and also when the press is in use (see fig. 18). The inlet and outlet pipes are separated with a wall to prevent the hot and cold air from mixing (See Fig. 18).

The blank holder has been made in two separate parts. The top plate is 1mm thick aluminium, which has been cut from stock sheet and fits onto the lower plate. The lower plate has a lip on the inside radius to ensure that the top plate aligns correctly (see fig. 19).

Hot air, which heats the bottom of the blank holder is supplied using two dual temperature heat guns, rated 1500W at 240V. To ensure that the heat guns do not overheat, air has to be blown through a length of steel pipe, a PTFE nozzle, which has a melting temperature of 200°C, gradually reducing in diameter to a small bare copper pipe which is tapered at one end before entering the bottom of the blank holder.

The 6mm aluminium plate was purchased from Righton, see appendix R for the order form.

Fig. 19: Exploded view of how the top plate will be placed securely on the bottom of the blank holder.
2.1.5 Bottom of the Blank Holder

The guides on the bottom of the blank holder are used to position the clips in the correct place. This ensures the localised pressure applied by the clips is applied to the correct quadrants of the composite sheet.

The guides are places around the bottom of the blank holder at 45° to each other. This evenly distributes the localised pressure applied by the clips (see fig. 20).

Fig. 20: Guides on the bottom of the blank holder

See Appendix G for the dimensions of the guides on the bottom of the blank holder

The dimples on the top of the distribution plate are used to position a sphere on the inside edge of the clips. The sphere has to be positioned correctly to ensure the localised pressure from the clips is in the correct position, (see fig. 21).

Fig. 21: Dimples on the distribution plate.

See Appendix H for the dimensions of the dimples on the distribution plate.
2.1.6 Modifications to the Female Tool

The bottom of the modified blank holder has to be sunken into the female tool for the composite to be formed without ripping. To do this a 5mm recess has been machined from the original female tool (see fig. 22). The recess positions the modified blank holder and prevents it from moving in the linear and transverse directions during forming. It also allows the blank holder to sit flush with the female tool (see fig. 23).

Fig. 22: The original female tool

See Appendix I for dimensions of the original female tool.

Fig. 23: The modified female tool

See Appendix J for the dimensions of the modified female tool.

To ensure the original blank holder is compatible with the female tool modifications, PTFE pegs will have to be used to raise the blank holder to the correct height. The PTFE pegs will also be used with the modified blank holder to insulate against heat from the female tool, allowing independent control of the tooling and blank holder.

The original and modified blank holders have to be at the same height when in the press so two different lengths of PTFE pegs will be used.
2.1.7 Abaqus for the Female Tool Modifications

To determine the maximum Von Mises stresses and the maximum displacement on the original and modified female tool the finite element analysis package Abaqus was used. Since Abaqus is compatible with the 3D CAD program, Solid Edge, both of the female tools CAD models were imported into Abaqus CAE environment.

**Global Size**

The global size of the elements used in Abaqus was varied to determine if it had any effect on the results. The global size relates to the size of the elements, the smaller the elements the more refined the mesh, and hence, the greater the accuracy of the simulation. (Fig. 24) shows the modified female tool with a global size of 38, which has 1,162 element whereas (fig. 25) has a global size of 11 with 19,012 elements.

A global size of 11 was used throughout the simulations for the female tool as it is more accurate and the computer processing time is not significantly longer.

**Boundary Conditions**

The boundary conditions and applied load on both the modified and female tools were kept constant throughout the analysis. The lower surface of the female tools was fully fixed (see fig. 27). A pressure of 6.313MPa, has been applied to the inner surface of the female tool (see fig. 26).

The applied load on the female tool is the maximum pressure being applied to the surface of the male tool, therefore the applied load is at least the maximum pressure applied to the female tool. The maximum pressure was calculated through experiments by (Maurel, 2005)
2.1.7 Abaqus for the Female Tool Modifications

To ensure the female tool does not plastically deform when the press is in operation, the maximum Von Mises stresses and the maximum deflection had to be determined. As the original female tool has to be modified to compensate for the bottom of the blank holder. It was necessary to ensure the maximum stresses on the female tool had not changed significantly. (see fig. 28)

See Appendix K for the maximum displacements of the original female tool.

See Appendix L for the Von Mises stresses acting on the original female tool.

Fig. 28: The maximum Von Mises stresses on the original female tool.

See Appendix M for the maximum displacements of the modified female tool.

See Appendix N for the Von Mises stresses acting on the modified female tool.

Fig. 29: The maximum Von Mises stresses on the modified female tool.

The maximum Von Mises stresses on the original female tool is 23.45MPa (see fig. 28) whereas the maximum Von Mises stresses on the modified female tool is 24.45MPa (see fig. 29), therefore the difference is insignificant.

The maximum displacement on the original female tool is 1.7mm whereas the maximum displacement on the modified female tool is 1.9mm. Once again, the modifications on the female tool are insignificant.
2.1.8 PTFE Rod Design Concepts

It is important to insulate the bottom of the blank holder from the female tool so that they can be set at different temperatures during pressing. The first concept was a ring of Polytetrafluoroethylene (PTFE) could fitted onto the female tool. PTFE is an extremely good insulator with a thermal conductivity of only 0.2W/m°C and has a melting temperature of 200°C, compared to aluminium which has a thermal conductivity range of 75-235W/m°C.

To ensure that both the original (see fig. 22) and modified (see fig. 23) blank holders are compatible with the same female tool, two PTFE rings of different thicknesses would have to be used. However, PTFE sheet is very expensive therefore this concept will not be used.

Figure 30 shows how the PTFE ring would be placed on top of the modified female tool. The PTFE ring has a lip to insulate the edge of the blank holder against the side of the female tool.

A more cost effective solution to this problem would be to use PTFE pegs, cut from PTFE rod. These would be used to alter the height of the original and modified blank holders. Different lengths of PTFE pegs would be cut for the female tool, so that both blank holder are compatible. When using the original blank holder, discs 3.5mm high would have to be used, and when using the modified blank holder discs 2mm high would be used. This solution is more cost effective as only one PTFE rod has to be purchased.

Figure 31 shows where the PTFE pegs would be placed. This concept for the PTFE insulator is most likely to work as air can circulate in the small gaps between the blank holder and female tool, therefore creating a greater thermal resistance.

The PTFE rod was purchased from a company called Direct Plastics.
2.1.9 Clip Concepts

The function of the clips is to apply a localised pressure on the composite sheet while it is being formed. The sheet has to be held under constant tension, but has also to be able to slip through the jaws of the clips without ripping. To do this, we use eight clips evenly distributed around the distribution plate (see fig. 32). The composite sheet is placed between the bottom of the blank holder and the distribution plate to prevent the material from tearing and warping while being formed.

![Diagram of a clip with hinge and bolt]

Fig. 32: Clip with hinge and bolt. See Appendix O for the dimensions of the clip with hinge.

The composite will be dragged into the female tool while being formed by the male tool. The first concept for the clips comprised of the clips having enough space to allow for overhang of composite sheet (see fig. 32). A bolt runs through the clips to control the applied pressure at the grips.

The end of the clip is hinged to decrease the fatigue stresses at the back end of the pads and makes the clip easier to open and close (see fig. 32). The grips on the clips will be smooth to minimise friction as the composite is drawn into the female tool.

To apply the pressure to the composite sheet, the bolt will be tightened to a set torque by a screwdriver with a torque limiter. The clips will be made from a stiff material to minimise the deflection at the jaws.

This concept was rejected as it would not apply a localised pressure on the plate. This would cause the composite to tear as it is drawn into the female tool.
2.1.9 Clip Concepts

The second concept for the clips was to use magnets. The magnets is another method for providing tension to the composite sheet.

![Magnets](image)

Fig. 33: Clips with Magnets

See Appendix P for dimensions of the clip with magnets.

This design incorporates eight clips each of which have six magnets. The magnets will have opposite polarity and so will attract each other, hence closing the jaws and applying a force on the distribution plate (see fig. 33).

There are two potential types of magnets, Neodymium a Samarium Cobalt.

Samarium Cobalt magnets:
- High resistance to demagnetisation
- High energy (magnet is strong for its size)
- Good temperature stability

Samarium Cobalt magnets are not suitable as they would not create a large enough holding force and they are too large at 6mm in diameter and 10mm thick. This size cannot be used because the clips have to have 7mm clearance between the jaws. Also, the clips cannot be too thick so that the blank holder can hold several layers of composite. Although Samarium Cobalt magnets do not loose their magnetisation when exposed to high temperatures.

Neodymium magnets:
- Very high resistance to demagnetisation
- High energy for their size
- Low working temperature for heat applications

Neodymium magnets are not suitable as they would lose their magnetisation when exposed to temperatures of approximately 110°C and are too bulky at 10mm in diameter and 6.4mm thick, although they provide excellent holding forces.

After having extensively researched magnet technology, it has been concluded that they are too bulky, would not be cost effective to provide the forces required in high temperature and it is not possible to vary the force applied to the distribution plate. For those reasons the magnetic concept development will cease.
2.1.9 Clip Concepts

This final clip design incorporates a simple spring and bolt mechanism. It is fully controllable and is able to produce a localised pressure at the jaws. The holding force is controlled by varying the deflection of the spring.

![Diagram of a clip with a bolt and spring](image)

Fig. 34: Design of the clips with a bolt and spring.

See Appendix Q for the dimensions of the clip with a bolt and spring.

The sphere at the jaws of the clips is used to locate a dimple on the surface of the distribution plate (see fig. 34). The sphere is also used to maintain a constant position as the top of the clip has a tendency to bend upwards when the load is being applied.

From a previous report written by Phil Evans (Evans, P. 2005) it was found that the total blank holder force had to be 320N although from finite element analysis, it has been found that this has now at to be 480N, therefore each clips has to apply a force of approximately 60N.

By obtaining a compression spring with the correct stiffness, the applied pressure at the jaws of the clip can be calculated approximated by hand. A free body diagram of a simply supported beam which is rotational in the z-direction at the left hand side, as shown below in figure 35:

![Free body diagram](image)

Fig. 35: Free body diagram of a simply supported beam, rotational in the z-direction at the left hand side.

Equating the moments about A using

\[
W= 100N:\]

\[
(L - a) \times W = L \times R_A
\]

\[
\frac{(L-a) \times W}{L} = R_A
\]

\[
\frac{(170 - 70) \times 100}{170} = R_A
\]

\[
R_A = 58.82N
\]

(Young, and; Budynas, 2002)
2.2.0 Spring Stiffness

Calculating the Force Applied by the Original Blank Holder

The Free length of the original springs was 47 mm.
In order to determine the stiffness of the original compression springs a 11kg weight was placed on top of one of the springs and the deflection was 9mm.
Using the equation \( F = k \times x \) the stiffness was calculated to be 12.2Nmm.

While experimenting with the new press the compression springs were tightened to 25, 35 and 45mm. This corresponds to a force of:

\[
F = k \times \delta
\]

---

<table>
<thead>
<tr>
<th>Free Length (mm)</th>
<th>( \delta ) (mm)</th>
<th>( x ) (mm)</th>
<th>( k ) (Nmm)</th>
<th>( F ) (N)</th>
<th>( F_{\text{total}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>47</td>
<td>25</td>
<td>22</td>
<td>12.2</td>
<td>268.4</td>
<td>1073.6</td>
</tr>
<tr>
<td>47</td>
<td>35</td>
<td>12</td>
<td>12.2</td>
<td>146.4</td>
<td>585.6</td>
</tr>
<tr>
<td>47</td>
<td>45</td>
<td>2</td>
<td>12.2</td>
<td>24.4</td>
<td>97.6</td>
</tr>
</tbody>
</table>

Table 1: The forces applied to the original blank holder.

Modified Blank Holder

Free length of the new springs is 9.7mm
The springs were replaced as the original springs were too big as the bottom of the blank holder has to be compact.

\[
F_{\text{total}} = F * 8
\]

---

<table>
<thead>
<tr>
<th>Free Length (mm)</th>
<th>( \delta ) (mm)</th>
<th>( x ) (mm)</th>
<th>( k ) (Nmm)</th>
<th>( F ) (N)</th>
<th>( F_{\text{total}} )</th>
</tr>
</thead>
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<tr>
<td>9.7</td>
<td>5</td>
<td>4.7</td>
<td>30.63</td>
<td>143.961</td>
<td>1151.688</td>
</tr>
<tr>
<td>9.7</td>
<td>7.5</td>
<td>2.2</td>
<td>30.63</td>
<td>67.368</td>
<td>539.088</td>
</tr>
<tr>
<td>9.7</td>
<td>9.5</td>
<td>0.2</td>
<td>30.63</td>
<td>6.126</td>
<td>49.008</td>
</tr>
</tbody>
</table>

Table 2: The forces applied to the modified blank holder.
2.2.1 Abaqus for the clips

To verify the reaction force at the end of the clips, the clips were also modelled in Abaqus. Within the CAE environment of Abaqus, the clip was modelled as a 2 dimensional simple cantilever beam. To simplify the model, only the top half of the clip was modelled as shown below in Figure 38.

Fig. 38: The simplified model of the clip, the boundary conditions and loads applied.

At the left hand side, the clip was fully fixed in the x and y axis and rotational in the z axis. The right hand side of the clip is constrained on the y direction to obtain the contact pressure (see fig. 38), The load was applied at the bolt location on the clips and varied from 100N to 1000N to determine the difference in the reaction force at the end of the clip. At the right hand side, the clip is fully fixed in the y direction.

Fig. 39: The path obtained to determine the reaction force at the end of the clips and the deflection of the beam when the load is applied.

A path was created at the end of the clip to determine the reaction force. The nodes along the path each had an individual force. The sum of the forces from nodes determine the reaction at the end of the clip. To increase the accuracy of the finite element analysis the mesh was refined.
2.2.1 Abaqus for the Clips

The mesh was used at the right hand side of the clips was refined, to determine whether the mesh played a role in the accuracy of the simulation. The mesh was refined to include 3 elements, 5 elements and 10 elements vertically (See fig. 40).

![3*3 elements](image)
![3*5 elements](image)
![3*10 elements](image)

Fig. 40: The vertically refined mesh.

The results are shown in the Figure 41. The graph is of resultant force at the jaws of the clips versus deflection.

![Changing the no. of elements vertically](image)

Fig. 41: Graph of the results of refining the mesh at the jaws of the

The results show that by refining the mesh, the force versus deflection does not change significantly and the computer processing time did not increase significantly. Therefore, when carrying out the finite element analysis, the 3*5 mesh will be used as it is more accurate than the 3*3.
2.2.1 Abaqus for the Clips

The boundary conditions at the left end of the clip was model as a fully fixed cantilever beam to begin with. Therefore the left end of the clip was fully fixed in all directions. The applied load at the bolt varied from 100 to 1000N, and the results are shown in Figure 43. The graph is the same as fig. 41 although the mesh has been refined in the horizontal direction (see fig. 42).

3*5 elements 5*5 elements 10*5 elements

Fig. 42: Horizontally refined mesh

Fig. 43: Graph of the left hand side of the clip being modelled as a simple cantilever beam.

To improve the accuracy of the results, the boundary conditions were changed from fully fixed to fully fixed in the x and y directions but allowed to rotate in the z-direction as the clip can bend in the corner. The results are shown in figure 44.

Fig. 44: Graph of the left end of the clip fully fixed in the x and y direction but rotational in the z-direction.

By changing the boundary conditions the results did not change significantly because of the low thickness of the material.

The finite element analysis determined a reaction force of 63.3N whereas the analytical results produced a reaction force of 58.82N. There is a small discrepancy with the results as the finite element package, Abaqus calculates the stresses at the four Gauss points within the element.
2.2.1 Abaqus for the Clips

The aim of this model was to determine if varying the thickness of the clip affects the deflection, hence affecting the reaction force at the jaws of the clip. The boundary conditions for this simulation was fully fixed in the x and y directions and rotational in the z direction at the left hand side of the clip. The boundary conditions at the right hand side of the clip were fully fixed in the y-direction. This did not change throughout the analysis. The applied load at the bolt was varied from 100 to 1000N. The thickness was varied from 1mm to 5mm thick as shown in figure 45.

Fig. 45: Graph of varying the thickness of the clip.

The above graph shows that when increasing the thickness of the clip, the deflection decreases and therefore, the reaction force at the jaws of the clip decreases. The clip will be made from 1.5 mm thick steel to achieve the optimum reaction force when the load is being applied. The 1.5 mm thick steel is also more controllable than the 1 mm thick steel as the 1.5mm does not deflect as easily as the 1 mm.
2.2.2 Miscellaneous Design Items

Nozzle

The nozzle (see fig. 46) is used to gradually decrease the diameter of the heat gun nozzle to the diameter of the hole in the bottom of the blank holder. The nozzle is made from PTFE as it has a high melting temperature of 200°C and is a good heat insulator. This minimises the amount of heat loss before entering the bottom of the blank holder. PTFE is also very easy to machine.

Fig. 46: Diameter reducing nozzle.
See Appendix U for the dimensions of the nozzle.

Stencil

The stencil (see fig. 47) is used to mark lines on the composite sheet. The lines are used to calculate and quantify the shear angles on the composite once it has been formed. The stencil was produced to ensure all of the markings on the composite sheets are equally spaced.

Fig. 47: Stencil used for marking the composite sheet.
See Appendix V for the dimensions of the stencil.

Heat Gun Holder

The heat gun holder (see fig. 48) is used to hold the dual temperature heat gun while the bottom of the blank holder is being heated. The heat gun holder has a heavy base to provided stability and the clamp is fully adjustable. This allows the nozzle of the heat gun to align with the pipe attached to the bottom of the blank holder.

Fig. 48: The heat gun holder.