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1.0 Background

1.1 Summary

This report consists of the detailed design, analysis and the testing process of the thermoforming station and the specimen used in it called polypropylene which is at University of Glasgow. After going through the problems which are currently incorporated with the present system, modifications are made in the design of the blank holder and the pressure distribution plate, design of clips and the heating system of the blank holder. The main criteria of the blank holder is that it is heated independently and as that several blank holders can be stacked upon each other and that is called multi-layer composite forming, but this project’s main criteria is to get the best formed specimen (polypropylene) from the composite forming of the thermoforming station with no or very less folds or wrinkles in it. The final design consists of the modified pressure distribution plate and modified blank holder with redesigned clips, and with five flexible heaters which are purchased from watlow heaters. The composite (polypropylene) and the pressure distribution plate are placed one after another on top of the modified blank holder. The eight redesigned clips are used to hold these composite and the pressure distribution plate in position so that localized pressure is provided on the composite sheet while it is press formed. Finite element analysis has been conducted on the blank holder by Mr. Faraj (PhD student in material science, University of Glasgow) on my behalf, as to decide whether to use flexible heaters or cable heaters for the modified blank holder. Clips have been modified in accordance with finite element analysis made by Ms. Alana Richards who already worked on similar project of Thermoforming station. Stiffness has been calculated for the new redesigned springs which are used with the clips.

Experiments were conducted using the old blank holder and the previous heating system and also using the modified blank holder with new heating system of flexible heaters. And quality of the formed composite is determined by using the Mat lab software and shear angle analysis. The thickness and the intensity of the wrinkles or folds are made visible by the 3D histograms using Mat lab software. And the improved quality of the formed composite from the modified blank holder and the redesigned clips using the new heating system of flexible heaters is compared with the formed composite of the old system using the 3D histograms of Mat Lab and. Thus the results have been analyzed and wrinkling, inter-ply slippage, fibre extension and shear angles have been quantified using the formed hemispheres.
1.2 Project background and overview

This project looks into one best way of forming the composite material. The most common method used before is hand-lay-up method. This procedure of manufacturing consumed a lot of time and needs skilled labour and is also costly. So, modern Zwick Roell Machine is used for the forming of composite material i.e. Polypropylene. Polypropylene can be heated, moulded and set to the required shape as it is a thermoplastic. And this thermoforming process by Zwick Roell Machine involves controlled heating of both material being formed and the mould which its being shaped into.

The procedure of forming the flat sheet of composite into the required hemispherical shape is done as follows: The composite sheet should be raised to a temperature just below the melting point of the resin and both the male and female tool should also be raised to the required temperature and then the composite sheet is trapped between the male and female tool inorder to form the sheet into the shape of the tool (mould). And the both the formed specimen and the equipment should be brought back to the room temperature before the tooling is separated from the specimen.

This is a common overview of the manufacturing process and 5 similar closely related projects which had been done previously by previous students under the supervision of Dr Philip Harrison. During press forming of composite materials, fibre-re-orientation and excessive wrinkling can occur, and the main obstacle in attaining an optimum textile composite structure is wrinkling. Each and every previous project which was supervised by Dr Philip Harrison was aiming at obtaining an optimum textile composite structure by doing some modifications in the thermoforming process and the machine. And this project’s aim is also is to obtain a best quality textile composite structure with very less or no wrinkles. And inorder to attain that, modifications were made in blank holder, clips and the heating system of the blank holder and the specimen.

Figure 1: Example of formed specimens from thermoforming station.
1.3 Project Description and Objectives

1.3.1 Project Description
For the forming of composite sheets, the composite sheet has to be held between the blank holder and the temperature distribution plate. So the design of the blank holder and the temperature or pressure distribution plate plays a main role in the thermoforming process. And also the design of the clips is also important as it distributes the pressure along the distribution plate to the composite sheet. And the main aspect is the source and the way of distributing the heat to the blank holder and the composite sheet. And in this project modifications are made in the design of the blank holder and the clips and the radiant heater which is the previous method of heating the composite is replaced by the flexible heaters which are stick on to the newly designed blank holder and heating both the composite and the blank holder. And the experimental and the theoretical results of the thermoformed composite are compared to show the extent of the quality improved.

1.3.2 Project Objectives
- Designing the blank holder and the pressure distribution plate in a manner to facilitate the flexible heaters to be stuck on the blank holder.
- Conducting finite element analysis on the design of the blank holder.
- Doing a little design modification in the clips according to the newly designed blank holder and calculating the spring stiffness.
- Purchasing five flexible heaters from Watlow Company.
- Conducting forming experiments and generating and comparing the results using Matlab.
1.4 Composites

Composites offer a range of properties such as tremendous durability and high specific strength which are impossible to match with traditional materials. Moreover, they allow the design of complex geometric forms and the engineering of bespoke materials precisely tailored to meet the demands of the particular application. These beneficial characteristics have enabled the rapid incorporation of composites within a wide range of industries from deep sea, polar and space exploration to household appliances and building facades. (http://www.compositesworld.com/articles/ct.aspx). There can be many secondary reasons why polymer composites may be chosen for the manufacture of particular articles or components, but the primary reason is because of weight saving for their relative stiffness and strength. (http://www.rapra.net/vircon/1_2.asp)

Figure 2: Structures made of Composites.

(http://www.gurit.com/library-media/images/Windwand%202%200310.jpg)
And, the composite used in the thermoforming station is unconsolidated Polypropylene, which is supplied by Don & Low Ltd. Polypropylene is harder and has a higher temperature resistance than HDPE (High-density polyethylene) (http://www.goodfellow.com/E/Polypropylene.html). Polypropylene does not present stress-cracking problems and offers excellent electrical and chemical resistance at higher temperatures. While the properties of PP are similar to those of Polyethylene, there are specific differences. These include a lower density, higher softening point (Polypropylene doesn't melt below 160°C, Polyethylene, a more common plastic, will anneal at around 100°C) and higher rigidity and hardness. Additives are applied to all commercially produced polypropylene resins to protect the polymer during processing and to enhance end-use performance. (http://www.bpf.co.uk/plastipedia/polymers/pp.aspx). Unconsolidated Polypropylene has tensile strength between 250 and 350 MPa and a density of 905 kg/m³. (Houshayar, S and Shanks, R.A, 2004).

Figure 3: Cut Polypropylene sheets
1.5 Literature Reviews

**Title:** The Mechanical Properties of Woven tape all-propylene composites  
**Author:** B. Alcock  
**Summary**  
This paper describes all polypropylene composites made from woven tape fabrics and reports the tensile and comprehensive properties of these, with reference to composite processing conditions and compares these mechanical properties to those of commercial alternatives. The discovery of this highly oriented, co-extruded polypropylene tape allows the production of recyclable ‘all- polypropylene’ composites, with a large temperature processing window and a high volume fraction of highly oriented PP molecules.

**Introduction**  
All-PP composites are designed to compete with traditional thermoplastic composites such as glass fibre reinforced PP, so must possess comparable or superior mechanical properties. Enhanced recyclability is the main advantage of all-PP composites. The polymer laminates are created by welding highly oriented PP fibre bundles or PP tapes by careful heating. The parameters such as temperature and pressure are considered during consolidation in order to prevent the relaxation and shrinkage which will lead to the reduction of tensile properties.

**Specimen Preparation**  
The tape used is co-extruded three layer tape, with A:B:A (copolymer:homopolymer:copolymer) structure. The tape was woven into a balanced, plain weave fabric possessing an areal density of ~100gm-2. Layers of this fabric are cut into square pieces measuring 180mm*180 mm, and stacked in close fitting mould up to a maximum depth of 7mm. The mould is then subject to heat and pressure to consolidate the fabric plies into biaxially reinforced composite laminate.

**Mechanical testing of woven tape all-PP composites**  
Tensile strength and modulus were measured using Instron 5584 tensile testing machine, two types of tests were performed – tensile deformation at low strain to determine moduli and poisons ratio and deformation to failure to determine strength and strain to failure.

**Conclusion**  
Parameters applied to consolidate all-PP composite specimens determine the mechanical properties. Despite the high temperature involved during the consolidation process, the high strength and stiffness of a highly oriented polymer tape can be retained in a composite laminate, and all-PP composites agree with the rule of mixtures prediction of mechanical performance.
Title: Shrinkage and Retractive Force of Drawn Isotactic Polypropylene during Heating

Author: F. DE CANDIA, G. ROMANO, V. VITTORIA

Summary

The paper describes the shrinkage at the free end and the retractive force stress at fixed ends of a drawn isotactic polypropylene heated after drawing to temperatures between room temperature and a few degrees below melting temperature. The asymptotic values of the changes of the absorption and diffusion coefficients in drawn and drawn and annealed isotactic polypropylene were just reported.

The experiment was carried out and the results were obtained, according to the measurement of drawn linear polypropylene and nylon fibres even at the melting point, the sample free to shrink never returned to the length before the drawing. During the drawing some chains slipped irreversibly and hence do not show any tendency to return to the length of the initial sample. At sufficiently high heating all crystalline bridges of TTM melt and hence do not prevent a full recovery, but the pulling out of the ends of TTM from the crystal blocks they are anchored is an irreversible process. Such an explanation is in full agreement with the observations on drawn nylon.

The shrinkage below 100°C is usually considered as a sign of the intrinsic instability of the drawn material. It shows up in drawn iPP as it does in drawn linear and branched PE. At room temperature it is part of the aging process that continues over months and years.

But one must not forget that after the drawing, annealing and standing at room temperature the slow crystallization of almost fully extended TTM in the bridges crossing the amorphous layers between the crystalline blocks of each microfibrill increases as the sample length. Hence the shrinkage or expansion is the difference of both effects, the true shrinkage, and the partial recovery of the amorphous deformation on one side and the slow crystallisation on the other side.

The retractive stress of the sample with the fixed ends was investigated in repeated heating and cooling cycles. The maximum of the retractive stress moves consistently to lower temperatures if the draw ratio increases.

At each temperature the retractive stress as a function of time, first rapidly increases to a maximum as a consequence of the gradual heating of the sample and subsequently drops to a limiting value $\sigma_{\infty}(T)$. The whole time dependence of the retractive stress is an interplay of the temperature distribution in the heated sample.

The limiting retractive stress shows very much the same behaviour as formerly observed in the retractive stress during the first heating.

The discussion of the shrinkage and restoring force will be given in terms of the microfibrillar model of the fibrous structure that was mainly based on the experiments of drawing of linear PE.
of medium molecular weight and of iPP. the model seems to be sufficiently realistic for the straight forward explanation of the newly observed effects on drawn iPP.

Conclusion

The higher the draw ration, the more stable the drawn sample is against the thermal effects of annealing. The TTM are longer and included in more crystal blocks and wider bridges. As a consequence of the smaller surface to volume ration, they depress less the crystallization or melting point. At any temperature the probability of their melting during the annealing is less than with smaller λ. But their number and hence the number of melted bridges and the thus activated TTM increases with λ as seen from the increasing of the restoring stress.
**Title:** Non-Isothermal Stamp Forming of Continuous Tape Reinforced All-Polypropylene Composite Sheet.

**Author:** N.O. Cabrera, C. T. Reynolds, B. Alcock, and T. Peijs.

**Summary**

- According to the paper the thermoforming behaviour based on co-extruded polypropylene on a self–extruded polypropylene (PP) tapes is described. In the traditional one the deformation was sole mode either inter or intraply shearing and was made of continuous woven glass fabric reinforced polypropylene materials. The PP composites have an additional mode of deformation with the deformation of the fibres which can still be found. The importance of this additional deformation mode is investigated in a range of stamping experiments in combination with 3D strain mapping experiments. Non-isothermal thermoforming experiments also reveal that all PP woven fabric laminates based on flat tapes deform in a different manner to traditional GF/PP.

- The deformation of the main mode is investigation of dome parts and much lower energy is required for the deformation of PP-laminate.

- Due to the requirement of high energy because of which residual stresses in the final part is higher and should be avoided during the deformation of the tape by drawing.

**Non-Isothermal Stamping**

A specially designed stamping press for the test is described in this paper and is shown in Fig. 4. A hydraulic pump (Hussh ENERPAC GPER-5000) was combined with a precision double acting 80kN ENERPAC cylinder. With this hydraulic pump, the cylinder extension speed depends on which one of two discrete pressure ranges the pump experiences. The cylinder moves at a higher speed at lower pressures and lower speed at high pressure. To measure the position of the punch and pressure of hydraulic system a displacement transducer is used and a pressure transducer is used. These allow the derivation of the force developed by the cylinder. Hemispherical dome geometry was chosen for the metal die mould in order to draw a comparison. A photograph of a stamped all-PP composite dome produced by iso-thermal stamping is presented in this paper as shown in fig 5. The dome of the outside diameter is of 60 mm. The 3 layer all-PP composite plates (0.43mm thick) were stamped by a 58 mm diameter punch while a 56 mm punch was used for the GF/PP composite laminates and the all-PP laminates made from 9 plies (1.25mm thick) and 12 plies 7mm thick). In all cases, the stamping mould was preheated to 40ºC. Although this is below the temperature conventionally used to
stamp GF/PP, it was deemed suitable for stamping all-PP plates, and so to aid comparison between GF/PP and all-PP composites, the same temperature is used for both materials throughout this paper. From consolidated all-PP plates disks were cut in 140mm diameter. These circular-shaped laminate disks were placed between two steel rings of 100 mm internal and 140 mm external diameter. A torque of 5 Nm was applied to the 12 screws of the clamping rings. Some plates were partially clamped with 4 screws tightened to a torque of 2 Nm and placed at 45º with the fabric directions, allowing some sliding towards the dome along the warp and the weft directions and maximum intraply shearing. A thermocouple was attached to the surface of the laminate to hold the composite laminate in the clamping ring. The all-PP specimens were heated to 150ºC while GF/PP laminates were heated to 160ºC. The composite laminate (still inside the holding frame) was directly transferred to the press for stamping after heating. The transfer time is almost equal to 3 seconds because the oven is adjacent to the stamping press, and there will less drop in temperature while removing from oven and the beginning of the stamping operation. The pole of the dome coincided with the centre of the laminate. The temperature of the laminate, the punch force (from the hydraulic oil pressure) and the displacement of the punch were recorded by a data acquisition system. (Spider8, HBM). Same equipment was used in the past to reproduce the conditions of the non-isothermal thermoforming in the industry. Laminates which were partially clamped were heated identically but not stamped in order to use them for testing to check the loss of fabric as a mechanical property during heating. Tensile test coupons of these heated but unstamped laminates were produced with a gauge length of 70 mm and a width of 15 mm. With the help of Instron 5584 which is universal testing equipment, these were tested and were tested at a crosshead speed of 5mm/min.
Conclusion
Glass and carbon fibre yarns were mostly used for textile composites. These fibres are brittle and non-extensible under solid state or melt processing conditions of the polymeric matrix. Plastic deformation can occur due to forming stresses at elevated temperatures, because the same polymeric material is used as composites for the reinforcement and the matrix of all-polypropylene. It is possible to create geometries by non-isothermal stamp forming of all-PP composite laminates. Although the hemisphere geometry is a simple one, it is a good model to prove the feasibility of stamping all-PP composites. When compared to GF/PP deformation of PP woven fabric is totally different based on flat tapes when forces are applied along the reinforcement directions. The PP tape can be drawn even when high strain rates is applied in stamping.

![Figure 4](image)

**Figure 4**: Photograph of an all-PP composite dome formed by non-isothermal stamping. The clamping frame is clearly visible around the edge of the stamped all-PP composite dome. The steel rings shown have an internal diameter of 10cm and an external diameter of 14cm.
1.6 Thermoforming Process

Thermoforming is a process in which a flat thermoplastic sheet is heated and deformed into the desired shape. The process is widely used in packaging of consumer products and to fabricate large items such as bathtubs, contoured skylights, and internal door liners for refrigerators and also in textile industries.

Thermoforming consists of two main steps: heating and forming. Heating is usually accomplished by radiant electric heaters, located on one or both sides of the starting plastic sheet at a distance of roughly 125 mm (5 in.). Duration of the heating cycle needed to sufficiently soften the sheet depends on the polymer, its thickness and color. The methods by which the forming step is accomplished can be classified into three basic categories: (1) vacuum thermoforming, (2) pressure thermoforming, and (3) mechanical thermoforming. The forming tests conducted in Zwick Roell machine of University of Glasgow is of Mechanical Thermoforming and most of thermoforming operations are performed on thin films. (http://www.osho.com/products/archived/thermoforming.html)

Researchers and studies are being carried out in the composite press forming. During the press forming composite can wrinkle, rip or wrap. There are many factors which contribute to these defects, such as the temperatures of the tooling, the level of pressure on the composite sheet by the blank holder, uniformity in heating the composite sheet, means of heating the composite sheet and the time taken to cool the tooling, etc.

Figure 5: Mechanical Thermoforming
1.6.1 Hand Lay-up Forming

Hand lay-up is the simplest and oldest open molding method of the composite fabrication processes. It is a low volume, labor intensive method suited especially for large components, such as boat hulls. Glass or other reinforcing mat or woven fabric or roving is positioned manually in the open mold, and resin is poured, brushed, or sprayed over and into the glass plies. Entrapped air is removed manually with squeegees or rollers to complete the laminates structure. Room temperature curing polyesters and epoxies are the most commonly used matrix resins. Curing is initiated by a catalyst in the resin system, which hardens the fiber reinforced resin composite without external heat. For a high quality part surface, a pigmented gel coat is first applied to the mold surface.

There are various types of composite forming process where the required type of process is determined by the properties of the material, size of the component, shape and its cost. Hand Lay-up process is one of the best forming process where it comes out with good quality but it is not widely preferred as its costly, time consuming and requires skilled workers. So Press forming is preferred as each product has its own mould shape and can be produced quickly. And, process can be repeated many times and desired reliable shapes can be formed without defects. Moreover it doesn’t need any skilled workers as like Hand Lay-up process.

![Hand Lay-up forming](image)

**Figure 6: Hand Lay-up forming**
1.6.2 Zwick Roell Machine

Press forming is carried out in this machine and even this machine is used for some other projects and purposes. The male tool and female tool is designed especially for the thermoforming process. The male tool is attached to the top part of the machine and the female tool is clamped to the base. The tools should be aligned properly before experimentation so as to acquire accuracy in the forming results.

Figure 7: Zwick Roell Machine in the Thermoforming station of University of Glasgow.
1.7 Previous Student Work

The present thermoforming machine had been worked on by four previous students such as Lauren Maurel, Gordon Pettigrew, Gail Gemmel and Alana Richards. Each and every student’s aim was to make the thermoforming machine more efficient and to get the desired outcome from it so they altered many parts of it and designed and re-designed it. A gist of what they did is as follows,

1. Lauren Maurel

He designed the male and female tooling system with the cooling system for the thermoforming station. The male tool and the female tool are heated by the cartridge heaters and cooled quickly by the recycling tap water. And the simple blank holder holds the composite sheet and the composite sheet is heated in oven before it is been held in the blank holder.

2. Gordon Pettigrew

He designed the radiant heater which is the pre-heating system for the composite sheet. This was designed as a pneumatic mobile radiant heater which was manufactured as a replacement for the oven heating system as the problem with the oven heating is that the blank holder should be transferred manually from the oven to the forming press and the sudden loss in temperature when it is exposed to ambient temperature while it is transferred from the oven to the forming press. The radiant heater can be heated up to 540° C. The radiant heater can be
fixed up with the forming press and can be removed from it manually. The radiant heater is moved in between the male tool and the blank holder and it is made possible by the pneumatic system provided in the radiant heater system. It is moved in smoothly by the pneumatic system and it aided by a small portable compressor which has a maximum pressure of 10 bar. And the velocity of the piston is controlled by the flow control valve.

3. Gail Gemmell

He designed the hollow blank holder which was manufactured as a replacement for the square blank holder. Hollow blank holder was designed so as to provide independent heating to the held composite apart from the heating provided from the tooling system. And it was made in aluminium with a light weight whereas the square blank holder is heavier in weight and difficult to be transferred from the oven to the forming press. Moreover the hollow blank holder is designed in a way that the composite could be heated by a hot air gun or by a hot liquid passing through it. He also designed the eight clips which are used to hold the composite in between pressure distribution plate and the blank holder and it is used to apply pressure to the composite through the pressure distribution plate.

4. Alana Richards

She re-designed the clips which are used for the hollow blank holder so as to regulate the pressure distributed to the composite material through the pressure distribution plate. And calibrations were carried out on the radiant heater inorder to find out which is the optimal distance between the radiant heater and the blank holder and also to know the time taken by the heater to be set the required temperature on the composite material.
1.8 Heating systems for heating the specimen (or) the blank holder

There are two heating systems available in the thermoforming station lab for heating the specimen; one is the default oven heating system and the other is the radiant heater which was designed by previous Msc student Gordon Pettigrew. The radiant heater was designed two years back and when it was used for heating the specimen it is noticed that it had a technical fault in it i.e. the temperature goes on increasing and it could not be controlled by the temperature controller even though it is connected with the temperature controller. Tremendous heat started coming out from the radiant heater such that the specimen started melting in 2 minutes. And apart from that reason the radiant heater radiates heat only on the region of the specimen where it is exposed to the atmosphere but on the region of the specimen where it has got held by the blank holder and the pressure distribution plate.

Figure 9a: Radiant heater over the Gail’s hollow blank holder.

Figure 9b: Hot air passing through Air Gun into the hollow blank holder.

Figure 9c: Blank holder setup heated inside the oven.
During forming, the regions of the specimen which are held by the blank holder turns into folds and wrinkles and so those regions should be necessarily heated up inorder to avoid the folds and wrinkles but the radiant heater doesn't heat up those regions completely but only a smaller part along the edges of the blank holder are only heated up. And in oven heating there are two disadvantages, one is heat is lost during the transformation process of the blank holder from oven to the forming press and the second one is that there is a slight difference in temperature between the specimen region which is exposed to the ambience and to the specimen region which is held by the blank holder. And the air gun heating did not turn out well as the air gun heating costs more and it fumes after two minutes and also it was noticed that the heat was not distributed properly all over the blank holder. So an alternative heating method is required for heating the specimen through blank holder and also it should be considered that the specimen along the blank holder held region should be heated to the desired temperature. So flexible heaters or the cable heaters were decided as the heating system for the blank holder and two blank holder designs are generated in such a way that one can facilitate flexible heater and other can facilitate cable heater. And the best one is selected after the finite element analysis and the cost factor of two designs.
2.0. Heated Blank Holder

2.1 New Heating Concepts

2.1.1 Cable Heaters
The versatile Watlow cable and coil heater can be formed to a variety of shapes as dictated by its many applications. Cable heaters are small diameter, high-performance units, fully annealed and readily bent to a multitude of configurations. So as like that it can bent according to the circular groove which is designed at the back side of the blank holder and can be inserted into it. Its input and output can be controlled by a temperature controller.

Figure 10: Image of the Cable heater.

Performance Capabilities
• Continuous operating temperatures to 1200°F (650°C) with intermittent operating periods achieving up to 1500°F (815°C) dependent on the type of element wire used.
• Sheath watt densities on the cable to 30 \text{ W/in}^2 (4.65 \text{ W/cm}^2), and as high as 75 \text{ W/in}^2 (11.62 \text{ W/cm}^2).

These are available in 0.132” square cross section and 965mm of length and it costs 140 GBP.
2.1.2 Flexible Heaters

The Watlow Flexible silicone rubber heaters are rugged, yet thin, lightweight and flexible. With these heaters, one can put the heat where it is needed and, in the process, improve heat transfer, speed warm-ups and decrease wattage requirements. Fiberglass-reinforced silicone rubber gives the heater dimensional stability without sacrificing flexibility. Because very little material separates the element from the part, heat transfer is rapid and efficient. Five 2” * 5” flexible heaters are used and each heater is of cost 14.90 GBP. Each heater is stuck to the back side of the blank holder and the newly designed eight clips provide extra hold or support for the flexible heaters. The input and the output temperature is controlled by a temperature controller.

Performance Capabilities

• Operating temperatures to 500°F (260°C)
• Watt densities to 80 W/in² (12.5 W/cm²) dependent upon application temperature
• 0.055 in. (1.4 mm) thick with a wire-wound element; only 0.022 in. (0.56mm) with an etched foil element.

Figure 11: Image of the Flexible heater and its components
2.2 An Overview

The design of the blank holder is one of the major aspects influencing the forming of composite. The previous hollow blank holder was designed by Gail and it was designed in a way that hot air can be blown through it from the air gun through the pipe attached to the two sides of the hollow blank holder. The pressure distribution plate on the top blank holder is designed to be 1mm and it is made of aluminium and the bottom blank holder a bit complicated design as it has a hollow space inside with small walls in regular space intervals along the centre, this hollow space is used for the circulation of hot air which comes out through the air gun. And Alana made some small change in the Gail’s blank holder by increasing the size of the air-flow outlets so as to control the intensive heating by the hot air-gun. During their experiments it was observed that plastic nozzle glowed red, Guns smoked intensively after the use and it was stopped at two minutes and protective gloves were worn for safety. Moreover the results after the forming experiments were not as expected in-spite of the alterations made in the thermoforming station.

![Image of Gail's hollow blank holder in two views.](image_url)

**Figure 12:** Image of the Gail’s hollow blank holder in two views.

So this project was aimed at getting the desired results from the forming experiments in the thermoforming station i.e. having the formed specimen with no or very less wrinkles or folds in it.

This project carries the basic design concept of the hollow blank holder but altered according to the new heating system for the blank holder. The heating system for the blank
holder is changed because of some problems encountered with air-gun as stated above and also the uniform temperature was not reached all over the blank holder with the air-gun. And as far as the oven heating of the blank holder is concerned, the problems observed are the temperature loss during the transformation of the blank holder from the oven to the forming press and the difference in temperature between the exposed central part of the specimen and the outer surface of the specimen which is covered or held by the blank holder.

This temperature difference between outer surface and the central part of the specimen can also be the reason for the wrinkles and the folds along the hemispherical edges of the formed specimen. In order to have a uniform temperature along outer surface of the specimen where it is held by the blank holder, cable heaters or flexible heaters can be used. Two designs of blank holder is developed using solid works, one blank holder is developed inorder to facilitate the cable heaters and another is designed inorder to facilitate the flexible heaters. Finite element analysis was conducted on both of these blank holders to decide which heating system provides the best and reliable heating to the composite specimen via the blank holder. Aluminium is used as the material for the blank holder as it has the property of good heat transfer efficiency.
2.3 Blank holder design for Flexible heaters

The new blank holder for flexible heaters differs from the Gail’s blank holder by increase in outer diameter by 40mm but having the same inside diameter. And, Gail’s hollow space design inside the blank holder was replaced by solid aluminium which is of 4mm thickness. The inner circular edges of the blank holder are given a fillet of 1mm on both the top and the bottom side. This is the design formulated for flexible heaters. The main reason behind the increase in the outer diameter of the blank holder is that more area of the composite specimen can be held by the blank holder and the pressure distribution plate and eventually more area of the specimen is utilized for heating along the area where pressure distribution plate and blank holder is in contact with the specimen. In Gail’s blank holder only very less area of the specimen comes into contact with the pressure distribution plate and blank holder and eventually most of the held region comes into the female tool while it is formed and only very less region of the specimen stays in contact with the pressure distribution plate and the blank holder. There is lot of chance for wrinkles and folds to be formed because of this. So the outer diameter of the blank holder is increased for facilitating more area to be held by the pressure distribution plate and blank holder. (see appendix H & I) And also it enables the cable or flexible heaters to be fixed with it, according to the heating system we are going to select. The below figure 13 shows that how the flexible heaters are can be stuck on the bottom side of the blank holder. Five flexible heaters should be stuck on the bottom side of the blank holder each of size 2” * 5” and of width 0.055” (1.4 mm).

Figure 13: 3D views in CAD, of the newly designed bottom blank holder.
Figure 14: Figure 11: 3D views in CAD, of the newly designed pressure distribution plate (or) the upper blankholder.

Figure 15: The position of the flexible heaters stuck on to the bottom side of the blank holder.
2.4 Blank holder for Cable Heaters

The design of blank holder for the cable heaters is same as the design of flexible heaters except which a circular groove of length 965mm is drawn at the bottom side of the blank holder. The groove is of square cross section i.e. 0.132". As these specifications provided for cable heaters from the Watlow company.

Figure 16: Blank holder designed for the Cable Heaters.
2.5 Finite element analysis for finalizing the heating system for the blank holder

Two designs of blank holders were developed in solid works, one design of blank holder was developed inorder to facilitate cable heaters on it and other design was developed inorder to facilitate flexible heaters on it. Both the designs were then imported to abaqus CAE environment. Simulation was done considering that cable heater is fitted inside the groove channel of the blank holder. Both fine mesh and coarse mesh analysis was done in abaqus and in both the analysis it can be noticed that intensity of high temperature is found only along the sides of the cable heater but not all along the blank holder (see appendix) but in simulation on blank holder with 5 flexible heaters, it can be noticed that in both coarse and fine mesh analysis the intensity of high temperature is found all along the area where the flexible heaters are in contact with the blank holder. And more over even the outer surface of the flexible heater blank holder attains a quite higher temperature than the outer surface of the cable heater blank holder. (See appendix K,M,N & O).

And more cable heaters can’t be used as like flexible heaters because one cable heater costs 140 GBP but one flexible heater costs14.90GBP. And flexible heaters cover more area of the blank holder so that the efficiency is high but the cable heaters covers very less area of the blank holder and so intensity of heat is less than the intensity of heat of the flexible heaters. Therefore the blank holder design for the flexible heaters is preferred.

Figure 17: Photo image of the new blank holder and pressure distribution plate.
Figure 18: 3D image of the new blank holder and pressure distribution plate.

Figure 19a & 19b: DC3D20 a 20-node quadratic heat transfer brick hexahedral-dominated elements (fine mesh with mesh seed size = 0.003) for (the blank-holder for cable heater (a) and flexible heater (b) )

The below graphs shows the time taken to reach the set temperature on the blank holder by both cable and flexible heaters.
Figure 20: Temperature distribution across the top surface of the blank-holder with cable heater (fine mesh). [Temperature scale corresponds to °C and time in seconds]

Figure 21: Temperature distribution across the top surface of the blank-holder with 0.004m (fine mesh) & temperature distribution across the top surface of the blank-holder with five-rectangular heaters (fine mesh) [Temperature scale corresponds to °C and time in seconds]
2.6 Finite element analysis for finalizing the thickness of the blank holder

Heaters has been finalized for the blank holder and the thickness of the blank holder should be analyzed now so as to get best heat transfer efficient blank holder. There were two flexible heater blank holders designed, one is of 2 mm thickness and the other is of 4 mm thickness in solid works and it was then imported to Abaqus CAE environment. Both the designs were analyzed in coarse mesh and fine mesh analysis of abaqus with the specifications of flexible heaters. The results showed that efficiency of heat transfer is high with the increase in thickness of the blank holder because aluminium has good conductivity and transferability of heat. As the thickness of the blank holder increases the efficiency of heat transfer and conduction increases so the 4mm thick blank holder is selected, this can be revealed from the simulation results of the two blank holders. (see appendix J,K,L & M). Fig & shows the time taken by the flexible heaters to heat up the two blank holders of 2mm and 4 mm thickness.

Figure 22: Photo image of the pressure distribution plate.  
Figure 23: Photo image of the new blankholder.
Figure 24: Temperature distribution across the top surface of the blank-holder with 0.002m (fine mesh). [Temperature scale corresponds to °C and time in seconds]
3.0 Clips

3.1 Design of Clips for the blank holder

The clip design for the blank holder is same as like Alana’s clips except which the size of the clips had been changed both in terms length and breadth. The length of the clip is increased to 190 mm from 170 mm and the breadth has been increased from 11 mm to 15 mm. (see appendix). The reason behind increasing the length and breadth is that the blank holder’s outer diameter is increased to 370 mm from 330 mm, according to the new design. And also 5 flexible heaters are going to be stuck at the back side of the new blank holder and weight of the pressure distribution plate has been increased from 82.22 g to 189.5 g. Considering all this above factors the length and breadth of the clips had been increased so as to provide more pressure for the extended solid blank holder and also to have more contact area with flexible heaters so that it can hold up the flexible heaters which are going to be stuck at the bottom side of the blank holder. The screw head is welded with a key twister so that screw drivers shall not be used for tightening the screws and thus time is saved.

Figure 25a & 25b: Image of the new clip and the ease of tightening and loosening the screws by the key type screw head.

Eventually the springs and the screw sizes are also increased. (see appendix C,D,E,F).

Figure 26: From left, Image of the new clip, Alana’s clip, Gail’s Clip.
**Figure 27a & 26b: Image of the new clips fixed up with the new blank holder.**

### 3.2 Springs

The free length of the spring is increased to 33mm and outer diameter to 8 mm and inner diameter to 6 mm. (see appendix G) In order to know the plastic deformation of the clips, the calibrated force of the spring should be calculated and the extent to which it can be compressed. The, ultimate aim is to know how far the screw can be turned before it exceeds the deformation force.

The new springs are placed in the Zwick Roell machine at a spring free length and the force was applied till the spring compresses by 50%. The figure below shows the graph of force applied on the spring vs displacement of the spring.

**Figure 28: 3D view of the spring.**
The free length of the spring is 33mm. The formula for calculating the spring stiffness is,

\[ F = k \times x \]

The weight of the pressure distribution plate is 189.5g i.e. 185.7 N. The average force of pushing the spring by 11mm is 185.7N.

Substituting the values in the formula, \( F = k \times x \),

Then, the K value is calculated to be 16.88N.

\[ F_{\text{total}} = F \times 8, \text{ since there are 8 clips attached with the blank holder.} \]
Table 2: Spring test results

<table>
<thead>
<tr>
<th>Free length (mm)</th>
<th>δ (mm)</th>
<th>X (mm)</th>
<th>K (Nmm)</th>
<th>F(N)</th>
<th>F&lt;sub&gt;total&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>22</td>
<td>11</td>
<td>16.88</td>
<td>185.7</td>
<td>1485.6</td>
</tr>
<tr>
<td>33</td>
<td>26</td>
<td>7</td>
<td>16.88</td>
<td>118.16</td>
<td>945.28</td>
</tr>
<tr>
<td>33</td>
<td>31</td>
<td>2</td>
<td>16.88</td>
<td>33.76</td>
<td>270.08</td>
</tr>
</tbody>
</table>

δ = Change in length of the spring in mm.

X = difference in free length of the spring and the change in length of the spring

K = spring stiffness

F = The point force applied by the clips on the pressure distribution plate.

F<sub>total</sub> = The point force applied by all the clips on the pressure distribution plate.
4.0 Experimentation and results

4.1 Forming experiments with Gail’s hollow blank holder and Alana’s Clips

Aims

The main aim is to get the best formed specimen by varying the temperature of the blank holder, specimen and the male and female tooling system. And to observe, how different variables affect the outcome of formed specimen. The variables such as clip pressure, temperature of radiant heater, temperature of blank holder and temperature of the tooling will be monitored and changed during the subsequent experiments. Many experiments were carried out by Gail and Alana in this hollow blank holder and with different temperature variables, so only two experiments were only conducted this time after assessing the previous experiments results at certain conditions which can bring out best formed specimen. These two experiments was conducted at high temperature of 100°C as best formed specimens are obtained from forming at high temperatures as observed from the previous rough experiments done in the thermo forming station and also from the experiments done by the precious students. So the two forming experiments were carried out at high temperature of 100°C. For, heating the specimen radiant heaters was not used as it had some technical fault in it. The radiant heater could not be controlled by the temperature controller so oven is used to heating the blank holder.

**Experiment 1a:** Hot tooling (100°C) and hot specimen (100°C) and hot specimen at medium pressure.

**Experiment 1b:** Hot tooling (Male tool: 100°C, Female Tool: 100°C) and hot specimen at 100°C and at high pressure.
4.1.1 Experiment 1a:

The aim of this experiment is to observe how the material reacts and forms when at medium pressure and high temperature of 100°C.

Figure 30: Forming using the Gail's blank holder and Alana's Clips.

Method:

Equipment

- Gail's Hollow blank holder
- Heated male and female tooling to 100°C
- Roell Zwick machine
- Circular cut pre-consolidated composite sheets
- Alana's Clips.
- An oven.
- A thermocouple.
Procedure:

1. Heat the male and female tool to 100°C.
2. Heat the material with blank holder which attached with clips – 14 mm spring displacement (for medium pressure) in the oven to 120°C as there will be a temperature drop of 20°C when the material is taken out from the oven and exposed in the atmosphere.
3. Place the blank holder specimen setup on the female tool.
4. Attach the thermocouple to the specimen to monitor its temperature.
5. Place on the male tool
6. Resting the male tool on the specimen for 10 minutes.
7. Then cooling the male and female tool by water till it reaches the room temperature and also allowing the specimen to come to the room temperature.
8. Remove the blank.

Figure 31: Formed specimen from experiment 1a

Results and Discussion:

It is observed that the specimen adhered to the shape of the mould but small folds are witnessed at the sides of the mould and small creases at the sides. Even some small folds are found out with the mould. The below figure shows the graph for force vs distance travelled for the experiment 1a.
Figure 32: Force vs displacement graph for experiment 1a (see appendix A)

4.1.2 Experiment 1b:
The aim of this experiment is to observe how the material reacts and forms when at high pressure and high temperature of 100°C.

Method:

Equipment

- Gail’s Hollow blank holder
- Heated male tool to 100°C and female tool to 100°C
- Roell Zwick machine
- Circular cut pre-consolidated composite sheets
- Alana’s Clips.
- An oven.
- A thermocouple.
Procedure:

1. Heat the male and female tool to 100°C.

2. Heat the material with blank holder which attached with clips – 10 mm spring displacement (for high pressure) in the oven to 120°C as there will be a temperature drop of 20°C when the material is taken out from the oven and exposed in the atmosphere.

3. Place the blank holder specimen setup on the female tool.

4. Attach the thermocouple to the specimen to monitor its temperature.

5. Place on the male tool

6. Resting the male tool on the specimen for 10 minutes.

7. Then cooling the male and female tool by water till it reaches the room temperature and also allowing the specimen to come to the room temperature.

8. Remove the blank.

Figure 33: Formed specimen from experiment 1b

Results and Discussion:

It is observed that the specimen adhered to the shape of the mould and the small folds are witnessed at the sides of the mould but less than the previous case. Even the small creases at the sides very also reduced. Very less small folds and creases are found with the mould. The folds and the creases are getting reduced as the pressure acting on the specimen increases. And even at high temperatures the folds and wrinkles of the formed specimen gets reduced.

The below figure shows the graph for force vs distance travelled for the experiment 1b.
Figure 34: Force vs displacement graph for experiment 1b (see appendix A)

The print screen of the force vs displacement graph for both the above experiments 1a, 1b can be seen from the appendix.
4.2 MatLab testing results for Gail’s blank holder

In order to quantify the wrinkles along the edges of the hemisphere Matlab is used. Two experiments were carried out with medium and high pressure. Figure 1 & 2 shows the formed specimen from medium and high pressure.

![formed specimen from medium and high pressure](image)

Figure 35: Gray scale picture for medium and high pressure using the Gail’s blank holder setup.

To quantify the wrinkles a 3D histogram is used to show the intensity of the wrinkles along the edges of the hemisphere. Dark edges in the grey scale picture show the amount of thickness of the composite. Not only the amount of wrinkling is revealed but also the thickness or the intensity of each wrinkle can be found out.
MatLab testing for Experiment 1a and 1b (or) Gail’s blank holder

Experiment 1: Hot tooling (100°C) and hot specimen (100°C) at medium pressure

Figure 36: Profile drawn along the outer edges of the hemisphere for both medium and high pressure.

In order to get the histogram for the line along the hemispherical edges of a specimen, a circular profile has to be drawn along the outer edges of the hemisphere after coding the respective codes in Matlab (see appendix for Matlab Codes) and then by pressing the enter key, the histogram is displayed.

Figure 37: Medium pressure histogram and High pressure Histogram using Matlab

In order to quantify the larger wrinkles along the hemisphere, the Z-axes properties are reduced for the two histograms so that the larger wrinkles along the hemisphere is showed.
Figure 38: Reduced axes Histogram for medium and high pressure specimens using Matlab.

The Fig & shows that the wrinkling decreases with increase in pressure applied to the composite sheet during forming. Even the thickness of the wrinkles decreases as the pressure increases.
5.0 Experimentation and results

5.1 Forming experiments with newly designed blank holder and eight newly designed clips

Along with the newly designed blank holder and clips this last set of forming experiments should have been carried out with the flexible heaters fitted with the blank holder. Since the ordered flexible heaters did not arrive from the Watlow Company, the final forming experiments were carried out with the newly designed blank holder and the eight new clips alone.

**Experiment 2a:** Hot tooling (100°C) and hot specimen (100°C) and hot specimen at 100°C high pressure.

**Experiment 2b:** Hot tooling (Male tool: 110°C, Female Tool: 110°C) and hot specimen at 110°C and at high pressure.

**Experiment 2c:** Hot tooling (Male tool: 120°C, Female Tool: 120°C) and hot specimen at 100°C and at high pressure.

5.1.1 Experiment 2a:

The aim of this experiment is to observe how the material reacts and forms when at high pressure and high temperature of 100°C.

**Method:**

**Equipment**

- New Circular solid blank holder
- Heated male tool to 100°C and female tool to100°C
- Roell Zwick machine
- Circular cut pre-consolidated composite sheets
- Newly designed Clips.
- An oven.
- A thermocouple.
Procedure:

1. Heat the male and female tool to 100°C.

2. Heat the material with blank holder which attached with clips – 20 mm spring displacement (for high pressure) (free length of the spring is 33mm) in the oven to 120°C as there will be a temperature drop of 20°C when the material is taken out from the oven and exposed in the atmosphere.

3. Place the blank holder specimen setup on the female tool.

9. Attach the thermocouple to the specimen to monitor its temperature.

10. Place on the male tool

11. Resting the male tool on the specimen for 10 minutes.

12. Then cooling the male and female tool by water till it reaches the room temperature and also allowing the specimen to come to the room temperature.

13. Remove the blank.

![Image of formed specimen](image)

**Figure 39: Formed specimen from experiment 2a.**

Results and Discussion:

Some wrinkles are noticed along the sides of the hemisphere And, it is observed that the specimen adhered to the shape of the mould and the small folds are witnessed at the sides of the mould but less than the previous case i.e. less than the wrinkles of the formed specimen from Gail’s blank holder.

The below figure shows the graph for force vs distance travelled for the experiment 2a.
5.1.2 Experiment 2b:

The aim of this experiment is to observe how the material reacts and forms when at high pressure and high temperature of 110°C.

**Method:**

**Equipment**

- New Circular solid blank holder
- Heated male tool to 110°C and female tool to 110°C
- Roell Zwick machine
- Circular cut pre-consolidated composite sheets
- Newly designed Clips.
- An oven.
- A thermocouple.
Procedure:

1. Heat the male and female tool to 110°C.

2. Heat the material with blank holder which attached with clips – 20 mm spring displacement (for high pressure) (free length of the spring is 33mm) in the oven to 130°C as there will be a temperature drop of 20°C when the material is taken out from the oven and exposed in the atmosphere.

3. Place the blank holder specimen setup on the female tool.

14. Attach the thermocouple to the specimen to monitor its temperature.
15. Place on the male tool
16. Resting the male tool on the specimen for 10 minutes.
17. Then cooling the male and female tool by water till it reaches the room temperature and also allowing the specimen to come to the room temperature.
18. Remove the blank.

Figure 41: Formed specimen from experiment 2b.

Results and Discussion

The material adhered to the shape of the mould and this time the wrinkles are slightly less when compared to the formed specimen of experiment 2a. As, the temperature is increased by 10°C for the forming test and with the same high pressure it is noticed that wrinkles are getting reduced as with the increase in temperature.

The below figure shows the graph for force vs distance travelled for the experiment 2b.
5.1.3 Experiment 2c:

The aim of this experiment is to observe how the material reacts and forms when at high pressure and high temperature of 120°C.

**Method:**

**Equipment**

- New Circular solid blank holder
- Heated male tool to 120°C and female tool to 120°C
- Roell Zwick machine
- Circular cut pre-consolidated composite sheets
- Newly designed Clips.
- An oven.
- A thermocouple.

![Standard force N](image_url)

**Figure 42: Force vs Displacement graph for experiment 2b.(see appendix B)**
Procedure:

1. Heat the male and female tool to 120°C.

2. Heat the material with blank holder which attached with clips – 20 mm spring displacement (for high pressure) (free length of the spring is 33mm) in the oven to 140°C as there will be a temperature drop of 20°C when the material is taken out from the oven and exposed in the atmosphere.

3. Place the blank holder specimen setup on the female tool.

19. Attach the thermocouple to the specimen to monitor its temperature.

20. Place on the male tool

21. Resting the male tool on the specimen for 10 minutes.

22. Then cooling the male and female tool by water till it reaches the room temperature and also allowing the specimen to come to the room temperature.

23. Remove the blank.

Figure 43: Formed specimen from experiment 2c.

Results and Discussion

The material adhered to the shape of the mould and this time the wrinkles have reduced drastically such that only one wrinkle is visibly seen when looked on a gray scale. As, the temperature increases the wrinkle decreases. By increase in every 10°C the decrease in wrinkles is witnessed. Even though there is very less wrinkles in the specimen there is a symptom of slight shrinkages and creases at a distance which is slightly away from the outer edges of the hemisphere. Even this could be avoided when flexible heaters are implemented in heating the blank holder, as those regions of specimen which is held by the blank holder are nicely heated up and so that it doesn’t tend to shrink or wrinkle while forming.

The below figure shows the graph for force vs distance travelled for the experiment 2c.
Figure 44: Force vs Displacement graph for experiment 2c.(see appendix B)

The print screen of the force vs displacement graph for the above three experiments 2a, 2b, 2c can be seen from the appendix.

Figure 45: From left specimen of 2a, 2b and 2c.

Fig shows the extent decrease in wrinkles in specimen as the forming temperature increases.
5.2 MatLab testing for Experiments 2a, 2b, 2c i.e. for the modified blank holder

The below shown gray scale image of the specimen is taken by holding the specimen on a glass light box and then taking the image of it, the main reason for taking this kind of image is that it shows the wrinkling in dark and the composite material in light so that one get to know the where the wrinkling has taken place and to what extent or thickness the wrinkling has formed. Then these gray scale images are imported to the Matlab software and then the histograms are developed using Matlab codes. (see appendix)

![Gray scale image of high pressure 100°C formed hemisphere.](image1)

Figure 46: Gray scale image of high pressure 100°C formed hemisphere.

![Gray scale image of high pressure 110°C formed hemisphere.](image2)

Figure 47: Gray scale image of high pressure 110°C formed hemisphere.

![Gray scale image of high pressure 120°C formed hemisphere.](image3)

Figure 48: Gray scale image of high pressure 120°C formed hemisphere.

Both histogram (Fig) and reduced axes histogram (Fig) for the outer edges of the hemisphere are drawn using the Matlab codes. The dark pixels on the histogram depict the amount of wrinkles and the thickness of the wrinkles.
Even in this set of forming experiments it is observed that the amount of wrinkles decreases as the temperature increases.
5.3 Wrinkle analysis

Wrinkle analysis for specimen from experiment 2a

The hemisphere of the formed specimen is of circular i.e. of 360°. So the wrinkles along the outer edges of the hemisphere can be located by its angle. For specimen from experiment 2a, fourteen wrinkles are found along the outer edges of the hemisphere and they are located in the respective angles such as 10°, 40°, 50°, 60°, 90°, 140°, 183°, 210°, 230°, 235°, 242°, 247°, 261°, 290°. Out of which wrinkles at 10°, 40°, 60°, 90°, 140°, 183°, 230°, 261°, 290° are denser wrinkles i.e. nine of fourteen wrinkles are denser wrinkles. The remaining five wrinkles are of finer ones. The circumference of the specimen’s hemisphere (circle) is 961.32mm, out which 19.5mm constitute wrinkles in this specimen i.e. 2.02% of the outer edges of the hemisphere constitute wrinkles in this specimen.

Wrinkle analysis for specimen from experiment 2b

Sixteen wrinkles are found on the formed specimen from the experiment 2b, and they are located at 35°, 45°, 53°, 95°, 145°, 180°, 190°, 210°, 215°, 221°, 230°, 237°, 252°, 273°, 300°, 330°, 350°. Out of which wrinkles at 95°, 180°, 273°, 300°, 45° are found to be denser wrinkles the remaining eleven wrinkles are of finer ones. Even though the number wrinkles in 2b specimen is little higher than number of wrinkles in 2a, the number of denser (or) thicker wrinkles in specimen 2b is much lower than the number of denser wrinkles in specimen 2a. It is observed that density of the wrinkles reduces as the forming temperature increases. The circumference of the specimen’s hemisphere (circle) is 961.32mm, out which 17.4mm constitute wrinkles in this specimen i.e. 1.81% of the outer edges of the hemisphere constitute wrinkles in this specimen.

Wrinkle analysis for specimen from experiment 2c

Hardly three wrinkles are noticed for the formed specimen from the experiment 2c and they are located at 300°, 310°, 350° respectively. The wrinkle at 350° is found to be little denser than the other two. The other two wrinkles are finer ones. So, it reveals from the experiments 2a, 2b and 2c that the number of wrinkles and the density of the wrinkles reduces in the formed specimen as the forming temperature increases. The circumference of the specimen’s hemisphere (circle) is 961.32mm, out which 4mm constitute wrinkles in this specimen i.e. 0.042% of the outer edges of the hemisphere constitute wrinkles in this specimen.

So, it is revealed that the percentage of wrinkles decrease as the forming temperature increases.
5.4 Comparing the results of the hollow blank holder experiment setup the new blank holder experiment setup

The above two images are the specimens formed from the old hollow blank holder setup and the new blank holder setup and their respective reduced axes histogram is shown. It shows that the quality of the specimen formed in the new blank holder setup has been improved from the formed specimen of the old hollow blank holder setup. The level of decrease in wrinkles has been shown in the histogram and the reduced axes histogram using the Matlab software.
6.0 Conclusion

The new circular blank holder and the eight clips are designed successfully and tested in finite element analysis and then manufactured successfully. The design and the finite element simulation are done for the set up of the flexible heaters on the blank holder. The flexible heaters are ordered from the Watlow Company. Experiments were conducted both on old hollow blank holder and the newly designed blank holder with eight new clips, enhanced results were shown in the experiments which was done in the new blank holder and clips. The quality (number and thickness of the wrinkles) of the formed specimen obtained from the experiments with new blank holder and clips is analyzed in Matlab and histograms were formed and it is compared with the quality of the formed specimens of the experiments from the hollow blank holder. Eventually the quality of the specimen formed from the new blank holder setup is higher than the quality of the specimen formed from the hollow blank holder setup.

6.0.1 Future work

Flexible heaters should used for heating the new blank holder and experiments should be conducted with it and its results should be analyzed and compared using Matlab Histograms and shear angle tests. And multi layer forming should be carried out by having two or more blank holders staked on each other and then performing the forming experiment.
7.0 APPENDIX

APPENDIX- A: Force vs Displacement graph for experiments 1a, 1b.
APPENDIX- B: Force vs Displacement graph for experiments 2a, 2b, 2c.
APPENDIX- C: Male clip
APPENDIX- D: Female Clip
APPENDIX- E: Large Screw
APPENDIX- F: Small Screw
APPENDIX – G: Spring
APPENDIX- H: Pressure Distribution plate
APPENDIX- I: Bottom blank holder
APPENDIX- J: Temperature distribution of the blank-holder with 0.002m thickness (fine mesh).
APPENDIX- K: Temperature distribution of the blank-holder with 0.004m thickness (fine mesh). &

NT 11 Nodal temperature at nodes of a blank holder with five-rectangular heaters (fine mesh).
APPENDIX- L: The unique-nodes of the blank-holder with 0.002m (fine mesh).
APPENDIX- M: The unique-nodes of the blank-holder with 0.004m (fine mesh). & Figure (10d): the unique-nodes of the blank-holder with five-rectangular heaters (fine mesh)
APPENDIX- N: NT 11 Nodal temperature at nodes of a blank holder (of 4mm thickness) with cable heater. (fine mesh).
APPENDIX- O: The unique-nodes of the blank-holder (of 4mm thickness) with cable heater (fine mesh).
APPENDIX- P: Matlab Codes:

The below shown codes are used to import the image of the specimen into Matlab and draw the histogram in order to show the amount and the thickness of the wrinkles formed.

To importing image into Matlab, Code used: \( I = \text{imread}('picture1.jpg') \) (or)

Specifying the directory through the tools tool bar and as a block inside the window shows the list of JPEG files stored inside that directory then we can right click on the respective image to be imported and then clicking import, thus the image can be imported into Matlab.

To show the image on the screen, Code used: \( \text{imshow}(I) \)

To change the class of the image from unit 8 to double, Code used: \( I = \text{im2double}(I) \);

To change the image to gray scale image, Code used: \( \text{colormap}('gray') \)

To save the image and its details, Code used: \( \text{whos} \)

To save the image in to Matlab, Code used: \( \text{Save I} \)

To draw the profile and create the Histogram, Code used: \( \text{improfile} \)

After this by drawing the profile where the amount and intensity of the wrinkles have to be shown, the return key has to be pressed in order to get the histogram of the drawn profile and the reduced axes histogram can be obtained by reducing the Z-axes properties by using the File→ Axes properties.
8.0 References

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9.0 GANTT CHART:

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