Design and value engineering of a high temperature high pressure multifunctional compression moulding unit to manufacture zero defect parts

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Abstract. Hot compression moulding is one of the better techniques employed to make zero defect products. This paper mainly discusses about the conversion of a conventional hydraulic press into a high pressure, high temperature compression moulding unit at a low cost using local state of the art methodology. A normal press used for blanking, drawing and various metal forming operations is modified here by addition of top and bottom platens with heating coils controlled by PID controllers to operate up to 500°C within which high Temperature Plastics, Aluminium, Tin, Lead, Magnesium etc. can be hot compacted with foil films and reinforcements or can be hot forged with matching dies. In this paper, hot compression moulding as a sound technique for manufacturing zero defect thermoplastic and advanced thermoplastic based composites is demonstrated and emphasized based on a defect evaluation of the moulded parts using an ultrasound scanning technique.

Keywords: High Pressure Hot Compression Moulding, Thermoplastics, Composites, Zero defect, C Scan, Value Engineering.

1. Introduction
The potential of high performance materials can be improved to maximum utility by choosing suitable manufacturing techniques based on their applications. Compression moulding is one of the most common manufacturing techniques used for products made of plastics, metals, ceramics and composites. The quality of the product depends on various parameters of moulding such as temperature, product size, pressure, material properties, cycle time and porosity levels. Compression moulding has been in use from making swords in ancient days till recently to make automobile and aircraft parts and in many areas where advanced materials or high performance parts are fabricated and used [1]. With the advent of material processing science and special moulding methods [2][3], enhanced mechanical properties can be achieved which in turn are necessary for novel high end applications.

A hydraulic press is a machine used to shape, mould, straighten and crush materials by applying compressive force through platens or a bed. It works on the basis of Pascal’s law which states that force acting on confined fluid at any point is uniformly transmitted throughout the fluid. Thus pressure created by a small actuated effort in a confined area on a small piston is transferred through the hydraulic fluid to apply greater force on the larger piston [4]. This compressive force is primarily utilized in hydraulic pressing for metal forming operations, plastics moulding, forging, blanking, shaping, deep drawing and shearing.
Hence, the focus of the present study is about upgradation of an existing conventional hydraulic press into a high pressure high temperature compression moulding unit at an affordable cost. The importance of hot and high pressure compaction to make superior quality zero defect products are further established through non-destructive ultrasound testing of the fabricated laminates. The significance of this work is the cost effective and value engineering [5] based manner in which the parameters required to fabricate zero defect products are achieved. A brief statement of the investment costs for the design and development of such a new platen press and its modification is also provided at the end.

2. Experimental details of the platen press

A four column pillar hydraulic press in the lab consists of two cylinders, piston pumps, relief valves, a control unit, oil reservoir, ejector, pressure gauges and two flat normal dies. Since heating facility is not available in the existing dies and platens, it can only be used for shaping, powder compacting and other simple pressing processes for which only a compressive force is required between the platens with no rise in temperature.

Further, the existing press is only intended for use in fabrication processes like blanking and powder compaction by applying high speed compressive forces for a short period of time and achieve mass production through short cycle times. Table 1 and Figure 1 provide the details of the existing unmodified press.

| Table 1. Existing Hydraulic Press Specifications |
|-----------------------------------------------|
| Type of Press | Hydraulic four pillar compacting press |
| Capacity | 15 Tons |
| Stroke | 300 mm |
| Day light | 300 mm |
| Slide size | 400 mm × 400 mm |
| Table size | 400 mm × 400 mm |
| Power | 5 HP |
| Supplier | Press Form Industries, Chennai, India. |
3. Upgradation of the existing press

High pressure hot compaction method is very effective for fabrication of certain advanced materials and parts with zero defect. Hot compaction of certain materials for instance polymers, plastics and composites requires precise temperature and pressure settings to be applied for forming. The objective of this work is to integrate high pressures with high temperatures and achieve a controlled synergic effect on the moulding material and improve its structural integrity and quality. The formability of polymers owing to temperature variations differ from one another. With the advent of high temperature plastics that require forming temperatures in excess of 400 °C a precise control of temperature and pressure are priority. Hence a precise control of temperature over and pressure over a wide range is necessary. At the same time caution is to be taken to avoid very high temperature at which an otherwise normal press would suffer thermal loads and a rise in hydraulic fluid temperature higher than its normal working level. In the present investigation, 53°C which is the maximum permissible temperature for the typical hydraulic oil used, would affect the functionality due to evaporation and boiling in a confined tube or piston that would alter the partial pressures and affect the control over the pressure of forming.

Based on the above factors the platen materials and heater coils to be used in platens are selected. Hardened mild steel integrated with Kanthal heating coil is selected and installed as the heated platens. The design requirements and fabrication work were provided to an external small scale casting industry “Vellore Foundries” and ‘ready to fix heated platens’ were procured from them.

In order to control the temperature precisely a PID – Proportional Integral Differential controller which is a closed loop mechanism that employs feedback of a continuously calculated difference
between a desired set point and measured process variables is applied. Here, the input values and corrections based on Proportional, Integral and Differential terms maintain the required temperature precisely. Though Kanthal heating element can be used to heat up to 1000°C, the maximum temperature permitted here is restricted to 450°C beyond which hardened mild steel platens would not be suitable for forming due to hot deformation related issues.

The next challenge was to hold a high compression pressure of the heated platens for a required duration of time contrary to the existing design. Normally the ram up and ram down movements are hydraulically actuated through the oil pumped by the motor in the cylinder manifold block. With the existing design, for prolonged compression the ram down switch in the control unit needs to be operated manually keeping the motor running continuously as long as a high compression up to 120 Bars is needed. This is a tedious process when the operating pressures are higher as the motor coil may heat up and incur damages during sustained operations.

Hence it was proposed to hold the pressure created in the main cylinder by installing a piloted check valve which would arrest the hydraulic fluid flow from the main cylinder unless a ram up switch is pressed in the control unit. So, the ram down condition with high pressure acting on a platen can be maintained for a sustained duration and the part material being moulded by the platens will be under a precise compressive pressure at the desired temperature. A piloted check valve was installed in the hydraulic press. It was attached to the manifold block of the main cylinder. Figures 2 and 3 show the technical details of the manifold block and the installed check valve. The pressure lines shown in the Figure 4 allow the hydraulically actuated oil flow to the main cylinder and the relief valve releases the oil back to the reservoir tank. Both the pressure line and relief valve were connected through the piloted check valve. During the ram down operation the hydraulic oil from the reservoir is pumped into the main cylinder through the check valve by the motor and then it is turned off. At the same time the relief valve is closed thus maintaining the pressure as long as the ram up switch is ON. Once the compression moulding is completed the motor can be turned on again to allow a ram up and release the moulding pressure which would allow the oil to flow back to the reservoir through the piloted check valve. The maximum capacity of the press is 120 bars. The pressure can be increased gradually or through stages from the atmospheric value independent of the temperature settings. At the room temperature loading the pressure slightly drops from a high 120 bars by a few bars because the oil in the main cylinder is maintained at room temperature which would be low in partial pressure. This compels the use of the ram up switch manually to maintain the pressure constant. But at higher temperatures in the main cylinder this issue is not observed as the applied high pressure is stable due to the generation of partial pressure of the gas out of evaporation of oil. However, the loss of oil due to possible leaks and continuous evaporation are to be topped up periodically. The oil temperature gauge and the level indicators in the main tank assist in the monitoring and maintenance of these requirements. Thus, the existing press was upgraded for a high pressure high temperature compression moulding operation that facilitates multifaceted solutions in the manufacturing of zero defect parts.
**Figure 2.** The Manifold block in Blue

**Figure 3.** Check valve to maintain moulding pressure.

**Figure 4:** Block diagram of Hydraulic Press with Check valve
4. Fabrication of zero defect composite laminates

After successful installation of heated platens and check valve, the press was operated and checked for any leakages with and without loading. Leakage if any was successfully stopped through detection and repair. It was decided to fabricate a flat laminated composite plate made of fibre reinforced thermoplastic material of thickness 3mm. Kevlar -29 bidirectional fabric and polyethylene films were chosen as the moulding materials. The layup sequence followed was that of two layers of polyethylene film and one layer of Kevlar fabric in a sequence till a 3 mm thickness was moulded [6]. Initially the heater was turned on for an hour so as to reach the desired temperature of hot compaction of polyethylene [7][7]. Then readily cut, oriented and stacked Kevlar fabric and polyethylene sheets were placed between the platens and release films. A pressure of 100 bars was applied for 30 minutes by turning on the ram down switch in the control box and maintaining the pressure through the check valve operation. Then the sample was left to cool down in the platen at a reduced pressure until it reached room temperature. The fabricated sample was trimmed at the edges and after visual inspection it was checked for defects through an ultrasound non-destructive scanning technique applied to laminated composites [8].

Figure 5. Modified Press with piloted check valve
5. Results and discussion

The sample was inspected using Ultrasonic C scan. The scan parameters are given in Table 2 as follows:

| Scan parameters                  | Values |
|----------------------------------|--------|
| Probe type                       | Pulse echo[9] |
| Pulse type                       | Bipolar |
| Sampling frequency(MHz)          | 25     |
| Probe frequency(MHz)             | 2.3    |

The sound attenuation C- scan images obtained for the various laminate layers at specified depths are illustrated as follows:

![Figure 6](image-url)  
**Figure 6.** At a depth of 1.2mm for top.
Figure 7. At a depth of 1.8mm from top

Figure 8. At a depth of 2.0mm from top
Figure 6 to 9 show a depth profile of the sound attenuation plots at specified depths of the fabricated composite laminate. The scanned images are obtained by through the thickness scanning [10] of the specimen immersed in water which is used as a coupling fluid. The transducer runs perpendicular to the surface of the specimen. The ultrasonic sound reflected from the specimen layers is captured by the transducer. Based on the amplitude of the received sound energy the data is presented by an Automatic Data Acquisition (ADA) system integrated with the computer. The scan images at different layer depths show uniformity in the attenuation patterns. It is evident from the scanning results that the sample is virtually defect free through the layers and the attenuation patterns are acceptable and very minimal as evidenced through excellent bonding between the layers. No delaminations were observed that otherwise would have produced a characteristic attenuation pattern as seen in the blue-green and blue regions of the colour bar in the C Scan images. The colour bar on the right side of scan images is the scale for determining the defects in the specimen. Bright red colour at the bottom most part of the colour bar with zero mark is an indication of smooth transit of ultrasonic sound waves. In the bar, the colour changes from bright red to normal red, yellow, green, thick blue, light blue and finally to white depending on debonding, delaminations and the associated sound attenuation patterns. Thus, as seen from the C scan images this machine qualifies for use in the high pressure, high temperature moulding of ballistic grade parts and gadgets. As mentioned earlier, this is a multifunctional equipment which can also manufacture hot forged, stamped, blanked, diffusion bonded, moulded and hot compacted parts normally not manufactured through conventional compression moulding machines.

6. Capital investment and costing

The essence of this project is the cost savings at which zero defect products are achieved. A brief note on the capital investment costs will give clarity. The cost of existing unmodified press is about 15 lakhs and the cost of upgradation is about 3.5 lakhs. Hence, the total cost incurred for an upgraded high pressure high temperature compression moulding press is about 18.5 lakhs. The cost of a new custom
made high pressure press with an inbuilt check valve and heated platen unit is about 30 lakhs for the
temperature and pressure ranges specified here, in the market. Currently, the available compression
moulding presses in the market can fabricate parts only up to 300°C and 25 bars of pressure in the 10
tons capacity range. Thus at least about 65 % cost savings were achieved in the present upgradation
exercise, comparatively. As this equipment can be more than substitute for a composite fabrication
autoclave with similar capabilities, a costing comparison reveals that such an autoclave would cost a
minimum of Rs.70 Lakhs in the market. A technology transfer and commercial sale only would increase
the costs of the equipment upgraded here which is not the intention of the present exercise. The margin
of returns for a superior quality of products is hence very high and the goals of value engineering stand
achieved through industry partnerships

7. High end applications

Fabrication of products by the hot compaction method using upgraded hydraulic press with high
temperature and high pressure control is now a proven method for producing superior quality and zero
defect composite products. A wide variety of materials including fiber-metal composites [11], metal-
metal laminates[11], ballistic materials, thermoplastics [12], several thermosetting plastics and high
temperature advanced composites can be processed using this heated platen press for novel applications.

It is to be emphasised that the above said parts cannot be fabricated or manufactured even by advanced
additive manufacturing methods using the existing state of the art knowhow in deposition as compaction
and consolidation are still issues.

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