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Design and Development of Tooling and Production of GRP Liner Components

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Abstract: Glass Fibre Reinforced Plastic (GRP) moulding is a relatively new technology developed in recent years Tooling for fabrication of GRP components calls for a critical examination of the process, design and problems. This article presents the problems encountered and remedial measures suggested during the production of GRP (glass filled phenol formal dehyde) components. The requirement of high surface finish, homogeneous structures, high strength and close dimensional control was achieved by extensive experimentation. This study also presents the control of critical parameters such as temperature, pressure, curing time, charge pattern etc.

Key-Words: Glass filled reinforced plastic(GRP), Moulding tool, Cartridge heater, clearance, Pinch off edge, CAD/CAM

1 Introduction

Glass Fibre Reinforced Plastic (GRP) is very widely used material for production of components required for space and rocket application due to its ablative properties. Moulding of this material is a relatively new technology developed recently. Tooling for production of GRP components needs to meet stringent requirement of process and design. The reliability of the process leads to the reliability of product essential for aerospace applications.

In a sense, the tooling for GRP is no different from tooling for any other material. The designer gets from its tool precisely what he puts into it. If one needs a high quality product with a good surface finish, one must provide high quality tool with a good surface finish

During the developmental phase of R & D projects, the lot size being small, a highly productive tooling is required due to its high cost and high cycle time for production. This article highlights the simplifications made in order to get a cost effective tooling fabricated in a short lead time, although it may not be really suitable for mass production. Besides, it presents in detail the various design factors such as the method of mould heating, mould size, material, pressure applied to the mould, accuracy and surface finish of mould, type of pinch off edges, die and punch clearance, type of guide pins and method of part removal from the mould[1] .This article also presents the problems encountered and remedial measures suggested during the production of GRP (glass fibre phenol formal dehyde) components. The requirement of high surface finish, homogeneous structure, high strength and close dimensional control was achieved by extensive experimentation and control of critical parameters such as temperature, pressure, curing time, charge pattern, type of pinch off edge and others. Other design aspects like material, accuracy and ejection system have also been discussed. Incidentally the use of CAD and CAM is a recent addition to this field.

Types of Moulding process:
Mainly there are two types of moulding process:
a) Transfer moulding and b) compression moulding
Transfer moulding: Transfer moulding is normally done with preforms and for small batch, compression moulding is preferred.

2 Design Factors for moulding tools

In designing the metal moulds for the production of GRP products, the following points are to be considered.

i. Heating of Mould
ii. Size of Moulding Tool
iii. Moulding Tool material
iv. Moulding pressure
v. Required surface finish and accuracy of moulding and tool

vi. Clearance and pinch off edges
vii. Design and type of guide bushes and pillars
viii. Method of component ejection from the mould.

2.1 Heating of Mould

The total heat input depends upon the cup surface area of the component. In this moulding tool, the mould heating was carried out by cartridge heaters, though the other alternatives like band heaters and furnace heating could be used, but were not considered because of the configuration of tool and availability.

2.2 Moulding tool Material

Normally materials like aluminium, silicon, bronze and mild steel for small batch production and heat resisting steel alloys (tool steel) for large production are used. Mild steel was used for this tool in view of small production (proto type) required during development phase of the products.

2.3 Moulding Pressure

It is difficult to predict the actual moulding pressure during moulding. It is much more difficult to measure it accurately. A pressure of range between 140 to 300 kg / cm^2 is usually adequate to close the mould and to cause the fluid resin to be distributed throughout the entire mould area. However, when the resin is in fluid state, it resists mould pressure by moving into areas of lower pressure. By the time, the resin becomes semisolid or polymerized, the mould is closed and the impregnated component shape conforms to the space between the halves. Therefore, the only actual pressure exerted against the mould surface will be that of the resin entrapped by the pinch-off rings.

2.4 Dimensional Tolerances

The cost of making mould rises almost exponentially as dimensional tolerances are required to be held to progressively closer limits. Tool designer must, therefore, consider the actual application of mould component and real needs for close tolerances when specified for mould machining. In this case closer tolerances of the order of 40 microns were essential because of its fitment into closely toleranced component. The profile tolerances had to be maintained to avoid any gap between matting components.

2.5 Surface Finish

It is well known that the reinforced plastics reproduce the surface of the mould in which they are made. Any porosity in a mould leads to poor coverage or partial disappearance of many mould release agents, so that adhesion of moulded part to mould surface can occur. The best performance, therefore, is usually obtained from a well finished surface with minimum pitting or porosity. In the present case, the moulds were highly polished to a surface finish of 0.05 mm as mould was made of MS. The mould surfaces were free of porosity, scratches and under cuts.

2.6 Pinch-off edges

The point at which the two mould halves come together is known as "pinch-off" or "cut-off" edges. Essentially, however, this particular area of the tool is quite critical with respect to mould performance since its purpose is to trim off the excess glass extending beyond the required surface of the moulded component. The pinch-off edge also seals the mould after closing, so that resin does not escape during distribution and cure. It is advisable to incorporate a taper of about one angular degree to allow for possible misalignment of the mould halves during closing. The above aspects have been taken care of in our jobs. Different types of pinch-off edge, normally adopted shown in Fig 1 [2].

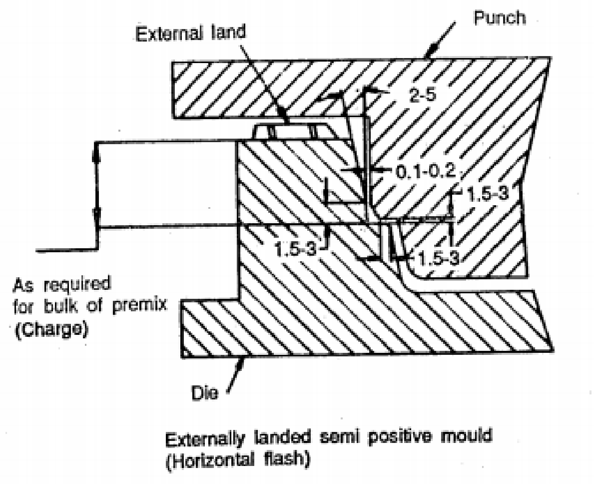

Figure 1: Pinch off edge

2.7 End Clearance

As stated above, the pinch-off edges trim off excess glass and confine the resin to the mold cavity. It is necessary that a shearing action results while still allowing for slight mould "breathing" with escape of entrapped air and small amount of excess resin. If insufficient clearance is provided, the mould will be sealed, resin will not move properly and the press will not come down against the stops. This will result in parts that are too thick, with improper resin distribution. If the clearance between pinch-off edge is too great the glass shearing action does not take place and a crushing effect is seen. We have used the end clearance between 0.1-0.2 mm depending on the diameter of the cavity.

2.8 Guide Bushes and Pillars

For proper movement and aligning of the mould in the final closing portion of their travel, guide pins are incorporated into the design. It has been found that pins of relatively large size, spaced adequate distances away from the cut-off rings, will provide the necessary alignment without breakage or fouling. Generally, the guide pillars of circular cross-section are used. It has been found that placement of the pins on mould diagonals with mutually orthogonal pin center line, aids in maintaining good tool alignment, even when differential temperature exists in the halves. This tool consists of bushes and pillars (Fig 2) placed diagonally opposite numbering. The material 40 Ni2 Crl Mo28 IS: 1570 for guide pillars and guide bushes was used [3].

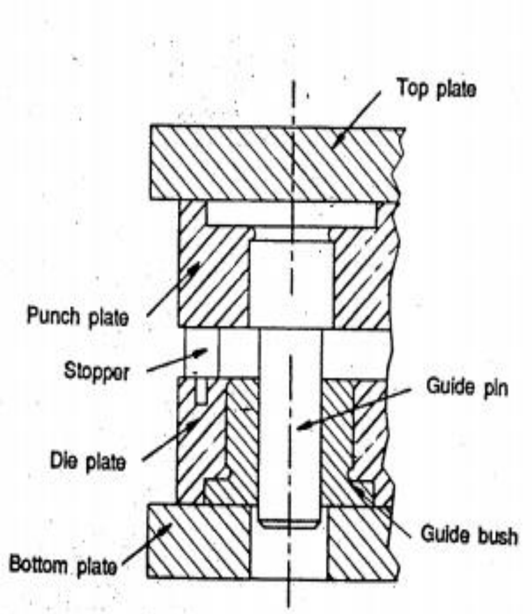

Figure 2: Guide pillar and bush assembly

2.9 Stoppers

Stoppers help to avoid damage or breakage of tool towards the end of closing. They also determine the correct thickness of the component. Stopper height is decided depending upon the flash requirement which in turn, helps in ejecting the component.

Stoppers are mainly of two types:

a) Disc or plain stopper, and
b) Stepped stopper as shown in Fig 3.

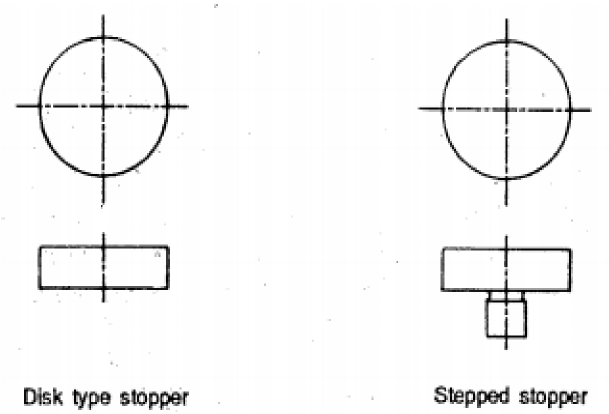

Figure 3: Stopper

3 Method of Part Ejection

In general, the use of ejector pins in moulds for reinforced plastics is to be avoided. The viscosity and flow of polyester resins is such that they will penetrate even the hairline clearance surrounding ejector pins. When the resin polymerises, the pin is frozen in place and its desired action is prevented. Normally, the taper in moulded parts is such that the removal is not difficult. While in this case, no ejector is used as the component is sticking with the punch due to shrinkage and is easy to remove.

3.1 Process Control Parameters

By considering the properties offered by resin moulding compound it should be understood that these properties can be achieved only if process controls are adhered correctly. Once an acceptable moulding is produced and performance tested, rigid controls on the process must be maintained to ensure repeatability.

These process control parameters are mainly

a) Moulding and curing temperatures and curing time
b) Moulding pressure
c) Weight of raw-material within 5% extra
d) Closing speed
e) Charge pattern and placement and
f) Use of cooling fixture.

Moulding temperature and cure time - Resin moulding components can be cured at temperature in excess of 120^o C. It is recommended that for most applications the temperature range should be between 130^o - 150^o C. An accurate temperature guide cannot be given since components involving deep draw and complicated mouldings required high flow which in turn is possible with low temperature. For simple shape or components with uniform wall thickness, fast cycling is possible with higher temperature of 155^o-165^o C. Thick section mouldings are cured for longer time with lower temperatures from 120^o-135^o C.

It is a normal practice to maintain both punch and die at the same temperature, but in some cases small temperature difference between the male and female tool may be employed. In this case the part will be retained on that half of the tool which is at the lowest temperature. The cure time will vary with the shape and thickness of the parts (moulded). As per literature it was suggested to provide 1 min/1 mm thickness.

3.2 Moulding pressure

Since in resin moulding compounds, no volatiles are liberated, low moulding pressures can be applied as compared to PVC moulding / transfer moulding. For simple shapes the lower pressures of the order of 150-200 kg/cm^2 are more than sufficient. However, for complicated shapes with deep ribs higher pressures of the order of 200-300 kg/cm^2 are to be applied. For low shrinkage grades it is preferable to use higher moulding pressures for good surface profile.

3.3 Closing speeds

Because resin moulding components are fast curing, fast operating presses are required. Any delay during press closure can result some precure of the material which is in contact with the hot mould surface and this restrict the flow of the material and results in short or over size mouldings. The last 10 mm of mould should be closed within 10-15 seconds depending on shape and size of the component. For deep draw components it is necessary to use higher closing times to ensure the materials flow slowly, uniformly to various sections of the mould. At higher speeds of closing there is always a possibility of glass and resin being separated.

3.4 Charge Pattern and Placement

The charge pattern is the most important factor in determining performance. It must be remembered that the development of a charge pattern has more importance than just filling out the part. It is the prime contributor in establishing the glass orientation in the part being moulded and hence its performance.

The size of the charge should generally cover 60-80% of mould surface. If the size of the charge is too small excessive orientation of fibres would occur in the direction of flow thereby increasing the strength in the direction of flow and reducing the strength drastically in the direction perpendicular to flow. (This would also cause weak points known as weld or knit lines).

If the charge is too large this could cause mechanically very poor mouldings since the fibres buckle in a form similar to a sinusoidal wave's shape thereby reducing the strength to a very small fraction of the expected strength.

Charges must be built in a pyramid shape which helps the charge to force the air out of the mould as it flows to the extremities. The same method was followed in our mouldings.

It is very necessary to establish a good charge pattern initially by trial and error and test the components to find the best possible mechanical properties achievable. Once the charge pattern is established care should be taken of placing the charge as close as possible on the same areas of mould to ensure repeatability.

4 Use of CAD/CAM in Design and Fabrication of Moulding Tools

The production of a wide variety of FRP components needs a number of moulding tools. This is the area where CAD-CAM has brought a revolutionary change in production engineering and best results have been achieved by integrating CAD and CAM into a single system [4].

First the product surfaces are defined by the 3D Model and stored for further use. Then the basic parameters (discussed earlier) of the compression moulding tool are arrived at by mould cavity and plastic flow studies. The detailed design of the tool is now made by using a 2D drafting system. For this, there are a number of computer aided drafting systems (softwares) available in the market.

Though CAD facility is available for the design of moulding tools for GRP components, the experience and knowledge of GRP moulding characteristics are still necessary to produce the component tool design. A modification may be required to be carried out on the tool or product before finalizing the tool design. Such modifications are to accommodate for shrinkage of the plastic components, material thickness, surface geometry, pressure, etc.

With the help of a surface model, the designer will be able to adjust these requirements. The model can be analyzed for such factors as suitability of thickness, strength, and weight. Various components used in tooling requires critical functional checks like clearance between punch and die, interference fit between the guide pillars and guide bushes (figure 5&6), and differential thermal expansion of a number of components in the moulding tools are to be visualized before their production. Once the selection of hardware is completed, the designer needs to see the complete design, so that he can inspect, refine and develop it as necessary, which is done by using the standard graphic editing facilities.

The display of colour picture on the computer screen (monitor) can enhance the communication by calling attention to specific data, by making information more comprehensive and appealing. It enables the section of different colours for each part with assembly or each component in the layout. This helps in distinguishing the components which are near to each other.

The most significant advantage of a CAD system is the creation of a data base. In the first stage, the component, geometry, its dimensions or note only will be required to be defined once, and thereafter it can be transferred from one layout to other, from layout to analysis, from layout to detail, from detail to machine tool path, and from one item to the next. The tool library for standard components like nuts, bolts, washers, dowels, screws and clamps, guide pillars, bushes, stopper pins and ejectors is also a constituent of data base. These components can be retrieved from the library and fitted at the required place in assembly of moulding tools.

Computer Aided Process Planning (CAPP) is an important intermediate stage between CAD and CAM. A process planning sheet contains the information about component routings, manufacturing process, machine tools, cutting tools, process parameters etc. It dictates directly the cost, quality and the rate of production in a manufacturing set-up. The computer aided tool engineering (CATE) is based on the maximum reuse of data, and it is essential that CNC machining is employed wherever possible. This has become more feasible and tool engineers are aware of the utility of CAM, and most of the modern tool rooms have CNC capacity.

Tool assembly is shown in Fig 4 to Fig 7.

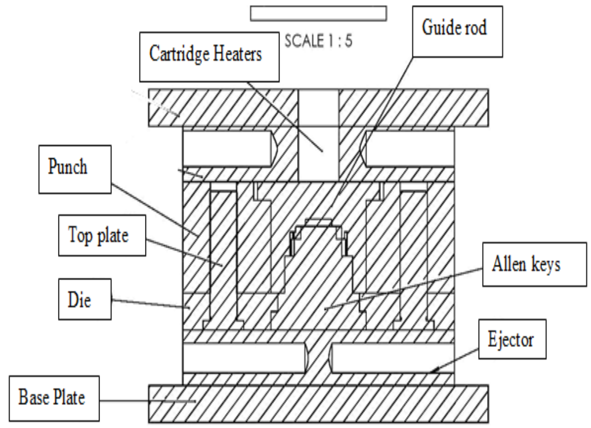

Figure 4: Moulding Tool

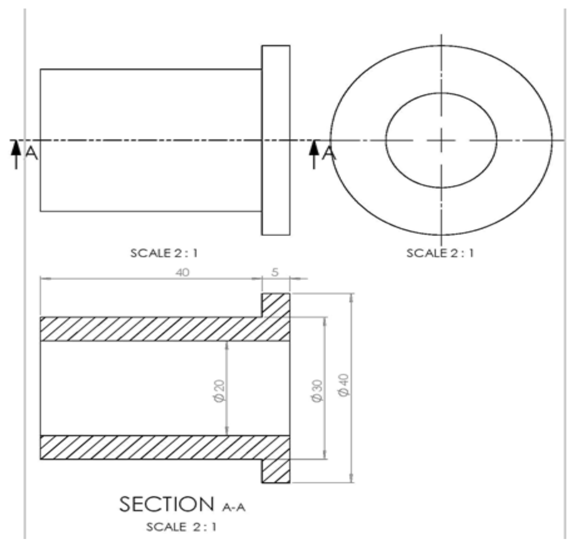

Figure 5: Guide Bush

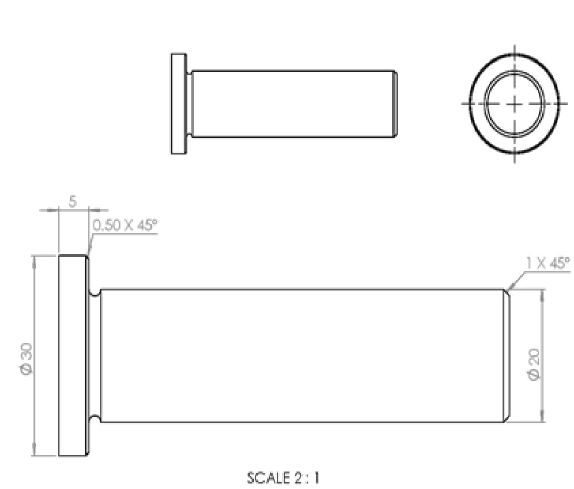

Figure 6: Guide Pillar

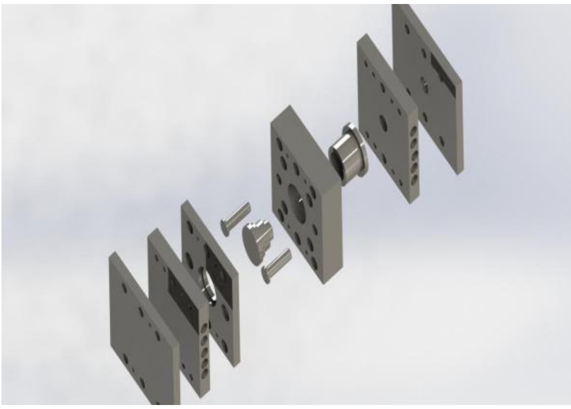

Figure 7: Exploded view of Moulding Tool

After fabricating the individual components, the tools are assembled and tried out. The fabricated parts are then dimensionally inspected and deviations are recorded. Taking the inspection data, the die and punch profiles are corrected.

5 Fault Diagnosis and Remedies

Following is the study made during the moulding of FRP components, the defects encountered, cause established and possible cures attempted. The probable causes and remedies not encountered are also given for guide lines in Table 1.

TABLE 1
PROBABLE CAUSES AND REMEDIES

Fault	Causes	Possible Cure
Shrinkage marks	Uneven shrainkage of Moulding during cure	Increases charge weight Use lower shrinkage grade of Charge.
Cracks	Excessive stressing Fibre orientation Excessive exotherm Thick sections Flow or weld lines (weak points caused Due to meeting of two Flow fronts near Jellation)	Check ejectors (for proper ejection) Adjust charge size and location for minimum orientation and low. Redesign to minimize thick sections Adjust charge location to minimize flow around tool obstructions. Add heavier section to area below tool restriction to disperse weld lines. Pinch-off clearance must be uniform
Distortion	Fibre orientation Excessive warpage Excessive Shrinkages Handling Under cure	Adjust charge size for minimum flow Use cooling fixture Change grade of charge. Examine ejector system for correct Operation Examine operator's handling Methods Eliminate any stress conditions During cooling or finishing Increase the cure cycle. Increase temperature
Blistering	Trapped air or gas Between the charge	Reduce charge dimensions Pyramid type charge pattern Reduce temperature
Porosity	Material pressure too low Worn shear edges of tool	Increase charge weight Increase Moulding pressure Increase punch temperature or reduce cavity temperature. Repair the tools.
Porosity (in or Near thick section)	Air entrapment or due to exothermic action	Increase charge in heavy areas Relocate charge to sweep air out of ribs, etc. Reduce charge area Reduce temperature
Shorts	Insufficient charge weight Insufficient charge flow	Increase charge weight Increase charge size, reduce

Fault	Causes	Possible Cure
	Improper charge location Charge storage life expired	temperature Relocate charge to non-fill area. Use fresh charge
Poor release	Mould temperature too low / uneven Poor mould surface Improper ejector system Tool Contamination Shrinkage properties of charge	Raise temperature, equalise Check for undercuts, porous Areas, rough machining in the Tool. Use external release agent o Mould Check for level ejection action Add ejectors in rib areas to Prevent keying Clean tool surfaces and coat with suitable release agent. Use alternate grade of charge with different shrinkage Machine undercuts in vertical Tool surface to hold parts on to Desired half. Check draft angles on vertical Surfaces.
Poor gloss	Under cure, moulding Pressure too low, compression of air, styrene vapour within tool cavity causes mixture to ignite and blacken moulding	Increase time and temperature, increase pressure. Arrange charge so that air is totally expelled as material flows or provide venting.

6 Conclusion

It has been experienced that moulding of GRP components is a skill and experience of the shop or an art rather than mere theoretical know how. Though ample technical literature is available, it provides only guidelines. Nonetheless, good quality components can be produced by considering the design factors and controlling the process parameters discussed in this article. The quality of the components is to be achieved by trials and based on previous experience on the same type of materials, moulds, and components. The components manufactured by these tools have met all the quality, strength, and functional requirements. The rejection rate was well below one percent.

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