FPCM-9 (2008)
The 9th International Conference on Flow Processes in Composite Materials
Montréal (Québec), Canada
8 ~ 10 July 2008

THE NOBLE ART OF CLOSED MOULD PRODUCTION

Alan Harper [1, 2]

[1] *RTM Technology, Magnum Venus Plastech*
[2] *Corresponding author's Email: Rtmharper@aol.com*

SUMMARY: Liquid composite moulding with or without the addition of vacuum has now become a proven method of moulding composite parts. Specialising in this field for over three decades, we now realise good production standards being achieved and expectations on quality of part unquestioned. The major process developer has been Light RTM, a process which has found much advance in the general moulding community world-wide. Not commonly realised however is the increasing use of the process for high fibre volume fraction structural parts which traditionally are made by film infusion and pre preg autoclave routes.

The paper provides examples of successful general LRTM application and leads towards the more advanced composite sector application. Details of temperature controlled economic composite tooling is described which is applied to form engineered surfaces to both sides of the part. Novel strategies for speeding up mould fill times even with 55% fibre volume ratios are discussed added to which precision control of resin flow rates and thus in mould pressures are discussed. It is also shown that with precision automatic mould fill equipment currently available, optimised production is easily achievable. Without doubt closed mould liquid composite moulding techniques have now come of age and bring a narrowing of the technical gap between aerospace sectors and the general frp sectors.

INTRODUCTION

There is no doubt that the Light RTM (LRTM) moulding process is now well established throughout the composites world as a primary manufacturing closed mould process and now leads all other closed mould processes as the preferred route to manufacture in the general composites manufacturing community. Introduced towards the end of the last century, LRTM has proved to be a very versatile process both in adapting to small and very large mouldings and is equally applicable in low and high fibre volume fraction composite parts.

Objective

The objective of this paper is to provide a source of information on the latest technology focusing on LRTM manufacturing. Examples of early technology thinking are now superceded by well proven and widely accepted advances which are described strongly arguing the case for further investment in continued advancements to meet today's ever increasing awareness and demand for cleaner moulding systems

LRTM Process

The basic accepted process of LRTM utilizes a light weight matched composite mould set into which dry fibre reinforcement is placed and clamped under vacuum. Catalyzed resin is then injected at low pressure and characteristically follows an injection flow path around the product cavity and converges to a central vacuum vent point.

LRTM Mould Design

The heart of any closed mould moulding operation is naturally the mould design itself and, from the early days of development, LRTM offered a low cost economic alternative to the then only equivalent contender, high pressure RTM moulds.

LRTM has always been attractive due to its only need for relatively light weight vacuum mould construction to achieve excellent production service life and product quality. Thus the use of atmospheric pressure to provide all the clamping force needed to hold the mould closed and provide a degree of energy to aid resin impregnation of the fibre pack became the main attraction to the process

The requirement for secure seals to prevent loss of vacuum and contain resin within the mould cavity led, at the outset, to many variations of mould seal configurations and design styles.

There was a strongly held view in the early days that the bigger the mould flange width, a corresponding greater flange closing force was obtained and thus greater clamping security. Whilst this view is true, today a standard flange width of no more than 130 mm has proven to be all that is necessary to provide all the clamping force required, regardless of the mould size.

Again early mould flange vacuum capacities where considered to be best if they included a large dome chamber between the two seals to increase vacuum capacity. This philosophy required that much additional counter mould shaping and profiling was carried out to provide this large additional chamber shape. Today a far simpler mould flange parallel gap of no more than 1 mm is built into the matched mould flange and provides the entire clamping vacuum force needed. It is clear that only the plan area and not the capacity which dictates the necessary clamping force. This approach also means less evacuation is needed to bring the mould to a fully closed position. The result of these modern standards is that lower mould building costs and lower energy requirements are provided.

There has always been a need for two mould seals in LRTM. One seal (primary resin seal) is positioned as close as possible to the mould cavity and the other at the mould outer edge (secondary vacuum seal). Fig. 1 illustrates typical standard seal sections commonly used today.

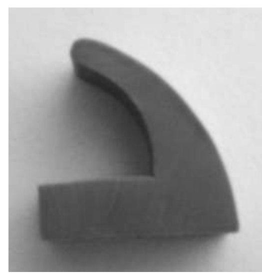
Little change to the outer secondary seal design has taken place over the years of the developing LRTM technology. And it is still common to use a soft compliant, lip seal profile (wing seal). However many designs and styles exist for the inner primary seal.

Initially a solid small silicon seal profile (mushroom profile design) was standard, which provided reasonably good service life however it did suffer from poor sealing efficiency over complex flange profiles and has become used only for simple flat, single plane flange designs. The need for a more reliable primary seal saw the introduction of the, now common, larger 12 x 14 mm rounded nose seal. This has become available in solid silicon to hollow silicon section styles. The latter has a feature in that the hollow seal profile may be inflated and deflated and is thus described as a dynamic seal. This seal internal pressure control feature provides far better seal efficiency. The possibility to pressurize the seal has also led to it being used to aid the mould opening, after part cure, as when the mould vacuum clamp force is removed the inflated seal pressure lifts the two mould faces evenly apart aiding initial mould opening action and release. This style of initial mould opening has been termed “pneumatic wedge action”

Dynamic seal

Mushroom seal

Wing seal neoprene



Wing seal Silicone

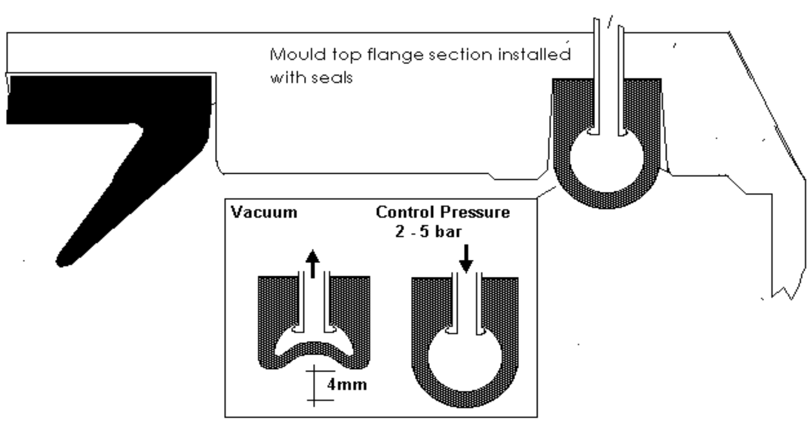


Fig 1 Examples of primary and secondary seal cross section styles and dynamic seal action.

Mould Inserts

To achieve the necessary vacuum and resin management connections to the LRTM closed mould a means of pipe attachment needs to be considered. Thought by many to be a simple task led to as many variations of insert attachments as there were companies applying the process and thus there was no standardization. Demand for professional fittings and inserts led to a degree of standardization becoming commercially available lead by UK company Plastech TT Ltd in 2001. Inserts for flange vacuum connection through to Catchpot and injection fittings where introduced and copied by the whole supply industry until 2007.

In the latter part of that year a new universal insert was introduced and featured compatibility with previous catchpots and injection fittings but included a new locking clip proprietary design.

One simple design metal insert common to ALL the needs of the various connection styles became available and provided a universal standard for the industry. For example whether a 10mm pipe is used or an automatic injection valve to connect the injection machine to the mould, the same mould insert is applicable. The experience of many years application indicated that double O ring seals and simple safety locking mechanisms were required for security of mould connections and these features are present in the new standard. Fig. 2 illustrates the universal insert application range.

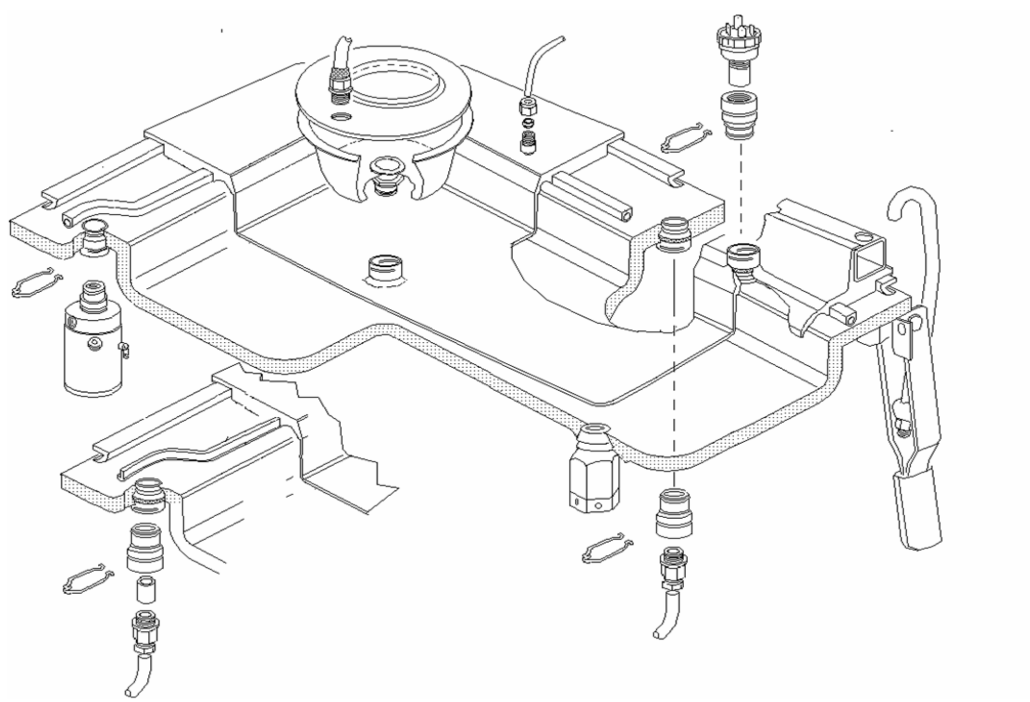


Fig. 2 LRTM mould cross-section illustrating the universal insert application.

Mould Clamping

To achieve initial clamping of LRTM moulds so that the secondary seal engages and thus enables the vacuum to take over and fully close and clamp shut the mould was, on many early mould designs provided with no means to do this other than manual pressure or the inefficient use of manually attached “G” clamps as clamping aids. Even today LRTM moulding shops have not always approached this problem to solve it with an efficient technical solution.

The common standard now employed has focused on the use of simple latch clamps as illustrated in Fig. 3. These are simply used to apply sufficient initial clamping force onto the dry fibre pack in order that the outer mould vacuum seal engages allowing vacuum to take over and fully clamp the mould. Another approach to this initial clamping solution has been to design into the mould edge an extension of the flange in the near vertical plane (in line with the mould draft axis). A second edge lip seal is installed in this area which allows vacuum engagement and thus mould closing assistance at 50mm open position. This principle was introduced in the very early days of VARI (Vacuum Assisted Resin Injection) circa 1980 however it has not been so popular more recently as it does involve much more pattern edge work and corresponding mould build detail. It is best applied to mould designs which have a simple single plane edge similar to boat hulls and deck designs.

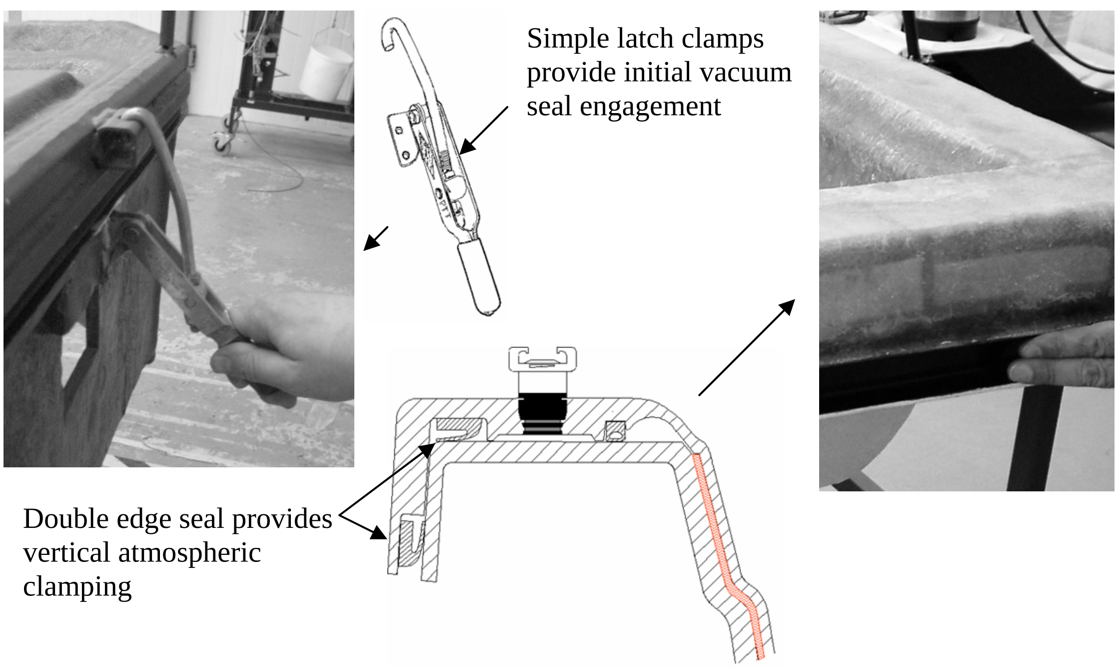


Fig. 3 Toggle clamping or vertical flange design to aid mould initial closing.

Methods of Injection and Edge Wastage

Common to the first LRTM mould until the present time the injection of the resin has always been from the periphery to centre. However the “gate” for resin feed around the periphery of the mould has developed over the years. Formerly a 20 mm wide 4 mm deep resin rich feed channel was commonly designed into the edge of the mould. From here the resin entered the mould cavity without any restriction.

Nowadays it is common to provide a bigger flow channel around the mould cavity periphery and feed the resin into the cavity through a restricted gap of only 0.5 to1 mm. The reason for the larger flow channel has been a result of the need for quicker fill and easier post trimming of the part. The new standard is now a 20 mm by 10mm dome shape fed channel as illustrated. For moulds less than a 4 m peripheral flow length a smaller cross section is available. Both sections are available as reusable silicon section profiles to aid speedier composite mould building as calibration profiles in the mould build stage.

The gap between resin feed and mould cavity being reduced to 1 mm or less has more recently provided a means of moulding more economic net shape mouldings whereby the product edge finishes at the 1mm flash point. This requires that the mould must be loaded with the dry fibre pack accurately, but it has been found more easy to do so than have a full thickness flash (over mould waste zone) which is equally necessary to be accurate when trimming the part. The new net shape style approach results in a faster post trimming operation, less dust, less wastage and far more economic .

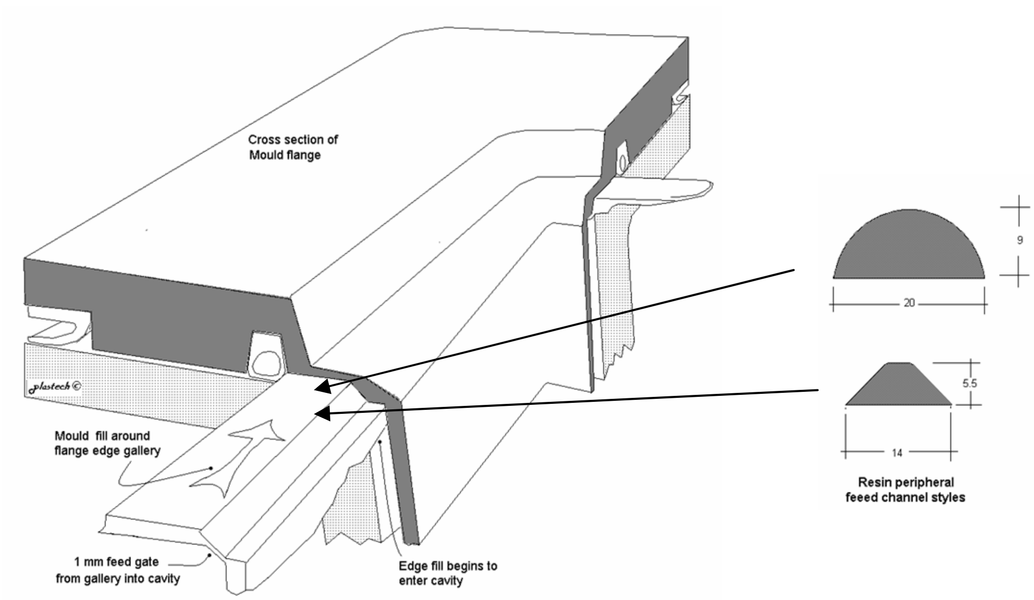


Fig. 4 Resin feed flow channel and edge detail present day options shown on right.

Fig. 5 below shows a typical large truck hood with moulded net shape. Moulded edge thickness 7 mm requires no post trimming.

Fig. 5 Truck hood moulded net size.

New Central Resin Keyhole Feed

It has already been emphasized that LRTM employs peripheral resin feed with central vacuum flow convergent path however there is merit in reversing this flow philosophy for certain high aspect ratio shaped parts. Consider a moulding having a length of 3 m, but with only a width of 0.5 m as illustrated in Fig. 5. The plan view of the mould is shown in four views. The first two left hand views are typical resin flow from edge to centre whereas the last two RH views are from centre to edge flow.

In the first it can be seen clearly that the chances of the resin meeting simultaneously and in a controlled manner at the centre are not high and as a consequence, there appear central trap offs where air voids will remain and need extra venting. Experience has shown that peripheral fill with moulds, of this typical geometry, are difficult to fill reliably without multiple central vacuum vent points to reduce the probability of spurious trap off zones.

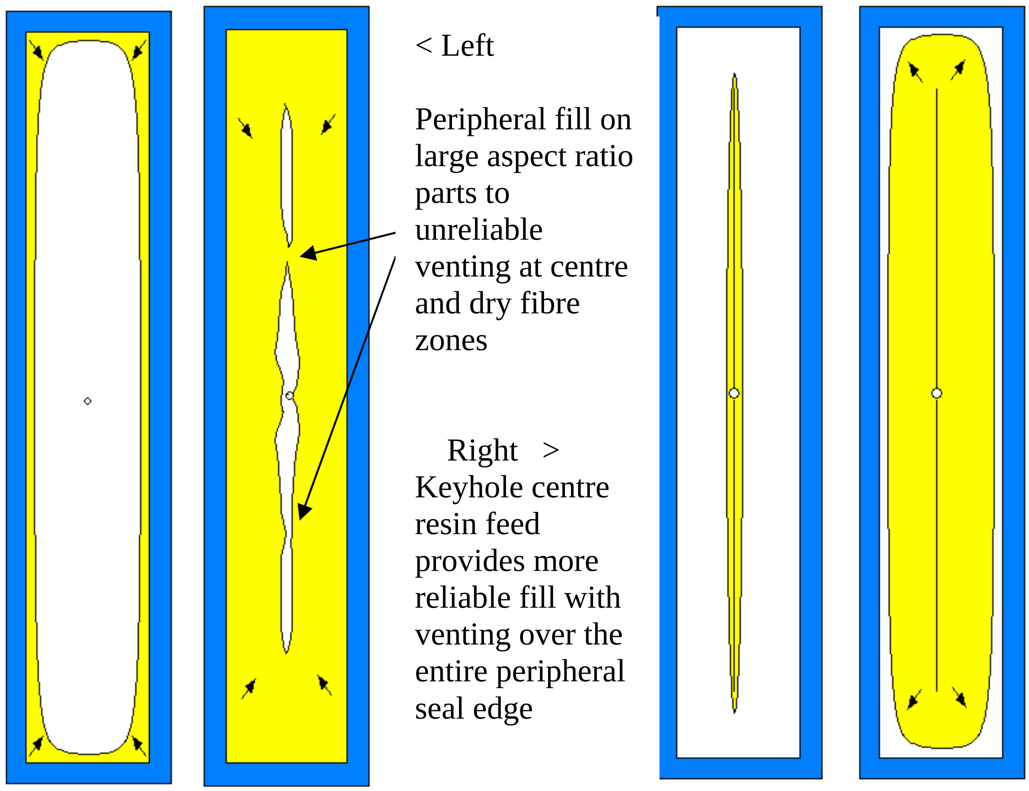
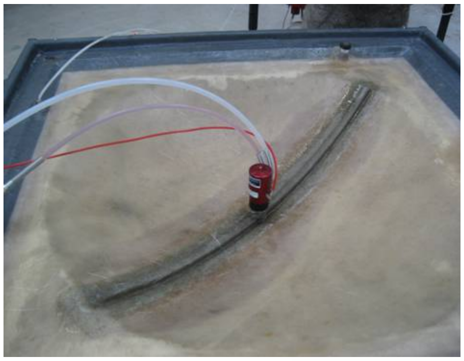


Fig. 6

The alternative keyhole central positioned resin feed gate provides a significantly lower risk of unreliable and incomplete mould fill as the remaining voids are presented with a much greater chance of venting through the entire mould edge primary seal. This seal, although effective to seal resin, can be made to allow free passage of air and thus vent the resin as it fills the cavity.

The introduction of keyhole injection now offers an alternative to film injection of large turbine blades in that the higher fibre volume fractions shorten the maximum flow lengths due to lower permeability of the dense fibre pack. A series of the keyhole flow channels, strategically positioned in the counter mould, can radiate lengthways like the veins in a leaf and give predictable flow speeds and successful fills even for product lengths greater than 50 m. The obvious advantages of LRTM over film infusion is that all the tooling is reusable and there are no consumables of tacky tape, films, peel ply and feed pipes and under film channels.

It was carefully researched and presented in a 2006 paper (1) that LRTM proved to be more economic and considerably less wasteful than Film infusion if more than a production of 17 -20 parts were envisaged.



Keyhole resin flow section shown in operation. Resin enters cavity through 1mm slot in silicon feed profile

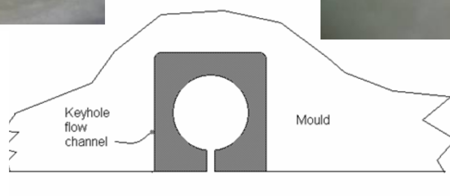


Fig. 7

Mould open, leaves keyhole and cured resin feed to be snapped off moulding rear face

Mould Temperature Control

The need for epoxy and phenolic moulding by the LRTM route has proven to be no less difficult than the use of ester based matrix as long as the moulds are temperature controlled. As with RTM composite moulds, LRTM versions can equally be designed to include either close to surface in mould electrical heating or liquid temperature heating and cooling systems. Recirculating water is more common and provides ideal temperature conditions for the current range of two component epoxy injection grade resin systems.

The methods and techniques to include composite in mould temperature control are now standard and are always included in our international courses for mould building.

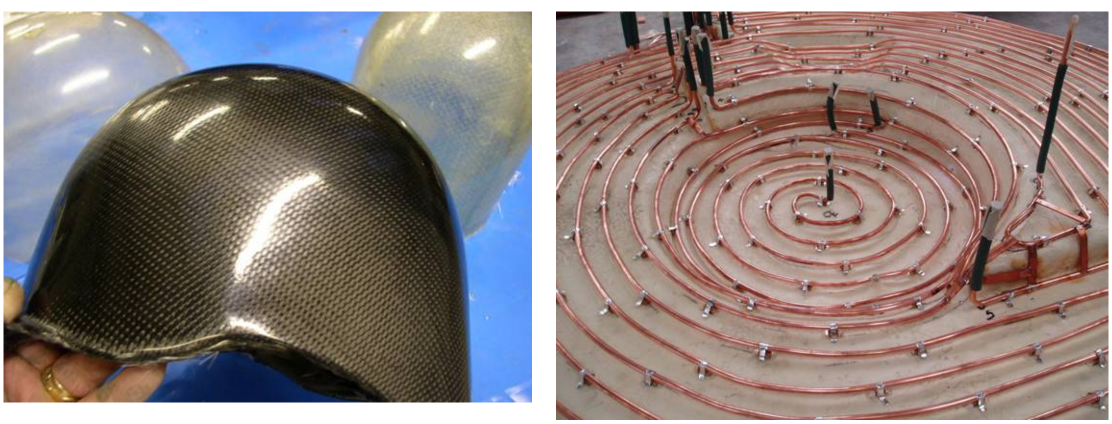


Fig. 8 (left) Carbon/epoxy helmet moulding produced from water temperature controlled mould; (right) series of copper temperature control pipes being installed on the rear face of a composite LRTM production mould.

Machine to Mould Resin Delivery Connection

Considering how the resin is delivered to the mould, great improvement is now evident from the early days of wasted pipes and manual crimping, after mould fill, of the delivery pipe. This old system has been superceded with the pneumatic controlled injection valve mounted into the mould edge. A signal is provide from the meter mix injection machine to open this valve on command which consequently allows the free flow of mixed resin into the mould feed channel. On completion the valve automatically closes and is then flushed through with a high speed solvent and air mix. No pipes are consumed and no drips of resin are seen. Very low solvent volume is needed and the latest valve design allows over 1000 injections between services. This approach provides a very clean and secure operation. A typical injection valve "Turbo Autosprue" illustrated below is shown in cross section with its main flow operation stages.

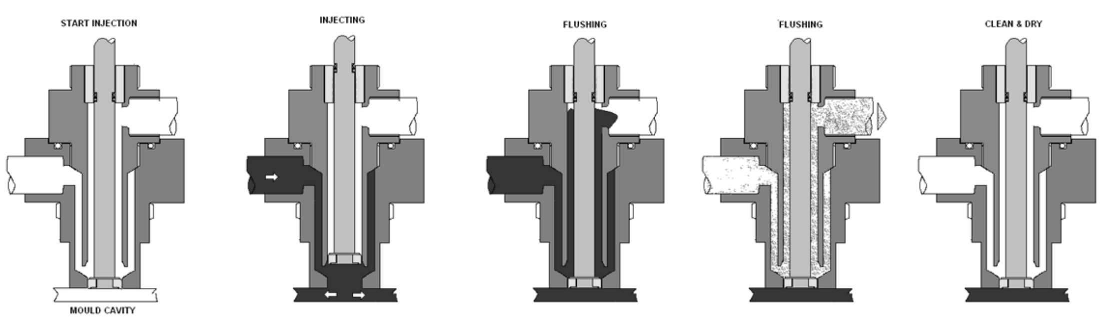


Fig. 9 Injection valve.

Operational stages from left to right,

1/ Start,
2/ Open & injection flow into mould,
3/ Closed,
4/ Commence flushing,
5/ Flushing complete – clean and dry

Injection Machine Low Pressure Control

One of the most significant technology improvements which has taken place for LRTM has been the various methods of controlling the meter mix machines output pressure so that it does not exceed the mould atmospheric clamping pressure. The industry has seen many attempts to do so with various degrees of success. The major concern is that any meter mix machine on the market today can easily overwhelm the vacuum clamped mould with excessive pressure leading to out of tolerance over thick parts, resin leakage, resin ingress into the vacuum system and at worst major distortions of the mould cavity and failures to mould good parts.

Many try to have the operator decide and control the machine output flow and thus control injection pressure as the mould fills. Unfortunately even if the machine is fitted with a nozzle pressure sensor it is not possible to definitively optimize and control mould fill precisely without further operator intervention during the filling stage. A pre determined mould fill volume counter is employed on most modern machine systems however this only controls the volume of resin and not the flow rate and pressure. The only guaranteed way to do this successfully is to employ a mould pressure sensor sensitive enough to read and control, at pressure levels, in the millibar range, the internal mould pressure. A sensor positioned in the actual mould flow channel, allows the mould to read the actual injection in-mould pressure precisely. (see Fig. 10) This pressure signal can be fed to the machine which is designed to respond automatically to reduce flow rates and thus safe pressures as the mould progressively fills. This provides total hands free operation and gives sufficient confidence to the operator to leave the mould automatically inject safely by itself.

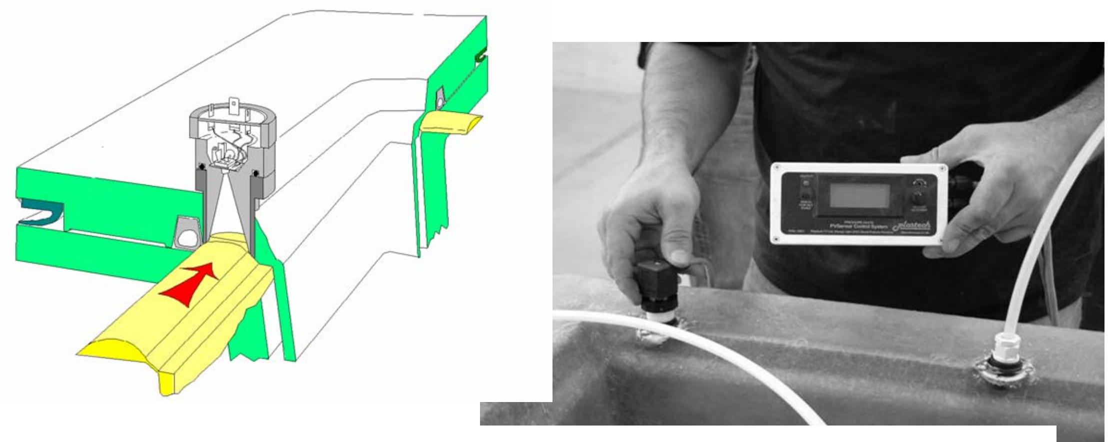


Fig. 10 Mould pressure sensor mounted in the flow channel provides safe automatic mould fill.

As an example, some producers have moulds which need 300 Kg or more of resin to fill and which may take more than 50 minutes to do so. In these and smaller mould fill circumstances the in-mould pressure feedback system requires no operator intervention.

There has been, and still exists today, a common misconception that a machine nozzle pressure is the same as the pressure inside the mould. This is not true. Considering that there is always a length of pipe and fittings between the machine nozzle and the mould internal resin feed channel between which a pressure drop is created during mould fill then the pressure at the machine nozzle will always be higher than that of the mould. This pressure drop is dependant on flow. The higher the flow, the larger the pressure drop.

If, for example a mould fill rate of 4 kg/min is set, the pressure at the machine nozzle could be as high as 2 bars. Given that the LRTM mould will only accept much lower pressures, below or at atmospheric pressures without distortion i.e., zero bar it is apparent that maintaining the machine potential feed pressure at 2 bars is going to lead to over pressurizing and distorting the mould. In these circumstances it is necessary that the operator is on hand to constantly re program the machine speed as the mould progressively fills and the back pressure correspondingly increases.

The operator’s adjustments can only be made through experience as the machine nozzle pressure is not what is needed to be controlled but the pressure <u>inside</u> the mould. If a reading of mould pressure is available then the operator would know exactly the safe pressure level to control the machine output. This requirement has been addressed by the development and introduction of a robust purpose built pressure sensor to read the actual internal mould pressure. It is also a very useful vacuum and resin leak indicator and has been welcomed by the industry as taking away any guess work to manage the safe rates of mould fill.

Further Machine Control Sophistication

Standards are now reaching a pitch of fine refinement in the process control. This is no more so than the LRTM machine refinement feature. Machines are now available with sophisticated automatic heads with internal interlocks, Pre determining counters, intelligent resin gel and pump stall alarms, and more recently a pneumatic safe control of catalyst ratio to change the resin reactivity on the fly.

For polyester and Vinyl ester resins, the Catalyst ratio has traditionally been set at one level for the entire mould fill however development of a system to easily increase catalyst ratio as the mould progressively fills is now on the market. This degree of control sophistication was formally available on far higher priced PLC machine models but is now available at a much lower price.

In essence the breakthrough in price reduction has resulted in the use of safe geared air motor adjustment of the Catalyst ratio. An example of this is the MotoCat which has a miniature reversible air motor driven catalyst ratio adjuster. This can be remotely set and adjusted either manually through a manual switch or automatically using pneumatics or micro controller system.

The advantage of being able to adjust catalyst ratio “on the fly” is that the resin reactivity can be finely adjusted to match the mould fill time so that much greater daily productivity can be realised from the same mould. As the mould fills, the resin is given more catalyst resulting in correspondingly shorter gel times so that full gel and cure of the injection shot is reached much faster.

The system can be set to move catalyst in discrete steps corresponding to mould fill shot count. The use of an air motor provides safe machine mechanical movement which is essential for today’s more stringent legislation and concerns over power electricity present on chemical mixing machines.

Workshop Vacuum Systems

Traditionally the LRTM moulder has selected a vacuum pump from the market place and carried out the necessary installation of a full vacuum system within their workshop.

Many have used one high volume vacuum pump to provide the two vacuum levels required by LRTM and adjusted the different levels with a vacuum controller. Also there has been a trend to fit large vacuum tanks into the system. Further there had been few standards set in a method of routing all the vacuum pipes to each mould. Many used plastic drain pipes with solvent welded joints and a variety of non vacuum designed connectors.

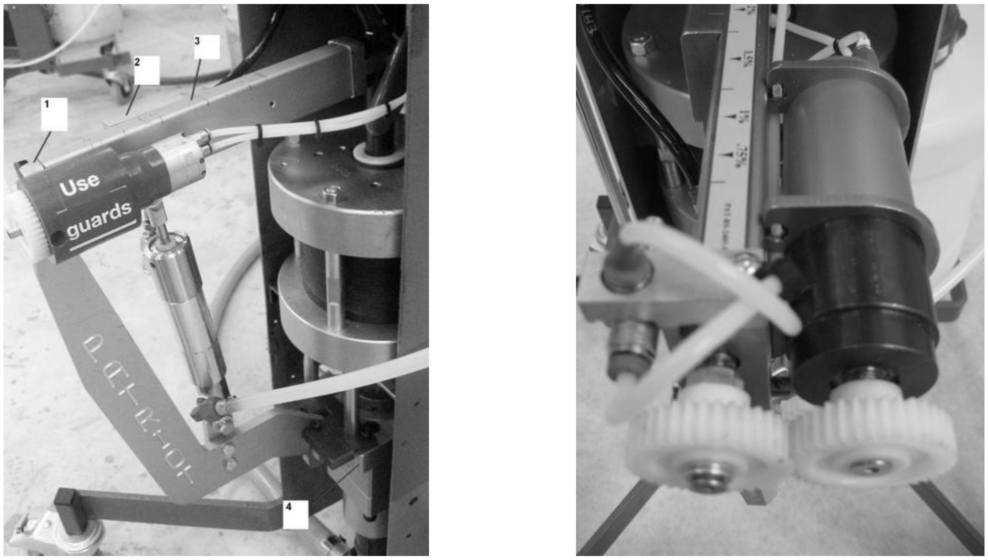


Fig. 11 MotoCat – safe air powered catalyst adjustment.

One issue with these early systems is that should the operator have a problem of achieving quick vacuum security on one mould it could adversely effect another already injected and filled mould or moulds down the line. One major problem exists with large vacuum reservoirs in that when vacuum is lost they take much longer to regain vacuum than a system without reservoirs. The traditional thermo vacuum forming of plastic sheet is commonly fitted with these types of systems but they are not necessarily appropriate to LRTM.

A simpler system developed whereby no large vacuum reservoir is employed and each mould station vacuum outlet is fitted with automatic security valves to protect the vacuum on all moulds regardless of the main line vacuum variations and periodic vacuum loss.

Vacuum pipe installations are now preferred to be clear flexible pipe with simple cut/push and seal connectors providing instant vacuum security at all temperatures. Each mould vacuum outlet have internal filters as earlier systems without notoriously sucked in fibre and over time partially blocked the non transparent rigid plastic pipes at joints and fittings. In these circumstances the user could not determine where these blockages were and thus the whole system has to be renewed at great cost.

The modern LRTM shop provides all vacuum and other service connections from above using swinging arm support over each moulding station thus leaving the production floor totally free of any incumbent pipes.

Mould Manipulation

In the days of heavy traditional RTM moulds there was a need for costly equally heavy duty industrial lifting systems. It has been observed that this traditional approach continued to be the mindset when manipulating LRTM moulds. Now it is realised that some LRTM moulds must require a 1 - 2 tons rated industrial lift system but many do not, even when they are as large as 10 m^2.

A trend has now focused away from this earlier philosophy by the introduction of much lower cost electric industrial hoists costing less than 200 USD each. They are certificated to handle up to 220 kg and are becoming widely used by the industry as they are fit for purpose and very economic to buy.

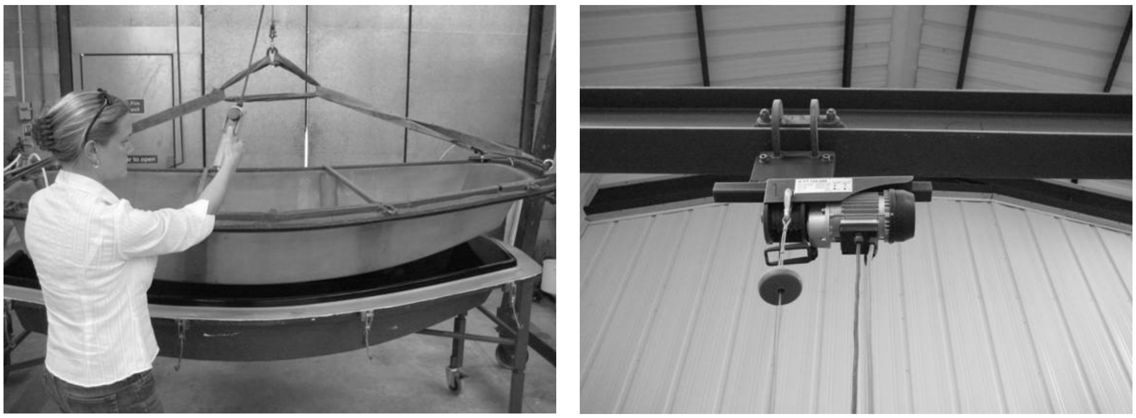


Fig 12 5 m^2 small boat mould being lifted with low cost industrial hoist.

CONCLUSIONS

There is no doubt that LRTM continues to be the most popular closed mould production method in the general FRP industry. The developments in the technology, witnessed over the last decade, demonstrate the investments made and the desire to bring this manufacturing route to a full zero emission and more professional level. Constantly witnessed are success stories in the trade press featuring even larger and more sophisticated LRTM parts.

The trend towards total automation is evident and has uplifted the quality of FRP mouldings away from the erstwhile hand lay or spray up quality which has not endeared the moulding customer to always choosing FRP parts for their products

REFERENCE

1. Cost Analysis Between Film Infusion and LRTM Production. Alan R Harper, *Plastech TT UK, Paper 38 Feipla Composite* 2006, Brazil