RIM PUR ON VACUUM FORMED FOILS: THE RIGHT CHOICE FOR AESTHETIC STRUCTURAL PARTS

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Abstract

An innovative solution is presented for the production of finished structural and aesthetical parts based on the synergies between the polyurethane foaming and the vacuum forming technologies. Reaction injection molded parts are created by back-foaming a PVC or PET film with standard or reinforced PU in a single working station. Cost reduction, low weight, excellent mechanical properties, and elimination of painting are driving the expansion of this process, making it extremely suitable for a wide range of industrial applications: external body parts for earthmovers and agricultural vehicles, household appliances, bathroom showers, television cabinets, etc.

Foaming Equipment

An innovative method for the co-injection of polyurethane formulations with a large variety of fillers has been developed and manufactured. The innovative aspect of this new technology lies in the excellent wetting of the fillers, which is achieved using a special co-injection concept within the mixing head chamber. This ensures a thorough wetting of the solid component and a homogeneous dispersion in the mixture, hence its name: InterWet (Internal Wetting).

This process is characterized by high mixing efficiency, excellent foaming performances, a homogenous blend and a significant production cost savings. Thin-walled molded parts reinforced with non-reactive fibers, or filled with low cost additives, can be produced with excellent chemical, physical and mechanical properties and characteristics.

The Cannon InterWet[1] technology was originally designed for the production of structural parts, reinforced with glass fibers as an alternative solution to the traditional production process based on glass mats or cut glass fiber pre-blended with polyol. More recently, however, its use has been successfully extended to very different industrial applications, combining the flexibility of the foaming process with the advantages of using a wide range of fillers.

Innovative Concept

The mixing technology is based on a specially modified Cannon FPL[2] high pressure mixing head. The head is well known for its proven efficiency, compact design and L-shaped geometry.

It is equipped with an appropriate feeder mounted on the upper section, which allows the use of a wide range of solid fillers: glass fibers, iron powder, and mineral fillers such as expanded calcium carbonate, marble granulate, barite, graphite, sand, etc.

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[1] Cannon Trademark name for InterWet (Internal Wetting)
[2] Cannon Trademark name for the patented FPL high pressure mixing head.

In a controlled processing sequence, the chemical components are injected at high pressure into the mixing chamber. At the same time, the solid component is metered and fed by the upper section of the head through a specially designed chopper hydraulically controlled and assisted by pressurized air. Each single step is monitored by a sophisticated control system to ensure constant process repeatability and component ratios.

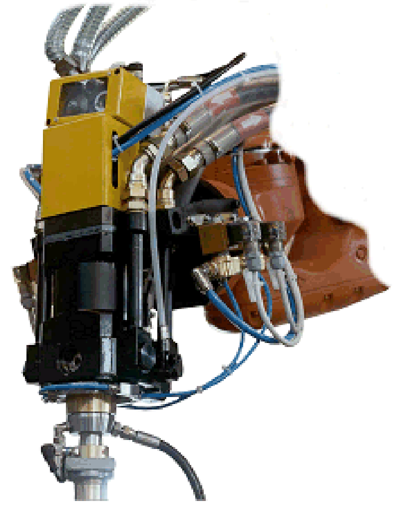

Figure 1. FPL Mixing Head Modified for Interwet

The innovative concept introduced by the InterWet permits the solid component to meet the liquid formulation just in front of the mixing chamber in order to facilitate a synchronized and instantaneous internal mixing of both, followed by injection of the final blend into the mold. This means that the kinetic energy generated from the turbulence of pressurized liquids is used to wet the solid component thoroughly, guaranteeing a homogeneous mix and efficient filler dispersion.

By means of a specially developed pneumatic deflector-device, mounted at the outlet of the mixing head, a superior quality and optimum blend lay down has been achieved. This excellent distribution of the mixture can be important when dealing with complex mold geometries. When the pouring phase is ended, an air flush cleans out any residual material from inside the filler-feeding duct, avoiding clogging problems during successive shots.

Technological Advantages

InterWet technology offers significant technological advantages and it is recognized worldwide as a successful, proven alternative production system, which is:

- characterized by high reliability as a result of our innovative mixing concept (patented), which allows use of abrasive fillers without affecting the life of the mixing head.

- equipped with a FPL high pressure mixing head compactly designed for reduced size and weight, thus it does not require heavy-duty pouring robots for handling and for the quick lay down of fast-reacting blends on large, open molds.

Figure 2. Finished Part on Upper Half and Interwet Laydown on Lower Half

- fully automated and controlled by special safety devices for monitoring every single production step (filler feeding, fiberglass cutting, co-injection and mixing phases), to maintain optimum foam homogeneity and quality.

- not only limited to long fiber injection but also designed to ensure a flexible use of more than one type of additional components. Depending on specific customer requirements, the mixhead can be either equipped with a glass-fiber chopper unit or easily converted to process a large range of bulky, irregularly sized fillers by mounting a special dosing unit. A dedicated and automatic system allows changes to be made to both output and fiber-length independently, shot by shot, during the pouring process.

- equipped with closed-loop control of output

Additionally, innovative equipment to meter and mix a three-component slurry has recently been developed[3]. A high-solid-content slurry, obtained by blending powdered ultra fine solid fillers in non-catalysed polyol as the carrier, is fed as a third stream at low-medium pressure to a mixing head via the axial port of the mixing chamber originally used for metering color paste.

Figure 3. Interwet Mixhead and Chopper Mounted on 6-Axis Robot

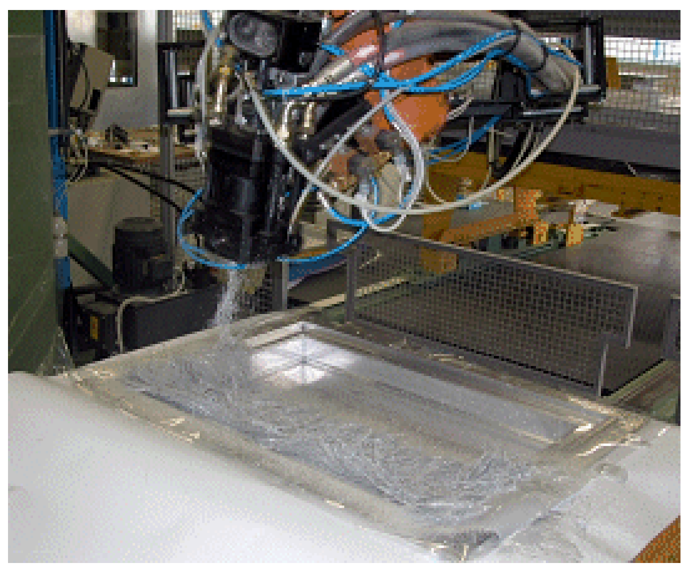

Figure 4. Interwet Being Applied to Mold

[3] *Developed by Cannon USA*

Process Advantages

In contrast with other technologies available on the market, the InterWet co-injection of polyurethane and fillers presents several advantages during the foaming process, such as:

- increase the productivity by eliminating most of the traditional problems related to the expensive dispersion of filler into the raw material (i.e. possible absorption of additives into the filler, abrasion, clogging of lines and tanks, fluctuating percentages of filler in the liquid, etc.).
- reduction of management and logistical costs. This “lightweight installation” does not require additional equipment such as premix, cylinder machines, pre-formed part storage areas, special handling equipment, etc.
- significant cost savings in terms of reduced manpower and reduction of raw material costs by utilizing low cost additives and fillers. In comparison to glass mat and pre-cut glass fiber, glass fiber rovings are less expensive.
- reduction of scrap due to a fully automated foaming process. Furthermore, the mixing system is based on just a few standard parts, which are cheaper than specially developed systems and are easily maintained.
- significant improvement of the product’s physical, mechanical and qualitative characteristics, due to a homogeneous and random long glass fiber dispersion in the PU foam.
- improved working conditions and quality of life within the production plants, with a profitable and sustainable technology based on a solvent free process that respects the health of the workforce and, more generally, the environment.

Synergistic Developments

InterWet is a flexible and proven technology, suitable for use in a wide range of industrial applications. Reinforced parts for the automotive market, heavy trucks and earthmovers (i.e. door panels, parcel shelves, tractor hoods, fenders, internal and external body parts, etc.), all fields where the mechanical resistance and the product's weight are mandatory and unavoidable characteristics.

InterWet has been chosen by GMP SpA Italia, to introduce a new development step of its patented **Foiled Pur Technology – FPT**[4], which consists of co-molding a part in rigid polyurethane directly on to a thermoformed and pigmented film. This combination provides the molded part with an external aesthetic finish. With this procedure, the productive process ends when the part is extracted from the mold.

[4] *Patented by GMP SpA Italia*

The most important advantages of this process are summarized as follows:

- elimination of painting phase
- more production potential versus traditional technologies
- up to 30% cost reduction compared with the traditional PUR-RIM technology
- freedom of design
- ability to create undercuts and thickness reductions (for handles and/or other hollowed details which enrich the external surface)
- ability to mold large parts

FPT has been introduced with great success for the production of refrigerator doors in Italy. Because of these excellent results in terms of aesthetical benefit and advantages, it became clear there was an opportunity to apply this process in other potential application niches.

Figure 5. Example Of Refrigerator Doors Obtained With FPT

Approaching new sectors (i.e. agricultural, industrial & building machines), it was necessary to improve a structural part's technical, mechanical and economical performances to compete with the traditional technologies already in use.

This was the main reason to explore the possibility of using a reinforced compound. By adding a certain percentage of glass fibers to the polyurethane, a lightweight structural part, characterized by a higher rigidity than a steel structure with the same dimensions and weight can be obtained.

Internal and external body parts made with reinforced material aids in a vehicle's overall weight reduction (bodywork parts, cabins, spoilers, control boards, tool carrier panels, light holders and bumpers) resulting in a lower consumption of resources and a wider working autonomy.

On this basis, the idea of the new **Foiled FiberPur Technology – FFT** was born. It consists of foaming a compound of polyurethane and glass fibers in only one shot on a thermoplastic foil positioned and vacuum formed in an open mold.

Due to the flexibility of this technique, a part can be designed and tailor-made for the specific customer requirements: since the quantity and length of the glass fibers poured can be varied during the foaming process, different areas of the same part can have different strengths. Basically, glass fiber length can vary in the range of 25-50 mm, while its presence in the mix can range from 15% to 40% in weight.

Especially in the case of body parts for excavators, tractors and other earth moving machines, it is common to have daily damage caused by working duties. In presence of a structure made of PU + GF, the energy developed by the impact of stones or rocks is absorbed and spread along the oriented glass fibers.

Figure 6. Earth Moving & Agricultural Machines body parts made with FFT

Table I. Thickness Comparison At Same Rate Of Technical And Mechanical Properties. Up To 50% Of Weight Reduction On A Finished Part Can Be Achieved With FFT Compared With Sheet Metal

Material	Process	Specific Weight g/cm^3	Thickness mm	Weight Kg	Relative Weight
STEEL	Forming	4.8	0.8	3.7	100
SMC	Compression Molding	1.9	2.5	2.8	75
PU + GF	**F.F.T.**	1.5	2.5	1.95	55

Compared with metal surfaces, there will not be any deformation or cracks due to the highly elastic modulus of the molded parts. In addition, with proper part design and with the advantage in terms of flexibility offered by FFT, mechanical properties can be modified (diversifying the performance of a single component from side to side) according to technical requirements by increasing/decreasing the amount of glass fibers and thicknesses.

In regard to shrinkage and possible defects, it should be noted that the linear expansion coefficient of FFT molded parts is very similar to steel and aluminum, with the consequent reduction of vibrations and loud noises on working machines.

The use of colored film as a cover (also available in a wide range of surface finishing) allows the elimination of the paint process traditionally required. The varnishing phase elimination allows a drastic reduction of production costs such as the complete elimination of solvents resulting in a production technology with a more favorable environmental impact. The foil is scratch proof and is UV ray resistant.

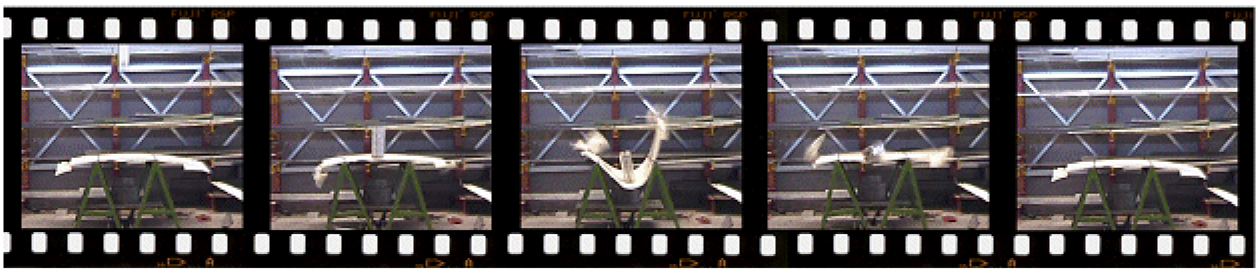

Figure 7. Impact trials sequence[5]. (36 kg falling from a height of 3.25 m). On the surface, some signs and abrasions remain present but easily recoverable).

Basically, the foil consists of a PVC-or PET -G based support (for external use the support base is PVDF), but for specific applications it can be made with other bases (i.e. methacrylate) and thicknesses. Depending on the system used as support, it can achieve different levels of aesthetical finishing: from opaque to a brightness of 90 gloss.

A coating of transparent thermoplastic acrylic resin is applied on the front to give the necessary surface resistance and the required aesthetic properties. During the process the film is protected by means of a removable LDPE (low-density polyethylene) film with a thickness of about 50 micron.

Table II. Reduced Production Steps Offer Significant Cost Reductions. Additional Savings And Benefit Come From The Ability To Put Inserts In The Mold, Simplifying The Assembly Processes.

Production Phases	SMC	STEEL	FFT
Assembly	Adhesive bond	Welding	Adhesive bond
Pre-painting	Sealer/Primer Sanding	Anti-corrosion	NO
Painting	On-line In-line Off-line	On-line	NO

[5] *Impact trials sequence performed by GMP SpA Italia.*

Although the production cycle is longer than a common thermoplastic processing technology, as a result of the elimination of painting, it becomes shorter if compared with PU-RIM and SMC processes, thus increasing the production volume. For example, considering a standard production scheme based on two work shifts and four molding stations, an annual production capacity of about 360,000/440,000 pieces can be achieved.

FFT uses aluminum molds, significantly less expensive if compared to steel molds normally used in SMC and metal sheet forming processes. This feature is an extremely important topic for customers, who play in market niches characterized by small volumes, offering affordable and flexible technology for frequent model changes. It is possible to design easily modifiable molds in several versions to obtain brand differentiation, model updating, etc.

Table III. FFTechnology's Values Related To A Compound Of PU Filled With 50 Mm Length Fiberglass.

** According To HDT Test ISO 75 1987/B Standard*
*** Depending On Percentage Of Filler Applied*

	BAYDUR	FFT	TELENE	FIBERGLASS	SMC
Density (Kg/dm^3)	1.05	**1.35**	1.05	1.45	1.8
Elasticity Modulus (Mpa)	1500	**4/8000****	1500	5000	8000
Strength (KJ/m^2)	30	**>70**	50	40	40
Thermal Resistance* (°C)	+115	> **+150**	+115	+160	+160
Self Extinguishing	V0 –V5	**V0-V5**	V0	-	V0-V5
Thermal Expansion	$8x10^{-5}$	**$2x10^{-5}$**	$8x10^{-5}$	$2x10^{-5}$	$2x10^{-5}$

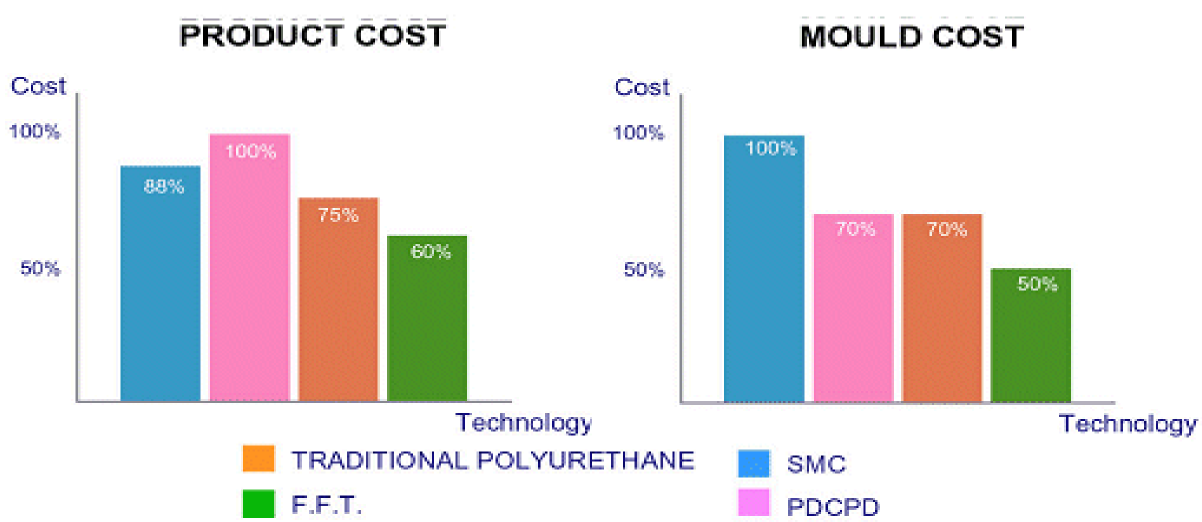

Figure 8. Product and Mold Costs Among the Competing Technologies

As an example of this technology, a hood for KOMAT'SU is being produced to protect the engine which illustrates the characteristics described so far. The development of this product started from input given by the client for whom a similar product was already being molded but with traditional polyurethane.[6]

In order to successfully pass some resistance tests as shown in the video clip, the hood in production needed reinforcements because of its relatively fragile nature. That is why in the original version a piece of material charged with fiberglass, copying the shape of the piece, was glued on the inside part of the top. In this way, it was possible to make the upper part suitable for the type of structural stresses it would normally encounter.

Figure 9. Example of a product created by FFT: Engine Hood

Unfortunately, in rare cases, after experiencing a horizontal stress, the assembly encountered breakage on the sides. This is why the client demanded a research study on the engineering of the piece which would lead to a more realistic solution and which also could be applied to specific requests.

With the development of the FFT, all these problems were solved. In addition, the new process resulted in lower costs than the previous production method.

In the current version, a hood kit is made up of two SIDES and a TOP mechanically and chemically assembled. This is because like in all technologies with an open mold, the ability to have three-dimensional pieces is relatively compromised.

The mechanical assembly takes place with self-tapping screws which are screwed in areas provided by the molding process. The screws maintain the three components of the kit in a fixed position allowing a bonding agent, that is spread in conduits which are also molded in, to cure and tie the three components into one piece.

Summarizing why the customer chose FFT, we list the aspects that correspond to the client's requests.

- To pass the tests that the manufactured products must undergo
- Resistance to environmental factors
- Lower costs compared to alternative technologies with an increase in mechanical performance
- Ability to mold in attachment points or inserts, making part assembly easier.
- More output potential (compared to traditional PUR)
- More efficient assembly

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[6] *GMP Italia provided Komatu'su the product molded with traditional polyurethane*

- And also:

    - Increase of the elastic behavior (resistance to piece deformation)
    - Remarkable increase of the resilience parameters depending on the weight
    - Great reduction in thermal expansion
    - Dimensional stability (less dimension problems while in use)
    - No need for varnishing

Product Technical Data Card
Dimensions : 740 x 1500 x 750 high
Weight : 12 kg
Nominal thickness of sides: 3.5 / 4 mm
Molds: aluminum

Dressing The Tractor

Besides the hood, the lateral flanks that incorporate the metal grids, the front side of the hood, the front and the rear mudguards have also been manufactured via this method.

Figure 10. Tractor Body Components Molded With FFT

Piece By Piece

The most significant aspect of this molding technology involves the ability of manufacturing parts with different technical/mechanical properties and performance depending on their specific use. In particular FFT can produce parts with different thicknesses and different percentages of glass fibers within the same part thus varying the features of the component from area to area.

In addition, it is possible to manufacture internal ribs to further strengthen the piece: in this case, the difficulty lies in making the glass fibers reach, up to the deepest point of the rib; however, the parts made to date have been successful in achieving this.

In the case of this tractor part, the advantage of FFT molding allowed for the production of a single component which meets different performance requirements. Resistance to vertical fall of heavy weights was the main requirement for the hood of the engine cover. Resorting to FFT, there were no problems in creating a base for this part with a different thickness, a higher percentage of fiber and some stern sheets on which metal inserts were submerged.

Figure 11. Hood for Engine Cover

Figure 12. Flanks Hosting Metal Ventilation Grids

Figure 13. Front Mudguard

Figure 14. Rear Mudguard

Technical Advantages

Using a single technology and a single manufacturer for all machine body components has several implied advantages. First of all, optimization of material can be realized by reducing it where unnecessary and increasing the weight or amount of polyurethane or fiber only when required, thus avoiding waste and cutting costs. Other advantages concern uniformity of shades throughout the whole machine: in the FFT a pigmented film is used, co-molded with the material. The color consistency is excellent and all the problems of "color matching" are avoided.

Engineering performed by a single designer avoids, or at least greatly reduces, mistakes and misunderstanding in the interpretation of data and coupling tolerance.

Grids, handles and possible inserts are assembled by a single supplier providing the customer a piece that is ready for assembly on the machine.

The versatility of the FFT process has also enabled the use of simple molds which could be modifiable in several versions. For example the greater length for the longer version of the hood and mudguards was achieved with the addition of a simple insert to the original mold. In this way it is possible to easily obtain brand differentiation, model updating, etc.

The following table shows two tractor hoods made with FFT but with different mechanical properties based upon thickness and fiber content. The flexibility of the process is demonstrated by the ability to produce similar parts but designed to meet different requirements.

Table IV: Comparison of Technical Parameters of the Hoods

TRACTOR HOOD			
Thickness	mm	4	3
Raw density	Kg/m^3	1380	1270
Glass fiber content	%	30	15
Glass fiber length	mm	50	25
Flexural modulus	Mpa	6000	4000
Flexural strength	Mpa	200	140
Impact strength	Kj/m^2	70	40
Tensile strength	Mpa	100	70
Head distortion temperature	C°	> 200 (HDT/B)	> 200 (HDT/B)
Dimensional stability	K^{-1}	2x10^{-5}	2.5x10^{-5}
Surface hardness	Shore D	> 65	> 65
UV Ray discoloration resistance **	Δe	< 0.48	< 0.48
Scratching resistance	Pencil hardness	≥ F	≥ F
" "	Bucholz	> 87	> 87

Conclusions

Today, the success achieved in the automotive market by InterWet Technology and the connected production process developed and based upon it such as FFT, has produced another challenge: to industrialize new applications for other sectors. In light of the experience gained from investing in continuous R&D activities, dealing with special tailor-made projects and putting many real applications worldwide into production (for instance insulated sandwich panels for air conditioning plants, furniture parts, bar tables, etc.), InterWet could almost certainly be successfully applied to the production of:

- energy absorbing panels
- structural parts for automotive, furniture and cold chain industry
- decorative parts
- agricultural containers
- insulating parts for building (blocks, structure etc.)

Biographies

Christian Cairati – born in Milan, Italy, in 1970 – has technical education in Information Technology specializing in Plastics Technologies and a Master in Quality Systems Management. He worked for ten years in processing companies as production manager and for more than four years as marketing & quality consultant for the Italian Association of Plastic Processing Machinery Manufacturers – Assocomaplast in Italy and abroad. After a couple of years spent in the UK working as marketing consultant, he joined Cannon Afros in 2001 as Company Communication Manager.

Guido Furlanetto has been collaborating with GMP SpA Italia since 1988 and is presently responsible for sales activities. He has more than 15 years experience in the polyurethane field and is specifically responsible for the activities of a team overseeing new product development for Oderzo, an Italian-based firm. In this role he is responsible for promoting materials and process innovations developed by the GMP SpA Italia research team in various markets and industrial sectors.

Barry Pile is currently an Industry Manager at Cannon USA specializing in plastic processes for automotive interior part production and is a member of Cannon's International Business Team. He has been with Cannon for ten years bringing with him a Mechanical Engineering degree from the University of Pittsburgh and a Business Management degree from Indiana University of Pennsylvania.