Injection Moulding Processes
– Yesterday, Today and Tomorrow

**Integrative Processing Technology.** As one of the most important processing technologies, injection moulding has experienced, by far, some of the greatest advances in recent decades. From its origins based on simple moulding of thermoplastic resins, a product-specific processing technology has been developed that has as its objective production of complex parts via a combination of various individual processing techniques.

Injection moulding machines are, without a doubt, complex high-tech products. Nevertheless, their importance for the manufacturing process – here, the injection moulding process – should not be overestimated [1]. It is only the appropriate combination of machine, mould and processing technique that provides the necessary framework for economical production. Moreover, the more challenging the product design and functionality, the more complex are the components from which the products are assembled. This development is closely linked to the processing technology, the complexity of which grows with that of the components.

It will probably never be possible to determine when “processing technology” first appeared. This question is comparable to that of which came first, the chicken or the egg. Fact is that at some
point end users and processors alike decided to incorporate several functions into components, while at the same time eliminating additional assembly operations. This led initially to "special processing techniques" that, after several years, became "normal" processing techniques.

**Functional Integration via the Multi-component Technique**

A prominent example can be found in the multi-component technique, which was introduced over 15 years ago. Processing of two or more plastic melts in a single mould, however, can be accomplished in various ways. Depending on the application, terms such as multi-material or multi-colour moulding, sandwich moulding and in-mould assembly are employed. As a rule, material-bonding, adhesive connections are the objective. If, however, combinations of incompatible materials are involved, adhesion can be achieved through use of primers, flame treatment, corona- or plasma treatment (Fig. 1). The desired properties are the deciding factor, for instance,

- sink-free surfaces,
- combination of different colours,
- improved tactile properties (haptics),
- integration of seals or vibration-damping elements.

Currently, multi-material injection moulding is concentrated primarily on integration of functions and improvement of surfaces. Development projects are focussed on combinations of thermosetting (cross-linking) resins or ceramics materials with thermoplastics.

**Foam Moulding Improves Part Properties**

The direct gas injection technique that has been known for about 35 years – originally, a version of structural foam moulding – is intended to achieve densities of 0.3 to 0.6 g/cm³, produce parts without sink marks and reduce clamping force requirements. To accomplish this, a blowing agent is injected at high pressure into the melt-containing screw channel. After expansion to form a gas, foam structures result. A few well-known applications from the automotive industry include decorated panels, coverings, housing parts and also connectors.

In a modified form and using improved technology, this technique is currently experiencing a renaissance as micro-structural foam moulding. As the result of advancements in chemical blowing agents, the physical and chemical foam moulding techniques are competing with one another today. The benefits of each technique include (Fig. 2)

- cycle time reduction (–20%),
- weight reduction (–10%) and
- improved dimensional properties.

Lower melt viscosity is a side effect of gas incorporation, which permits longer flow paths and clamping force reductions of up to 30%. The opportunities resulting from this have not yet been exhausted.

**Surface Improvement Techniques – Internal and External**

Two additional and related low-pressure injection moulding techniques, back injection and back injection compression of decorative materials in the mould, were developed to production readiness at the end of the 1980s/beginning of the 1990s. In-mould laminating, as these techniques are also called, represents an alternative to the usually more involved adhesive bonding approach.

While pillar covers, door inserts and similar applications can be backmoulded on modified conventional injection machines, backpressing initially required special vertical machines to permit deposition of the melt in the open mould. For a long time, this principle served to produce large decorated door and luggage compartment panels as well as instrument panel coverings. In the meantime, back injection compression has been developed for use on horizontal machines, as a result of which the above-mentioned products can now be produced on conventional machines (Fig. 3).

High-quality surfaces are no longer reserved exclusively for luxury automobiles. The interiors of mid-sized and compact cars are also expected to impart an impression of quality, for instance, a pleasant, leatherlike feel to the surface or soft-touch effects.
Processors and automakers wish to have a reliable method capable of high-volume production that requires no secondary finishing operations and is suited to complex, highly three-dimensional surfaces with tight radii.

While originally developed for production of automotive interior components, both techniques are now employed for numerous other applications such as office furniture, backmoulded films for electronic displays and the front halves of mobile telephones. They also serve as the basis for backmoulding of paint films. This technique is suitable for production of exterior auto body panels and could replace the complicated wet painting process. If the required surface quality of the film can be achieved, both the requirement and wish of automakers for short model runs, variety, flexibility and modularity would be met.

Development projects with textured films in colours matching those of the vehicle are already in process, as is initial series production [2]. For example, the number of concrete examples of applications is limited at present. The weak link is colour matching, i.e., matching the film colour to that of other painted parts, and providing a complete range of colours for the line of vehicles. In addition to Class A surface quality, the absence of dust and foreign particles must be established. Even though a few important fundamental aspects are still missing, the use of plastic components for auto exteriors is getting closer.

**Transparency with Functionality**

**Thanks to Injection Compression**

For more than 30 years, injection compression moulding, which, by the way, is also a low-pressure process, has served to produce warp-free thermoset parts. For relatively flat parts, the surfaces of which must be very dimensionally accurate as well as for optical lenses and inside mirrors in cars, it is superior to conventional injection moulding. More recent process variants are suited to production of other high-quality, stress-free parts, for instance data media.

With the development of suitable poly-carbonates (PC), new automotive applications have become possible, for instance, headlamp lenses (1993) and the first automotive glazing (1998) in the Smart car. This led to additional process variants for injection compression involving clamp motion, breathing, wedges and rotary platens (turntables) for production of two-component glazing (Fig. 4). With its expansion compression technique, Krauss-Maffei has developed a method for producing large transparent PC parts. The current size limit is 1.5 m² in series production. The benefits of plastic glazing are obvious, for instance
- relatively great design freedom,
- opportunities for integration of functions,
- significantly lower weight and
- high impact strength.

Unconventional design ideas such as windows with tight radii (cockpit windows) for automobiles have failed to date in glass because of the limited design freedom and the associated lack of a high-volume production technique. Given the right injection moulding technique, this situation could change in the near future with PC (Fig. 5).

**Injection Moulded Long-fibre Reinforcement**

There are increasing attempts to replace GMT (glass mat-reinforced) parts with long-fibre-reinforced thermoplastics via direct processing (D-LFT-ECM), in-the-press processing or injection moulding of long-fibre-reinforced pellets (LFG-IM) as well as via direct compounding (D-LFT-IM) (Fig. 6). Compared to classical GMT processing, screw injection, whether of long-fibre-reinforced pellets or rovings, is considerably simpler, since cutting to size, loading and heating the mats is eliminated.

Long-fibre-reinforced pellets have been processed on injection moulding machines for about ten years now as a way of producing parts with improved mechanical properties (Fig. 7). This became possible through the development of special fibre-preserving screw geometries, suitable non-return valves, along with nozzles and hot runner systems.

The development of direct compounding on injection moulding machines was based initially on economic considerations. The objective was to complement, if not replace, the involved GMT process [3]. Today, the process that was first introduced seven years ago has achieved even greater importance than previously. It provides processors with the ability to develop individual formulations with customers. At the same time, production can react more flexibly to changes with an injection moulding compounding (IMC).

In direct compounding, the matrix components and reinforcing fibres (chopped glass fibres or rovings) are fed directly to the injection moulding machine, where they are compounded and processed into the moulded part in “one heat” (Fig. 8). This allows the processor to customise the system of matrix, fibre and adhesion promoter, for instance, in order to match the fibre content and fibre length in the part exactly to the specific technical requirements. In this way, very long fibres, whether in mats, fabric or unidirectional strips, can significantly improve the property profile noticeably.

With direct compounding, the value added at the processor increases significantly, keeping in mind that the potential of the process is far from being exhausted (Fig. 9). If long-fibre reinforcement alone is not adequate for parts subject to high loads, the load-critical regions can be optimised by inserting additional reinforcing fabric, which can subsequently undergo backmoulding. How such inserts, prepared as necessary, are transported, positioned and held in the mould
is known from experience with backmoulding and backpressing.

Additional potential for this technology can be found in filling with large amounts of fillers, blending of resins and even reactive extrusion with subsequent part forming.

A definite plus of this one-step process is the greatly reduced thermal history of the materials to be processed. It is even conceivable that this may be the only way to process thermally sensitive materials or material components.

“New Surfaces” with Improved Properties – the SkinForm Process

For many years, the expression “synergies” was overused and more often wish than reality in the plastics industry. It took a long time for various processing techniques to come together and ultimately create completely new possibilities. In a joint project involving a processor, material supplier and Krauss-Maffei as machine builder, a new technology for production of moulded parts with a high-quality surface has been developed, the so-called SkinForm Process (Fig. 10).

In this process, injection moulded substrates are overfilled with a soft cast PU system in a single process step requiring no secondary finishing operations. The process utilises two mould cavities and permits localised changes in wall thick-
ness. The PU component is partially foamed, thus providing the surface with certain soft-touch regions. Since the process replicates the surface of the mould cavity, various surface structures (graining, decorative stitching and the like) can be reproduced exactly. A new design effect that was previously not attainable with soft painting of moulded parts or in-mould laminating (back-moulding) has now become possible. A few important benefits of the process are:

- pleasant leather-like feel to the part surface,
- high scratch resistance in spite of very thin surface layer,
- suitable for highly three-dimensional surfaces with tight radii and openings,
- no distortion of the decoration or loss of graining.

The process is already suitable for high-volume production, with costs no higher than for a soft-painted part. As a result of this initial development, many promising new applications are currently being considered, especially where new surface qualities are required.

**Retain and Refine Know-how**

Research and development in the plastics industry occur largely in a customer-oriented and product-specific manner. Considerations are focused on the moulded parts and their production, that is, on the process technology. Ideally, the end user, processor, material supplier and machine builder are striving to achieve the same objective of combining or developing the appropriate materials, machines and processes. This requires close cooperation among trusted partners that should not end after success has been achieved.

The next objective must be to retain and refine the acquired know-how, since a trend that is known to observers from other sectors is becoming increasingly apparent even in the plastics industry – especially with regard to processing technology: patenting of already known, yet still important process steps in order to subsequently make them available only after payment of expensive licensing fees. A possible consequence of this phenomenon, already known from the consumer software branch, could be that important advancements either become uneconomical or are blocked completely because to the licensing fees that must be paid. To permit this would be to rob the plastics industry of the momentum that has characterised it as one of the most innovative branches of industry.

**REFERENCES**


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