From this very low-viscosity melt, the fine impurities can be removed very effectively by filtration with fine-mesh screens (mesh size below 20 µm). The cleaned PET melt can subsequently be returned to the esterification process where it is polymerised into virgin material.

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Title photo. Direct extrusion also results in a glass-clear, speck-free film even with non-pre-dried PET

Fig. 1. Proof of quality: Processing of non-pre-dried PET on a ZSK: Relative decrease in the iV in relation to the standard throughput (all pictures: Coperion Werner & Pfleiderer, Stuttgart)
Durchsatz = Throughput

Fig. 2. Machine diagram: Direct extrusion of non-pre-dried PET into a flat film
EPC Prozessleitsystem = EPC process control system; Dosierung Granulat = Metering of granules; Dosierung Rückware = Metering of reclaim material; Entlüftung= Atmospheric venting; Entgasung = Vacuum venting; Vakuumpumpe = Vacuum pump; Schmelzepumpe = Melt pump; Siebwechsler = Screen changer; Breitschlitzdüse = Slit die; Chill-roll-Anlage = Chill-roll unit; Dickenmessgerät = Thickness gauge; Zur Weiterverarbeitung = For further processing

Fig. 3. A side vent prevents deposits getting into the melt

Fig. 4. Unit for processing non-predried PET material for direct further processing into film, fibres or granules

No Steel, No Paint

Plastic Bodywork. The production of in-mould laminated film parts for vehicle exteriors covers a variety of different products and processing stages. This article surveys the materials and technologies used in back-moulding the films.

ACHIM GREFENSTEIN
KAAN KAYMAK

High-gloss film has been used since the mid-1990s for pillar trim, bodyside mouldings, exterior mirrors, roof drip mouldings, wheel covers, door sills and radiator grilles [1]. Prominent examples of this in Europe are the radiator grilles of the old Ford Fiesta and the current Renault Laguna.

These films can be in-mould laminated to different back-moulding materials based on styrene copolymers, their thermoplastic blends and polyurethane foam systems (Fig. 1), whatever the method of coloration. In conjunction with its Elastogran GmbH subsidiary, BASF AG posseses the materials and expertise in all three product groups and is thus able to cover the entire spectrum of in-mould film lamination. The back-moulding materials with their very diverse properties can be used to produce virtually all conceivable automotive exterior components. The third partner in the BASF's expert combine for automotive construction is BASF Coatings AG, which provides the paints and coating processes for the in-mould lamination films [2]. Accordingly, all three companies together offer a wide range of plastics solutions for automotive exteriors. For the thermoplastic back-moulding materials, the development process moved in the direction of long-fibre-reinforced composites with low thermal expansion and good crash properties. The Class A surface capability of these materials can only be achieved with film [3, 4]. The glass fibres can be incorporated both in injection moulding and extrusion/compression moulding [5, 6]. The possibility of producing in-mould laminated components by back-injection compression moulding with the vertical flash face sealed by the film was demonstrated. The production in principle of very large components from thermoplastic materials is therefore possible.

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Technologies for Back-moulding the Films

The choice of a suitable back-moulding material must generally take account of the bimetallic effect (in this case, it would be better to talk of the bi-plastic effect). This means that the film and back-moulding material should have almost identical shrinkage and linear expansion values. Generally, the warpage properties of composite films made from semicrystalline materials (e.g. polypropylene) must be regarded more critically on account of their greater moulding shrinkage.

Up until now, despite various attempts by manufacturers of SMC and film, no films have been made that are compatible with SMC as the gases escaping from the SMC cannot escape through the high-gloss films and so lead to bubble formation after the part has been made or, at the latest, is aged under standard climatic conditions. This is regrettable because SMC offers many advantages for parts designers (including highly rigidity and low linear expansion). The following information is therefore intended to show which alternatives are available that offer similar properties and reduced system costs.

Back-injection with fibre-reinforced thermoplastics: Amorphous thermoplastics, such as ABS, can be used to produce long-fibre-reinforced parts with no fibre marks on the film side, even after heat aging. To an extent depending on the fibre content, the back-moulding material has a rigidity of 3000 to 6500 MPa combined with good crash properties and a linear expansion of 35 to 45×10^{-6} 1/K.

The fibres may be added as chopped strand by converting a commercial injection moulding machine with a special ("gentle on the fibre") mixing section and a gravimetric feed. Where investment in a new machine is required, a better option would be to use an injection moulding compounder (manufacturer: Krauss-Maffei).

At K 2001, the ABS boot lid (grade: Terluran) shown in Figure 3 was made in a fully automated production cell (Fig. 2) [5]. The glass fibres were added to the injection moulding compounder in concentrations of 15 to 30 wt.% in the form of rovings. The cycle time was 65 seconds. In collaboration with Montaplast and DaimlerChrysler, the concept was transferred to prototypes of the boot lid shown in Fig. 4 [7]. The horizontal and vertical panels were back-injected with ABS and bonded to a support of (PBT+ASA) blend (grade: Ultradur S) or (PA+ABS) blend (grade: Terblend N). The films used for the panel parts were co-extruded and paintable films. As was the case on earlier trade-fair parts, a maximum heat resistance of 90 °C for the ABS film composites was also demonstrated for this large part. This value is adequate for vertical parts that are not exposed so much to the sun. Work on increasing the heat resistance further is in hand.

Back-compression moulding with fibre-reinforced thermoplastics: A critical role in the mechanical properties of long-glass-fibre-reinforced parts is played by the attainable fibre length. In back-injection and back-injection compression, it is essentially limited by the flow processes in the gate area of the mould. The shear forces generated there preclude a fibre length longer than approx. 5 mm in the part. The mean fibre length is around 1 mm.

An alternative to injection moulding is long-fibre-reinforced thermoplastic compression (LFT) or molten-layer deposition. In this, the fibre is incorporated in a twin-screw machine in a manner similar to that used on the injection compounder. A layer of melt is then extruded through a die, cut to a predetermined length and reshaped in a compression mould. Because the shear forces are much lower, the fibre lengths in the part can be substantially greater than 10 mm. Table 1 compares the resultant mechanical properties with those for injection moulding using the example of a back-moulded rear panel (see also [8]).

The following inferences may be made:

- On account of the longer fibres, even if the fibre content is low, the matrix material must have a low viscosity in order that the mould may be filled.
- The longer fibres lead to higher part rigidity combined with lower anisotropy (orientation effect).
- Part toughness can be drastically increased, especially at high glass contents.

In collaboration with Dieffenbacher, the latest machine generation was used to produce parts, initially without film, with different matrix materials by so-called LFT-D-ILC molten-layer deposition (Fig. 5) so that they could be characterised mechanically. LFT-D-ILC stands for direct in-line compounding. In this two-stage process, melting and, as necessary, admixing of aggregate or re-grind into the matrix material occurs in one extruder, while fibre wetting and gentle incorporation takes place in another. As a result, particularly high fibre lengths and thus outstanding mechanical characteristics can be obtained.

Parts of roughly the same weight were produced in a thickness of 2.5 mm. To this end, the PP reference material was reinforced with 40 % glass fibre, while the styrene copolymers were reinforced with 30 %. The specimens were removed from flat part surfaces lengthwise and crossways

Films and back-moulding materials

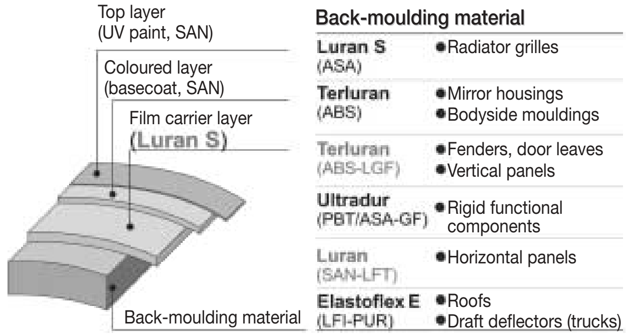

Fig. 1. Films may be back-moulded with various materials derived from styrene copolymers

Back-moulding materials

Back-moulding material (ABS)	Terluran GP-22	Terluran GP-35	Terluran GP-35	Terluran GP-35
Fibre carrier material	ASA	ASA	ASA	ASA
Glass-fibre content %	15	15	30	30
Injection moulding (IM), compression (LFT)	IM	LFT	IM	LFT
Glass-fibre length mm	1–5	> 10	1–5	> 10
Elastic modulus N/mm²	2930–3490	3365–3734	3250–4710	4135–4642
Yield stress N/mm²	47–58	42–47	49–73	44–46
Impact strength ISO179/1fU at 23°C kJ/m²	18–21	30–36	13–17	53–69

Table 1. Influence of the processing method on material properties (measured in all cases lengthwise and transverse to the fibre orientation)

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Parts without film

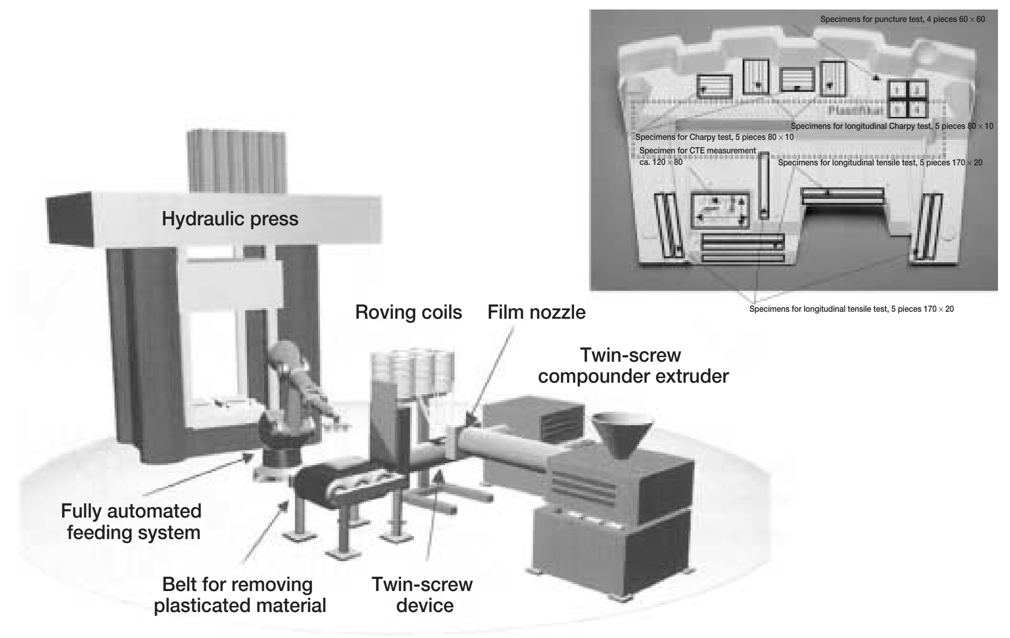

Fig. 5. Molten-layer deposition method used in LFT direct in-line compounding (developed by: Dieffenbacher) and test part

alongside the layer of plasticated material in order that the maximum influence of fibre orientation could be established. For use as a flat bodywork panel, isotropic part behaviour is key.

It can be seen that the styrene copolymers, despite the lower fibre content, offer in some cases much higher rigidity, especially transverse to the fibre orientation (Fig. 6). A maximum of roughly 10 000 MPa, comparable to the value for SMC, is possible. The much lower degree of anisotropy is also reflected in the coefficient of linear thermal expansion, which is less dependent on the orientation. Even transverse to the fibre, results desirable for plastic bodywork parts are obtained. All materials remain splinter-free in the puncture test. Even in the case of the SAN matrix, which is more brittle than ABS, the long glass-fibres hold the part together. This means that the much more heat resistant SAN can be used (Vicat B of 120 °C).

Apart from the good mechanical properties, reasons for using styrene copolymers in this application are:

- excellent adhesion to the film,
- less processing shrinkage and warpage, and
- less show-through of melt layer or glass-fibres though the film.

Although still in its infancy and especially since the mould and processing technology for the production of large Class A parts by back-compression moulding with styrene copolymers and LFT still needs to be developed, this technology can be expected to have a good future, especially for large and horizontal parts. Compared to the PP-LFT front-ends made today, which feature a high blend content (e.g. breakthroughs), hoods and roofs are ideal candidates for efficient manufacture by compression methods (less blending, no undercuts).

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Back-foaming with thermoset PUR systems: A proven alternative to manufacturing large parts consists in back-foaming the film with a glass-fibre-reinforced PUR [8 to 10]. ArvinMeritor has been using this technology since 1998 in the production of the all-plastic roof modules for the MCC Smart (title photo).

The advantages of such a roof module are as follows:

- easy integration of functions (e.g. foaming of antenna and cables),
- simplified one-shot manufacture,
- film eliminates time-consuming painting,
- weight reduction of around 50 % relative to glass roof or similar sized steel roof, and
- easier assembly of parts in the interior through the roof opening.

The roof module consists of a coextruded, in this case, grained black film that is inserted into the lower part of the foaming mould. The film is manufactured by Hagedorn in Lingen/Germany. The glass-fibre-reinforced PUR foam (grade: Elastoflex; manufacturer: Elastogran) is applied to the film by means of long fibre injection. The textile, located on the upper part of the foaming mould, is directly foamed as well. Typical cycle times, including curing of the foam after the mould has been closed, are around three minutes. When the part has been produced, it is trimmed to remove projecting film and foam that has been expelled through the mould seals.

Unlike back-injection and back-injection compression moulding, the LFI process generates only low pressures of a few bar inside the mould. Consequently, even the tiniest flaws in the thermoformed film (caused, for example, by dust on the draw mould) cannot be “ironed out”. Whereas the surface quality of the mould and its cleanliness are the determining factors in back-injection, back-foaming presupposes a Class A surface.

Major advances have been made in recent years in optimising thermoforming in conjunction with various development partners (thermoformers, machine manufacturers and automotive subcontractors). Key factors for obtaining a Class A surface are:

■ Surface quality and annealing of the shaping mould (positive moulding),
■ Cleanliness of the environment around the film and mould, and
■ Quality of the raw-material employed.

The first series application of back-foamed Class A parts is the roof module panels that ArvinMeritor has been making for the MCC Smart since April 2002. The panels consist of two, black high-gloss parts that are adjacent to a sliding glass roof and, like it, have glass optics featuring extremely low surface waviness. The film is a coextruded Senotop film from the company Senoplast (1.3 mm overall thickness; PMMA on ASA/PC). ■

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Title photo. All-plastic roof module of the MCC Smart (manufacturer: ArvinMeritor, Gifhorn/Germany)

Fig. 2. Boot lid, produced in the fully automated production cell of the Krauss-Maffei injection moulding compounder

Fig. 3. The exhibition part from K 2001 was back-injected with long-fibre-reinforced ABS

Fig. 4. Prototype of a boot lid that can act as antenna
Beplankung horizontal = Horizontal panels; Klebenaht = Bonding seam; Antennenträger mit Antennen = Antenna carrier with antennae; Innenträger = Internal carrier; Alu-Profilrahmen = Aluminium frame profile; Beplankung vertikal = Vertical panel

Fig. 6. Properties of LFT materials: Styrenic polymers offer in some cases much higher rigidity despite the low fibre content
E-Modul = Elastic modulus; Bruchspannung = Breaking stress; Längenausdehnung = Linear expansion; längs = Longitudinal; quer = Transverse

Modern Chainmail

Optimising Safety Systems. Chainmail was not only used as combat armour in Ancient Rome and the Middle Ages. It is still used today, but with a different function. The combination of chainmail technology and ultramodern composites opens up new fields of application, for example in the security industry or as protection against stones.

JÖRG WELLNITZ

Chainmail was used by the ancient Romans. In the Middle Ages, armourers made chainmail shirts (known as hauberks), hoods, gloves and other clothing intended to protect against stabbing and cutting. This was a very labour intensive process. First, wire drawers produced the wire by repeatedly heating iron and drawing it through increasingly smaller holes. Then the armourers cut the wire into small pieces and formed it into loops. The loops were then skilfully linked together and closed individually to form rings. To increase the strength of the chain mail, the ends of the loops were welded or riveted together as they were closed. Usually 1:4 and sometimes 1:6 mail was produced. That means that one ring is always linked to four or six rings respectively. In individual cases a 1:8 or 2:8 mail was used, the latter being known as the "King's mail".

Outside Europe, similar mails were also used in Asia and Persia. These mails are extremely complicated and cannot be made by machine. Making these chainmails at that time was labour intensive and time consuming to a degree that is hard for us to conceive nowadays, and the material was therefore very valuable. Hence, it was only worn by rich knights and noblemen. Now, the chainmail makers have all but vanished. Chainmail can now also be machine made and is used almost entirely in the food industry, for example for protective gloves and aprons.

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Combining Old Technology and New Materials

If the technology is used together with modern materials, it can produce state-of-the-art composites and chain tensioning systems that are characterised by high energy absorption, variety and light weight

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