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Developments in Plastics Technology – 4

Edited by
A. WHELAN
and
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ELSEVIER APPLIED SCIENCE

DEVELOPMENTS IN PLASTICS TECHNOLOGY—4

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DEVELOPMENTS IN PLASTICS TECHNOLOGY—4

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PREFACE

Because of the sheer size and scope of the plastics industry, the title *Developments in Plastics Technology* now covers an incredibly wide range of subjects or topics. No single volume can survey the whole field in any depth and what follows is, therefore, a series of chapters on selected topics. The topics were selected by us, the editors, because of their immediate relevance to the plastics industry.

When one considers the advancements of the plastics processing machinery (in terms of its speed of operation and conciseness of control), it was felt that several chapters should be included which related to the types of control systems used and the correct usage of hydraulics.

The importance of using cellular, rubber-modified and engineering-type plastics has had a major impact on the plastics industry and therefore a chapter on each of these subjects has been included.

The two remaining chapters are on the characterisation and behaviour of polymer structures, both subjects again being of current academic or industrial interest. Each of the contributions was written by a specialist in that field and to them all, we, the editors, extend our heartfelt thanks, as writing a contribution for a book such as this, while doing a full-time job, is no easy task.

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Chapter 1

PROCESSING OF CELLULAR THERMOPLASTICS

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1 INTRODUCTION

The processing of cellular thermoplastics now constitutes an established, definable sector within the conventional thermoplastics processing industry. Cellular thermoplastics can be produced by use of the most established thermoplastics processing techniques. The injection moulding and extrusion of cellular thermoplastics have been the subject of an ongoing development intended both to reduce density and (probably of greater importance) to improve surface quality, eliminating or minimising surface finishing operations. Other areas where development in processing is apparent include rotational moulding and press moulding techniques.

Improvements in process development, together with relevant advances in expansion systems and polymer systems used, are outlined in this chapter together with possible areas of future development.

Developments in expandable PVC plastisols are not discussed. Whilst it is realised that the area of coated fabrics and other substrates used in the production of cellular floorcovering and wallcovering, etc., constitutes a major area of end application for mainly chemical expansion systems, it is felt that the technology differs considerably from that discussed in the chapter and it has therefore been excluded.

2 INJECTION MOULDING

The processing techniques used in the production of cellular thermoplastic mouldings have been the subject of an ongoing development programme since the original concept in 1962.[1]

The original concept of foam moulding was the development of a low-cost moulding technique for the production of very large mouldings with a high projected surface area. Advantages of the process include low mould clamping forces, with a high degree of design flexibility in the mouldings, giving the mouldings distinct cost advantages over homogeneous mouldings of similar weight and configuration.

Initial applications for such cellular mouldings were in the wood replacement areas, i.e. furniture parts and audio equipment, where full advantage of the low-cost processing technique could be utilised. However, changes in the performance requirements of such mouldings, if they were to compete with homogeneous mouldings in semi-metal replacement areas and at a later stage in metal replacements, quickly dictated changes in both processing techniques and polymer systems.

The transition from wood to metal replacement applications posed immediate problems such as

(1) the need to improve the surface quality of the mouldings by improving moulding techniques to minimise 'out-of-mould' finishing, or to improve surface finishing techniques;
(2) the need to improve and maintain the physical properties of consecutive mouldings (particularly impact and deflection loading characteristics).

Details of the sequence of developments in cellular moulding techniques are shown in Table 1. Details of the development of the individual moulding techniques, the polymer systems utilised, and the types of expansion systems, will be discussed individually. Where applicable the process techniques are compared to enable assessments of possible future developments, in the injection moulding of cellular thermoplastics, to be made.

2.1 Process Development

Table 1 lists the theoretical stages in the development of areas of application for cellular mouldings and highlights the increasing complexity of the foam moulding process. The pattern of development outlined is *theoretical.* Whilst progression from wood replacement to semi-metal application areas has occurred, progress on the use of cellular mouldings in true metal replacement applications remains limited; this is probably attributable to the lack of adequate engineering design data and doubts on the reproducibility of physical properties.

TABLE 1

SEQUENCE OF DEVELOPMENTS IN THE MOULDING OF CELLULAR THERMOPLASTICS

Foam classification	*Performance requirements of the moulding*	*Polymers currently utilised*	*Additives present in the polymer*	*Expansion system*	*Moulding system*
(1) Wood replacement	Smooth surface Stain-free surface Uniform fine cell structure	Impact polystyrene Polyphenylene oxide/styrene alloys	Flame retardants Impact modifiers Pigments	Physical Chemical	Low-pressure
(2) Semi-metal replacement	As above, but improved surface quality	Polypropylene ABS Polyphenylene oxide/styrene alloys HIPS	Flame retardants Reinforcing fillers Reinforcing fibres UV stabilisers Pigments	Chemical Physical	Low-pressure High-pressure Counter-pressure Integral skin
(3) Metal replacement	As (2) above	Polycarbonate Thermoplastic polyesters Polyamides ABS Polyether sulphone Polypropylene	As (2) above	Chemical	As (2) above
(4) Speciality foam systems	Dependent on end application, i.e. resilience, density levels, etc.	Composite polymer structures based on polyolefins, or styrenics	As (2) above + crosslinking systems, bonding additives	Chemical	As (2) above + specialist moulding systems

The reasons for the changes in application areas are essentially economic, resulting from:

(1) the virtual collapse of the audio/TV housings market during the 1976–1980 recession—essentially a wood replacement market;
(2) the emergence of a market for cellular mouldings in housings for computers, business machines, etc.—essentially semi-metal replacements, where dimensional stability, high surface quality, non-flammability and electrical insulation characteristics are essential;
(3) the improved economics of processing polymeric materials by comparison with metal stamping or casting techniques and associated metal finishing costs.[2]

Whilst the pattern of application is similar in most geographic areas, a considerable market for wood replacement applications still exists in North America in the area of reproduction antique furniture.

Individual cellular moulding techniques outlined in Table 2 are, for convenience, divided into two groups—the low-pressure and high-pressure moulding techniques, (independently of the polymer and expansion technique used).

2.2 Low-Pressure Moulding Systems

The term 'low-pressure moulding' describes a moulding technique in which a highly vented mould cavity is partially filled by the high-speed injection of a polymer melt in which a dissolved gas is held in solution. Immediately after injection and the subsequent decay of melt pressure to a level below the solution pressure of the dissolved gas, the polymer begins to foam, expanding the polymer melt to fill the mould cavity completely.

This process with slight modifications still remains the most widely used technique for the production of cellular thermoplastic mouldings today. Whilst the mechanics of the process have been adequately documented,[3,4] the two major moulding techniques are outlined below.

2.2.1 Conventional Low-Pressure Moulding

This process, based on the above principles, is the most widely established system currently used and will probably remain so in the future. Whilst the mouldings produced are suitable for use in a wide range of end applications, the increasing demands for improved surface finishes and more uniform physical properties will result in little further mechanical development in the process. Additional development is apparent, however, in the area of physical expansion systems where the use of both fluorocarbons and hydrogen[5,6] are reported to give improved cycle times and smooth surfaces. Improvements in surface quality by the thermal cycling of the mould have been claimed,[7] but long cycle times and mould design problems appear to make this approach uneconomic and no commercial operations are thought to exist.

2.2.1.1 Advantages of conventional low-pressure moulding. The obvious advantages of the process include the following.

(1) Minimal modifications to the standard 'in-line' moulding equipment, e.g. boosted injection speeds and positive displacement shut-off units (nozzles), permit its use for the production of cellular mouldings. However, the use of a screw pre-plasticising ram injection machine is essential for large mouldings and the economic utilisation of clamp capacities.
(2) The low clamping forces involved still permit the production of mouldings with a large shot weight and projected surface area.
(3) Low internal mould pressures (25–30 psi; $0{\cdot}2\,MN\,m^{-2}$) permit the use of low-cost steel tooling with, if necessary, aluminium inserts to improve heat extraction in an inherently long cooling cycle.[8]

2.2.1.2 Disadvantages of conventional low-pressure moulding. These advantages are offset to some degree by the following aspects.

(1) The reduced clamping capacity precludes the use of the equipment for the production of large homogeneous mouldings, although recently designed equipment has increased clamping capacity to permit dual usage.
(2) Within the limitations of density reduction, moulded parts will require 'out-of-mould' secondary finishing operations, particularly in semi-metal replacement applications.
(3) Increased cycle times attributable to the long cooling cycle require careful consideration of the economics of producing equivalent homogeneous mouldings for extremely long runs, unless a multi-station mould carriage is used. The use of multi-station units does pose restrictions (particularly on rotary table systems) on the size and weight of moulds acceptable, although this problem may be partially offset by the range of shot weight combinations which may be incorporated.[9]
(4) The high injection speeds necessary to fill complex mould configurations necessitates the use of high-MFI (melt flow index)

polymers, resulting in limitations on physical properties, i.e. impact properties.

2.2.2 Integral Skin Moulding

Integral skin moulding is a logical progression in the development of a moulding technique for the elimination of 'out-of-mould' surface finishing problems, with improved and more uniform physical properties, together with reduced polymer costs.

Clamping forces are higher than those used in conventional low-pressure moulding and the process could probably be defined as a medium clamping pressure system. For the purpose of comparison it has been included in the low-pressure moulding section to illustrate the pattern of process development (see Table 2).

The original concept of integral skin foam moulding was developed by ICI (UK) as a high-pressure moulding technique which also involved the use of a retracting mould face to induce foaming after injection.[10]

The process was subsequently, by mutual legislative agreement, licensed by Battenfeld, FRG, who, after extensive development, produced a medium-pressure integral skin foam moulding technique utilising multichannel nozzles for injection in conjunction with melt-metering control systems.[11] Details of the relevant stages in the development of the integral skin moulding process are shown in Table 3.

2.2.2.1 Advantages of integral skin moulding. The obvious advantages of this moulding technique include:

(1) the elimination of 'out-of-mould' finishing operations is possible;
(2) the variations in the thickness of both the foam core and the homogeneous outer layers give reasonable freedom in the selection of polymers in either level layer which permits the design of mouldings to satisfy environmental and/or mechanical design considerations;
(3) the equipment currently available has increased locking forces permitting its use, when necessary, for the production of homogeneous mouldings which utilise the total shot capacity (i.e. combined foam and homogeneous shot weights).

2.2.2.2 Disadvantages of integral skin moulding. The disadvantages of this moulding technique are minimal; however, various points should be noted.

TABLE 2
CELLULAR INJECTION MOULDING PROCESS

Process name	*No. of inj. stations*	*Type of blowing*	*Mould pressure*	*Surface condition*	*Mould action*	*Machine action*	*Machine type*
Dow	One	Trichloromethane	Low	Poor	None	None	Mod. CIM[a]
UCC	One	Nitrogen	Low	Fair	None	None	Special
UCC–Mod.	One	Chemical	Low	Fair	None	None	Special
Variotherm	One	Chemical	Low	Good	Heat–Cool	None	Special
Dow–TAF	One	Chemical—Freon	Medium	Good	Motion req.—pressurised	None	Special
Allied	One	Chemical	Medium	Good	None—pressurised	Egression	Special
Bulgarian	One	Chemical	Medium	Good	None—pressurised	Reservoir	Special
USM	One	Chemical	High	Good	Motion Req.	None	Mod. CIM[a]
ICI	Two	Chemical	High	Excellent	Motion Req.	Sequential injection	Special
Hanning	Two	Chemical	High	Excellent	None	Simultaneous injection	Special
Battenfeld	Two	Chemical	Medium	Excellent	None	Sequential injection	Special
Battenfeld	One	Chemical	High	Good	Pressurised	None	Mod. CIM[a]

[a] CIM, conventional injection moulding.

TABLE 3

INTEGRAL SKIN MOULDING TECHNIQUES

Process	*Moulding system*	*Nozzle configuration*	*Inject sequences*[b]	*Comments*
Original ICI system	High-pressure (retracting face)	Single channel	(a) Skin layer (b) Cellular core (c) Skin layer Foaming induced by the reduction in melt pressure	Found limited application, but was introduced very early in the development of foam moulding
Battenfeld Stage 1	Low-pressure[a]	Twin channel	(a) Skin to face opposite the gate (b) Simultaneous core/skin (c) Skin injection to seal the gate area	Most widely used system, can be used with suitably designed sprue and runner systems for multi-cavity systems
Battenfeld Stage 2	Low-pressure[a]	Three channels	As above	Whilst developed for mouldings with long flow patterns, e.g. containers, the system is currently restricted to centre-gated single-cavity systems

[a] Whilst referred to as 'low-pressure', clamping forces are 2·5–4·0 times greater than conventional low-pressure systems.

[b] Injection sequences are schematic with regard to Battenfeld systems since control valve systems allow variations in both feeds to permit mixed injection streams and variations in injection speeds during feeding in any channel to control skin thickness. Other factors to be considered include melt temperature and viscosity, together with mould surface temperature if surface break-through problems are to be minimised.