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Polymer Composite Research at LTC-EPFL

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Abstract: The activities of the Composite and Polymer Technology Laboratory of the Ecole Polytechnique Fédérale de Lausanne (LTC-EPFL) are presented. Based around eight core competencies, the laboratory's research focuses on innovative materials and processes for the rapidly developing polymer and composite field. The principle results of the research are highlighted and work on implementing these results into industrial production is described.

Keywords: Composite · Life Cycle Engineering · Material tailoring · Polymer · Processing

The overall objective of research at the Composite and Polymer Technology Laboratory (LTC) is to create the scientific base on which the next generation of materials and processes for the fast-growing polymer and composite field will be established. This implies novel approaches for tailoring material systems and process cycles. To this end, the laboratory is organised around eight interdisciplinary core competencies:

- Material tailoring
- Surface and interface engineering
- Impregnation and consolidation
- Material and process integration
- Internal stresses and dimensional stability
- Life Cycle Engineering
- Equipment and test method development
- Implementation of new materials technologies.

The research results in new materials with controlled rheology, solidification kinetics and surface characteristics (Fig. 1). Models for process simulation and techniques for cost-effective processing are developed. Quantitative durability analyses are derived for optimal life cycle strategies.

Emphasis is also placed on scaling to an industrial context. The laboratory's Industrial Implementation Group, IIG-LTC, collaborates closely with selected partners on the implementation of the innovative technologies resulting from the laboratory's research.

Among the teaching activities of the laboratory, courses are given in

- Polymer processing
- Rheology
- Recycling
- Polymer composites
- Life Cycle Engineering
- Materials technology

Furthermore, members of the laboratory regularly teach several continuing education courses.

Material Tailoring

Material and interface tailoring is investigated for improving material compatibility, bonding and mechanical properties. Particular emphasis is placed on the use of multifunctional modifiers based on dendritic molecules (Fig. 2). Fibre wetting, interfacial adhesion and durability are studied for structural composites, polymer foams and for functional composites. Knowledge of chemical and physical interactions in the bulk and at interfaces allows the development of novel high-performance materials.

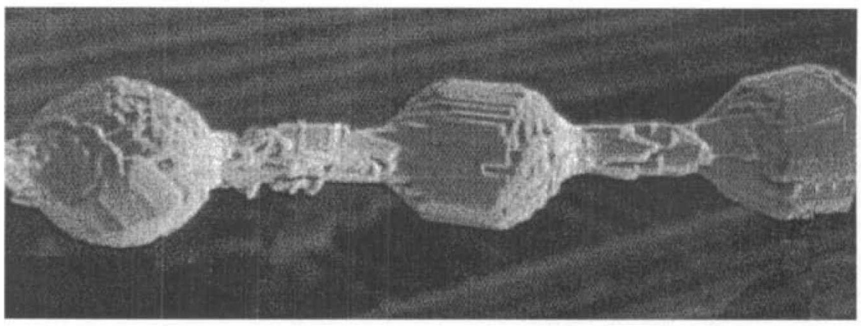

Fig. 1. Lactam-12 droplets crystallised on a carbon fibre.

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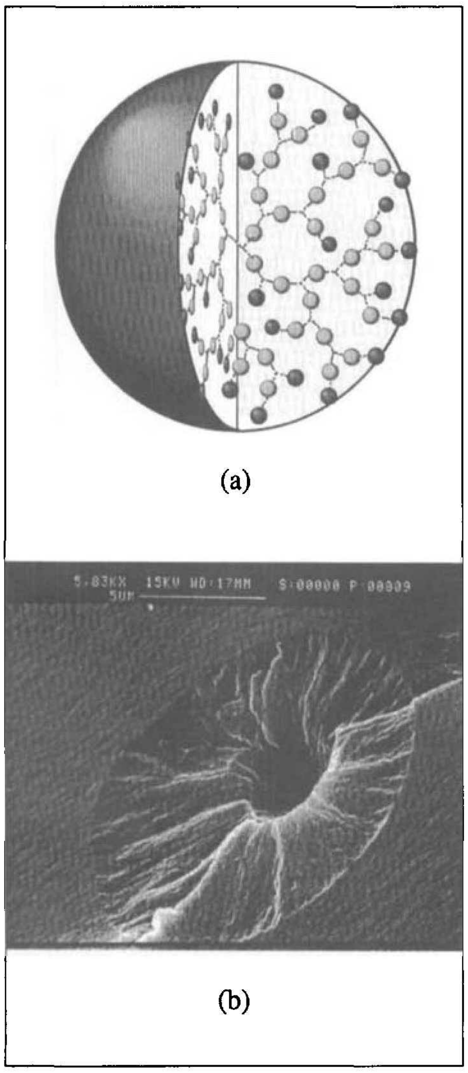

Fig. 2. a) Dendritic molecules designed with controlled surface chemistry and polarity for compatibilisation and b) toughening.

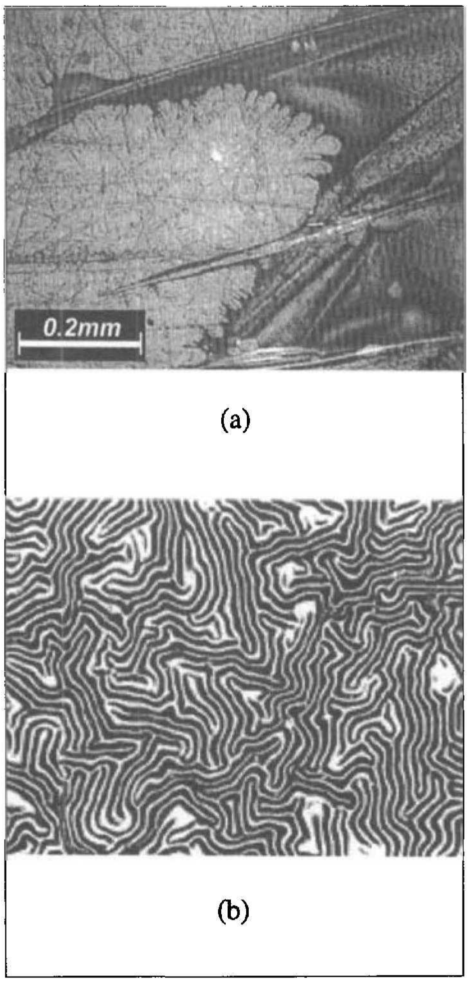

Fig. 3. a) Surface morphology of a polypropylene/glass fibre composite. b) Surface morphology of a matte coating by confocal laser scanning microscopy.

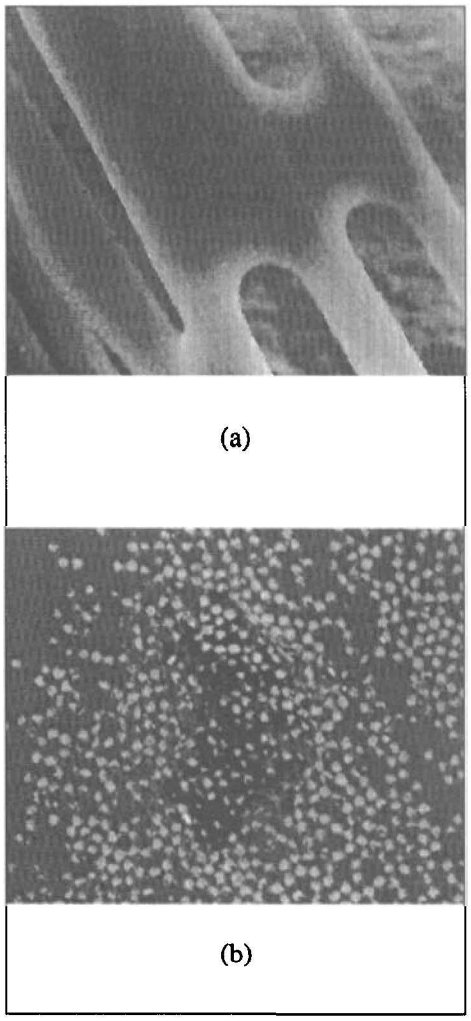

Fig. 4. The influence of a) capillary effects and b) air entrapment during consolidation of a fibre-reinforced thermoplastic.

Surface and Interface Engineering

Research is carried out on the interrelation between flow behaviour, solidification kinetics and microstructure in order to predict the quality and nature of surfaces and interfaces (Fig. 3).

The main topics of study, closely linked to the processing activities of the laboratory, are:

- fibre-fibre interactions during flow
- surface texture development during solidification
- blend and filled polymer compounding
- novel processing techniques for both thermal- and radiation-cured systems
- flow simulation in processing equipment.

Impregnation and Consolidation

Analytical and numerical models are developed to describe the mechanisms governing impregnation and consolidation. The occurrence of features such as voids and reinforcement distribution at both micro and macro scales is investigated. The models are used to define process windows, which guide the choice of optimal process parameters, for both conventional and non-conventional materials, such as adaptive composite materials. These are developed using the functional properties of Shape Memory Alloys as active damping materials (Fig. 4).

Material and Process Integration

The integration of materials and processing techniques aims to optimise manufacturing efficiency and to provide added value in parts. Various types of polymeric materials and composite preforms are developed and combined to offer a high degree of design freedom, geometric complexity and multi-functionality.

This research addresses several topics in processing and materials science (Fig. 5):

- tailoring of new composite preforms
- development of novel thermoplastic materials for liquid moulding and stamping of composites
- modelling of polymerisation kinetics and of rheological behaviour
- crystallisation and healing at interfaces
- interfacial adhesion and fusion bonding
- integration of consolidation steps and control of non-isothermal *in situ* bonding processes
- control of stress state and dimensional stability
- selective reinforcement of integrated parts
- synchronised moulding operations.

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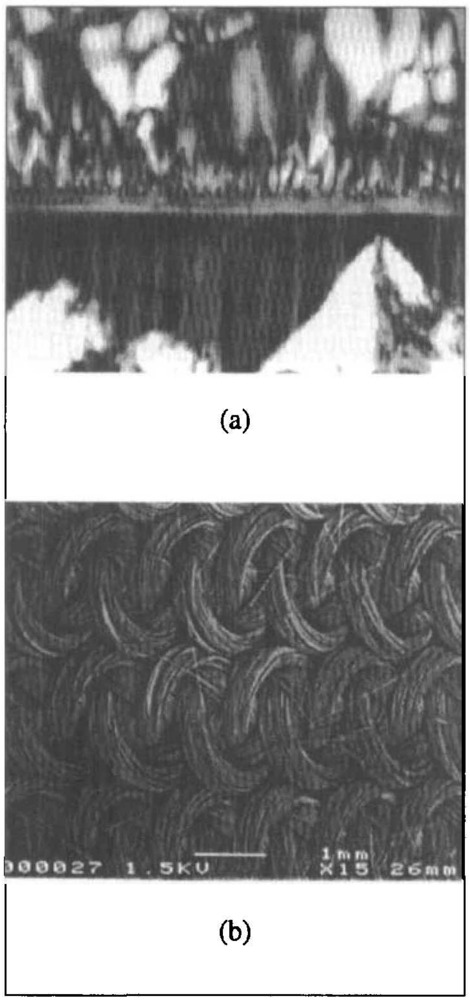


Fig. 5. a) Interfacial crystallisation under non-isothermal bonding conditions provides shorter bonding times during integrated processing. b) Novel knitted skins are used in thermoplastic sandwiches to achieve complex-shaped structures by direct cold stamping of flat panels.

Internal Stresses and Dimensional Stability

The mechanisms responsible for internal stresses in anisotropic viscoelastic systems are studied, in order to optimise process cycles and derive 'stress-free' materials. Measurement techniques and numerical prediction tools are developed to quantify the effects of internal stresses at both macro- and microscopic levels (Fig. 6).

Life Cycle Engineering

The objective of the work on Life Cycle Engineering is to tailor the durability of polymer-based materials. To this end, coupling analyses of time-dependent phenomena such as viscoelasticity and ageing are developed for accurate durability prediction. Research also focuses on nanosized gas-barrier coatings, reactive processing and recycling of polymers, and composites reinforced by renewable natural fibres (Fig. 7).

Systematic attention is paid to the modelling and control of interfacial interactions using specialised multifunctional molecules, and of stress fields by means of adapted process cycles.

This work provides vital input for environmental engineering strategies for increased resource efficiency.

Equipment and Test Method Development

In relation to the research activities, several innovative pilot installations have been developed for the manufacturing and characterisation of novel composite materials (Fig. 8):

- integrated processing system
- pultrusion line
- tow and sheet impregnation lines
- special moulding techniques
- instrumented thermally active moulds.

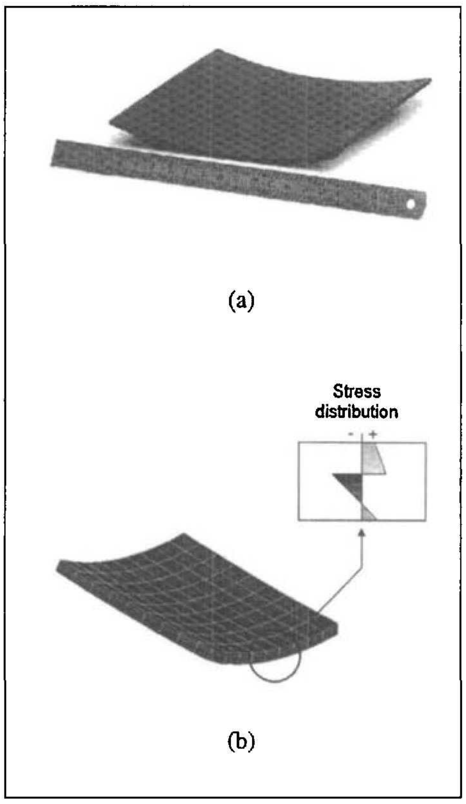


Fig. 6. a) and b) ANVIS, a 3D numerical tool for ANisotropic VIScoelastic materials, allows the evolution of internal stresses during both processing and service to be predicted.

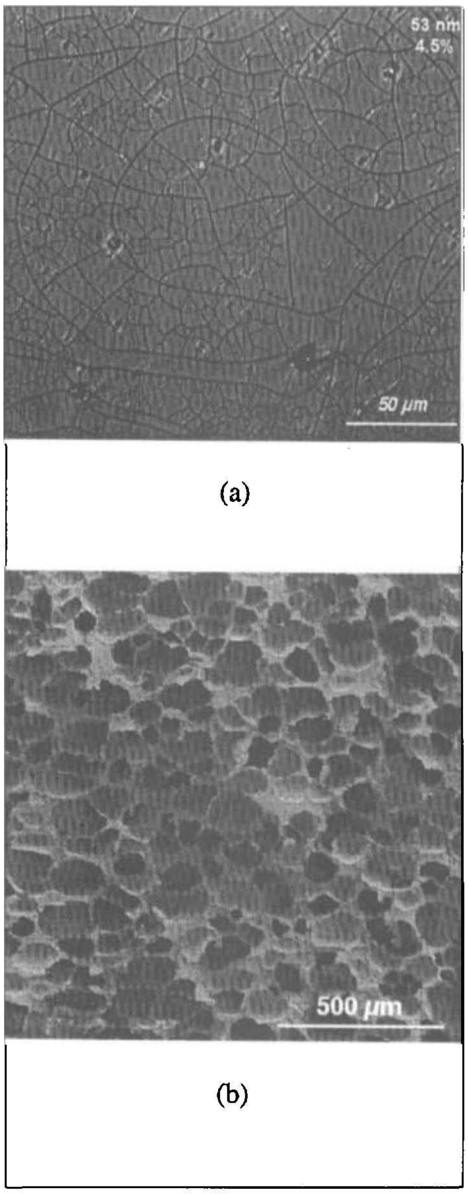


Fig. 7. a) The fragmentation of nanosized silicon oxide gas-barrier coatings on polymers is analysed to tailor the resistance of the multilayer system. b) Closed-cell microstructure of a recycled and branched polyethylene terephthalate (PET) foam produced using supercritical CO_2.

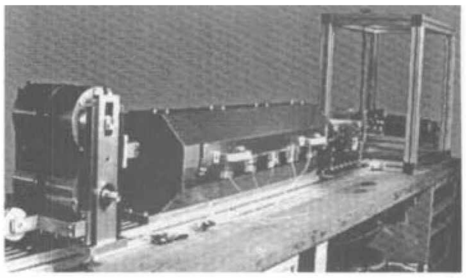
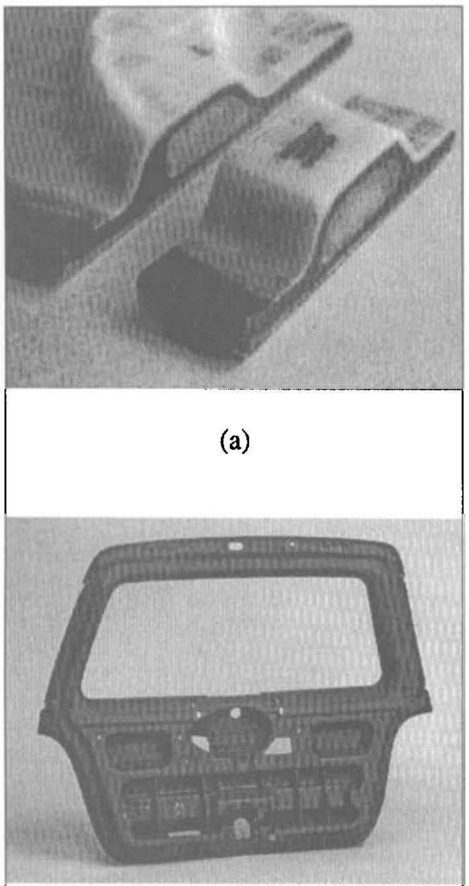


Fig. 8. Pilot line for fibre impregnation.

Implementing New Materials Technologies

To assess the strategic, financial and technological implications of introducing new materials technologies, a methodology has been developed in collaboration with the International Institute for Management Development (IMD). The approach quantifies the advantage/cost relation for a new technology, in terms of a 'Reason For Change' index. This methodology has been applied to developments in the construction, sport and automotive industries (Fig. 9).



(a) (b)

Fig. 9. a) and b) Application of integrated processing to a structural automotive part.

Industrial Implementation Group (IIG-LTC)

An activity has been established in the EPFL Science Park focussing on the industrial implementation of the innovative composite material and process technologies developed in LTC. Through close collaboration with selected industrial partners, the group develops cost-effective engineering concepts for prototype and production applications.

Main Research Achievements

The main achievements that have given the laboratory its profile and reputation in the scientific community can be summarised as follows:

- Design of novel dendritic molecules for unique processability, exceptional compatibility and highly enhanced toughness properties (patent).
- Development of a 'low-stress' hyperbranched polymer-modified epoxy.
- Identification of the two key interactions in concentrated fibre suspensions, with related constitutive equations.
- Derivation of the governing phenomena responsible for surface texture development in UV-curable powder coatings.
- A methodology and model for particle break-up in blends with high viscosity ratios.
- A generic methodology for impregnation, consolidation and process window modelling for a large range of novel polymer systems.
- Control of the vibration frequency of uniquely designed shape memory alloy reinforced composites.
- An integrated processing methodology for high-rate production with advanced composite materials (patents).
- Development and modelling of optimised preforms based on flexible hybrid yarns and tailored fibre architectures.
- Design and modelling of the polymerisation kinetics and of the rheological behaviour of a novel polyamide 12.
- Development of analytical tools for anisotropic viscoelastic materials and a related numerical code (ANVIS).
- Experimental and predictive tools for process-induced internal stresses, dimensional stability, defect initiation and interfacial adhesion in materials under thermomechanically and/or hygroscopically active conditions.
- Stress control method to increase the resistance of thin coatings on polymer substrates (patent).
- Low-density closed-cell foams based on recycled PET, using non-CFC based techniques (patent).
- Industrial implementation of preform systems for complex shape forming.
- Methodology for determining the technological, economic and strategic factors controlling implementation.
- Creation of an Industrial Implementation Group to implement new materials technologies.

The members of the laboratory publish regularly in acknowledged journals and conferences, with over 180 publications in the last three years. Seven patents have been filed on the results of the laboratory's research. Laboratory members are also active in international committees and organisations.

The laboratory is equipped with a range of processing equipment for the full-scale processing of polymers and composites.

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