Composites: Part A 91 (2016) 203–210

Contents lists available at ScienceDirect

Composites: Part A

journal homepage: www.elsevier.com/locate/compositesa

# In-mould gel-coating for polymer composites

Zoltán J. Gombos, John Summerscales *

Advanced Composites Manufacturing Centre, School of Engineering, University of Plymouth, Plymouth PL4 8AA, UK

ARTICLE INFO

Article history:
Received 4 August 2016
Received in revised form 7 October 2016
Accepted 8 October 2016
Available online 11 October 2016

Keywords:
A. Polymer-matrix composites (PMCs)
B. Adhesion
D. Surface analysis
E. Resin transfer moulding (RTM)

ABSTRACT

Surface coatings (gel-coats) are often used on commercial composite mouldings for cosmetic and/or durability reasons. They have traditionally been prepared in open moulds with styrene vapour allowed to escape to the workspace and environment. This paper considers the development of in-mould gel-coating processes. A Double Glass Plate Mould (DGPM) was used to prepare flat composite test panels. Laminates were manufactured by liquid composite moulding processes. Conventional hand painted gel-coat, innovative In-Mould Gel-Coating with a trilayer separator fabric (IMGC) or In-Mould Surfacing with a silicone shim (IMS) were studied. The surface quality of the final products was measured using a Wave-Scan device while the adhesion of the gel-coat was characterised by pull-off tests. The new processes offer reasonable properties in a cleaner, more controlled process.



## 1. Introduction

The fibre reinforced polymer matrix composites industry recently had annual production of nearly 3 million tonnes of material in the United States of America [1] and over 2 million tonnes in the European Union [2]. The high-performance sectors (aerospace, biomedical and defence) make up a significant proportion of the economic value. More than 80% of the market mass is "commercial" mouldings (e.g. automotive, chemical plant, construction, marine, rail, and energy) which often have a gel-coat surface for cosmetic and/or durability reasons. The gel-coat is normally applied by hand- or spray-painting onto the open mould followed by gel hardening in the open tool before composite lamination. This leads to consequent elevated levels of volatile organic compounds (VOC) in the workplace and the environment, and risk of human error in the production process. Harmonisation of styrene occupational exposure levels across Europe is expected to settle on 20 ppm, which will be difficult to achieve with open mould processes.

Technologies for in-mould gel-coating have recently been reviewed by Rogers et al. [3]. The principal drivers for change are the legislative framework for worker health, the environment and economic considerations. The principal in-mould gel-coating techniques are either insertion of a coating film into the mould tool or mould opening to create space for the injection of the coating. The latter technique is not suitable for surfaces/draft angles normal to the mould opening direction as little or no additional space is created in this plane.

Two recent patent publications have proposed methods which may address this limitation for liquid composite moulding technologies: In-Mould Gel-Coating (IMGC) using a separator fabric [4], and In Mould Surfacing (IMS) with a silicone shim [5]. Di Tomasso et al. [6] reported ranges for styrene time-weighted average (TWA) concentrations to be 28–70 ppm for the open mould gel-coating process and 0.23–0.37 ppm for the IMGC and IMS closed mould technologies studied in this paper. The new processes reduce average styrene emission levels by over 98% with obvious benefits for worker health and the reduction of environmental burdens. The two methods are discussed below.

### 1.1. In-mould gel-coating (IMGC)

The alternative to open-tool gel-coating is to mould the laminate in a closed mould tool then slightly open the mould to create space where the gel-coat can be injected. The mould-opening technique is adequate for flat mouldings but requires complex tooling for 3D components if a uniform gel-coat thickness is to be achieved. The initial concept for an IMGC process was to develop a spacer/barrier fabric (separator layer) to create a permeable void space adjacent to the mould tool surface into which gel-coat could be injected while keeping the laminate and gel-coat resins apart. This technique allows complete manufacture of a composite component in a closed mould tool system, thus minimising styrene emissions, and provides a controlled thickness gel-coat surface which sensibly conforms to the tool face topology. The concept is applicable to all Liquid Composite Moulding (LCM) processes,

* Corresponding author.
E-mail address: jsummerscales@plymouth.ac.uk (J. Summerscales).

http://dx.doi.org/10.1016/j.compositesa.2016.10.014
1359-835X/

especially Resin Transfer Moulding (RTM) and Resin Infusion under Flexible Tooling (RIFT, a.k.a. SCRIMP™ or VARTM). Automation of gel-coat application could deskill the process and improve repeatability of gel-coating.

The tri-laminate separator layer systems tested to date have proven to be the weak link when testing gel-coat-to-laminate adhesion strength. All components of the system should be unaffected (e.g. not swollen or dissolved) by the resin system in use. The tri-laminate must be achieved within an economic framework that allows the technology to compete with current low-skill processes until the legislative framework forces changes in the industry. The tri-laminate challenge for advanced textile processes is to generate a conformable, chemically stable, tri-layer spacer fabric with good mechanical integrity (adhesion between layers and cohesion within layers). The use of a separation layer could permit infusion of incompatible laminate and coating resins. Mechanical interlocking of the matrix and gel-coat by the separator layer could ensure greater adhesion. This could allow phenolic coatings for fire resistance, or poly/vinyl-ester coatings for good cosmetic finish, on any laminate resin system. The optimum separator layer has not yet been identified. Failure may occur where the separator layer joins to either the gel-coat or the laminate or there may be cohesive failure within the spacer/barrier fabric. The material combinations studied to date may limit the wider application of the technology. The merits and disadvantages of IMGC relative to hand lay-up are summarised in Table 1.

**Table 1**
The relative merits and disadvantages of IMS and IMGC relative to hand lay-up.

| IMGC | IMS |
|---|---|
| Advantages<br>• More controlled process for lay-up and gel-coat thickness control<br>• Faster gel-coating time<br>• Reduced gel-coat thickness relative to HLU<br>• Minimal styrene emissions throughout the process<br>• May be one of a limited number of choices if occupational exposure levels for styrene are reduced<br>• Incompatible laminate and gel-coat resins easily implemented<br>• Possibility of simultaneous gel-coat and laminate resin injection subject to appropriate control systems | Advantages<br>• More controlled process for lay-up and gel-coat thickness control<br>• Faster gel-coating time<br>• Reduced variation in gel-coat thickness<br>• Gel-coat thickness determined by chosen shim<br>• Minimal styrene emissions, except while removing shim<br>• May be one of a limited number of choices if occupational exposure levels for styrene are reduced<br>• Shim may be ~€20/m$^2$ with potential for >10 product cycles/shim |
| Disadvantages<br>• Collapse of the separator layer under consolidation pressure leading to reduced permeability and inhibiting the flow of gel-coat<br>• Print-through of fibres in the separator layer, or close to the gel-coat surface, affecting surface finish and compromising customer acceptance, service, durability and repair<br>• Potential for wicking of moisture through the fabric, particularly over extended timescales<br>• Separator layer drape/conformability may be limited for complex three-dimensional tools<br>• Folds, wrinkles and joints where components exceed standard fabric roll widths<br>• Sharp corners in the tool could pierce the separator layer<br>• Reduced permeability to the resin system adjacent to 3D features in the mould<br>• New technology without service history biasing clients against adoption<br>• Additional costs may be unacceptable to industry until driven by changes in VOC regulations<br>• Development separator fabrics are likely to cost >€5/m$^2$ in production | Disadvantages<br>• Styrene emissions to the workplace when the mould tool is opened to remove the shim<br>• Silicone transfer to the mould and component surfaces with the potential for weak interfaces where subsequent bonding (or painting) are required<br>• Control of part alignment on very large structures (boat hulls or wind turbines) especially if the component separates from the mould during shim removal<br>• Shim handling and consequent labour requirements<br>• Potential for sagging issues dependent on mould geometries<br>• Limited options for different chemistry in the gel-coat and the laminate resins<br>• Limited durability of the shim over repeated process cycles<br>• Scalability of the process for very large components<br>• Additional costs may be unacceptable to industry until driven by changes in VOC regulations |

### *1.2. In-mould surfacing technology (IMS)*

An alternative approach investigated was the IMS technology patented by Alan Harper Composites (AHC) [5]. This uses a removable, preferably reusable, low adhesion elastomeric (silicone or similar) shim in the mould tool during lamination to define the space that will become the gel-coat layer. After laminating the component with the shim in place in the mould, the mould is opened at the appropriate degree of cure to remove the shim while the component remains attached to the counterface of the mould, then the mould is closed before gel-coat is introduced into the remaining space. The merits and disadvantages of IMS relative to hand lay-up are summarised in Table 1.

This paper considers both the IMGC and IMS technologies as potentially viable routes to closed mould gel-coating processes. Key performance indicators (surface quality and pull-off adhesion tests) are measured and referenced to values from conventional hand painted gel-coat techniques. Surface quality is often measured to quantify gloss, waviness and print-through [7–9] with the automotive industry using goniophotometry [10], ASTM E430–11 and Wave-Scan instruments [11–13]. It is essential for the composites producers in the European Union to be ready for any impending changes to permitted styrene levels arising from the Registration, Evaluation, Authorisation and restriction of CHemicals (REACH) regulations. As Robertson [14] drawing on Willard [15] and Doppelt [16], wrote "[p]reparing in a proactive orderly way is almost always more cost-effective than having to respond reactively to a changing regulatory environment".

## 2. Experiments

### *2.1. Materials*

The materials used during the experiments are described below. For mould release Loctite Frekote 770-NC semi-permanent mould release (batch LN2CAA9290 1632) and Meguiar's Mirror Glaze no. 8 wax M-0811 were used. DeIjssel (Moordrecht, NL) 'special VI ISO' white pigmented polyester gel-coat (manufacturer data sheet; 600 mPa.s viscosity; experimental measurements: 46.4 ± 11.1 MPa tensile strength, 3.9 ± 0.3 GPa tensile modulus, 1.4 ± 0.4% elongation at break, tested according to EN ISO 527-2 after 16 h cure at 40 °C then post-cure for 4 h at 80 °C) with 2% Butanox M-50, methyl-ethyl ketone peroxide (MEKP) catalyst; DSM Synolite 1967-N-1 unsaturated DCPD-based polyester resin (manufacturer data sheet for resin cured with 1.5% NL49P accelerator +1% Butanox M-50 MEKP catalyst, cure for 24 h at room temperature followed by 24 h post-cure at 70 °C: 160–180 mPa.s initial viscosity, 70 MPa tensile strength, 3.8 GPa tensile modulus, 2.3% elongation at break, according to EN ISO 527-2) with 1.5% Butanox M-50 MEKP catalyst and Scott Bader Accelerator G (1% solution of cobalt soap dissolved in styrene) were used. The reinforcement was 300 gsm Saint Gobain Vetrotex Unifilo U850 random swirl glass fibres. Baltex (Ilkeston, UK) and CentroCot (Busto Arsizio, Italy) supplied tri-laminate fabrics as separator layers. They consist of polyester (PET) knitted fabrics adhesively bonded on both sides of 50 μm impermeable polyurethane (PU) film. For RTM/IMS technology, a sprayed