# IMPORTANCE OF THE VACUUM IN RAPID TOOLING OF POLYMERIC-BASED MOULDS

*P. V. Vasconcelos, IPVC-ESTG, Portugal*
*F. Jorge Lino, FEUP, Portugal*
*R. J. Neto, INEGI, Portugal*

## Abstract

Metallic powders are typically mixed with epoxy and polyurethane resin systems to improve the moulds thermal conductivity. The critical problem to produce these mixtures for Rapid Tooling applications is the difficulty of eliminating the entrapped air, introduced during the processing due to the high viscosity of the mixture, especially in the presence of high aluminium concentrations. When air bubbles are retained in the resin/model interface, superficial defects are generated which render inoperative the Rapid Tooling moulds, and consequently the advantages of these new technologies.

In this work, a specific methodology is presented to reduce the porosity level, not only in these typical mixtures, but also in hybrid ones, manufactured with aluminium particles and milled fibres, which have a even worse tendency to produce pores in the composite interface.

## Introduction

Liquid epoxy resins exhibit a good mixture capacity with other reinforcement materials, used in the granular or fibre form. Composite materials with intermediate properties are created from these mixtures and are the result of the combined action of the individual constituents.

The filled resins (with metallic particles) are frequently used in the mould manufacturing, specifically in the scope of Rapid Prototyping (RP) and Rapid Tooling (RT) technologies [1-3]. The composite resin moulds, having a low cost processing, are very competitive when applied in the manufacturing of low volume series of plastic parts.

It was possible to show that small amounts of milled fibres, namely glass and carbon fibres enhance significantly the wear resistance of the resin moulds [4-6]. To avoid difficulties in the processing and great reductions in the aluminium concentrations, milled fibres of these two materials were used in small concentrations (fig. 1) [7]. Filled composites with high aluminium particles concentrations and hybrid composites (composed with aluminium particles and milled fibres) were produced and tested in laboratory and in an industrial mould for thermoplastic injection, with good results (see fig. 2). The study of techniques for the production of moulds with reduced porosity is considered of great importance for the implementation of these technologies that have the capacity of obtaining prototypes in a short period with reduced costs.

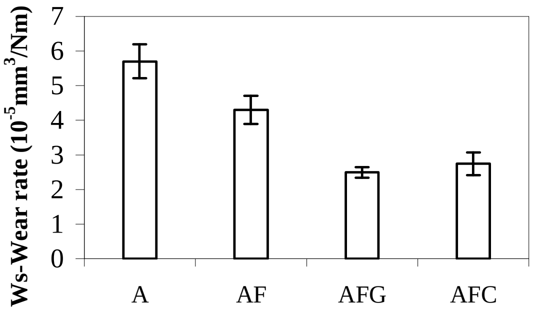


**Fig. 1.** Abrasive wear resistance of the studied materials (A-epoxy; AF-aluminium filled epoxy; AFG and AFV- aluminium filled epoxies with milled glass and carbon fibres, respectively) [7].

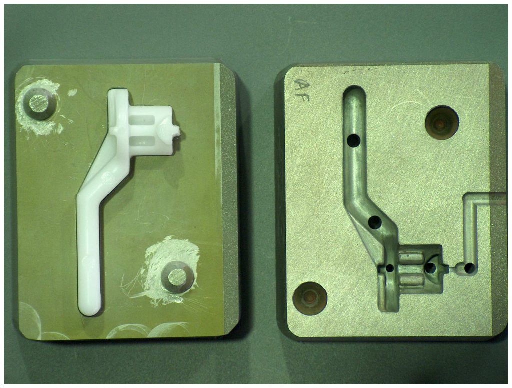

**Fig. 2.** Resin mould for thermoplastic injection with an injected part in polyacetal.

## Experimental details

### *Materials*

The epoxy matrix system of the studied composites was designated by the letter A. Its composition and main characteristics are indicated in the table I [8].

The two-phase composites were designated by two letters, with the first letter indicating the epoxy system (A) and the second one (F), the dispersed phase, which is aluminium particles of P200 degree.

The three-phase or hybrid composites were designated by 3 letters, where the two first letters have the same meaning previously defined. The third letter indicates the type of milled fibre glass (V) or carbon (C). The technical characteristics of the dispersed materials are presented in the table II. The composition in terms of volume fraction of the studied composites is presented in the table III. Figures 3 and 4 show the images of the polished surfaces of the AFV and AFC composites, obtained in an optical microscope.

**Table I** Epoxy system composition and characteristics.

| **Epoxy system** | **Araldite LY5210/Aradur HY2954 (Vantico-USA)** |
|---|---|
| Epoxy components | ● TGDDM = N, N, N´, N´- tetraglycidyl – 4, 4´ - diaminodifenylmethane ● butahedioldiglycidyl ether |
| Curing agent | ●2, 2'-dimetil-4,4'-metilenobis (ciclohexilamine) |
| Viscosity at 25ºC (mPa.s) | 700-900 (not filled) |
| Resin /hardener ratio | 100 / 53 |
| "Pot life" | 7 – 9 h |
| Curing time | 65 h |

**Table II** Technical characteristics of the aluminium particles and the milled fibres.

| **Fibre type** | **Manufacturer** | **Dimensions** | **Sizing** |
|---|---|---|---|
| Aluminium particle | Hexcel (France) | P200 degree | - |
| Glass fibres | PPG (USA) | 215/11 μm (l/d)* | Polyvinyl acetate with silane |
| Carbon fibres | Toray (Japan) | 63/7 μm (l/d)* | 1 wt% epoxy |

- l/d – fibre length/diameter.

**Table III** Composition of the studied materials.

| **Designation** | **AF** | **AFC** | **AFG** |
|---|---|---|---|
| Composition (volume fraction %) | A – 55.5<br>F – 44.5 | A – 57.5<br>F – 38.5<br>C - 4 | A – 57.5<br>F – 38.5<br>V - 4 |

## *Processing*

The vacuum processing ensures reproducible results, avoiding pouring repetitions, lost time and an excessive consumption of expensive raw materials. Figure 5 shows the vacuum equipment used in this study (pump vacuum capacity = 50 Pa).

In the present study, composites with high concentrations of additives were developed, which due to the high viscosities, disables the accomplishment of mechanical mixture in vacuum. However, with a specific technique it is possible to obtain mixtures almost free of porosity.

The basic idea consists of creating vacuum conditions that not only eliminate the air inside the camera, but also inside the liquid resin, before and during the pouring. This procedure allows the material of the mould to exhibit good physical integrity and mechanical performance, and a functional surface free of defects, namely air bubbles. The procedure that assures these reproducible results is the following:

1. In a first stage, the components are manually mixed (fig. 6a), and the introduced air removed in the vacuum chamber (fig. 6b). There is an abundant foam formation and the container should have an adequate height to contain the produced foam (4 times taller than the liquid mass height).

2. The material is placed in the moulding container (if the previous is insufficient) and submitted to a second degassing stage. The air still entrapped in small bubbles (produced in the mixture process) suffers expansion, forming larger bubbles that remain arrested inside the viscous mass. Additionally, it is necessary to promote the agitation of the liquid mass to drive the air bubbles

to the surface (fig. 6c). It is advisable a degassing period of time higher than 30 minutes to release a significant amount of retained air. This air removal stage is interrupted about 15 minutes before the pouring stage to allow the stabilization of the mixture.

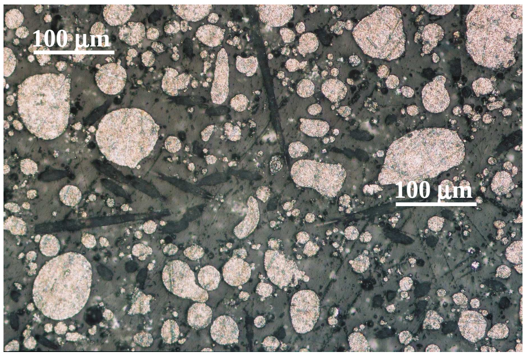


**Fig. 3.** Epoxy composites with aluminium and milled glass fibre (AFV).

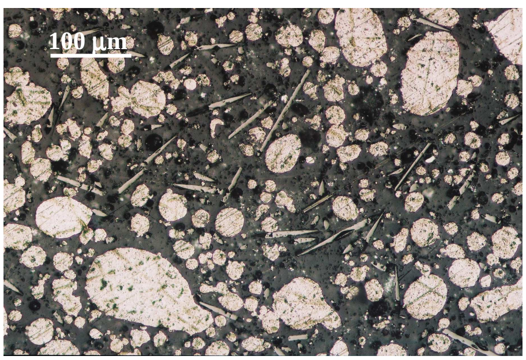


**Fig. 4.** Epoxy composites with aluminium and milled carbon fibre (AFC).

**Fig. 5.** Vacuum equipment is an indispensable tool to control the porosity level in resin composites.

3. The pouring of the composite should be performed at a slow rate to promote a laminar flow of the viscous mass and to release residual bubbles (fig. 6d).

This method proved to work with good results, even in resins filled with high concentrations of particles and exhibiting high viscosities. The probability of detecting macroporosity in the functional surfaces of the mould seems to be minimum.

The metallic fillers does not only affects the viscosity, but also the curing time of the filled resins that is about 60% longer than in the unfilled resins.

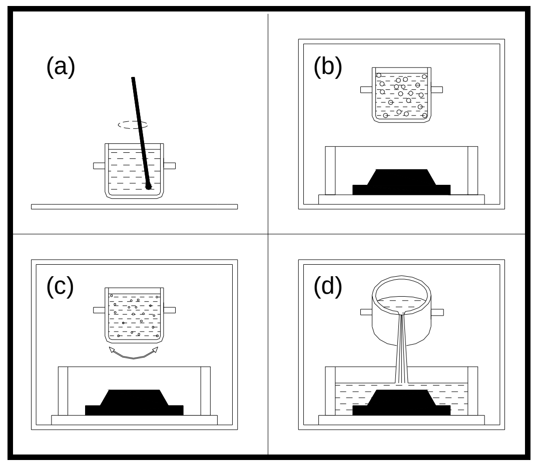


**Fig. 6.** New resin processing method using vacuum pouring: (a) manual component mixture; (b) first degassing; (c) second degassing with agitation; (d) pouring.

### *Porosity*

Automatic image analysis proved to be inadequate because some of the digitized images did not have enough contrast. Punctual analysis was used to evaluate the existent porosity in the studied materials processed in identical conditions. The method used the acquisition, through a video camera, of the image obtained in the microscope and a subsequent treatment in a computer program (binary image analysis through a histogram of grey levels).

The punctual analysis method consists in placing a net of points - mesh - over several random fields of the sample, and count the number of points of the mesh that are located over the phase to measure (in this case, pores). The volume fraction of the phase is defined as the ratio among the number of points that are located in that phase and the total number of points.

Digitised images were used and treated using the Photoshop software. On each image, a virtual mesh of 25 µm square width was superimposed and the magnification was selected to allow a clear observation. About 32 fields composed by 135 points were measured in each material (fig. 7).

The magnification and illumination were kept constant in the microscope. The image treatment with Photoshop program was performed under the same brightness and contrast conditions.

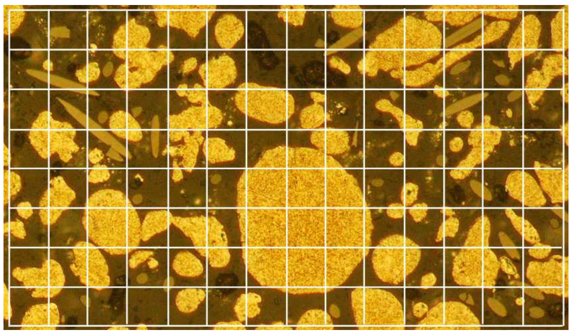

**Fig. 7.** Mesh type used for porosity determination by the method of punctual analysis. Black colour areas identify the pores.

The aluminium filled composites and the hybrid composites were analyzed. In relation to the first ones, after a previous degassing, three pouring methods were employed:

- Pouring at room pressure (V1);
- Pouring at room pressure, followed by new degassing (V2);
- Pouring in vacuum condition (V3).

All these methods were employed with AF composites and the porosity level was compared to evaluate the method performance. With AFG and AFC composites that exhibit higher viscosities and are more prone to generate porosity, only the V3 method was employed. In the hybrid composites, the degassing time to cast the composite, in vacuum conditions, was equal to the final degassing time accomplished in the V2 method.

## Results

The method of punctual analysis was employed to evaluate the microscopic porosity (not visible without magnification). The pore volume fraction results are indicated in the table IV. The vacuum pouring method (V3) proved to be the most efficient in reducing the porosity level of the resins composites. As one can see, for the same degasification time, the hybrid composites, due to the presence of the fibres, present higher porosity levels, as it was expected. The reduced fibre dimension and the packing difficulty, associated to their morphology, hinder the resin wettability. These conditions imply a more difficult processing and a tendency to increase the porosity level in the cured composite.

The macroporosity found on the moulds surface compromises seriously the moulds functionality. This porosity, introducing superficial defects in the moulded parts, can lead to the rejection of the mould. It was also verified that the V3 method is among all the more reliable method, because it reduces the probability of the porosity to take place.

## Conclusions

Composite moulds, based on polymeric materials, to be competitive alternatives in the area of indirect rapid tooling, need to be optimised in composition and processing conditions.

The processing condition presented in this work proves to be a reliable and efficient solution, which was already tested in industrial conditions with good results. If the vacuum machine is adapted to promote a better agitation of the mixture it is expected that the porosity concentration in the cured composite could be even more reduced.

**Table IV** Pore volume fraction in the epoxy-based composites obtained by the punctual analysis method.

| **Pore volume fraction (%)** | | | | | |
|---|---|---|---|---|---|
| | Aluminium filled composites | | | Hybrid composites | |
| Composite-Method | AF-V1 | AF-V2 | AF-V3 | AFC-V3 | AFG-V3 |
| Pore total > 3 $\mu m^2$ | 4.2 | 3.4 | 2.7 | 5.1 | 4.8 |
| Pores with area from 200 to 1000 $\mu m^2$ | 0.52 | 0.39 | 0.37 | 0.53 | 0.42 |

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## Keywords

Vacuum, Rapid Tooling, Epoxy based composites.

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