

INDIRECT RAPID TOOLING WITH ALUMINIUM AND MILLED FIBRE REINFORCED RESINS

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Abstract

It is well known that Rapid Prototyping (RP) and Rapid Tooling (RT) are fundamental technologies to reduce the time to market and consequently increase productivity and competitiveness of companies working in different industrial sectors. RT with epoxy resins is presently accepted as an established process of indirect rapid tooling. However, patents, processing difficulties and companies' limitations disable a wider implementation of this technology. This paper presents the experimental results of a detailed work, conducted at INEGI, to manufacture moulds for plastic injection, with tailored properties, using RP models and aluminium filled and fibres reinforced epoxy resins.

Keywords: Rapid Tooling, Injection Moulding, Epoxy Resin Composites, Milled Fibres

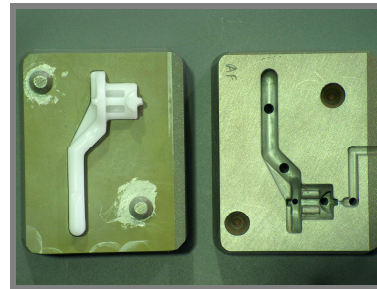
1. Introduction

The rapid development and the easy accessibility to CAD programs associated to the Rapid Prototyping (RP) and Rapid Tooling (RT) technologies were fundamental to give a new impulse to the resin tooling. The Design and Product Development departments of companies use RT systems for the production of prototypes moulds in silicone, polyurethane and epoxy resins, just to mention the more commons. These prototype moulds allow the production of dozens to hundreds of parts for visual aids, geometric and dimensional analysis, and frequently thermoplastic functional prototypes. Particularly, for these last prototypes, epoxy based composites are used to manufacture the injection moulds for thermoplastics that can withstand the high pressures and temperatures of the injection cycle. Naturally, the expected life of these moulds lies between 100 and 1000 cycles and is significantly lower than the one obtained with the conventional metallic moulds. As the development of an industrial product rarely demands a number of parts higher than 200, it can be concluded that these technologies are very attractive and well adjusted for this specific

application [1-4]. Fig. 1 shows two of these moulds that were used in the production of pre-series of an automatic teller machine and of a latch, respectively.



a)



b)

Fig. 1. Epoxy based composite moulds for thermoplastics injection: a) terminal of an automatic teller machine; b) latch. The figure also shows the injected parts.

The composite moulds based on high temperature epoxy resins, used in rapid tooling, exhibit an intermediate durability between the soft and the hard tooling. This is due to the combination of the high strength and good thermal stability of the epoxy resin, with the stiffness, hardness and good thermal conductivity of the metallic particles. This last characteristic reduces the thermal shock in the mould in each injection cycle, lowering the mould temperature and the injection cycle time. This work intends to contribute to the implementation of this rapid tooling technology as viable alternative for the production of prototypes and pre series with reduced costs and time-to-market, increasing companies' competitiveness [5-7].

2. Experimental

The main parameters considered in the selection of the polymeric matrix were:

- Behaviour at high temperature;
- Viscosity and adhesive capacity;
- Low cost.

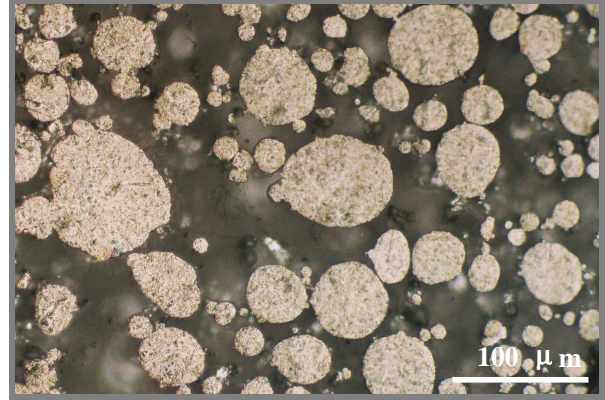
After the epoxy system selection, it is advisable to perform some experiences and tests to improve the mixture formulation and the processing technique and, consequently, the general properties of the composite mould. The components concentrations and the curing cycle should be properly adjusted to optimise the composite properties.

After studying the parameters that control the selection of materials and their processing, and characterize the epoxy-based composites, aluminium filled composites (AF), with different aluminium particles concentrations, and hybrid composites composed by aluminium particles and milled glass fibres (AFG) were produced [8, 9]. Their respective microstructures are presented in Fig. 2, and show grey aluminium round particles and dark elongated glass fibres.

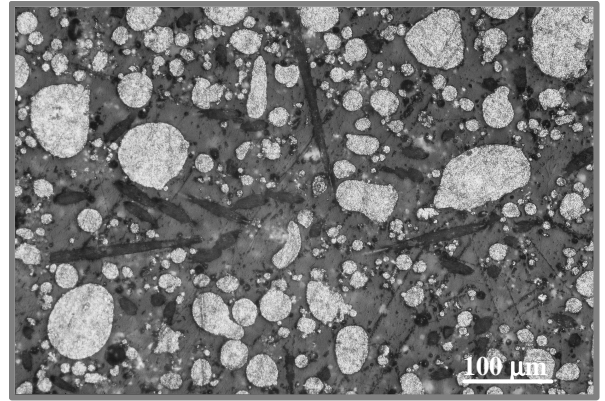
The epoxy matrix system composition is indicated in table 1 [10]. The technical characteristics of the dispersed materials are presented in table 2, while table 3 indicates the composition of the three materials produced.

The processing conditions, the dimensional changes occurring during the process, the mechanical and the wear resistance evolution with the temperature, and the thermal conductivity, were studied with detail, with the objective of producing moulds with optimised properties for thermoplastic injection.

After being characterized in laboratory, the most promising composites moulds were tested in an industrial thermoplastic injection machine.



a)



b)

Fig. 2. Epoxy resin composites filled with: a) round aluminium particles (AF); b) aluminium and milled elongated glass fibres (AFG).

Table 1. Epoxy system composition.

Epoxy system	Araldite LY5210/Aradur HY2954 (Vantico-USA)
Epoxy components	<ul style="list-style-type: none"> • TGDDM = N, N, N', N' - tetraglycidyl - 4, 4' - diaminodifenylmethane • butahedioldiglycidyl ether
Curing agent	<ul style="list-style-type: none"> • 2, 2'-dimetil-4,4'-metilenobis (ciclohexilamine)

Table 2. Technical characteristics of the aluminium particles and of the milled glass fibres.

Fibre type	Manufacturer	Dimensions	Sizing
Aluminium particle (>98.7% aluminium)	Hexcel (France)	P200 degree	-
Glass fibres	PPG (USA)	215/11 μm (l/d)*	Polyvinyl acetate with silane

*l/d – fibre length / diameter.

Table 3. Designation and composition of the materials produced.

Epoxy resin (A)	Aluminium filled composite (AF)	Hybrid Composite (AFG)
A – 100%	A – 59 % F – 41 %	A – 57.5 % F – 38.5 % G – 4 %
A – Epoxy resin; F - Fine aluminium particles; G – Glass milled fibres		

3. Results

3.1 Laboratorial

Considering the specification of the epoxy systems and the particularities of the processing techniques for these types of composite materials, the following conclusions should be highlighted:

Long pot-life resins (several hours) allow the use of more complex processing methods, ensuring the reduction of the micro and the macro porosity [11]. Fig. 3 describes the main steps used in this work that assured a very low level of porosity in the composites produced.

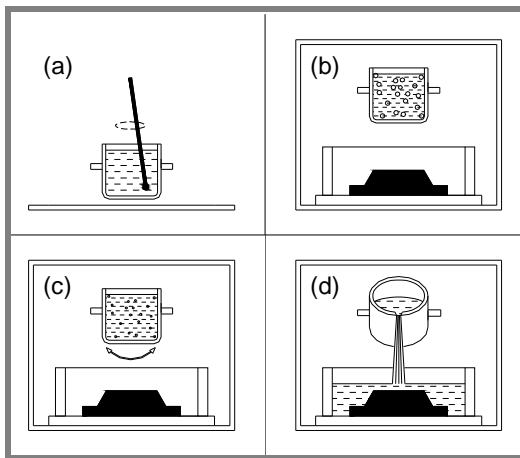


Fig. 3. New resin processing method employed in this work that uses vacuum pouring: a) manual component mixture;

b) first degassing; c) second degassing with agitation; d) vacuum pouring.

The gelation process of this resin system, occurring at a higher temperature (40°C) than the room temperature, promotes a thermal expansion of the model that reduces its dimensional accuracy. This is particularly severe when a silicone model is used, because this material has a higher coefficient of thermal expansion than other types of RP models.

- The post-cure at high temperature, necessary to guarantee the complete cure of the composite, leads to higher constraints, tensions and distortions than in less demanding resins.

- The complexity of the curing mechanism of these amino-glycidyl epoxy resins demands a high temperature and long thermal cycles to ensure their complete cure [12-14], representing a disadvantage in Rapid Tooling applications (more difficulties in controlling dimensions and distortions of the tools).

Flexural tests show that aluminium particles addition improves significantly the elastic modulus. The addition of milled fibres to these composites contributes to a small increase on the flexural strength, as one can see in the graph of Fig. 4.

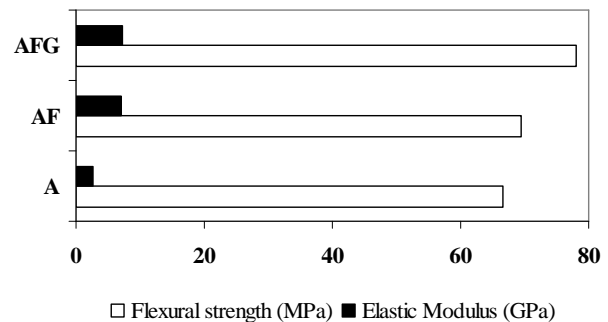


Fig. 4. Flexural strength and elastic modulus of the A, AF and AFG materials.

Fig. 5 presents the dynamic mechanical thermal analysis (DMTA) results, showing that the addition of metallic particles improves the material stiffness, at both room temperature and high temperatures (more

pronounced below 200°C). At 200° C the elastic modulus is abruptly reduced due to the glass transition temperature. The graph only presents AF curve because AFG exhibits a similar behaviour.

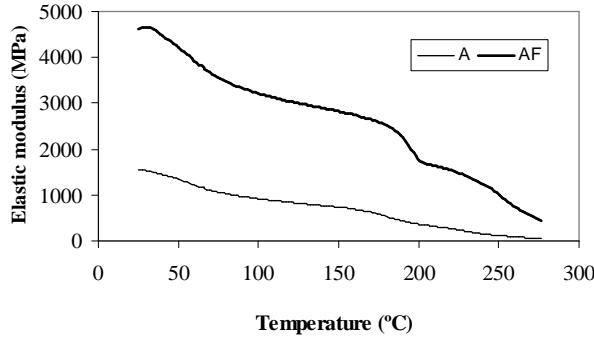


Fig. 5. Elastic modulus as a function of temperature, for the neat resin (A) and aluminium filled epoxy (AF), obtained in DMTA tests.

The incorporation of high aluminium particles concentrations allows a significant reduction on the coefficient of thermal expansion (CTE) (Fig. 6), which is very important for controlling the dimensional variations occurring from the initial prototype to the final mould. These aluminium particles have also the advantage of increasing the thermal conductivity of the composite, relatively to the epoxy matrix, by about an order of magnitude. This is a very important factor because it reduces the injection cycle of the mould. The milled glass fibres, although well mixed in the AFG composite, have a small negative effect on the thermal conductivity, as one can see in Fig. 7.

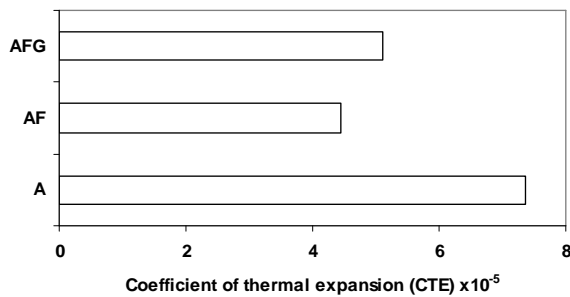


Fig. 6. AF and AFG composites exhibit lower CTE than the A epoxy resin.

Fig. 8 shows the specific wear rate results for the A, AF and AFG materials, at room temperature and at 160°C, determined in a reciprocating tribometer.

Details of this test can be obtained in reference [15]. The AFG hybrid composite exhibits a significantly better wear behaviour than the conventional AF composite. As expected, the temperature increase enhances considerably the wear rate, with drastic values for the AF composite.

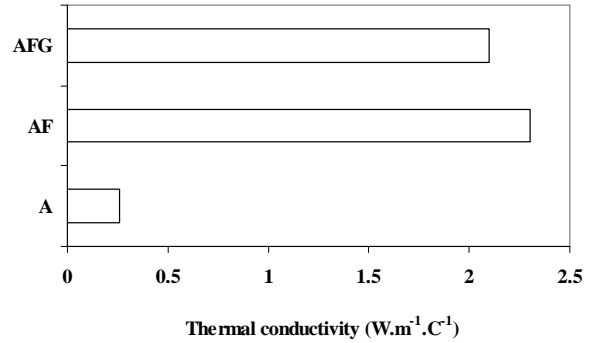


Fig. 7. Thermal conductivity of the three tested materials.

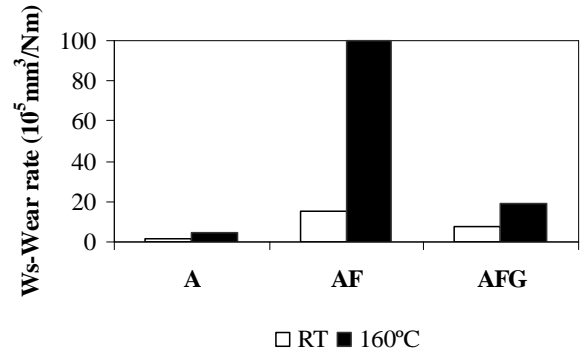


Fig. 8. Specific wear rate of epoxy (A), epoxy with aluminium (AF) and epoxy with aluminium and fibres (AFG) systems at room temperature and at 160°C, determined in the reciprocating tribometer.

3.2 Industrial environment

AF and AFG moulds of a latch were placed in an industrial machine and polyacetal parts were injected in them. The moulds wear was measured by an indirect approach, through the determination of the dimensional differences measured in the injected parts, spaced by 50 parts in the injection cycles. The six dimensions that were controlled in each part are indicated in Fig. 9. The results obtained are presented in Table 4.

After 50 injection cycles, AF mould reveals a small wear, while in the AFG mould no significant wear was detected (accuracy: 0.01 mm).

The mould surface finishing was also analysed, after 90 injection cycles. The initial medium roughness of both moulds was $0.85\mu\text{m}$ and, after 90 injections, it was $1.41\mu\text{m}$ for the AF mould and only $0.94\mu\text{m}$ for the AFG mould (Tab. 5). These results also confirm that the AFG composite mould presents better physical integrity and erosive wear resistance than the AF composite, which is in accordance with the laboratorial results.

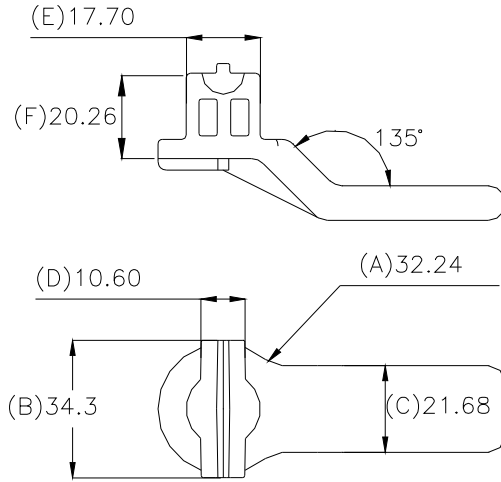


Fig. 9. Latch model dimensions used in the geometric control.

Table 4. Results of the dimensional control of the injected parts in the AF and AFG moulds, spaced by 50 injection cycles.

Dimensions Reference	A	B	C	D	E	F
AF difference (mm)	0.02	0.10	0.03	0.03	0.05	0.03
AFG difference (mm)	0	0	0	0	0	0.01

Table 5. Surface roughness of the studied moulds, after 90 injection cycles.

Mould	Roughness criteria, (μm)		
	Ra	Rz	Rmax
AF	1.41	11.37	13.83
AFG	0.94	6.84	7.96

SEM images of the two composites moulds surfaces (Fig. 10) also reveal a deeper excoriation in AF moulds, confirming the quantitative results.

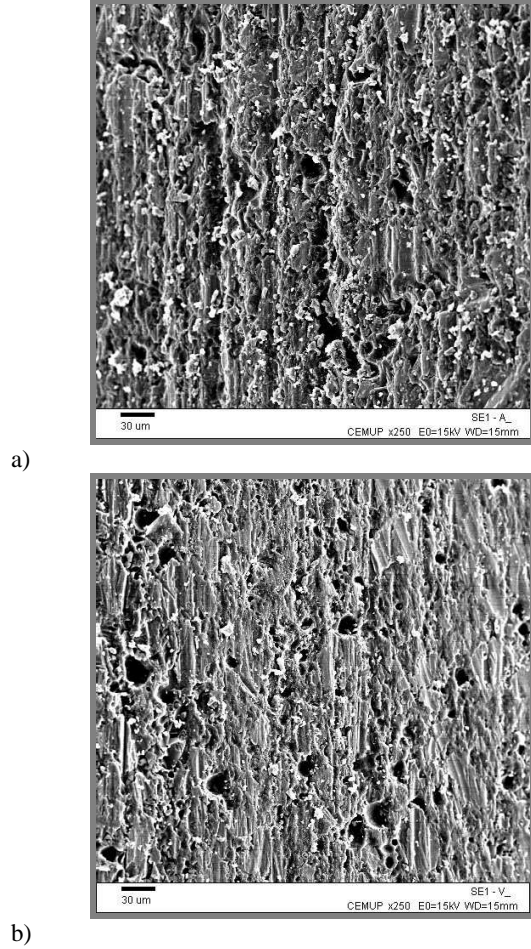


Fig. 10. SEM images of the moulding surfaces, revealing the degree of excoriation in the thermoplastic flow direction of the: a) AF and; b) AFG moulds. This mould shows a smoother surface.

4. Conclusions

Epoxy resin composites are suited for rapid tooling applications if adequate processing conditions and tailored concentrations of the different composite components are applied.

In this paper it was shown that:

- The thermal conductivity of the composites is related with the capacity of metallic loading allowed by the epoxy system. High metallic concentrations (40%) reduce the injection cycles and the thermal shock and increase the mould life. The addition of the metallic particles also improves the elastic modulus at low and high temperature and reduces the CTE;
- Milled glass fibres, when added in small concentrations (4 %) to the epoxy aluminium filled composites improve substantially the composite abrasive and erosive wear resistance and consequently

turn this type of composites particularly indicated for rapid tooling applications.

Acknowledgements

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