ELSEVIER

Journal of Materials Processing Technology 170 (2005) 277–283

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Impact fracture study of epoxy-based composites with aluminium particles and milled fibres

P.V. Vasconcelos [a], F.J. Lino [b,*], A. Magalhães [c], R.J.L. Neto [b]

[a] *Dep. de Ciências de Engenharia, ESTG/IPVC, Ap. 574, 4900-908 Viana do Castelo, Portugal*
[b] *INEGI – Instituto Engenharia Mecânica e Gestão Industrial, Rua do Barroco, 174, 4465-591 Leça do Balio, Porto, Portugal*
[c] *Dep. de Engenharia Mecânica, ISEP, R. António Bernardino de Almeida, 4200-465 Porto, Portugal*

Received 22 July 2004; received in revised form 5 March 2005; accepted 12 May 2005

Abstract

Epoxy-based composites moulds are frequently used for wax and polymer materials injection. Tri-phase materials, composed by an epoxy resin, aluminium particles and milled fibres, were produced, with mechanical and thermal performances better than the single materials, increasing the competitiveness of the epoxy rapid tooling processes. Charpy impact tests were employed to obtain a qualitative indication of the composites toughness. The electronic instrumentation of these tests allows a more accurate differentiation of the impact behaviour of the neat resins, the aluminium filled resins and the tri-phase composites (composed by epoxy, aluminium particles and milled glass or carbon fibres), and to consequently tailor the composites mechanical properties for rapid tooling applications.

Keywords: Particle reinforcement; Polymer–matrix composites; Milled fibres; Impact behaviour; Rapid tooling

1. Introduction

Aluminium filled epoxies moulds have been used in indirect rapid tooling for a long time [1,2]. These moulds, having a low processing cost, are very competitive when applied in the manufacturing of low volume series of plastic parts [3–5].

In previous research, tri-phase composites, composed of aluminium particles and milled fibres, were studied for the production of wax and plastic injection moulds [6,7]. The metallic filler was added to increase the thermal conductivity of the mould, while the milled fibres allow for the improvement of the wear resistance. These two critical parameters influence the moulds life and the respective time to market of the new products to be developed.

The mechanical performance, under static and dynamic stress conditions, also affects the mould durability. In this context, the impact behaviour of these materials was analysed in order to understand the effect of aluminium particles and fibres addition to an epoxy matrix. Using the instrumented impact test, it is possible to differentiate the glass and carbon fibre reinforced composites behaviour, which would not be distinguishable if the non-instrumented Charpy test was employed.

Nevertheless, impact tests are influenced by the specimen geometry and the equipment characteristics and, consequently, they are not able to evaluate independent materials characteristics. This is the reason why this research is only oriented to highlight the qualitative aspects of a comparative analysis of the studied materials.

2. Experimental

2.1. Materials

Two common epoxy matrix systems, of high (A) and medium temperature (B), suited for structural reinforcement, were employed. The A epoxy resin is based on an aromatic glycidyl amine, while the B resin is a result of the reaction

* Corresponding author. Tel.: +351 229578714; fax: +351 229537352.
E-mail address: falves@inegi.up.pt (F.J. Lino).

0924-0136/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmatprotec.2005.05.006

Table 1
Characteristics of the two epoxy matrix systems

Epoxy system (manufacturer)	Hardener	Mixture viscosity [mPa s]	Main curing process	T_g [°C]
A—based on aromatic glycidyl amine (Vantico, UK)	Cycloaliphatic polyamine	700–900	Addition of amine to the epoxy group Homopolymerization of epoxide and cyclization	200
B—based on bisphenol A/F + epichlorhydrin (Axson, France)	Cycloaliphatic polyamine	1200–1600	Addition of amine to the epoxy group	120

Table 2
Technical characteristics of the aluminium particles and milled fibres

Material	Manufacturer	Dimensions, μm (l/d)[a]	Sizing
Aluminium powder (F)	Hexcel (France)	P200 grade	–
Milled E-glass fibres (G)	PPG (USA)	215/11	Polyvinyl acetate with silane
Milled carbon fibres (C)	Toray (Japan)	63/7	1 wt% epoxy

[a] l/d: fibre length/diameter.

Table 3
Designation and composition of the materials produced

Epoxy matrix (neat resin)	Dispersed phase		
	Aluminium filled composites	Hybrid composites	
	F—fine aluminium particles	G—glass milled fibre	C—carbon milled fibre
A—100% B—100%	AF: A—59%; F—41% BF: B—59%; F—41%	AFG: A—57.5%; F—38.5%; G—4%	AFC: A—57.5%; F—38.5%; C—4%

between bisphenol A/F with epichlorhydrin (see Table 1). A cycloaliphatic polyamine was used as hardener.

Aluminium particles and fibres were added to the matrix resin as dispersed phases (Table 2), namely:

- fine class aluminium particles (F) (PD 200 grade);
- milled glass fibres (G) of 215 μm × 11 μm (length × diameter) with an elastic modulus (E_{Gf}) of 72 GPa;
- milled carbon fibres (C) of 63 μm × 7 μm with an E_{Cf} of 228 GPa.

Two different types of composites were produced: simple, with only one dispersed phase (aluminium filled epoxy) AF and BF, and hybrid, with a mixture of aluminium particles and milled fibres, AFG and AFC. The respective compositions (volume fraction) are indicated in Table 3. Milled fibres were not added to the B epoxy resin due to the low pot life that does not allow an adequate mixture. Fig. 1 shows optical micrographs of the hybrid composites, composed by an epoxy resin matrix filled with aluminium particles and milled fibres.

2.2. Tests

Charpy impact resistance was determined with a pendulum machine H.20 (Tensometer Ltd., Croydon, United Kingdom) with a weighing capacity varying from 0.14 to 9.07 N.

Unnotched specimens were cast in a mould, cured according to the temperature cycle recommended by the resin manufacturer (see Table 4) and finished with a 320 SiC paper. For each composition, 10 specimens of 50 mm × 6 mm × 4 mm (length × width × thickness) were produced and tested.

The use of electronic equipment associated to the Charpy testing machine allows for monitoring of the load/time response occurring during the deformation and fracture process of the test samples [8].

The instrumented tests were made with a 2.3 N weight. The testing machine was instrumented with the following equipment (see Fig. 2a):

- pulse dynamic analyser (Bruel & Kjaer 2035, Denmark);
- piezoelectric accelerometer with 1.008 PC/m s^{-2} sensitivity (Bruel & Kjaer 4371, Denmark).

The initial acceleration/time curve was converted, by integration, on velocity/time and displacement/time plots, allowing the establishment of the final force/displacement curve that permits the calculation of the absorbed energy. Fig. 2b shows some characteristic load points that can be obtained from the load/displacement curve [9]. The area under the load/displacement curve is associated with the absorbed

Table 4
Curing cycles applied with the A and B epoxy-based materials

Epoxy-based materials	Time/curing temperature	Time/post-curing temperature
A	14 h/40 °C	3 h/20–200 °C; 1.5 h/200 °C
B	24 h/RT	2 h/40 °C; 2 h/60 °C; 2 h/80 °C; 2 h/100 °C; 3 h/120 °C
AF, AFG, AFC	48 h/RT; 14 h/40 °C	3 h/20–200 °C; 1.5 h/200 °C
BF	24 h/RT	4 h/40 °C; 4 h/60 °C; 4 h/80 °C; 4 h/100 °C; 6 h/120 °C