Glass and **Carbon Fibre Reinforced Hybrid Composites** for Epoxy **Tooling**

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INEGI is a research institute that has been developing a noticeable activity promoting the use of Rapid Prototyping (RP) and Rapid Tooling (RT) technologies. Using these technologies, companies are able to reduce costs and the time to market of the new products with better design and quality, thus improving their competitiveness.
This communication is part of the work that has been conducted in a project that uses an indirect rapid tooling process to manufacture innovative tools for product development. Polymeric composite tools are produced pouring its mixtures over RP models. The tools produced are used in processes such as injection moulding, thermoforming of different types of thermoplastics, and sheet metal forming.

Introduction

Frequently, indirect RT processes are based in a RP model and in traditional technologies, which have low cost processing and equipments[1, 2].
The objective of this work is to develop an indirect RT process, based in RP models and in composite materials, to manufacture prototyping tools, which will then be used to produce functional prototypes and pre-series[1-5]. This indirect RT technique ("firm tooling")[6] offers a high potential for a faster response to market needs, creating in this way a new competitive edge. Using this process, companies will be able to produce thousands of parts, but with restricted geometries and poor tool reliability. This does not necessarily means a significant disadvantage, because a typical tool for prototypes is often used to produce a relatively small quantity of parts (around one hundred), and the strength of a long cycle run tool is not required. Although the indirect methods are more time consuming when compared with direct RT methods, such as DMLS (direct metal laser sintering), their low cost processing and equipments makes them a very attractive alternative[3].
The tools developed are composed by an epoxy resin and aluminium particles, added to improve the thermal conductivity of the tool, which is an essential parameter for plastic injection tools moulding[7-8]. However, this procedure also lowers the mechanical properties of the tool. In order to overcome this problem, fibres were added to the composite.

Experimental procedure

A high temperature epoxy, based on aromatic glycidyl amine, that exhibits a suited viscosity to be mixed with aluminium powder of 80 mm medium equivalent diameter, was employed. The curing agent was a cycloaliphatic polyamine showing a good level of reactivity.
To obtain a multifunctional material with good mechanical and thermal properties, a layered structure was produced. This objective was performed combining aluminium filled epoxy outer layers with continuous fibres reinforced epoxy inner layers (glass and carbon woven fabrics).
Specimen laminates were produced by the lay up manufacturing process. Aluminium rich outer layers were stacked with eight reinforced woven roving fabric inner layers and subjected to a 30 kPa consolidation force and the respective curing method. Two types of woven fabric, plain weave, with similar warp and weft weights, were used: E glass fibres (280 gr/m^2) and HS carbon fibres (196 gr/m^2) based in PAN (polyacrylonitrile) precursor.
To determine the mechanical properties of the composite tool to be produced, standard specimens for tensile test, impact test and thermal conductivity were made.

Sample Preparation

After curing, the specimens were sectioned with a water-cooled metal-bonded diamond cut-off wheel on a Struers Accutom-5 machine and, then, embedded in a low viscosity, cold hardening epoxy resin (Epofix). Samples were mounted into a six-specimen holder for semi-automatic grinding-polishing (Struers Planopol-3 and Pedemax-2). Mounted samples were ground with different grades of SiC papers and, finally, polished using an alumina suspension (Struers AP-Paste) on a Struers SP-PoliFloc 1 cloth. The details of all these steps are indicated in Table 1. After polishing, glass fibre reinforced composite samples were chemical etched for ten seconds, using dilute 10 vol% hydrofluoric acid, to enhance fibre visibility.

Results

As one can see in Table 2, aluminium filled epoxy samples have slightly lower deformation capacity. However, the aluminium addition significantly improves the thermal conductivity of the epoxy resin.

Process	Surface Cloth	Abrasive	Grain Size	Lubricant	Rotation Speed [rpm]	Force [N]	Time [min.]
Grinding	-	SiC	320	Water	150	120	2
	-	SiC	500	Water	150	120	3
	-	SiC	1000	Water	150	120	3
Polishing	SP-PoliFloc1	Alumina Suspension	F	-	150	120	2

Table 1: Sample preparation details for materialographic analysis of hybrid composites epoxy matrix based.

	Tensile Strength [MPa]	Tensile Modulus [GPa]	Extension at Break [%]	Impact Strength [KJ.m^{-2}]	Thermal Conductivity [W.m^{-1}.K^{-1}]
Epoxy system	40-50	3	2	6.5	0.2
Epoxy system + Al	40	7.5	0.9	6.5	2.1
Epoxy system + Al + GF	165	15.5	5	72	1.25
Epoxy system + Al + CF	295	40	0.75	73	2.1

Al: Fine Aluminium; GF: E Glass Fibre - plain weave (280 gr/m^2);
CF: Carbon Fibre HS 3K - plain weave (196 gr/ m^2).

Table 2: Mechanical and physical properties of the epoxy matrix based tools.

The thermal behaviour of these composites shows a straight dependence on the aluminium packing in the epoxy matrix, as one can see in the optical micrograph of Figure 1. Combining high conductive aluminium filled external layers with woven fabric reinforced inner layers, a tailored hybrid composite material can be obtained with optimised characteristics that were not possible to obtain with the single components[9].
Carbon fibres, when compared with glass fibres, exhibit better quality. With carbon fibres, the strength, the stiffness, the thermal conductivity and the materials processing are substantially improved. Nonetheless these composites are more expensive.

Materialographic analysis, using an optical microscope (Olympus PMG3), of the aluminium reinforced composite demonstrate that the aluminium and the fibres are well distributed in the tool, which is a result of an adequate processing of these materials. Optical micrographs obtained with different raw materials combinations show interesting patterns of the resultant hybrid laminate composite (Figure 2). Black points are pores that result from the air retention during the processing cycle. This is an imperfection that is always present in the manufacture of fibre reinforced resins.

Conclusions

The manufacturing process presented, which is based in an epoxy resin, aluminium fillers and continuous fibre reinforcement, is expected to be a valuable alternative for indirect rapid tooling.

Materialographic analysis of the composites provides important information about the degree and quality of the components mixture. The high thermal conductivity of aluminium powder and the carbon fibres resistance allow the manufacture of multifunctional laminates that meet the most important requirements of rapid epoxy tooling for plastic injection moulding applications, such as high tensile strength and thermal conductivity.

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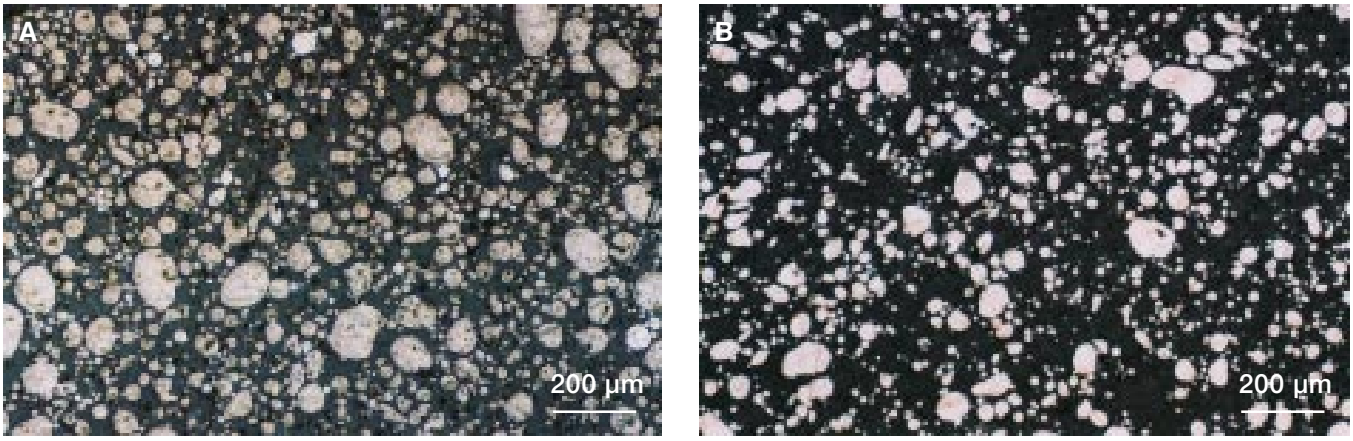
Figure 1: The thermal conductivity of the aluminium filled epoxies depends on the packing density of the aluminium powder. (A) system presents a thermal conductivity about twice the one of (B) system.



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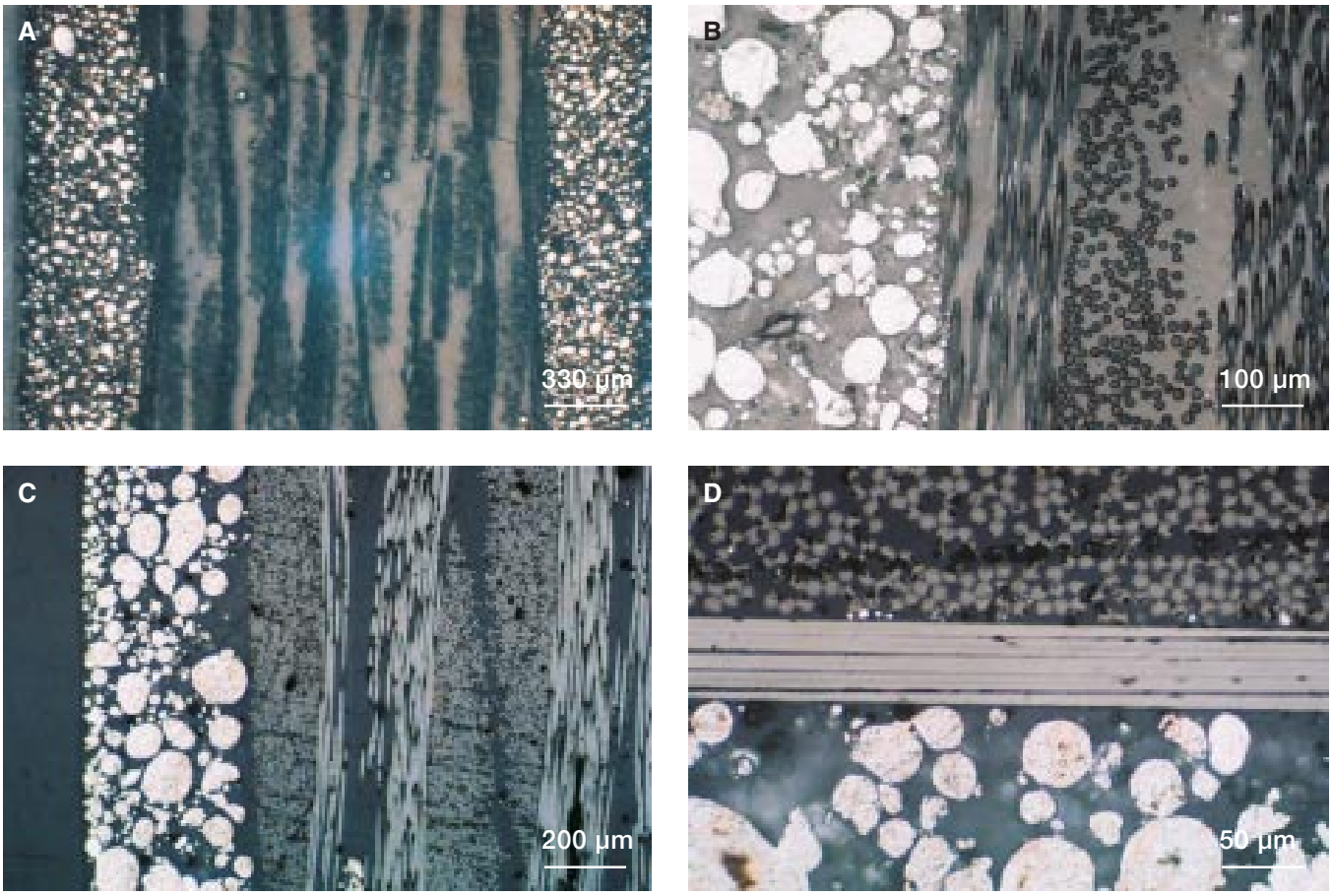
Figure 2: Layered microstructure obtained in an optical microscope (Olympus PMG3) showing spherical aluminium particles and cross and longitudinal sections of glass fibres ((A) and (B)); and carbon fibres ((C) and (D)).