Study of the abrasion resistance of new epoxy (ER) – ionic liquid (IL) materials with self-healing ability

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ABSTRACT
In the present work, new epoxy resin (ER) – ionic liquid (IL) dispersions have been obtained and their abrasion resistance has been determined by multiple scratch tests. The IL was added in a range of concentrations between 7 and 12 wt. %.After the scratch tests, the viscoelastic recovery and healing ability of the damaged surface has been monitorized using optical and electronic microscopy and profilometry. The results are discussed on the basis of the curing procedure and are related to mechanical, thermal and dynamic-mechanical properties, and to surface porosity of the new dispersions.
KEY WORDS: epoxy resin; ionic liquid; abrasion; self-healing.

1.- INTRODUCTION
There is an increasing interest in polymer nanocomposites with enhanced tribological performance due to their growing number of applications, from coatings to sliding parts. [1-3]. Epoxy resins combine toughness, high electrical resistance and thermal stability with ease of fabrication. Their applications range from electric and electronic systems, automotive parts, and aircraft components to biocompatible implants, protective coatings and adhesives [4].
It is well know that the tribological performance of epoxy resins is extremely poor due to their high brittleness, which induces severe wear by crack propagation and fracture [5].
Numerous precedents of self-repairing or healing epoxy resin systems [6-15] have been described. In most cases, the mechanism is that previously described [16], by releasing of curing agents which repair fracture cracks.
Room temperature ionic liquids (ILs) have been used to obtain new nanocomposites with improved tribological performance [16-21]. Recently, ILs have also been used to modify epoxy resin [22-32].
In previous studies [16, 18-20], we have shown the prevention of sliding wear and the first self-healing of abrasion damage on epoxy resin induced by the presence of an IL.
The main purpose of the present study is to determine the influence of the nature of the IL, the concentration of IL added to the epoxy resin and the curing process on the self-healing ability of the new nanocomposites.

2.- EXPERIMENTAL SECTION

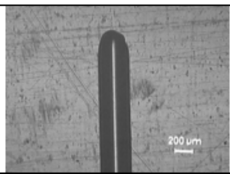
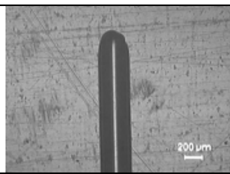
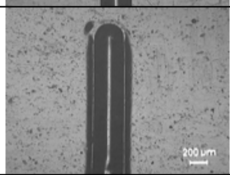
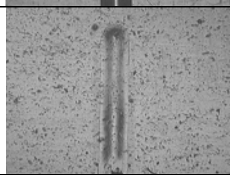
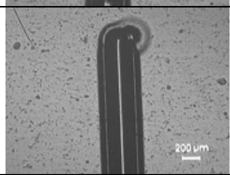
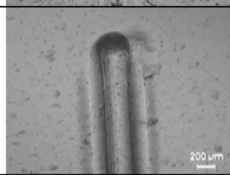
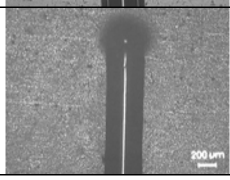
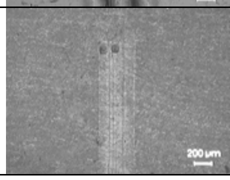
The preparation of epoxy composites and the experimental procedures have been previously described [19, 20]. In the case of ER+9%IL, two different methods have been used, the previously described one, and an alternative method where the curing process takes place under vacuum, in order to minimize porosity.

3.- RESULTS AND DISCUSSION

Effect of IL concentration

Table 1 shows the evolution of the abrasion grooves on each of the materials obtained following the previously described method, without vacuum. In all cases, the initial abrasion resistance of the ER+IL materials is lower (in agreement with hardness reduction as seen in table 2). After 22 hours, while the scar on neat ER remains unchanged, the ER+IL show a remarkable healing effect which seems to increase with IL content, as it is maximum for ER+9IL.

Table 1. Evolution of abrasion scars on epoxi resin and composites (cured wothiout vacuum) as a function of IL content.

Material	**0 hours**	**22 hours**
ER		
ER+7%IL		
ER+8%IL		
ER+9%IL		

As expected, the addition of the IL fluid phase reduces the hardness of the neat epoxy resin. An increase in the IL concentration further reduces hardness to reach the lowest values for the highest IL concentration, of a 9wt.% (table 2).

Table 2. Hardness values for materials cured without vacuum

Material	**ER**	**ER+7%IL**	**ER+8%IL**	**ER+9%IL**
Hardness (Shore D)	82.84 (0.230)	76.54 (0.654)	77.23 (0.463)	71.84 (0.780)

With the aim of studying the limit in the IL percentage that can be added to ER, the new ER+12%IL material was obtained.

Figure 1 shows the evolution of the abrasion groove on ER+12%IL (with a Shore D hardness of 75.8) with time.

a) b) c) d)

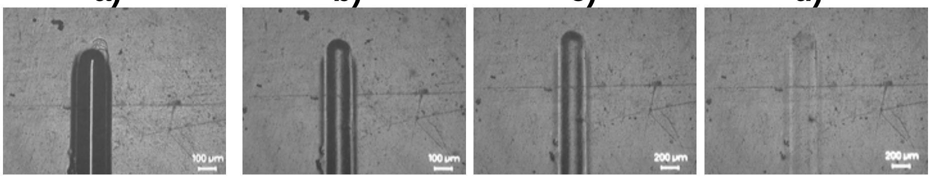


Figure 1. Evolution of the abrasion groove on ER+12%IL with time: a) 0 hours; b) 5 hours; c) 8 hours; d) 22 hours.

The presence of a 12 wt.% IL increases the self-healing effect, but the composite blend is not stable, as some IL exhudation was observed at room temperature.

Effect of curing conditions.

Figure 2 shows that when ER+9%IL is cured under vacuum conditions, removing the gas and minimizing porosity, no self-healing effect is observed after 22 hours. The porosity percentage has been measured using optical profilometry.

a) b)

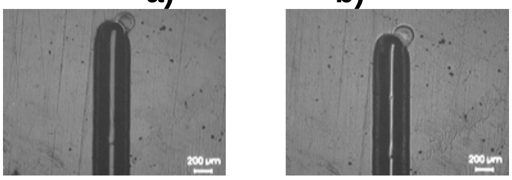


Figure 2. Abrasion groove on ER+9%IL cured under vacuum conditions: a) 0 hours; b) 22 hours.

ER+9%IL cured under vacuum shows a 10% increase in hardness with respect to the material cured without vacuum (table 3).

Table 3 also shows the comparative results of porosity measurements on cross sections of both materials.

Table 3. Porosity results

ER+ 9%IL	**Number of pores /mm^2** (standard deviation)
Shore D 71.8	7.83 (0.99)
Shore D 80.3	0.52 (0.05)

Figure 3 shows the surface topography profiles on two sections of both ER+9IL materials, cured without and with vacuum respectively.

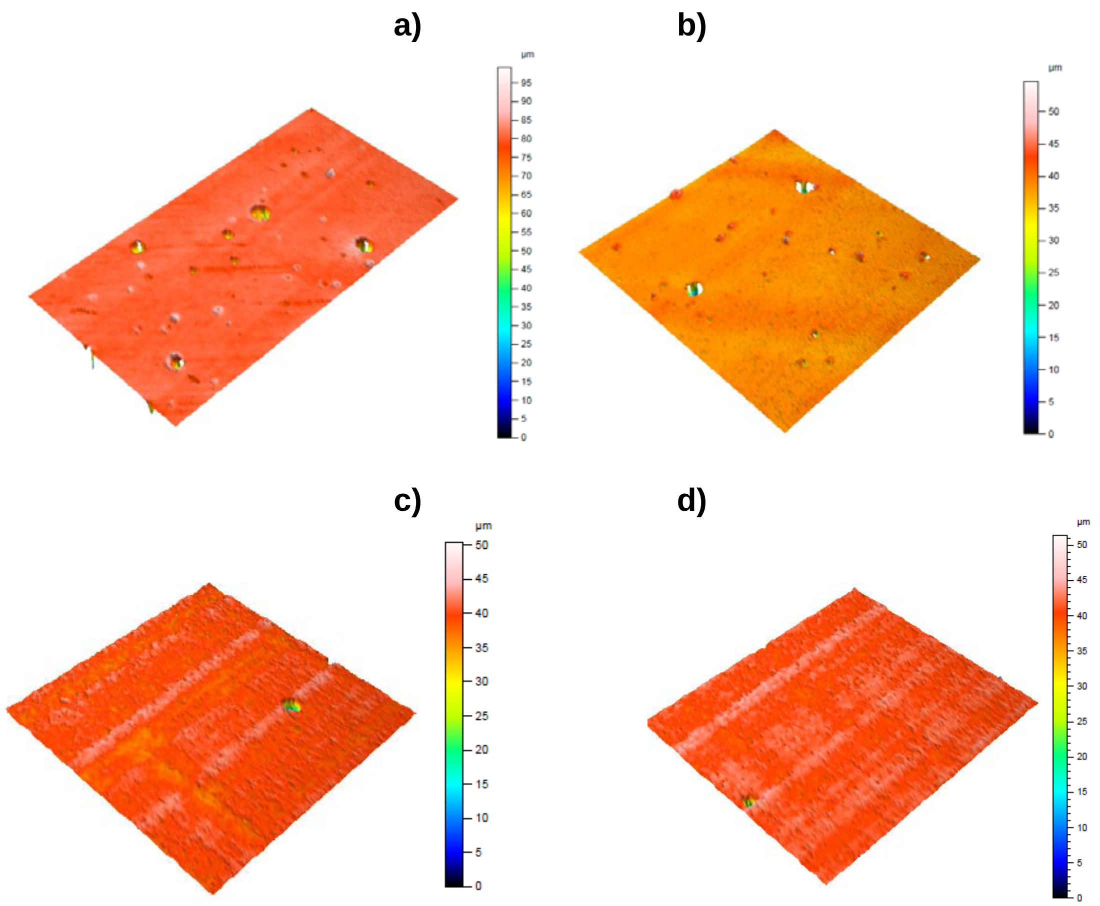


Figure 3. Surface topography images of cross sections of ER+9%IL: a) and b) Cured in vacuum; c) and d) Cured without vacuum.

4.- CONCLUSIONS

The results described here show that not only a threshold IL concentration is needed for the self-healing effect, but also a porosity network is necessary for the IL to reach the damaged surface.

New studies are being carried out at the present moment with different IL compositions and curing processes, to optimize the abrasion damage reduction on the new epoxy resin nanocomposites.

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