This article presents an experimental study on the surface properties of epoxy resin nanocomposites (EPNCs) manufactured with a thermosetting epoxy resin (EP)–bisphenol A diglycidyl ether (BADGE) –2-[[4-[2-[4-(Oxiran-2-ylmethoxy)phenyl]propan-2-yl]phenoxy]methyl]oxirane) and filled with alumina nanoparticles (NPs). The NPs consist of pretreated (with a silane agent) alpha alumina with irregular shapes and a 100 nm maximum size. Three weight fractions of NPs were studied: 1, 3, and 5 wt. (%). Two different epoxy (EP) resins were manufactured, one cured and postcured with bis (4-aminophenyl) methane (DDM); and another one cured with 3-dodec-2-enyloxolane-2,5-dione (DDSA) + 8-methyl-3a,4,7,7a-tetrahydro-4,7-methano-2-benzofuran-1,3-dione (MNA). The wettability and the surface roughness of the obtained EPNCs were studied through the measurement of contact angles and topographic images obtained with atomic force microscopy (AFM), respectively. Significant influence of both the loading of NPs and used curing agents was observed. EPNCs cured with DDM were shown to be hydrophobic for 0, 1, and 3 wt. (%) and hydrophilic for 5 wt. (%). Maximum surface roughness was observed for 5 wt. (%). EPNCs cured with DDSA+MNA were shown to be hydrophilic for 0 and 1 wt. (%) and hydrophobic for 3 and 5 wt. (%). The surface roughness decreased as the weight fraction of NPs increased until 3 wt. (%), and then increased for 5 wt. (%).

Thermosetting epoxy resins (EP) systems have been widely used as matrices for composite materials in several industries (e.g., aircraft, automotive, aerospace, shipbuilding, and civil construction industries). In particular, they have been used for metal substitution in several engineering applications (e.g., electronic devices, textiles, and machinery) and also as base materials for wear-resistant coating, adhesives, and advanced fibrous polymeric composites (PCs), among others. In spite of their excellent performances, EPs have some drawbacks, such as brittle failure (because plastic deformation is constrained), low toughness (weak resistance to crack initiation and propagation), low flow, high coefficient of linear thermal expansion, shrinkage, low thermal conductivity, and high sensitivity to cracks, which highly limit their application in some demanding fields. In order to solve these drawbacks, a considerable amount of research has been carried out to modify EPs, for instance by changing their molecular structure to increase the crosslink density, leading to higher stiffness and strength. In addition, the toughness of EPs can be improved by incorporating toughening agents such as liquids, rigid or hybrid rigid rubbery particles, or unreactive nano hardeners (i.e., nanoparticles (NPs)) at very low contents (usually described in terms of the weight fraction (wt. %) or volume fraction (vol. %)). In recent years, special attention has been paid to EPs filled with NPs. These nanofillers (e.g., silicon dioxide (SiO\textsubscript{2}), titanium dioxide (TiO\textsubscript{2}), aluminum oxide (Al\textsubscript{2}O\textsubscript{3}), are characterized by their specific shape and size (nanoscale), high surface areas, surface pretreatment, and the degree of dispersion into the EP matrix. In recent years, many studies have demonstrated that the inclusion of inorganic NPs into EPs has the capability to improve the stiffness, toughness, flexural modulus, fracture toughness, strength, hardness, and many other properties of the final PCs, which are necessary in many engineering applications. These improvements are achieved without sacrificing the basic properties of EPs and with low percentages of NP loading. Among the available NPs that have been studied and that can be used to reinforce EPs, alumina NPs constitute a good solution. The good results published in recent years, combined with the low cost of alumina NPs when compared to other NPs (for instance, alumina NPs are cheaper than titanium NPs), its high modulus (about 300 GPa), and high thermal resistance in comparison with others metal oxides NPs, show that functionalized alumina NPs are a viable and very promising solution to be used as nanoreinforcements for PCs. Among the curing agents used as hardeners for EPs, some studies show that bis (4-aminophenyl) methane (DDM) or 3-dodec-2-enyloxolane-2,5-dione (DDSA) + 8-methyl-3a,4,7,7a-tetrahydro-4,7-methano-2-benzofuran-1,3-dione (MNA) are suitable for EP systems.

Both the physicochemical and topographical properties of surface materials are important for adhesion and coatings applications. EP adhesives filled with NPs have also been recently investigated. It was found that the...
inclusion of NPs can improve the wetting behavior, surface roughness, wear resistance, and shear strength, which are important properties for the resulting epoxy resin nanocomposites (EPNCs) to be used as adhesives or coatings.

The wettability of solid surfaces, including PCs, can be studied through the contact angle (CA) or the spreading area of a liquid over the surface. The contact angle is the angle conventionally measured through the liquid, where a liquid–vapor interface meets a solid surface (see Figure 1). Smaller CAs or larger spreading areas imply higher wettability. The CA on a rough surface of the same material, also called the apparent (or measured) contact angle (see Figure 1), is smaller. Therefore, the material is more wettable. This is because the surface area is increased due to roughness (the real surface area is higher than the geometrical surface area). Therefore, wettability and roughness are strongly related. The wetting characteristics of surface materials using functionalized NPs depend strongly on the NP distribution within the surface layers.

![Definition of contact angle.](image)

The surface roughness of PCs can be analyzed by atomic force microscopy (AFM), which is a relatively new technique used for the surface characterization of polymers. By using AFM, it is possible to obtain images of a non-conducting polymer surface and study its mechanical properties. Compared with other microscopy techniques, AFM does not involve any chemical etching, staining, or electron beam radiation, which can damage the polymer surface. From the AFM topographic images, roughness coefficients can be computed, which represent the ratio of the real surface area to the geometrical surface area for identical external dimensions of the sample.

Wettability and roughness are important properties to be ensured for many applications, such as for painting and gluing components, for which the bonding to adhesives and coating substances are increased for wettable and roughened surfaces.

This article presents an experimental study on the wettability and the surface roughness of EPNCs manufactured with a thermosetting EP, which in turn is manufactured with two different curing agents (DDM and DDSA+MNA) and filled with functionalized alumina (Al₂O₃) NPs with different weight ratios, namely 1, 3, and 5 wt. (%). To study the wettability, CAs were measured. To study the surface roughness, AFM topographic images were first obtained. Next, two amplitude parameters were evaluated, namely the arithmetic average roughness and the root mean square roughness. These parameters were considered as measurements of the surface roughness, because AFM surface profiles can also be used to assess the nanofiller dispersion. The obtained results, namely the mean values of CAs, the images of surface roughness from AFM, and the related amplitude parameters, are presented and discussed with respect to the influence of the NP loading. The results are differentiated for the two different thermosetting EP systems, which were obtained by using the two different curing agents (DDM and DDSA+MNA).

It should be noted that no previous studies focused on the wettability and surface roughness of EPNCs systems similar to those studied herein were found in the open literature. For this reason, the presented study can be considered original, and the obtained results are of great importance for future studies.
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**Keywords**

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