Electric Conductivity of Modified Epoxies

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One of the most interesting and challenging researches about polymers regards the ways to modify their basic properties in order to enlarge their area of application. Among the purposed solutions one is regarding the mixture the polymer and some organic substances known for their properties to fit or to transform many other compounds. Starting with the idea of modifying a polymer by use a solution of a salt this study begins with an investigation regarding organic solvents susceptible to be used in this purpose with epoxy resins. A second idea was to find substances which easily can realise metallic complexes in order to use these complexes to modify the basic properties of epoxy resin. The third idea was to produce carbon structures (CNTs or fullerenes) direct inside the polymer matrix by local decomposition of an organic compound under laser radiation. The study concerns with three different epoxy systems and six organic compounds and targeted the specific weight and the electrical conductivity of formed materials.

Keywords: epoxy resin, organic solvents, potassium dichromate, organic powders, electrical conductivity

A way to change the very stable physical properties of epoxy resins is to mix them with other substances able to carry their properties inside the polymer network. To do that first of all the valuable substances have to be identified and then appropriate solvents have to be found. There are some well-known substances that are compatible with almost the majority of polymers[1]–[3]. In this category N,N-Dimethylformamide (DMF), 1-Methyl-2-pyrrolidinone (NMP) are two of the most used polymer solvents and they might be used to solubilize some metallic salts in order to transport metallic ions inside the epoxy resin network[4], [5]. Some studies had been reported both regarding the use of DMF[6] and the use of NMP[7] but for other purposes and not exclusively with epoxy systems. The two solvents might be used to solubilize some salts and the obtained solutions to be used to modify the basic properties of epoxy systems[8]–[10].

Other valuable organic compounds are the 1,4 Dioxane (Dioxan) and Polyethylene glycol (PEG) known for their ability to contribute to formation of metallic complexes together with glucose or other organic substances. Both these two agents were studied for polymer modification purposes as well as for metal complex formation[11]. The obtained complexes could be used to change the properties of epoxy resin by transporting metallic ions inside the polymer.

There are many ways (most of them described in literature) to obtain carbon structures such as CNTs[12]–[15] and fullerenes with appropriate precursors but one deserves more attention namely the one of obtaining these structures by use of microwave[16, 17]. Is this is possible then should be possible to form these structures directly inside the polymer by using appropriate laser radiation. In this regard glucose and folic acid might be used as precursors[18, 19].

This study was designed to identify the effects of above mentioned compounds over epoxy resins properties. Such a study is necessary to verify the hypothesis above.

Experimental part

Materials and methods

Three epoxy systems were chosen mostly because of their different bisphenol A content namely Epiphen RE4020-DE 4020 (Bostik), Epoxy Resin C (R&G Gmbh Waldenbuch), and Epoxy Resin HT-2 (R&G Gmbh Waldenbuch). The most important information about the epoxy systems are given in table. 1. All the systems are slow resins with a gel time between 20 and 45 min time which allows the manoeuvres required by moulding. All these systems were modified by mixing the main component (the resin) with various amounts of DMF, NMP, Dioxan, PEG, Glucose and Folic acid such as finally their weight ratios into the formed materials to be 2.5, 5, and 10%. For each pair of substances and for each concentration first of all the mixtures were homogenised by mechanical stirring at 300 rotations/min

	Epoxy Resin C	Epiphen DE 4020	Epoxy Resin HT 2
Physical state	liquid	liquid	liquid
Colour	light yellow	translucent	light yellow
Density [g/cm³]	1.18	1.15	1.137
Reaction product bisphenol-A-(epichlorhydrin) [%]	75	78	50
Mixing ratio (parts by weight of resin to hardener)	100:60	100:30	100:48
Curing time	24 h	7 days	24 h
Processing time	50 min	60 min	60 min
Density of polymer [g/cm³]	1.18	1.19	1,19

Table 1
PROPERTIES OF EPOXY SYSTEMS

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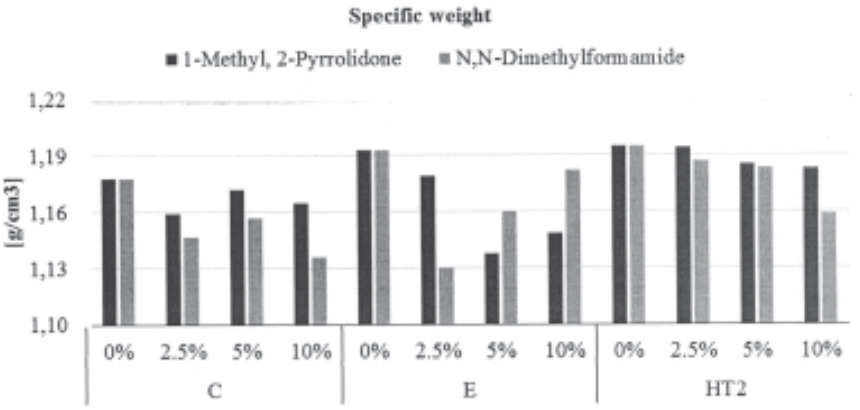

Fig. 1. Specific weight of epoxy resins with NMP and DMF

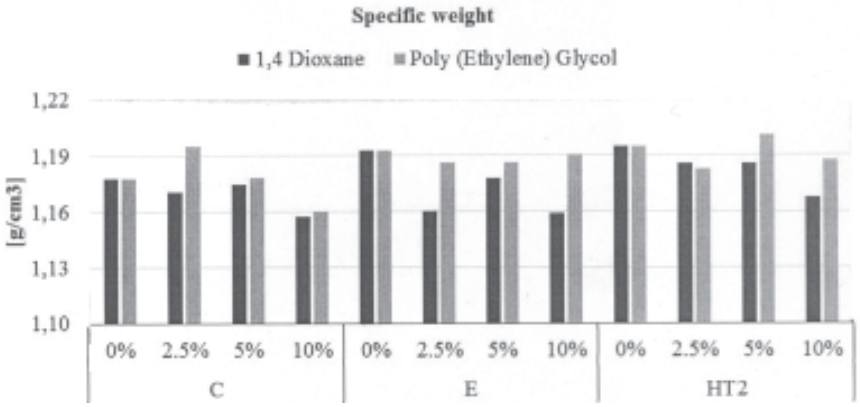

Fig. 2. Specific weight of epoxy resins with Dioxan and PEG

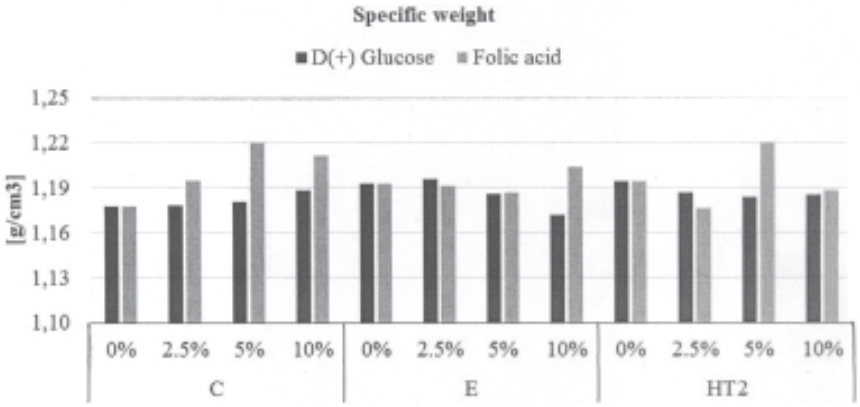

Fig. 3. Specific weight of epoxy resins with Glucose and Folic Acid

for 15 min. After the mixtures were uniformed the right amount of hardener was stirred for ten minutes to ensure the homogeneity. The pre-polymer mixtures were moulded in cylindrical moulds 6 mm diameter and 200 mm height. After moulding the moulds were vibrated to avoid the gaseous intrusions. To obtain the required vibrations the moulds were placed into a granular bed and this granular media was exposed to ultra-sounds produced by an air dynamic generator.

All the three resins were formed into the same type of mould to ensure the reference materials. All the organic compounds used to change the epoxies properties were provided by the same producer (Sigma Aldrich). After polymerization the samples were extracted from the moulds and thermal cures were applied according to each epoxy producer recommendations to get the best properties of epoxy resins. From moulded samples dedicated samples were extracted for particular tests such as bending tests, compressive etc.

Results and discussions

Specific weight and electric conductivity of materials were targeted for this study. The first is evaluated by the direct method of measuring the weight and the volume of the sample. For each material, six samples were analysed and the results (after statistical analysis) are presented in figure 1–3. Table 2 contains the densities of organic compounds used to change the epoxy systems basic properties. Based on these values and on polymers densities the mixing rule can be applied to evaluate the density of the mixture in solid state based on the weight ratios of components. Based on mixing rule the final densities of liquids modified materials have to be lower than epoxies values and that is observable from the figure 1 for DMF and NMP. In figure 2 just the Dioxan is lowering the final material density while the PEG produces the increase of the density but the modifications are not very large. The folic acid is increasing the density of all materials while the glucose has a variant effect lowering or increasing the density values depending on resin.

The electric conductivity was evaluated from electric resistance which was measured by the method of isolation resistance. The results in figure 4 show that NMP is lowering the electric conductivity of resin C as well as DMF. In the case of Epiphen resin the effect of NMP is the same independent on concentration and is increasing the electric conductivity. The DMF is increasing also the parameter but the increase is smaller when the concentration increases.

Organic compound	Density ρ [g/cm^3]
N,N-Dimethylfomamide	0.948-0.950
1-Methyl-2 Pyrrolidinone	1.028
1,4 Dioxane	1.034
Poly (ethylene glycol)	1.128
D(+) Glucose	1.54
Folic acid	1.6

Table 2
VALUES OF DENSITY FOR ORGANIC COMPOUNDS

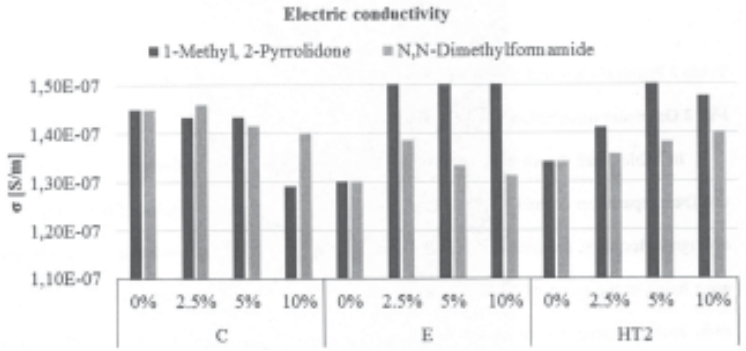

Fig. 4. Electric conductivity of NMP and DMF modified epoxy resins

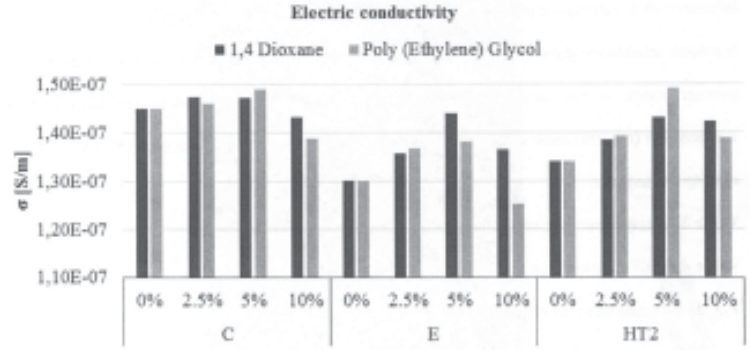

Fig. 5. Electric conductivity of Dioxan and PEG modified epoxy resins

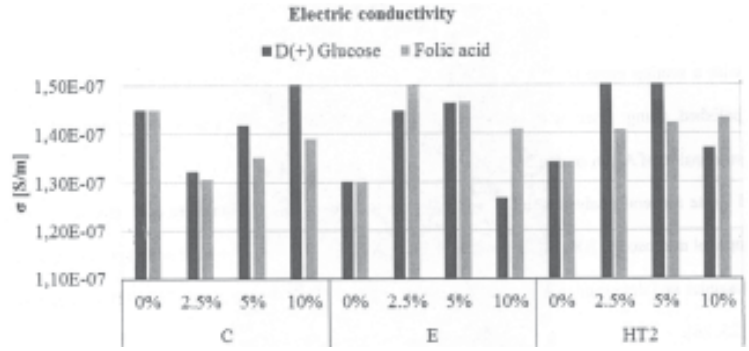

Fig. 6. Electric conductivity of Glucose and Folic Acid modified epoxy resins

For the HT resin both NMP and DMF are increasing the electrical conductivity.

The electric conductivity of Dioxan and PEG modified epoxy resins are, practically unchanged (independent on the concentration) for C resin and shows small variations for Epiphen and HT resins (fig. 5). The folic acid is increasing the electrical conductivity of Epiphen and HT resins but is lowering the value of the parameter for C resin. The use of Glucose produces a concentration dependent increase of electrical conductivity of C resin as well as the folic acid. In the case of Epiphen resin the decrease of electric conductivity is proportional with the increase in concentration of folic acid. In the case of HT resin both substances are producing increase of electric conductivity values (fig. 6).

The most important result is that all the mixtures had polymerize and the organic compounds used to modify produced effects on formed materials properties.

Conclusions

The main achieved goal of this study was to investigate if the epoxy systems still polymerize when they are mixed with some organic agents which could be used for other purposes. They were identified small variations of targeted parameters – electric conductivity and density. In this last case it seems that the mixing rule is giving appropriate values and one might conclude that the mixture of epoxies with the studied organic agents is only of physical nature.

Further studies have to analyse the use of DMF and NMP as solvents for ionic substances considering that metallic ions presence inside the polymer could change its basic properties. Another use, which is taking into account the fact that both DMF and NMP are polymer solvents, is to use them to mix epoxies with other polymers in order to obtain more reliable porous polymers for energy storage purposes – as a mixture of epoxy and polysulfone. Also the use of polysulfone could prevent the sedimentation of nano-sized (like nano-ceramics or nano-metals) solid phases dispersed into the polymer volume.

Dioxan and PEG had been chosen for their properties to interact with amino acids to form metallic complexes that could be used to change the basic properties of thermoset polymers. Glucose and Folic Acid were chosen because they could be transformed into carbon structures as CNTs

or fullerenes inside the polymers by using appropriate laser radiation.

Important is to completely characterize the presented materials form mechanical, thermal, and tribological point of view. Because the encouraging obtained results are almost useless if one of valuable properties of epoxy systems is irreversibly damaged.

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