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RHEOLOGICAL, MECHANICAL, THERMAL AND ELECTRICAL PROPERTIES OF UHMWPE/CNC COMPOSITES

D.Duraccio[1], R. Arrigo[2], P.P. Capra[3], G. Malucelli[2]
[1] Istituto di Scienze e Tecnologie per l'Energia e la Mobilità Sostenibili (STEMS)-UOS di Torino, Consiglio Nazionale delle Ricerche, Strada delle Cacce 73, 10135 Torino, Italy
[2] Politecnico di Torino, Dipartimento di Scienza Applicata e Tecnologia
Viale Teresa Michel 5, 15121 Alessandria, Italy
e-mail: giulio.malucelli@polito.it
[3] Istituto Nazionale di Ricerca Metrologica (INRIM), Strada delle cacce 91, 10135, Torino, Italy

Introduction

Ultra-high molecular weight polyethylene (UHMWPE) is an engineering polymer exploited in a wide range of application fields [1]. The interest in this polymer is mainly due to its intriguing properties, such as low density, ease of processing, outstanding chemical stability, good electrical insulating properties, good mechanical and wear resistance features.

In recent years, considerable efforts have been made to further enhance UHMWPE properties, aiming at widening its suitability for the formulation of energy devices (i.e. circuit boards, heat exchangers, and electronic packaging), for which the critical issues related to the heat removal are of fundamental importance. In this context, materials with high heat dissipation characteristics and good electrical insulating properties have paid an increasing attention, since economic lightweight solutions are needed.

The introduction of inorganic fillers into a polymer matrix is one of the most commonly methods exploited for developing high performance materials. Different fillers have been introduced in UHMWPE with the aim of improving its mechanical properties [2, 3] and/or thermal conductivity [4].

Cellulose nanocrystal (CNC) is a natural material obtained by the hydrolysis of cellulosic sources, and the interest in its use as an organic reinforcement in polymer-based composites has considerably grown in the last years. In fact, CNC can be obtained from renewable and abundant resources and has interesting mechanical properties, coupled with biocompatibility and good thermal properties. Several studies dealing with the evaluation of the mechanical behavior of CNC-reinforced polymer nanocomposites showed that superior mechanical properties can be achieved also for systems containing low CNC loadings, due to the intrinsic high stiffness of crystalline cellulose and the high aspect ratio of the CNC particles. However, to fully exploit the potential reinforcement provided by the CNC introduction, the right selection of the processing method and the optimization of the operative conditions are of fundamental importance.

Despite many systems and possible applications have been exploited, the use of CNC as a filler for UHMWPE to improve both the mechanical properties and thermal conductivity without modifying the electrical behavior has not been studied yet. In this work, we prepared UHMWPE/CNC composites by using different amounts of CNC (namely, 0.1, 2 e 5 wt.%) and different mixing procedures followed by compression molding. The thermal, mechanical and electrical properties of UHMWPE/CNC composites were thoroughly investigated. Additionally, the rheological properties and the effect of the CNC on the polymer chain dynamics were also evaluated.

Results and discussion

All the composites were prepared through hot-compaction. First, UHMWPE/CNC mixtures containing 0.1, 2 and 5 wt% of CNCs were prepared following two different approaches: 1) Dry approach, in which UHMWPE powder was mechanically mixed at room temperature with a proper amount of CNC particles. These last have been subjected to a preliminary ball milling process (mCNC) by using a ball milling unit; 2) Wet approach, in which proper amount of UHMWPE and volume of CNC solution were added to ethanol and stirred until the complete evaporation of the solvent was achieved. The obtained mixtures were dried overnight. In this case. either as received CNC or mCNC particles subjected to ball milling process were used.

Figure 1 shows the complex viscosity of the unfilled matrix and of all the composites as a function of frequency. All the CNC-containing composites, regardless of the adopted processing method, show higher complex viscosity values as compared to unfilled matrix, with a progressive increment according to the increased CNC loadings. However, this increment is large at 0.1 wt.% and becomes moderate for higher CNC loadings. These results can be explained by morphological analysis (Figure 2). In fact, in the composites obtained through dry method, the embedded particles are uniformly dispersed within the host matrix, with some agglomerates especially for the systems containing high CNC loadings. Besides, the agglomerates appear detached from the matrix surface, suggesting weak interaction between the filler and UHMWPE. Differently, the composites obtained through wet method present preferential segregation of the embedded particles within the interfacial region between UHMWPE grains: this is probably due to the beneficial effect of the dispersion of both CNC and UHMWPE particles in the solvent [1].

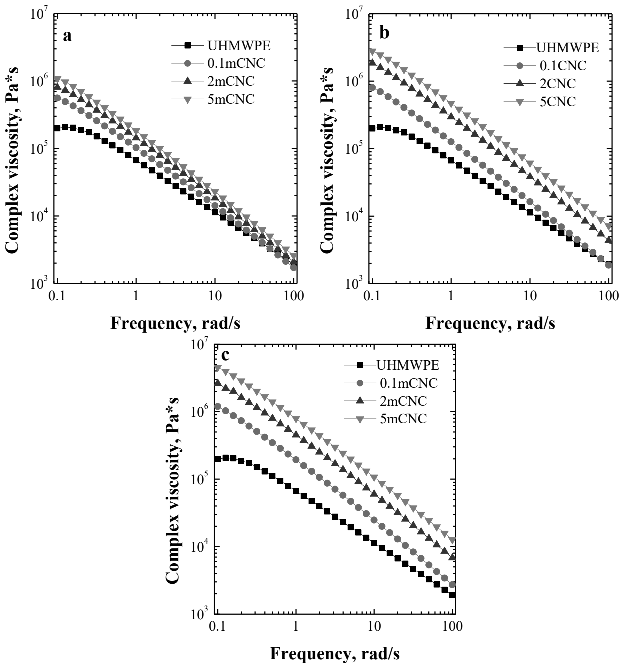

Figure 1: Complex viscosity as a function of frequency for composites obtained by (a) dry method + ball milled CNC, (b) wet method + no-ball milled CNC and (c) wet method + ball milled CNC.

As fas as no-ball milled composite systems are concerned, the distribution of filler around UHMWPE grains is not always uniform and well detectable (Figure 2e) and the presence of some agglomerates at micrometric scale can be observed (Figure 2f).

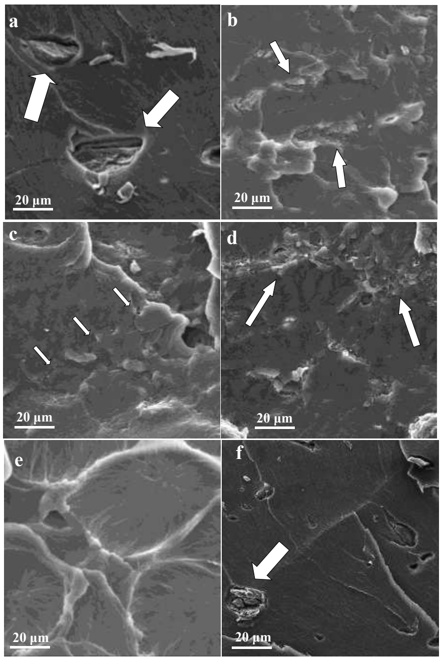

Figure 2: SEM micrographs of composites obtained by (a) dry method + 2 wt% ball milled CNC, (b) wet method + 2 wt% ball milled CNC, (c) wet method + 0.1 wt% ball milled CNC, (d), (e) and (f) wet method + 2 wt% ball milled CNC. White arrows indicate the presence of CNC.

The observed microstructure is responsible for the electrical resistivity and thermal conductivity behaviour. In the composites, the thermal conductivity coefficient (Figure 3, black bars) is always higher than that of unfilled polymer. UHMWPE/CNC composites obtained by solution mixing show slightly higher thermal conductivity and lower volume resistivity (blue bars) in comparison with the composites prepared by dry method, highlighting that the proper selection of the processing method plays a key role in determining the material final performances. Finally, mechanical tests indicate that all the CNC-reinforced composites exhibit improved values of Young's modulus and yielding strength with respect to unfilled UHMWPE.

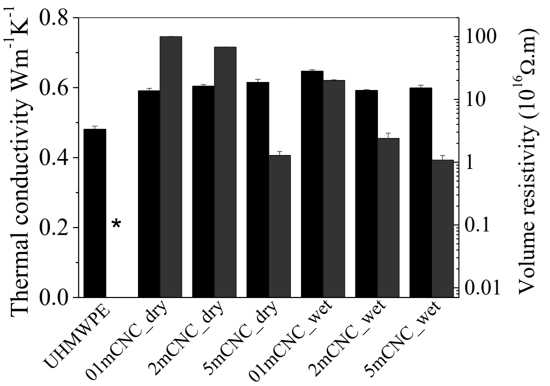

Figure 3: Thermal conductivity (black bars) and volume resistivity in log scale (blue bars) of UHMWPE and its composites (*: volume resistivity exceeds the maximum measurable value, i.e., 10^{18} Ω.m)

Conclusions

In this work, we have found that the proper selection of the processing method for preparing UHMWPE/CNC composites plays a key role in determining the material final performances. More in details, ball milling treatment is fundamental for obtaining UHMWPE composites showing a uniform distribution of the filler and reproducible results. Moreover, the preparation method involving a solution mixing step is more effective than the dry method in promoting the achievement of embedded CNC particles preferentially located in the interfacial region between UHMWPE grains, justifying their higher thermal conductivity and lower volume resistivity in comparison with the dry method-processed counterparts.

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