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Mechanical properties of graphene and graphene-based nanocomposites

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In this present review, the current status of the intrinsic mechanical properties of the graphene-family of materials along with the preparation and properties of bulk graphene-based nanocomposites is thoroughly examined. The usefulness of Raman spectroscopy for the characterization and study of the mechanical properties of graphene flakes and their composites is clearly exhibited. Furthermore, the preparation strategies of bulk graphene-based nanocomposites are discussed and the mechanical properties of nanocomposites reported in the literature are analysed. In particular, through the analyse of several hundred literature papers on graphene composites, we have found a unique correlation between the filler modulus, derived from the rule of mixtures, and the composite matrix. This correlation is found to hold true across a wide range of polymer matrices and thus suggests that the common assumption that the filler modulus is independent of the matric is incorrect, explaining the apparent under performance of graphene in some systems. The presence of graphene even at very low loadings can provide significant reinforcement to the final material, while the parameters that affect the nanocomposite strongly are thoroughly reviewed. Finally, the potential applications and future perspectives are discussed with regard to scale up capabilities and possible developments of graphene-based nanocomposite materials.

Abbreviations: ABS, acrylonite butadiene styrene; ATP, attapulgite; CB, carbon black; CF, carbon fibres; CHI, chitosan; CHIGEL, chitosan/gelatin; CNT, carbon nanotubes; $Co(OH)_2$, cobalt hydroxide; CTBN, carboxyl terminated butadiene acrylonitrile; EPDM, ethylene propylene diene monomer; EVOH, poly (ethylene vinyl alcohol); fGNP, functionalized graphene nanoplatelets; fMWCNT, functionalized multiwalled carbon nanotubes; frGO, functionalized reduced graphene oxide; GF, glass fibres; GN, graphene nanosheets; GNP, graphene nanoplatelets; GNR, graphene nanoribbons; GO, graphene oxide; Gr, graphene; HDPE, high density polyethylene; IIR, poly(butylene-*co*-isoprene); KGM, konjac glucomannan; LLDPE, linear low density polyethylene; MMT, montmorillonite; MVQ, methyl-vinyl-silicone (silicone rubber); MWCNT, multiwalled carbon nanotubes; NR, natural rubber; OPBI, poly[2,2′-(p-oxydiphenylene)-5,5′-bibenzimidazole]; OPE, oxidized polyethylene; PA6, polyamide 6; PBS, poly(butylene succinate); PC, polycarbonate; PDMS, polydimethylsiloxane; PE, polyethylene; PEI, polyethyleneimine; PET, poly(ethylene terephthalate); PF, phenol formaldehyde; PHO, polyhydroxyoctanate; PI, polyimide; PLA, polylactic acid; PLLA, poly(L-lactic acid); PMMA, poly(methyl methacrylate); PP, polypropylene; PS, polystyrene; PSF, polysulfone; PTFE, polytetrafluoroethylene; PTT-PTMO, poly(trimethylene terephthalate-block-tetramethylene oxide) copolymer; PU, polyurethane; PVA, poly(vinyl acetate); PVC, poly(vinyl chloride); PVDF, Poly(vinylidene fluoride); PVDF-HFP, poly(vinylidene fluoride-*co*-hexafluoropropylene); rGO, reduced graphene oxide; SBR, styrene butadiene rubber; SCF, sized carbon fibres; SiO_2, silicon dioxide; SR, silicone rubber; TPU, thermoplastic polyurethane; UHMWPE, ultra-high molecular weight polyethylene; VMQ, vinyl-methyl-silicone rubber; WPU, waterborne polyurethane; XNBR, carboxylated acrylonitrile butadiene rubber.

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Contents

1. Introduction

Seven years after the award of the Nobel Prize in Physics and thirteen years since the first report [1] of freestanding, monolayer graphene, the worldwide interest in this "*wonder material*" is still increasing, as can be realized from the number of publications per year and the massive investment in research. The reason for this interest is mainly due to the multifunctionality of this 2D-atomic crystal which combines unique properties such as thermal conductivity in the order of 5000 W/mK [2], high electron mobility in room temperature (250,000 cm^2/V s) [3], large surface area (2630 m^2/g) [4], high modulus of elasticity (~1 TPa) [5] and good electrical conductivity, making it attractive for use in a vast number of applications. The list of potential applications includes high-end composite materials [6,7], field effect transistors [8], electromechanical sys-