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Futuristic Nanomaterials and Composites I

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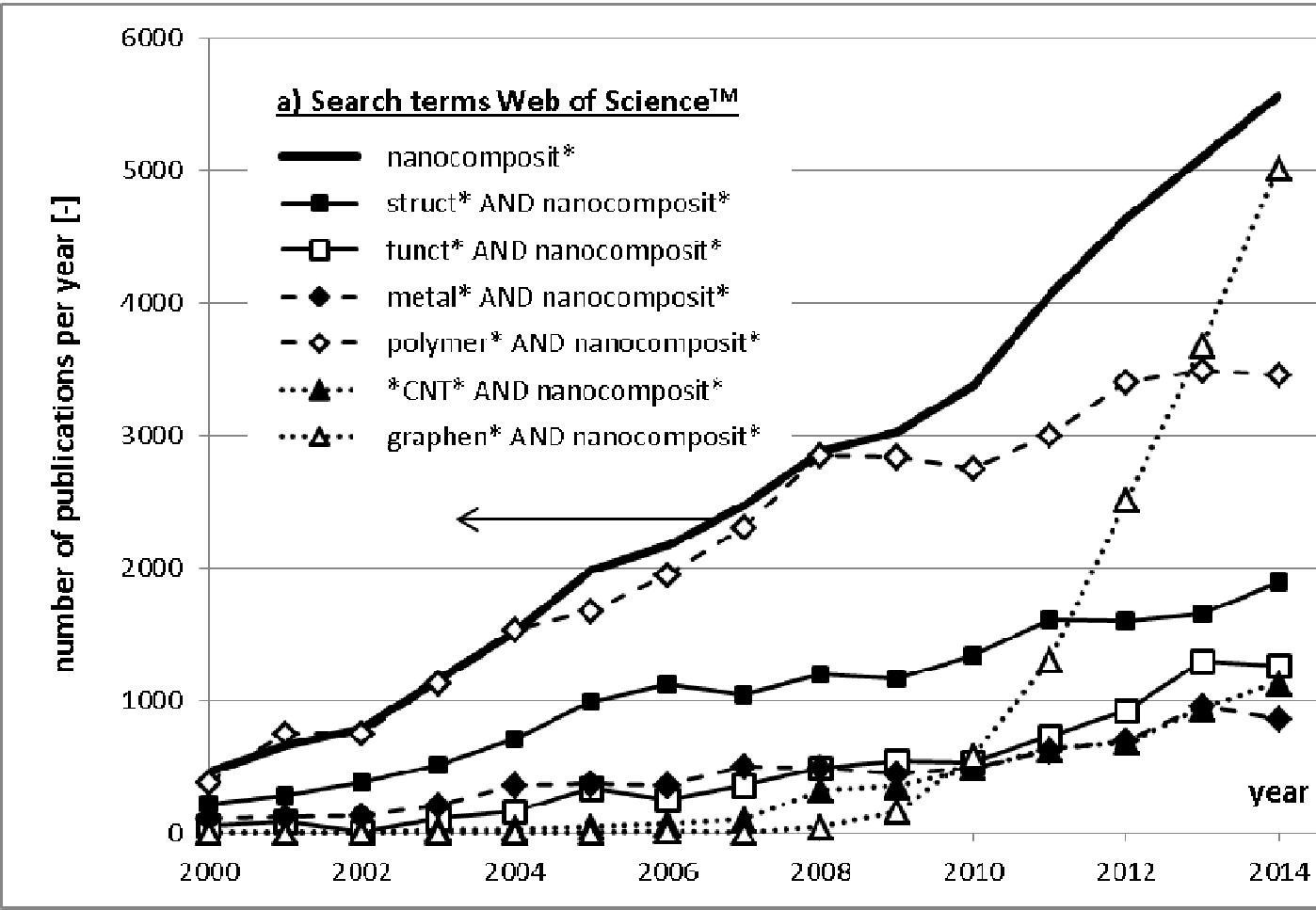
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Introduction

The present special issue topic “Futuristic Nanomaterials and Composites I” captures the structural as well as functional aspects of nanomaterials and nanocomposites that prove unique in some specific way when compared to their microscale counterparts. The uniqueness of structural qualities covered includes enhanced fracture toughness and wear resistance, while uniqueness in functional aspects include enhanced thermal conductivity, electrical transport, in addition to nanoscale sensing and characterization capabilities. Synthesis and processing routes leading to the nanostructures involved are also discussed. Inspiration for this special issue is drawn from two conferences: (1) NANOSTRUC 2014: International Conference on Structural Nano Composites held in Madrid (Spain) on 20-21 May 2014 and (2) Nanocomposites III symposium of the 2015 TMS Annual Meeting & Exhibition held in Orlando, Florida (USA), on 15-19 March 2015. By linking these two events, this joint special issue manifests a trans-atlantic networking in the field of nanocomposites that will be strengthened further in upcoming events of both series.

Even when considering that the number of publication figures are generally on the rise, analyzing nanocomposite-related data through sources like Web of ScienceTM or SciencedirectTM, it is clear that research on nanostructured materials is still gaining weight: Figure 1 illustrates this situation based on the aforementioned databases. What it reflects is the fact that foci will shift over time: Though the diagrams can offer a glimpse of the whole field only, they clearly underline that many researchers are currently focusing on graphene and its potential – both structural and functional - for nanocomposite formulation. Not surprisingly, our special issue reflects this trend, containing one article on this topic, complemented by three contributions looking at carbon nanotube (CNT) applications.



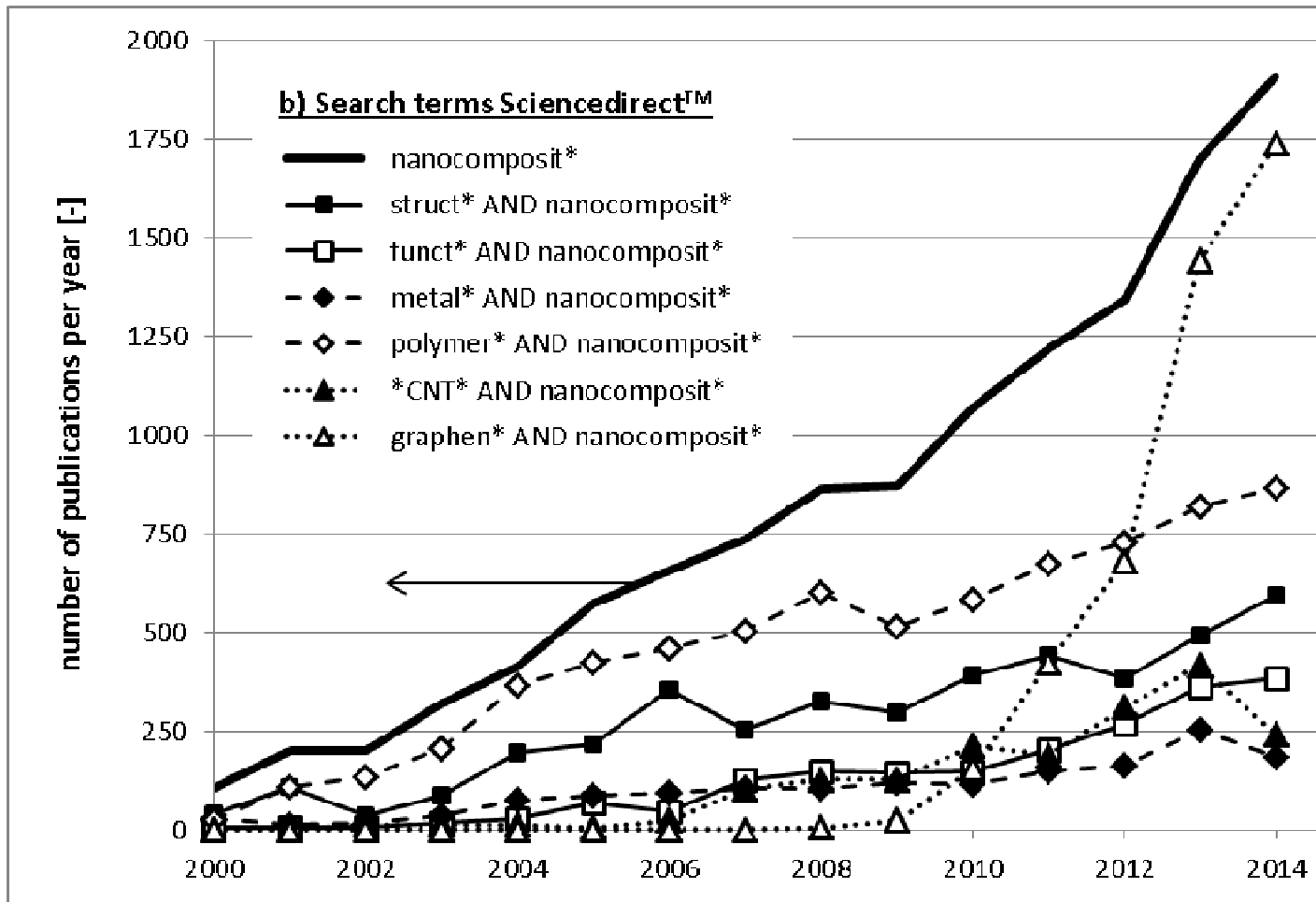


Figure 1. Publication numbers in the nanocomposite thematic field as found through (a) Web of Science™ (data retrieved June 14th, 2015) and (b) Sciencedirect™ (data retrieved June 12th, 2015) for different search terms and search strategies.

As is implied by the significant publication numbers, nanocomposites is a field as wide as materials science in general. Materials that match the nanocomposite definition can be of polymer¹, metal² or ceramic matrix³. Their second phase may be either organic or inorganic, including metals, depending on the purpose at the base of composite design: Dominant among the second phase variants are carbon-based materials like carbon nanotubes (CNT)⁴ or graphene⁵, not the least because of their applicability to optimizing either functional^{1,6} or structural properties⁷ - or both in parallel: An example of the latter is epoxy matrix strengthening in conventional fibre-reinforced composites by CNTs or graphene to simultaneously improve mechanical characteristics and conductivity to provide lightning strike protection in composite planes without weight penalty⁸. The wide variety of highly performant composites is facilitated by the unique properties that nanoscale structuring provides through phenomena like surface/interface area increase or crystal and electronic structure based effects. The general scope extends from improving mechanical strength^{2,9} to optimization of sensing^{10,11} and energy

conversion/harvesting^{12,13} properties, conductivity¹⁴, catalytic performance¹⁵ etc., all the way to enhanced energy storage materials^{6,16} and even improved antimicrobial effectiveness¹⁷.

With adequately covering the whole area being a truly Sisyphean labour, what links the publications in this issue is that they contain 'unique' aspects that constitute their immediate relevance concerning development in their respective fields of study. In the special issue, they are organized according to their focus in material development: Is it structural (i. e., in a broader sense used here, mechanical) or functional performance that is aimed at? Accordingly, the following sections will first look at contributions addressing the structural issue, and present them briefly, followed by those concentrating on optimized functional performance.

Structural Aspects

The study entitled 'Crack Formation in Powder Metallurgy Carbon Nanotube (CNT)/Al Composites during Post Heat-Treatment' by Biao Chen et al, post heat treatment (PHT) was applied to bulk pure Al and CNT/Al composites fabricated under different processes. It was observed that the nanocomposites consolidated by hot-extrusion formed micro-cracks, but those consolidated by spark plasma sintering (SPS) showed no crack. A high-temperature SPS process before hot-extrusion was effective in preventing crack formation. The release of residual stress in severe plastic deformed (SPD) materials was responsible for the cracking phenomena during the PHT process. Good particle bonding was essential and effective to suppress cracks for SPD nanocomposite materials in the PHT process.

In the article on 'Wear Characterization of Carbon Nanotubes Reinforced Acetal Spur, Helical, Bevel and Worm Gears Using TS Universal Test Rig' by Samy Yousef et al, CNTs were dispersed into acetal and nanocomposite gears were formed using injection molding. The wear resistances of the gears were measured and results indicated that the wear resistances of the CNT/acetal gears were increased due to the addition of CNT, especially in the case of the helical, bevel and worm gears.

Merie et al.'s work on "Nanocharacterization of titanium nitride thin films obtained by reactive magnetron sputtering" considers the influence of processing characteristics on mechanical and tribological behavior of titanium nitride thin films, showing a generally positive effect of substrate preheating irrespective of the former being based on steel or silicon. The properties improved include film adhesion, Young's modulus, nanohardness and surface roughness.

Functional Aspects

The article titled 'Improved Thermal Conductivity in Carbon Nanotubes-Reinforced Syntactic Foam Achieved by a New Dispersing Technique' by P. Bhat et al, describes the synthesis and characterization of carbon nanotube-reinforced syntactic foams. Carbon nanotubes were dispersed throughout the polymer matrix by growing them on the surface of the glass microballoons that as additives constitute the syntactic foam. Nanotube-grown microballoons improved the thermal conductivity of syntactic foam by 86% and 92% (at 50°C) compared to plain and nanotube-mixed syntactic foams, respectively. The improved thermal conductivity as

well as the microstructural analysis proved the effectiveness of this new approach for dispersing nano-scale reinforcements in syntactic foams.

In the report on ‘Nanocalorimetric Characterization of Heterogeneous Nucleation of Rapidly Solidified Bismuth Droplets Embedded in a Zinc Matrix’ by Linfang Li et al., Zn-10Bi (wt%) alloy with Bi droplets in size from micro to nanometers embedded in the Zn matrix was prepared. Nanocalorimetry was used to investigate the melting and solidification behavior of the embedded Bi droplets. Nucleation kinetics of rapidly solidified nano-sized Bi droplets were studied based on the hemispherical cap model of heterogeneous nucleation, and the calculated results revealed the validity of classical heterogeneous nucleation theory in nano-scale at relatively high cooling rates. Due to its high sensitivity and controllable cooling rate, nanocalorimetry is proven as promising technique to investigate the rapid solidification behavior of embedded nano-sized droplets.

In the article titled ‘Structural and Electrical Property of Sol-Gel Derived Nano-Films Lead Titanate-Based MIM Capacitor at Different Pb Content’ by Nurbaya et al. discuss the build-up of metal-insulator-metal capacitors from lead titanate nanofilms created through an adapted spin coating process on glass substrates. Structural and electrical properties of these electronic components were evaluated and linked to the observed lead acetate levels of 5 to 25 wt%, showing most promising functional characteristics at 10 wt% and frequencies below 100kHz. Further development towards data storage applications is suggested.

In their contribution entitled ‘Graphite to Graphene via Graphene Oxide: An Overview on Synthesis, Properties, and Applications’, D.P. Hansora et al. review the current state of graphene and graphene-based materials in terms of preparation, properties, functionalizations and promising applications. They complement this review with the presentation of a novel, arc-discharge technique for the synthesis of uniform graphene sheets dispersed in water, together with a description of the subsequent processing steps including purification, drying etc. necessary to obtain the final product. Characterization of the latter material using Raman spectroscopy, XRD, SEM and TEM techniques is added.

“Natural ceramic nanotube substrates for surface-enhanced Raman spectroscopy” have been investigated by Vinokurov et al., showing improvements in SERS studies underlined by enhancement factor estimates ranging between 3 and 5 orders of magnitude. The contribution provides details of the synthesis of these materials from halloysite clay nanotubes deposited on aluminium foil and covered by Au, Ag and Cu metal films produced by vacuum evaporation. The possibility of omitting a capping agent during analysis of the p-mercaptobenzoic acid used as reference substance opened up by the build-up of the substrates eliminated the respective background peaks from the spectra obtained and led to the aforementioned improvement.

Works by Li et al. as well as Chen et al. were presented at the 2015 TMS Annual Meeting in the framework of the symposium Nanocomposites III, while the studies by Hansora et al., Merie et al., Nurbaya et al. and Vinokurov et al. formed part of the NANOSTRUC 2014 Conference.

Summary

Nanomaterials including composites containing nanostructures are currently a dynamic field globally. Traditional composite technologies typically provide composites for singular applications and uses. In contrast, the nanoscale domain is well known for its potential to merge crystal structure (for mechanical properties) and electronic structure (for functional properties) modification, enabling the creation of unique multifunctional nanomaterials. In several ways, such achievements may contribute significantly to sustainability: By their enhanced overall performance per discipline, by enabling use of a single material to address several functional requirements in parallel, thus reducing the number of product or system components, etc.

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