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Fabrication of Nanostructured Coatings

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Abstract - The outstanding thermal, mechanical, electrical and electronic properties of nanocrystalline materials and carbon nanotubes has attracted considerable research interests, and is now one of the major identifiable activities for material scientists. However, the practical and commercial use of these materials requires efficient processing methods, which needs to be compatible with the existing processes. One of the problems limiting their application is preparation of these materials. Currently, these materials have been prepared in the laboratory by traditional method of compacting the metallic powders which consist of particles at nanoscale. This method has many limitations to achieve properties required at nano-scale. The development of surface nanostructured coatings has been considered as potential industrial application. The nanostructured coatings can be formed by various methods such as physical vapour deposition (PVD), sputtering, chemical vapour deposition (CVD), electrochemical deposition, electro-spark deposition. This study has reviewed the formation of nanocoatings by different processes, with emphasis on embedding carbon nanotubes in coating structure.

Keywords: CNT, Coating, Cold Spray, Nanostructured

I. INTRODUCTION

Nanostructured materials have achieved much attention in recent years due to their outstanding properties like having higher hardness, strength and corrosion resistance as compared to those of micron-size counterparts. These materials are characterizes by a microstructural length scale in the 1-200 nm regime. It is found that these are sensitive to process temperature because particle size strongly influences the particle thermal history, as small particles rapidly heat up and also rapidly cool down. It also affects the interlamellar adhesion of the splats and hence influencing mechanical properties of the coating. One of the problems which limits the work and applicability is the fabrication of materials/coatings and alloys at nanoscale. The traditional method of preparation of nanocrystalline alloys is the compaction of nano-sized powders, but there is risk of coarsen of these nanosized particles during high temperature compaction. Therefore these days instead of traditional preparation methods, the fabrication of these materials by surface coating method is emerging as a potential area. The nanostructured coatings can be formed by various methods such as physical vapour deposition (PVD), sputtering, chemical vapour deposition (CVD), electrochemical deposition, electro-spark deposition. The techniques of providing coated surfaces is also steadily becoming important because of increase in cost of bulk materials. There is need of preserving the ability of alloys to withstand highly aggressive conditions such as high temperature corrosive atmosphere and maintain their good mechanical properties. These requirements led to the development of different techniques for providing protective coating materials.

These days the research is focused in on carbon nanotubes (CNTs) because of their exceptional properties and is expected to have many potential applications for future [1]. However there are many challenges exists for micro-fabrication of CNTs. This study mainly reported the research related to the fabrication of the CNT composite coatings.

II.CARBON NANOTUBES

Carbon nanotube (CNT) is a third allotropic form of carbon along with graphite and diamond and is in the shape of a seamless cylinder of carbon atoms which are arranged in a hexagonal lattice [2]. The number of concentric rolling layers of graphene sheets have distinguished the CNTs such as singlewall (SWCNT), doublewall (DWCNT), and multiwall (MWCNT). It is mostly reported that diameter of SWCNT and MWCNT are upto 0.4-5nm and 100nm, respectively, with spacing between layers around 0.34nm [3]. The interest of the researchers in CNTs is tremendously increasing due to their exceptional electrical, thermal and mechanical properties. The properties of nanotubes are related to the length, diameter and orientation of carbon atoms in the rolled graphene sheets. Worldwide researchers are attracted towards the remarkable properties of carbon nanotubes, such as around 100 times tensile strength (~150 GPa) and five times elastic modulus (~1 TPa) with one-fifth the density in comparison to high strength steels [1]. Also thermal conductivity of around five times of copper is reported for CNTs with high electrical conductivity and capacity of carrying current [1]. Difference forms of CNTs are illustrated in Figs. 1 and 2.

III.FABRICATION OF COMPOSITE COATINGS

Pialago and Park [6] has successfully cold sprayed composite coatings with 5, 10 and 15 (vol.%) multiwalled carbon nanotubes (MWCNTs) by mechanical alloying (MA) with Cu using an attrition ball mill. Cu-CNT composite coatings were fabricated on 0.3-mm Cu plate substrates. The MWCNTs used in the coating process have diameter of 5–20 nm and approximate length of 10 μm with aspect ratio more than 500. It has been observed in this study that the coating surface contained 1.0–2.5 vol.% micropores, however, there were more pores in the composite coatings with10% MWCNT. It is also reported that there is decrease in deposition efficiency (DE) with the increase of CNT and the number of coating layers. The characterization results have confirmed the composition and uniform dispersion of MWCNTs within the cold sprayed

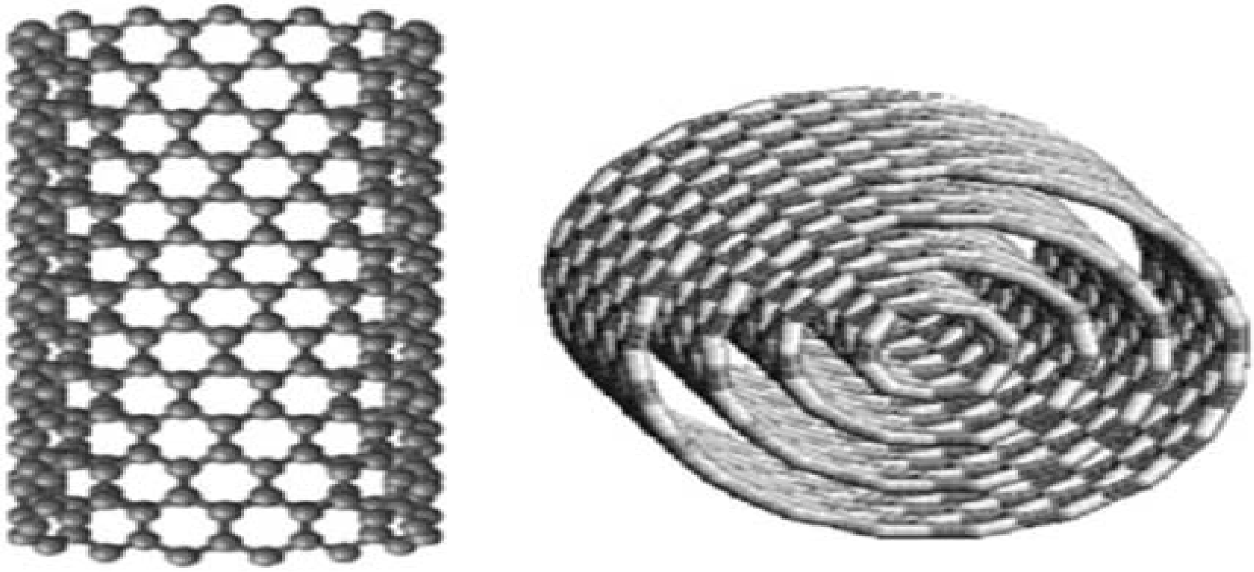

Fig. 1 SWCNT and MWCNT [4].

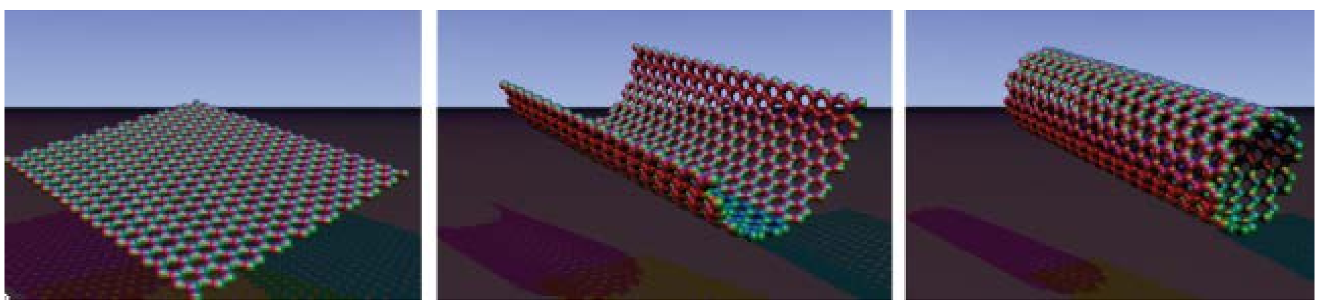

Fig. 2 Wrapping of graphene for SWCNT structure [5]

composite coatings. The microstrains have been observed in the composite powders and coatings. Bakshi et al. [7] have dispersed the Multiwalled carbon nanotubes (MWCNTs) within the Al–Si eutectic alloy powder by spray drying process for further cold spraying on grit blasted 6061 aluminum alloy substrate. The CNT diameter and length used was 40–70 nm and 1–3 µm, respectively, and its content in the powder was 0.5 and 1 wt.%. Eight layers of cold spraying have resulted in the formation of the coating of the order of 500 µm in thickness. The impact and shearing have resulted in reduction of lengths of MWCNTs. It is reported in the study that of the elastic modulus varies in the coating region varies from as high as 229 GPa for 0.5 wt.% CNT and 191 GPa for 1wt.% CNT coating. This variation is reported due to the locally high of CNTs and reinforcement effect of CNTs. This study reported that cold spray successfully sprayed the CNTs within the coating on aluminum alloy substrate using helium as main gas and nitrogen as powder carrier gas.

Cold spray process was successful in depositing ternary composite coatings of Cu-CNT-SiC, as reported by Pialago et al. [8]. The ternary powder was prepared by mechanical alloying (MA). It this study the 0.3 mm Cu substrate was cold sprayed by single-layer Cu,Cu–5CNT, Cu–5CNT–10SiC, andCu– 5CNT–20SiC (vol%). In this process multiwalled CNTs used with assumed density of 2.1g/cc, diameter of 5–20nm, length of 10 µm and aspect ratio > 500. It is reported that the deposition efficiency cold spraying increased when the SiC content in the composite coating was increased from 10 to20 vol%. Also the dispersion of SiC in the composite powder particles, as well as within the coatings was not homogeneous and the surface pores of the SiC containing coating was finer in comparison with other coatings.

Laha et al. [9] has reported the plasma sprayed synthesis of Al-based nanostructured composite with 10 wt.% CNTs (bulk density as 1.3–1.5 g/c.c., diameter 40–70 nm and 0.5–2.0 µm length) as second phase. The characterization results has reported that CNTs were stable chemically stable during spray process and did not reacted to form oxides or aluminum carbides. CNTs were retained in the composite structure and shape of hollow conoid (taper-length- 100mm, diameter-62mm and thickness -2mm). Hardness was enhanced with the addition of CNTs and measured density was reported higher than the theoretical.

Keshri et al. [10] reported the vaporization of CNTs during plasma spraying of liquid precursor. This behavior of carbon occurred due to the intense heat of the plasma which exceeds 4200 K. Carbon vapor is a stable phase at 1 atm and around 4200 K, as shown in Fig. 3 [11].

Balani and Agarwal [12] has examined the nanocomposite coatings prepared by blending of Al2O3 with 4 wt. % and 8 wt. % CNTs on AISI 1021 steel substrates. The plasma sprayed composite coating has shown improvement in fracture toughness. The coating microstructure is formed of fully and partially melted and solid state zone, as CNTs has an effect on the heat transfer characteristics due to their high thermal conductivity.

IV. CONCLUSION

Nanostructured materials and especially carbon nanotubes (CNTs) have tremendous future applications in the all fields of sciences and engineering. A rising trend is also observed in the field of composite material coatings with reinforcement of CNTs. There is need to explore different coating methods, mainly from thermal spray family, to develop nano-coatings and research is required for optimizing various coating parameters. Research is needed to test various the developed coatings under various environmental conditions.

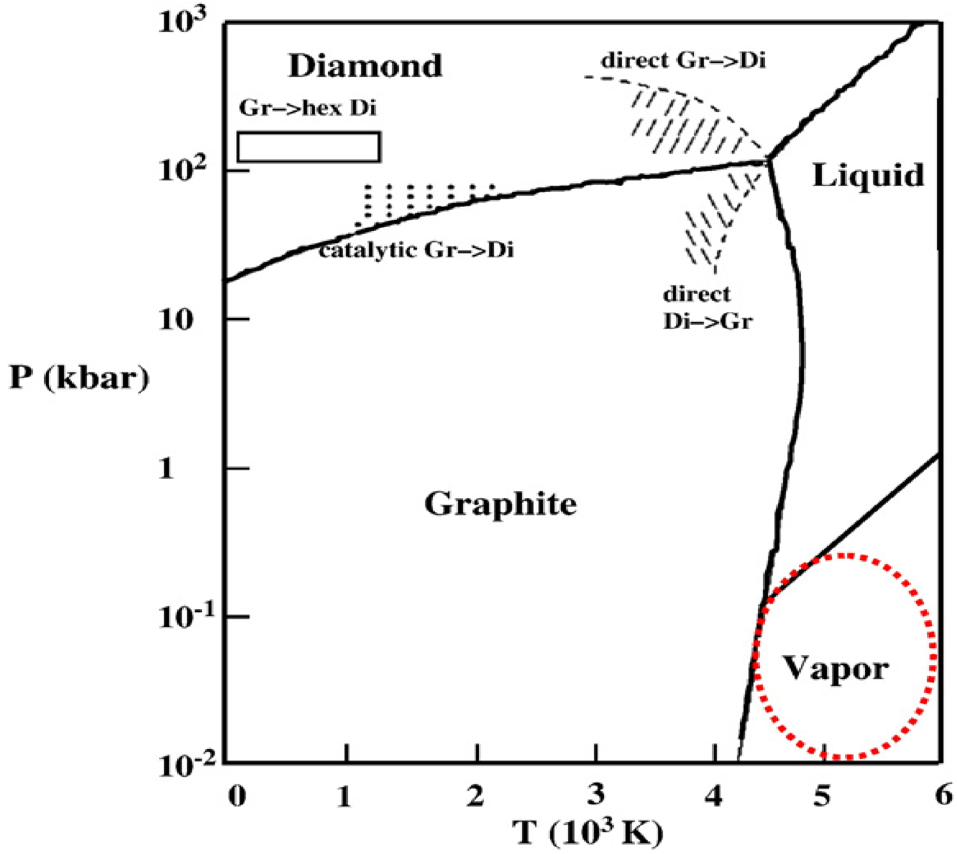

Fig. 3 P-T carbon phase diagram [11].

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