WAVE PROPAGATION IN MULTILAYERED STRUCTURES COMPOSED OF CARBON NANOTUBES AND RIGID INTER-LAYERS UNDER SMALL VELOCITY IMPACTS.

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Summary We study the wave propagation characteristics in periodic multilayered structures composed of compliant freestanding vertically aligned carbon nanotube (VACNT) arrays alternating with rigid inter-layers. We excite the structures with small transient excitations using a striker. These multilayer systems exhibit a highly tunable dynamic behavior and good energy absorption capabilities, suggesting their use for energy and vibration absorption applications.

INTRODUCTION

Vertically aligned carbon nanotubes (VACNTs) present a nonlinear, foam-like response when subjected to quasi-static compressive cyclic loading, with the ability to recover large strains up to 80% [1,2]. In addition, they present intrinsically graded functional properties that lead to strain localization and characteristic modes of deformation and buckling [1,2,3]. They also present nonlinear viscoelastic behavior [4,5] and ability to absorb dynamic impacts effectively [2,6]. The presence of nonlinear effects in the VACNTs enables the design of layered materials with tunable properties in which, for example, stiffness can be controlled over large ranges, and stress wave propagation properties can be dramatically tailored to specific applications.

SYNTHESIS OF VACNTS

In our laboratory, VACNTs are synthesized by a thermal chemical vapor deposition (tCVD) process with floating catalyst, at atmospheric pressure [2]. The system consists of a tube furnace with a 15 cm long heating zone, operated at 827 ^{0}C. CNTs are grown using thermally oxidized Si wafers as substrates. The reaction gas feedstock consists of a solution of Fe catalyst precursor (ferrocene) and carbon source (toluene), prepared at the ratio of 1 g : 50 ml. This solution is injected in the furnace at 1 ml min^{-1} together with a carrier gas, Argon, at constant flow equal to 800 sccm. This process results in an array of VACNTs of thickness in the order of ~1 mm, with an average bulk density of 0.229 g/cm^3. After growth, the VACNTs are removed from the substrate using a razor blade, and cut into circular specimens for mechanical testing.

EXPERIMENTAL SET UP

We assembled a multilayer array of VACNT samples alternating with rigid cylinders and studied the wave propagation characteristic in response to small impact loadings. The array was composed of cylindrical VACNT samples (diameter=4.76 mm; length ~1 mm) grown by the thermal CVD, alternating with steel cylinders (diameter=length =4.76 mm). The array was supported by 4 polycarbonate rods of 4.76 mm diameter arranged horizontally and by a rigid mild steel block mounted on an optical table acting as a rigid boundary [Fig. 1].

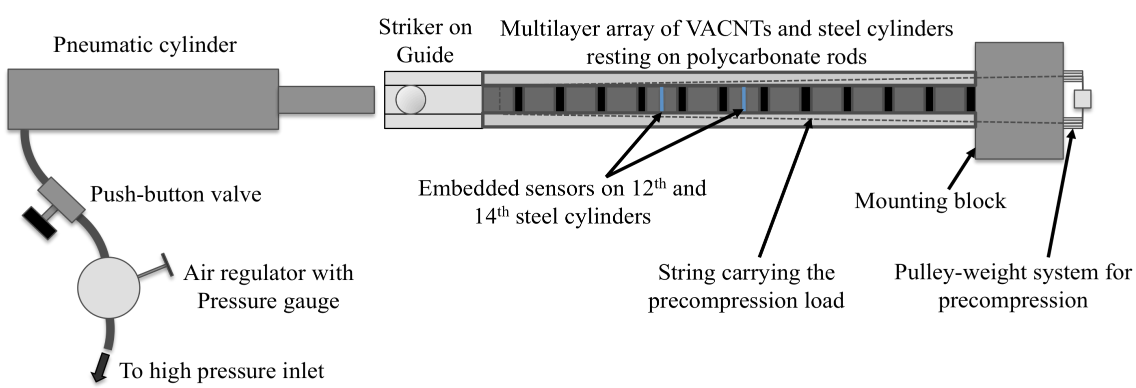

Fig.1: Schematic top view of the experimental set up.

Piezoelectric sensors were embedded in the 12th and 14th steel cylinders to measure the force time response of the system. The sensors were calibrated using conservation of momentum. Strikers of diameter, 4.76 mm and variable mass (PTFE, 0.12 g; Steel, 0.45 g) were launched on a low friction PTFE guide using a pneumatic shooting system. To verify the tunability of the VACNTs's response as a function of the applied pre-strain, we applied variable static precompression to the multilayer array. The pre-compression was controlled by hanging different weights on the array using a pulley system.

PRELIMINARY RESULTS AND DISCUSSIONS

From the preliminary experimental results obtained [Fig. 2], the effective velocity of the propagating stress was observed to decrease with increasing dynamic forces (F_d). Here, the effective velocity was calculated by dividing the distance between the sensors by the effective time the wave takes to travel that distance. The dynamic force was calculated by taking the average of the peaks of the two stress profiles recorded by the sensors. This observed response may be due to the localized buckling in compression. The static precompression (F_s) is observed to affect the elastic response of the VACNTs, by increasing the overall stiffness of the structure. Higher values of static precompression resulted in higher effective stress propagation velocity and decrease in the exponent of the power-law fit.

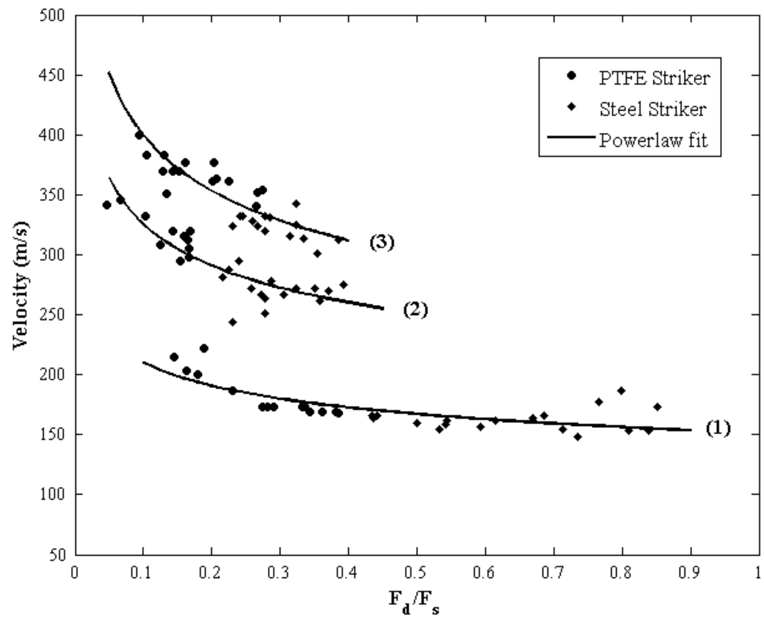

Fig.2: Experimental data for three different static precompressions: (1) 5N, (2) 15N and (3) 20N, and the corresponding power-law fits showing the variation of the effective velocity with the dynamic force (F_d) (generated by PTFE and stainless steel strikers) normalized by the static precompression (F_s).

Further experiments are being performed to understand the effects of variable aspect ratio of the steel cylinders on the response of the system. Experiments with polymeric cylinders are also being performed. Understanding the fundamental response of CNT-based systems will enable the design and synthesis of novel layered materials with tunable properties, lightweight and improved performances, particularly applicable to small impacts and vibration absorption.

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