IMPROVING CRASHWORTHINESS BY DAMPING VIBRATIONS IN CFRP COMPOSITE STRUCTURES USING CARBON NANOTUBES SPRINGS

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Abstract

Carbon nanotubes have tensile strength approximately 30 times higher than the conventional steel. Moreover theoretically these CNT moulded into springs can store potentially 1000 times more energy than steel. Carbon nanotubes have excellent damping characteristics, which is possibly due to interfacial friction between the carbon nanotubes and the polymer resins and also because of large surface area over given specific mass. There applications are still far from reality. But here in this paper I will try to bring the CNT springs to a new application to improve the crashworthiness of a car may it be a formula one or a supercar whose chassis is moulded out of Carbon Fiber Reinforced Plastic (CFRP). These springs combined with piezoelectric substance can give tremendous improvement in driver's safety during collisions. Here I have tried to combine the mechanical strength of Carbon nanotube with best suitable piezoelectric material to derive a new property which will transform impact energy into electrical energy and hence utilize it for driver's protection. In the paper I have studied various piezoelectric materials, their bonding and behaviour with carbon atoms. I have tried to generate a possible stable structure theoretically which can withstand high impact as well as generate enough potential energy for driver to be safe during the impact.

Keywords: *carbon nanotube springs, CFRP, piezoelectric substance, impact, crashworthiness*

1. Introduction

We are familiar with the name Jason Leffler who died in NASCAR, 2013 (Fig. 1), also Allan Simonsen who died in Le Mans' 24 Hr, 2013. Car crashes have not only been a nightmare for the driver but also for an automobile engineer, who always strives hard to put the best performance in the car so as to ensure the driving experience enjoyable and safe. History tells that car crashes have taken ugly shapes when slightest error was overlooked (Fig. 2). In that case it becomes very important for any chassis designer to ensure the safety of the driver at all costs. This can be done only when there are promising developments in advance material sciences.

Carbon nanotube springs have gained a lot of attention due to their remarkable properties. Especially their energy storage capacity is gaining a lot of momentum in development of new electrical devices which could be used as cells in near future. Tab. 1 shows the comparison of the various available alternatives which could serve the purpose of absorbing the impact energy and become a viable source for improving the crashworthiness. Undoubtedly Carbon nanotubes have a very high tensile strength, near about 30 times more than that of conventional steel (energy density of conventional steel is 1080 kJ/m^3 while upper bound energy density of CNT is 7.7×10^6 kJ/m^3 also effective stiffness of CNT is 1 TPa and strength approximately 100 GPa). This becomes a very useful tool in safety of the driver during a car crash.

The idea is to combine the strength of carbon nanotube and a piezoelectric crystal to derive a new property to absorb as well as utilize the energy coming during the impact. The spring action of carbon nanotubes has been studied over for quite a long now. Now we are trying to successfully synthesize the material in composite form. For this a methodology has been created which will help us to find the desired composite material and apply it to improve the crashworthiness of the car.

Fig. 1. NASCAR 2013 car crash

Fig. 2. Formula 1 car during a fatal crash

Tab. 1. Energy density, life cycle and efficiency of mechanical energy storage technologies

	Gravimetric energy density (kJ/kg)	Volumetric energy density (kJ/m^3)	Life cycles	Efficiency
Ideal CNT spring	5,000	7,700,000	Many cycles	—
PDMS spring [16]	5	4,900	—	—
Steel spring [4]	0.14	1,080	—	—
Rubber band	3	3,600	—	—
Isoprene spring	220	200,000	—	—
High modulus carbon fiber spring	7.0	15,000	—	—
High strength carbon fiber spring	46.1	83,000	—	—
Silicon spring	20.8	48,500	—	—
Fly wheel [9, 14]	36	40,000	10^7	90%
Pumped water [9]	3.6	3,600	50,000	75%
Compressed air [3, 9]	40-100	43,200	15,000	18-90%

2. Defining parameters of study

There are a lot of factors which are to be considered when finding the appropriate piezoelectric crystal. Since the properties of piezoelectric element depend largely on the temperature, hence it becomes crucial for the composite to bear high temperatures during a crash. The factors to be taken into account are mentioned below and briefly described.

Curie temperature

A piezoelectric element can only function as long as temperatures are well below Curie temperature.

Piezoelectric constants

These elements are anisotropic, hence their tensor properties like permittivity (*E*), Compliance (*s*), piezoelectric charge constant (*d*) and piezoelectric voltage constant (*g*) are to be related to the direction of applied stresses.

Frequency constant (N)

$$f_s = \frac{N}{d}, \tag{1}$$

where:
f_s – resonant frequency,
N –frequency constant,
d – diameter of the disc.

Coupling factor (k_{eff})

It is the measure of effectiveness with which electrical energy is converted into mechanical energy and vice versa. For frequencies well below the resonant frequency of the piezoelectric body keff is given by the expression:

$$k_{eff}^2 = \frac{\text{energy converted}}{\text{energy input}}. \tag{2}$$

Dielectric hysteresis

The ferroelectric property of the piezoelectric element is to be studies with the help of the hysteresis curve obtained using the relation:

$$D_i = P_i + \varepsilon_0 E_i, \tag{3}$$

where:
D – dielectric displacement,
P – polarization,
E – electric field,
ε_0 – permittivity of free space.

3. Finding best suited piezoelectric crystal

Depending on the above parameters the appropriate piezoelectric ceramic could be found, the following crystals/ceramics have come to light which could potentially be useful:

- Quartz,
- Tourmaline,
- Lead magnesium niobate – lead titanate (PMN-PT),
- Lead zirconate niobate – lead titanate (PZN-PT),

- Lithium tetraborate ($Li_2B_4O_7$),
- Lithium niobate ($LiNbO_3$),
- Barium titanate ($BaTiO_3$),
- Gallium phosphate ($GaPO_4$),
- Zinc oxide nano particles
- Lead zirconate titanate (PZT).

4. Synthesis of the composite

The most important step is to synthesize this kind of composite. The idea is to grow carbon nanotubes on the piezoelectric ceramic discs (Fig. 3). The piezoelectric ceramic is to be used as a base. The carbon nano particles are synthesized over the ceramic. These units are then cured in a suitable resin matrix to form a composite structure. The most viable resin matrix is epoxy. There are different grades of epoxy resin, but for experiment purpose the general purpose epoxy can be used which is easily available in the market.

The growth of carbon nano fibers can be achieved using the techniques mentioned below:

- laser ablation,
- arc discharge,
- Chemical Vapor Deposition on a substrate,
- Chemical Vapor Deposition in an aerogel,
- micro fabrication,
- electrospining,
- detonation of 2,4,6-triazido- 1,3,5-triazine in presence of transition metal.

Out of the above mentioned processes there can be other methods to synthesize but it all depends on the scope of research.

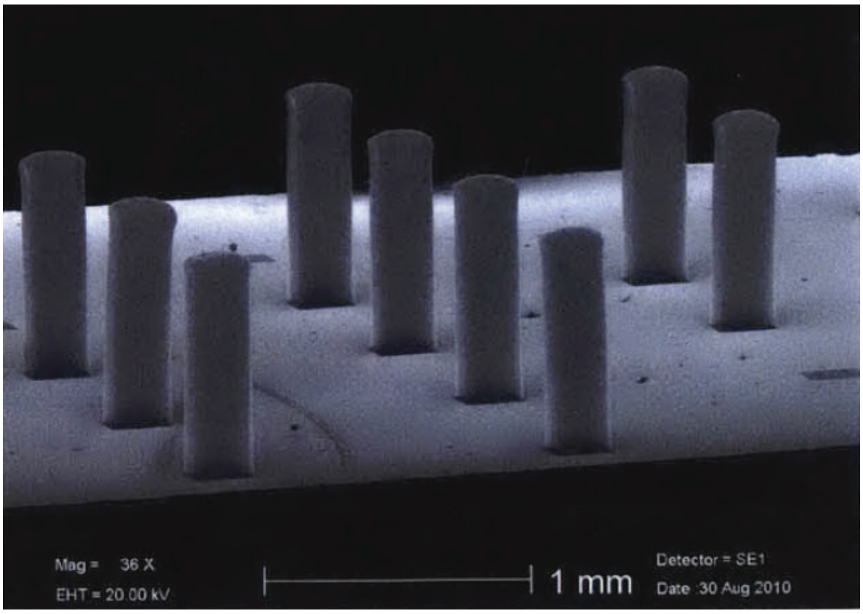

Fig. 3. SEM image of array of 200μm×200μm Carbon nanotube pillars

5. Analysis

After the specimen is ready the essential question arises whether the structure is meeting the requirements of the basic idea or not. Hence, for this various techniques have been studied, as mentioned below, under which this can be verified whether or not the composite material is good enough to serve the purpose.

1. Continuum mechanics model:
   The carbon nanotubes are modeled using the continuum assumption in which CNT is treated as a uniform cylindrical beam and each shell of the CNT is taken to contribute 0.34 nm to the beam's wall thickness.
2. Finite element simulation.
3. Raman spectroscopy.
4. Scanning electron microscope.
5. Transmission electron microscopy.

6. Conclusion

Carbon nanotubes have excellent damping characteristics, which is possibly due to interfacial friction between the carbon nanotubes and the polymer resins and also because of large surface area over given specific mass. During the study it was found that piezoelectric zinc oxide (ZnO) nanoparticles have a highly desired piezoelectric and semiconducting property also since these are not ferroelectric hence curie temperature doesn't come in to consideration, meanwhile using Chemical Vapor Deposition (CVD) via aerosol, aligned carbon nanotubes can be produced. Fig. 4. is a graphical presentation of the composite we are trying to synthesize. This composite forms the lining of the driver's cockpit region as shown in the Fig. 5. During the impact the cockpit region is isolated from the car. The isolation is achieved on the cost of the energy coming from the crash.

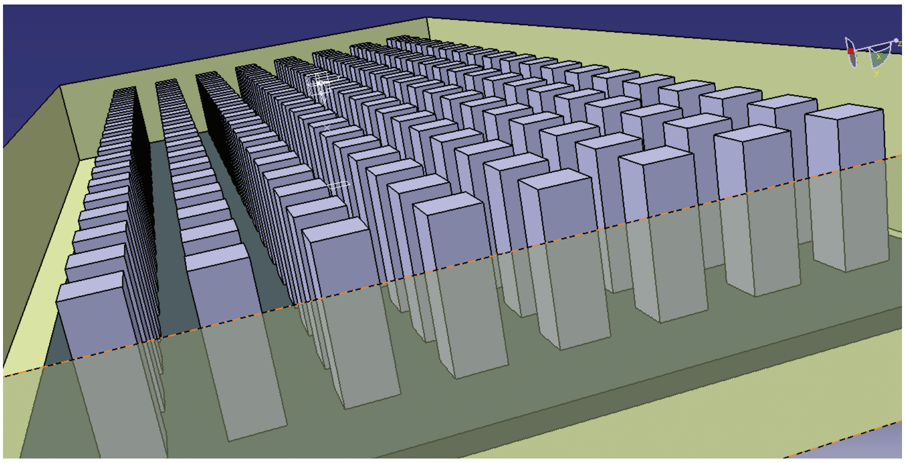

Fig. 4. Graphical representation of carbon nanotube array over piezoelectric ceramic enclosed in a resin matrix

Fig. 5. Graphical representation of composite lining in the monocoque chassis of a commercial car

The only thing this composite awaits is the experimentation and verification which could be possibly done in the near future depending on the supports from the labs and institutions.

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