INCORPORATION OF NANOTECHNOLOGY IN THE CURRICULUM OF CIVIL ENGINEERING EDUCATION

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EXTENDED ABSTRACT

Nanotechnology and nanoscience are scientific and technological fields that have attracted considerable interest in the last decade. Both deal with the science and technology at a scale smaller than 100nm (1nm=10^{-9}m). Due to their reduced size, nanomaterials properties vary considerably from those of bulk materials and thus they present exceptional mechanical, optical, magnetic and electric properties (Schaefer 2010). Applications to everyday life are increasing as well as the domains of applications.

Civil Engineering is not excluded from applications of nanotechnology. Applications include super-hydrophobic surface treatment in order to increase materials durability, self healing materials in order to reduced crack propagation, Micro-Electro-Mechanical Systems (MEMS) and Nano-Electro-Mechanical Systems (NEMS) for monitoring of structures with non-destructive methods, nano-cement and nano-steel for increased strength and durability, just to mention a few (Nanoforum Report 2006, Sobolev et al. 2006). Nanotechnology applications seem also very promising in environmental applications, a field in which Civil Engineers are increasingly involved (Observatory Nano 2010). The financial interest is demonstrated by the increased amount of budgets invested in nanotechnology research and development, a significant part of which is directed to the domain of tailor-made materials properties, while the scientific interest is demonstrated by the increasing rate of scientific publications, which originate from the fields of physics, chemistry and materials science and seem to involve an increasing number of civil engineers (Economidis 2010).

The need for better understanding of materials properties at the nanoscale and their use in application in engineering and more specifically in Civil Engineering is a special concern (ASCE 2007, Kim et al. 2006). It is also demonstrated by actions taken by the National Science Foundation (NSF) in the United States (US) for Civil Engineering Departments to introduce nanotechnology courses in their curriculum (Zheng et al. 2010).

In the present paper we discuss the need for the introduction of nanoscience and nanotechnology courses with relation to the syllabus as well as to pedagogical points where attention should be paid in order to achieve the best output. Understanding the difference of behaviour of nanomaterials and their importance on materials' behaviour will provide future Civil Engineers with advanced skills that will enable them to adopt emerging technologies and formulate innovative solutions to complex problems. Such skills will provide students with additional professional opportunities and competitiveness in the international economic and scientific environment.

KEYWORDS

Nanoscience, Nanotechnology, Civil Engineering Education, Civil Engineering curriculum.

1. INTRODUCTION

Nanotechnology and nanoscience deal with the science and technology at a scale smaller than 100nm (1nm=10^{-9}m). Due to their reduced size nanomaterials' properties vary considerably from that of bulk materials and thus they present exceptional mechanical, optical, magnetic and electrical properties (Schafer 2010). Due to these reasons these fields have attracted considerable interest in the last decade. The first mention to the evolution that would come is attributed to the Nobel Laureate Richard Feynman who mentioned "there is plenty of space at the bottom" in a lecture that gave on December 29th 1959 at the annual meeting of the American Physical Society at the California Institute of Technology (Feynman 1960).

The basic interest in nanotechnology was initially limited to research labs mainly of physics and chemistry and more lately to that of materials science. However, applications to everyday life are increasing as well as the domains of applications. Civil Engineering is not excluded from applications of nanotechnology since many branches are involved such as cement and concrete (Antonivic et al. 2010, Ge and Gao 2008), coating materials for construction production, health monitoring of structures etc (Lynch et al. 2009). Applications include super-hydrophobic surface treatment in order to increase materials durability, self healing materials in order to reduced crack propagation, Micro-Electro-Mechanical Systems (MEMS) and Nano-Electro-Mechanical Systems (NEMS) for monitoring of structures with non-destructive methods, nano-cement and nano-steel for increased strength and durability, just to mention a few (Nanoforum Report 2006, Sobolev et al. 2006). Nanotechnology applications seem also very promising in environmental applications, a field in which Civil Engineers are increasingly involved (Observatory NANO 2010).

The financial interest is demonstrated by the increased amount of budgets invested in nanotechnology research and development, a significant part of which is directed in the domain of tailor-made materials properties, while the scientific interest is demonstrated by the increasing rate of scientific publications which go out from the fields of physicists, chemists and materials scientists and seems to involve an increasing number of civil engineers (Economidis 2010, Lux 2004, Moradi 2005). We must mention here that nanotechnology constitutes a priority research files in US, Europe but also in Greece.

The need for better understanding of materials properties at the nanoscale and their use in applications in engineering and more specifically in Civil Engineering is a special concern (Kim et al. 2006, ASCE 2007). It is also demonstrated by actions taken by the NSF in the United states for Civil Engineering Departments to introduce nanotechnology courses in their curriculum (Kim et al. 2010), but also by the National Nanotechnology Initiatives (NNI 2011) and several actions realized in Europe.

In the present paper we discuss the need for the introduction of nanoscience and nanotechnology courses with relation to the syllabus as well as to pedagogical points where attention should be paid in order to achieve the best output. We present some cases of introduction of nanotechnology courses in the curriculum of Civil Engineering Departments in the US and Europe and then we present our proposal for the introduction of such courses in the case of Greece.

2. CIVIL ENGINNERING AND NANOTECHNOLOGY

Civil engineering is directly related to construction and thus to construction materials, the most representative of which are cement, concrete and steel as well as coatings.

Monitoring of structure health which may be critical in several constructions and solutions for healing or preventing damage are also of interest for Civil Engineers. Nanotechnology is related to the development of materials since at this scale materials present different properties from the classical macroscopic materials and their properties as we know them. This different and sometimes extraordinary behaviour originates from the fact that at the nanoscale the ratio of surface atoms to volume atoms becomes important. Taking advantage of this particularity novel materials containing nanoparticles have been developed for civil engineering applications. In the following we discuss briefly such applications concerning construction materials and health monitoring.

2.1 Construction Materials

2.1.1. Concrete

This is the most widely used material in constructions. Although the macroscopic behaviour of concrete has been extensively studied its properties and behaviour at the micro and nano-scale are not fully understood. Processes that are important in the case of concrete include hydration and the alkali-silicate reaction (Balaguru 2005). The study and understanding of the structure and behaviour at the micro/nano-scale is necessary for improving concrete properties and avoiding several problems like alkali-silicate reaction. Li (2003) found that the addition of nano-SiO_2 significantly increases its compressive behaviour. It has been shown that the inclusion of nano polycarboxylates into concrete permits consolidation without need for vibration, resulting in a significant labour cost reduction (Nanoforum Report 2006).

Carbon nanotubes (CNTs) are among the strongest fibers and are very promising for the production of high-performance materials. They have five times the Young's modulus and eight times the strength of steel while their density is six times smaller than that of steel. Studies have indicated that the distribution of CNTs across cement grains can improve the mechanical behaviour of the cement-CNTs composite (Makar and Beaudoin 2003).

2.1.2. Steel

Steel is another major construction material and is present in nearly all structures. Properties of significant importance are strength and corrosion resistance. In the US new low carbon high-performance steel for bridges has been developed (Kuennen 2004). This new kind of steel presents higher corrosion-resistance and weld ability through the incorporation of copper nanoparticles in the steel grain boundaries.

MMFX2 is a nanostructured steel produced by MMFX Steel Corp (2010) which compared to conventional steel has a different microstructure which results in three times larger strength, along with larger ductility, toughness and corrosion resistance. Stainless steel presents a high cost thus it is employed in high risk environments. The new MMFX2 steel has a lower cost while presenting a similar corrosion behavior like that of stainless steel and thus it would constitute a serious alternative (MMFX Steel Corp 2010).

2.1.3. Coatings

There are several types of coatings that have been developed for certain purposes. In fact the materials contain certain types of nanoparticles that produce the desired effects. These are coatings that due to their hydrophobic behaviour push away water. Hydrophobic coatings are commercially available (see for example NanoPhos 2011). Another class of coatings is containing titanium dioxide nanoparticles which is employed in glazing coatings. Due to the sterilizing and fouling properties of titanium dioxide organic dirt is disintegrated through a catalytic reaction (Arafa et al. 2005). Other applications of coating include anti-graffiti paints, anti-reflection coatings on glass etc.

2.1.4. Self healing materials

Cracks are a major concern for nearly all constructions. Research has been performed on the use of microencapsulated healing agents (Kuennen 2004). The idea is that when the crack breaks the microcapsule a healing agent is released in the crack region and the resulting polymerization bonds the two crack faces. This approach can be applied in cases such as bridge piers and columns (Mulenga and Robery 2010).

Vernet (2004) has investigated the effect of a high percentage of anhydrous material which remains after the reaction with the water in the initial mix. This anhydrous fraction can act as a source for further hydration which is exposed when a micro-crack develops. If the sample is soaked in water hydration can start again on the cracks and the new formed hydrates could rapidly fill the cracks.

2.2 Structure Health Monitoring

Several ideas have been proposed and examined for the structure health monitoring of structures including micro-sensors, Micro-Electro-Mechanical Systems (MEMS) and Nano-Electro-Mechanical Systems (NEMS) as well as structural components with special properties.

There are cases where thin films are assembled at the nano-scale with the use of single wall carbon nanotubes (SWNT) and polyelectrolytes (PE) in order to create a homogeneous composite with exceptional mechanical strength and with electrical conductivity that varies in response to stimulus such as strain and tearing. Thus this film can play the role of distributed sensing all over the structure (Lynch et al. 2009).

Another kind of applications are piezoelectric materials which can be bonded to the structure. It seems that the best way is not to use adhesives in order to bond the sensors to the structure but to fabricate the sensors directly onto the structure. A characteristic example are piezoelectric paints made from piezoelectric powders which can easily be applied on large structures without affecting the mechanical properties (Zhang 2006).

MEMS and NEMS sensors have been developed and employed in construction in order to monitor or/and control structure performance. Due to their small size they can be embedded into the structure during the construction phase. Use of such sensors can provide access to measurements of several critical quantities such as temperature, pressure, stress and strain (Saafi 2006). An example of incorporation of such sensors is *Intellirock:* a wired sensor (Engius 2005) that is embedded in concrete to measure its temperature during the curing process. Such technology has been used in highway projects allowing for faster and lower cost contraction. MEMS/NEMS sensors can be embedded into highways or cover an entire bridge for monitoring deterioration, and allowing for control before they are apparent to human inspectors. The Golden Gate Bridge now has an experimental sensor network of approximately 200 small MEMS sensors. Each sensor can measure movement due to traffic, wind, or seismic loads and all sensor readings are correlated, to create a 3-dimensional picture which may indicate structural abnormalities (Nano@PennState 2011).

4. SOME EXAMPLES OF INTRODUCTION OF NANOTECHNOLGY IN THE CURRICULUM APPLICATION OF CIVIL ENGINEERING

From the above not exhaustive presentation of applications it becomes obvious that nanotechnology is going to affect the future Civil Engineers. Thus it is necessary that the curriculum provides them at least with the basis of being able to understand the applications but also to be involved in the development of new products and processes based on nanotechnology. Thus, it seems necessary to introduce nanotechnology related courses in the curriculum; otherwise our future students will be nano-illiterate. This will also help them to collaborate with scientists and engineers from other domains that can be implicated in the construction development like materials scientists, electrical and electronic engineers. In the framework of international mobility, knowledge of nanotechnology and its possible l applications will also be of help. The objectives should be to obtain fundamental knowledge of nanoscience and nanotechnology, increase awareness of the possibilities that nanoscience and nanotechnology offer to civil engineering.

How can one introduce in the curriculum the courses and what kind of courses? One approach is to use specific civil engineering courses like a course in “Construction Materials” or “Advanced Construction Materials”. Such an approach has been employed in the Jackson State University in 2007 and 2008, the University of Oklahoma in 2007 and the University of Houston in 2008 (Zheng et al. 2011) where a course “Construction Materials and Lab” was implemented. This new course module included four lecture modules, four lab modules, two seminars by industry people and a co-curricular project. The course focused on four domains a) improved construction materials, b) sensing technology c) smart materials d) creativity strategies and innovative designs. The co-curricular project is formulated and implemented based on a problem-based learning pedagogy (Barrows 1996) and a self-regulated learning cognitive model (Zimmerman 1990). In the frame of the project students are asked to identify existing problems in civil engineering and propose innovative solution to them at their own choice by applications of nanotechnology. Zheng et al. (2011) performed a survey that shows that the four most interesting module topics ranked by students were:

1. Microfiber reinforced concrete
2. Nanotechnology application for civil engineering
3. Nanocoatings for infrastructure
4. Smart materials and application

While the four most practical module topics from the University of Oklahoma were:

1. Microfiber reinforced concrete
2. Wireless data acquisition and processing
3. Nanotechnology application for civil engineering
4. Nanocoatings for infrastructure

The lowest-ranked module is the module of innovative design and creative strategies. For full details the reader can consult (Zheng et al. 2011). Representative projects of students realized in the frame of the course are: “Warm in winter and cool in Summer: Nano-enhanced Home through the use of Nano-Particle Additives and Nanocoatings for enhancing Insulating factors of Construction Materials”, “Smart suspension bridges through the use of smart-material cables both as structural members and actuators to support bridges under traffic loads and control bridge movement under wind loads”.

It must be mentioned that this effort was supported by the Division of Engineering Education and Centers of the National Science Foundation. Under the action Nanotechnology Undergraduate Education (NUE) in Engineering NSF has already funded 39 such actions and there are new calls for 2011 (NSF 2011).

We must also stress the importance given to nanotechnology education in the USA, even at the secondary education level and which is shown by the funding of the National Nanotechnology Initiative (NNI) which is more than one million dollars per year (NNI 2011).

A course of "Nanotechnology and Nanomaterials Fundamentals" (code CE/ME 486/686 MNT 730) (North Carolina 2011) was introduced is the Department of Civil Engineering of North Dakota State University. This course covers principles of nanotechnology and nanomaterials and develops a framework for their understanding. In the frame of the course the basic tools of nanotechnology: nanoscale characterization, physics and materials design are also discussed in the context of current technological advances.

The USA is not the only country to introduce nanotechnology courses in the Civil Engineering Curricula. The renown French École des Ponts ParisTech (Ecoles des Ponts et Chausses) has also introduced a course Concerning nanomaterials which is mainly related to mechanical properties, point and line defect, fatigue and fracture, fracture modes, Hall petch effect, as well as with fabrication procedures (Ponts 2011).

Instruction of nanoscience and nanostructure is also a concern for other engineering disciplines like Electrical, mechanical, computer and chemical engineering (Kim et al 2006, Malsch 2007).

5. SUGGESTIONS FOR GREECE

Given the fact that our aim is to maintain the competitiveness of our graduates both at home and abroad, there is a dual goal that we must achieve. An engineer has to be an expert of a specific field (in our case civil engineering) with solid background, but he/she must also have the ability of interdisciplinary understanding and collaboration. There is a question on how to introduce new course material in a quite loaded curriculum and how to attract the interest of students. We identify and propose two general strategies that one could follow in order to achieve this goal.

The first one would consist of enriching an existing course appropriate for presenting nanotechnology applications, with notions of nanoscience and nanotechnology. Such courses could be the General Physics courses and courses related to Construction Materials and Materials Behaviour. In this frame one could include additional information about what happens when things get very small at the nanoscale, and how nanoparticles can affect the macroscopic properties of the materials. Of course, with such a choice one does not have enough time to cover all the subjects. Elective project works where the students would study subjects related to nanotechnology and its applications in bibliographic sources, and on the internet could be an option.

The author has applied this principle in an experimental trial in the frame of the course "General Physics II" taught in the first year of Civil Engineering at the University of Thessaly (Volos, Greece) during the 2011 spring semester, and found that students were particularly motivated. The students were electively assigned projects (they had a choice from a subject pool, but they had also the possibility to suggest another subject) at the beginning of the semester and were asked to prepare a report as well as to make a presentation in front of the class, so that their colleagues could have information and ask questions. The projects covered construction materials, self-cleaning materials, specific glasses, but also more general application like hydrophobic surfaces. The first impression is that the rest of the students were particularly interested in these new developments of technology. Similar techniques can be applied to other courses like Construction Materials, Structural Dynamics but also environmental courses since nanotechnology has applications in environmental remediation, water cleaning etc. The use of Information and Communication Technologies could also be of help, since one could provide additional material and presentations for self-study as well as access to virtual and remote labs in order to overcome the problem of additional cost (Karakasidis 2009).

The other strategy would be to offer a specific new course that would describe what nanoscience is and what are the current applications or the applications to come in the field of Civil Engineering. This could be an elective course so that the curriculum is not overloaded with an additional compulsory course, while the students who are interested in new horizons could have the possibility to cover their need. One could even think that in a School of Engineering with several engineering disciplines such as Mechanical, Electrical, Architectural etc, a general elective course about nanoscience/nanotechnology and their applications in all engineering fields could be a very interesting solution, since it would further provide interdisciplinarity not only through the course content itself but also through the interaction of students who would attend the course and come from different fields. Group projects as part of the course with members from different disciplines would also be a very interesting approach which would contribute a) work in groups b) interdisciplinarity, a situation that students will face once they graduate and they are going to enter the work market in homeland or abroad. This experience would also be an asset if they decide to follow a research or consulting career. A course like this would comprise a) structure of matter b) atomic structure c) some notions of statistical physics and the link of microscopic properties to macroscopic properties d) how the size of materials can affect their properties and how surface effects become important e) representative examples of the variation of mechanical, optical and electrical properties of materials as compared to bulk materials and f) some notions of atomistic modelling.

Of course one also could think of a compulsory course but this would be perhaps more difficult at the given stage. However, such a solution, if designed in collaboration with all the sections of the department, would expose all the students to the new knowledge and its possible applications. In all these cases, however, care should be taken in order to make students sensible to eventual Risks of Nanotechnology both at health but also social level (NSET Subcommittee 2011).

If one would like to go further, one could provide also insight into methods to model materials and phenomena at the nanoscale, where the continuum approach fails and appropriate methods are necessary such as Molecular Dynamics (Haile 1997) for atomistic modelling, Dissipative Particle Dynamics (Español and Warren 1995, as well as Kasiteropoulou et al. 2011a,b and references there in) for mesoscale modelling or multiscale modelling (Karakasidis and Charitidis 2007). However, this would be more appropriate perhaps at a postgraduate or doctoral level. The experience of the author during the last four years with the supervision of PhD students form Greek Engineering Departments (Civil and Electrical) in nanotechnology-related research (nano and microfluidics), showed that although students need a time of familiarization with such methodologies and notions given their previous background where the atomistic world is completely absent, they can achieve significant results and perform high level research (Sofos et al. 2009, 2010, 2011, Kasiteropoulou et al. 2011a, 20011b). PhD students could also act as intermediate agents in order to diffuse the knowledge and culture to undergraduate or graduate students.

The Diploma Thesis would also be a great occasion for students to enhance their knowledge. Nowadays there are several Research Teams in Civil Engineering Departments in Greece that are working in the field of nanotechnology. Such examples are the Laboratory of Building Materials in Department of Civil Engineering of the Aristotle University of Thessaloniki, the Laboratory of Hydromechanics and Environmental Engineering and the Laboratory of Strength of Materials and Nanomechanics in the Department of Civil Engineering of the University of Thessaly in Volos, just to mention few of them. Diploma theses in such nanotechnology-related subjects would be particularly profitable for the students but also for the development of Research in the Departments, and it may lead to collaborations with other Science or Engineering Departments.

6. CONCLUDING SECTION

The contribution of the paper is to enhance and provoke the discussion about the need for incorporating Nanotechnology and Nanoscience in the Curriculum of Civil Engineering Departments, particularly in the case of Greece. We believe that such incorporation is feasible and each Department can choose the way that fits best in its existing Curriculum and Research Profile. Given that nanotechnology is a priority research field both at national and European level it would be a great opportunity to advance in this direction. This also would increase the open mindedness of our students as well as their capacity for interdisciplinary collaboration, a quality that is currently necessary at the international level for work in the market or in the research domain. It seems that the enrichment of appropriate existing courses with nanotechnology notions and the introduction of elective courses, along with practice through the realization of course projects or Diploma Theses, constitute the most appropriate solution for the introduction of Nanotechnology in the curriculum, at least for the Greek Civil Engineering Departments.

REFERENCES

1. Arafa, M.D., DeFazio C. and Balaguru B. (2005), Nanocomposite coatings for transportation infrastructure: Demonstration projects. *2nd International symposium on nanotechnology in Construction*, 13-16/11/2005, Bilbao, Spain
2. ASCE (2007) ASCE Steering Committee to Plan a Summit on the Future of the Civil Engineering Profession in 2025, The Vision for Civil Engineering in 2025, Based on The *Summit on the Future of Civil Engineering—2025*, June 21–22, 2006.
3. Balaguru, P. N. (2005), Nanotechnology and Concrete: Background, Opportunities and Challenges, *Proceedings of the International Conference – Application of Technology in Concrete Design*, Scotland, UK, p.113-122.
4. Barrows, H. S. (1996), Problem-based learning in medicine and beyond: A brief overview, *New Dir. Teach. Learn*., **68:30**, 3–12.
5. Economidis, I. (2010), Investigation of nanotechnology applications with emphasis in the field of Engineering, Master Thesis (Supervisor T. Karakasidis), Department of Civil Engineering, University of Thessaly Volos, Greece (in Greek).
6. Engius (2005), IntelliRock system overview.http://www.engius.com/products/intellirock.html (accessed April 2011).
7. Español, P. and Warren P. B. (1995), Statistical-mechanics of dissipative particle dynamics. *Europhysics Letters*, **30:4**, 191–196.
8. Feynamn R. (1960), There is plenty of room at the Botom, *Caltech Engineering and Science*, **23:5,** 22-36.
9. Haile, J.M. (1997), *Molecular Dynamics Simulation: Elementary Methods,* Wiley-Interscience.

10. Karakasidis, T.E. (2009), Investigation of the use of virtual and Remote labs in the distant learning of physical sciences in Higher Education, Master Thesis, Greek Open University, (in Greek)
11. Karakasidis, T.E. and Charitidis C.A. (2007), Multiscale modeling in nanomaterials science, *Materials Science & Engineering C,* **27:5-8**, 1082-1089.
12. Kasiteropoulou, D., Karakasidis T., Liakopoulos A. (2011a), Dissipative Particle Dynamics Investigation of Parameters Affecting Planar Nanochannel Flows, in press Materials Science and Engineering: B, In Press, doi:10.1016/j.mseb.2011.01.023.
13. Kasiteropoulou, D., Karakasidis T., Liakopoulos A. (2011b), A Dissipative Particle Dynamics study of flow in periodically grooved nanochannels, *Journal of Numerical methods in Fluids, in press.*
14. Kim S., Lee J., Lim H., Park K.H. (2006) Modification of Undergraduate Courses for the Early Introduction of Nanotechnology, *9th International Conference on Engineering Education*, July 23-28, San Juan, PR.
15. Kim, S., Lee J., Lim H., Park K.H (2011), http://www.jsums.edu/nue-jsu/ (accessed June 2011)
16. Li, V. C. (2003), On engineered cementitious composites (ECC)—A review of the material and its applications. *J. Adv. Concr. Technol*., **1:3**, 215–230.
17. Lux Research (2004), Sizing Nanotechnology's Value Chain, October 2004.
18. Lynch, J.P., Loh K.J., T.-C. Hou and Kotov N. (2009), Nanocomposite Sensing Skins for Distributed Structural Sensing, 303-308, in *Nanotechnology in Construction 3,* Bittnar, Z., Bartos, P.J.M., Němeček, J., Šmilauer, Vít, Zeman, J., Eds., Springer Berlin Heidelberg.
19. Makar, J. M. and Beaudoin, J. J. (2003), Carbon nanotubes and their application in the construction industry, *Proc., 1st Int. Symp. On Nanotechnology in Construction*, Paisley, Scotland, UK.
20. Malsch, I. (2007), Nano-Education from a European Perspective, *ICNT2007, 2-6 July 2007, Stockholm, Sweden.*
21. MMFX Steel Corp. (2011) http://www.mmfx.com/products.shtml (accessed May 2011)
22. Moradi, M. (2005), Global Developments in Nano-Enabled Drug Delivery Markets, *In Nanotechnology Law and Business*, 2005.
23. Mulenga, D.M. & Robery, P.C., (2010) Can Nanotechnology Address Today´s Civil Engineering Challenges?, 2010 ASCE Structures Congress.
24. Nano@PennState 2011, http://www.gonano.psu.edu/research/transportation.asp, (accessed June 2011).
25. Nanoforum Report (2006): Nanotechnology and Construction (accessed March 2011).
26. NanoPhos (2011) http://www.nanophos.com/en/index_en.html (accessed April 2011).
27. NNI (2011), http://www.nano.gov/about-nni (accessed March 2011).
28. North Carolina (2011), http://www.ndsu.edu/fileadmin/bulletin/courses/201112.pdf, (accessed June 2011)
29. NSET Subcommitee (2011), Nanoscale Science, Engineering, and Technology (NSET) Subcommittee NNI Publications and Reports, Nanomaterial Instrumentation Research, Metrology and Standards for Nanotechnology Environmental Health and Safety Educational and Societal Dimensions, Jul. 19.
30. NSF (2011), National Science Foundation, call for http://www.nsf.gov/pubs/2011/nsf11524/nsf11524.htm (accessed June 2011).
31. Observatory NANO (2010), Economic Analysis of Nanotechnology for Environmental Applications, http://www.observatorynano.eu/project (accessed May 2011).
32. Ponts (2011) (http://gede.enpc.fr/programme/Fiche.aspx) (accessed April 2011).
33. Saafi, M. (2006). "Nanotechnology-based devices for quality control and durability monitoring of concrete material." *Proc., 85th Transportation Research Board Annual Meeting, Washington, DC*.
34. Schaefer Hans-Eckhardt, Nanoscience, The Science of the Small in Physics, Engineering, Chemistry, Biology and Medicine. Springer (2010).
35. Sobolev, K., Flores I., Hermosillo R., Torres-Martínez Leticia M. (2006), Nanomaterials and nanotechnology for high-performance cement composites*, Proceedings of ACI Session on "Nanotechnology of Concrete: Recent Developments and Future Perspectives,* Denver, USA, November 7.
36. Sofos, F., Karakasidis T.E., Liakopoulos. A. (2009), Transport properties of liquid argon in krypton nanochannels: Anisotropy and non-homogeneity introduced by the solid walls, *Int. J. f Heat and Mass Transfer*, **52:3-4**, 735-743.

37. Sofos, F., Karakasidis, T.E., Liakopoulos, A. (2010), Effect of wall roughness on shear viscosity and diffusion in nanochannels, *Int. J. Heat and Mass Transfer*, **53:19-20**, 3839-3846.
38. Sofos, F., Karakasidis, T.E., Liakopoulos, A. (2011) Surface wettability effects on flow in rough wall nanochannels*, to appear in Microfluidics Nanofluidcs.*
39. Vernet, C. P. (2004), Ultra-durable concretes: Structure at the micro- and nano-scale, *MRS Bull.*, **29:5**, 324–327.
40. Zhang, Y. (2006) In-situ fatigue crack detection using piezoelectric paint sensor, *J. Intell. Mater. Syst. Struct.*, **17:10**, 843-852.
41. Zheng W., Shih H-R., Lozano K. and Mo Y-L., (2011) Impact of Nanotechnology on Future Civil Engineering Practice and Its Reflection in Current Civil Engineering Education, *Journal of Professional Issues in Engineering Education & Practice*, **137:3**, 162-173.
42. Zheng, W., Mo, Y.L., Lozano, K., Ma X., Pei J-S. (2010), NUE: New Vision for Built Environment – Integration of Nanotechnology into Civil Engineering Undergraduate Curriculum, Sponsor: Jackson State University (2006-2010), http://www.jsums.edu/nue-jsu/ (accessed May 2010)
43. Zimmerman, B. J. (1990), Self-regulated learning and academic achievement: An overview. *Educ. Psychologist*, **25:1**, 3–17.