

Collaborative Research: Development of Multifunctional Nanocomposites with Engineered Carbon Nanopaper

G. Song, C. Chang and M. Fernandez

University of Houston, Smart Materials and Structures Laboratory, Department of Mechanical Engineering, Houston, TX 77024, USA. E-mail: gsong@uh.edu

ABSTRACT: As U.S. economy becomes more global, the classical definition of job qualifications for engineers is changing. In addition to technical qualifications, there is a great need for multi-national, interdisciplinary, and multi-cultural competence for engineers. In this project, two U.S. engineering students gained valuable research experiences at Harbin Institute of Technology (HIT), a top engineering university in China. China has a fast growing economy and is the largest trading partner with U.S. By combining the expertise of highly qualified faculty members from both University of Houston UH, and HIT, innovative research related to composite structures were conducted by using the-state-of-the-art facilities at HIT. One student performed novel research on the topic of self-heating concrete/composite using carbon nano fiber paper as electrodes. The other student performed the research of damage detection of a composite wind blade using fiber optical sensors. Additionally, the students also visited five other Chinese universities and joint student symposiums were organized during each visit. Through their summer research stay in China, the U.S. students were exposed to a totally different culture and learned the Chinese education and research systems, which will increase their readiness for a job in a global economy. One of the participants was a female student and this IREE supplementary fund increased the participation from the underrepresented population in engineering. In addition, this IREE project strengthened UH-HIT collaboration in the area of nano materials, nanocomposites and fiber optical sensors and stimulated innovative interdisciplinary research.

INTRODUCTION

This report summarizes the work carried out under the NSF IREE award granted to the Department of Mechanical Engineering at the University of Houston to collaborate with Harbin Institute of Technology (HIT) in China. During the execution of the project, we also collaborated with Dalian University of Technology (DUT) in China. Under the award, research projects pursuing advancement of nanocomposite materials, structural health monitoring (SHM) techniques, and nano structural materials were conducted. With the rapid expansion of the Chinese economy, large, structurally complicated buildings are planned to serve China's growing needs for space, opening an unprecedented opportunity for the implementation of SHM and novel construction materials. HIT and DUT are the leading Chinese universities in the field of SHM and are making major contributions to the area of advanced composite materials and construction materials. These universities' recent projects include SHM of the Chinese National Aquatics Center (Water Cube), the National Athletics Center (Bird's Nest), etc. The implementation expertise of DUT and HIT complement perfectly with the nanocomposite, sensor, and instrumentation experience of the Smart Materials and Structures Laboratory (SMSL) at UH. With extensive laboratory experience in sensor system integration with structures, the partnership of SMSL with DUT and HIT would allow all three universities to further research and implementation of cost-effective, robust, and integrated sensor systems for SHM.

To fulfill the mission of the IREE grant, two students were selected to travel to China and conduct research projects hosted at HIT by their Department of Civil Engineering. Christiana Chang, an entering graduate student, conducted research on the development of a self-heating composite/concrete system using

carbon nanofiber paper. Michael Fernandez, a rising undergraduate senior, implemented fiber optic sensors on fiberglass composite wind turbine blades for damage detection. With another IREE supplementary grant, three more students participated. Oliver Rivera, a rising undergraduate senior, tested shape memory polymer materials for feasibility in structural damping applications. Kevin Weaver, a rising undergraduate senior, tested the use of piezoceramic sensors for acoustic emission sensing of cracking in fiberglass composite wind turbine blades. Claudio Olmio, a graduate student, conducted research in structural control. The IREE project includes four Phases :

Phase 1 (May 7-20, 2008). During this phase, the students receive training in both the research that they will conduct at Harbin Institute of Technology (HIT) and the culture that they will experience in China from Dr. Song's graduate students and postdoctoral fellows with Chinese culture background.

Phase 2 (May 21-June 8, 2008). During this phase UH students, led by Dr. G. Song, visited seven technical and engineering universities and one company in China. These seven universities include Shenzhen Polytechnic, Harbin Institute of Technology – Shenzhen Graduate School, Hunan University, Wuhan University of Science and Technology, Beijing University of Science and Technology, Dalian University of Technology, and Harbin Institute of Technology – Main Campus. In each university, UH students visited related engineering and technology laboratories and had joint culture events with local students. In five universities, joint student symposiums were held. In these symposiums, UH students and students from the hosting universities presented their previous research findings. These student symposiums functioned as effective platforms for students from both countries to exchange technical information.

Phase 3 (June 8 – July 27, 2008). During this phase, students conducted seven-week research at HIT in China. Christiana Chang conducted research in development of an electric, self-heating structural system that uses embedded carbon nanofibers paper (CNFP) as electric resistance heating elements. Michael Fernandez conducted research in using optical fiber sensor for health monitoring of composite wind turbine blades. At the end of the program, both of them made a presentation to report their research finding at HIT.

Phase 4 (July 28 – August 12, 2008). Students wrote reports on their research finding and essay about their IREE trip in china. Phase 4 activities were conducted at UH after students returned to USA

In summary, with such a broad range of activities, the students were expected to leave China with a broadened view of international research culture and to have exchanged scientific and world views with the various students they would meet on their journey. With a rich research experience, it was hoped that the undergraduate students would seek further academic and research careers in graduate school. For the graduate student, it was hoped that the international research experience would equip her for international research collaborations in her own career in the future. Through the HIT hosted research, both of these goals were reached beyond the project's expectations.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

The general project protocol is described as follows: all IREE participant students were assigned a project and an HIT mentor, a PhD student or professor in the civil engineering department of HIT. Project mentors reported directly to Dr. Hui Li, professor of civil engineering and the HIT host of the IREE students in China. Project details, tasks, and techniques were assigned or taught to the students by their mentor. General project questions or concerns were brought to the mentor for discussion and resolution with the IREE participant. After technical backgrounds of the IREE students were reinforced by recommended literature study, the IREE students formed detailed research plans with their mentor, including testing procedures, implementation techniques, and materials lists needed for the completion of the project. Sourcing of testing materials was performed by the researchers at HIT, including obtaining two fiberglass composite wind turbine blades for testing, ordering loose carbon fiber for admixture into concrete, and the sourcing of fiber optic and piezoceramic sensors. Facilities were provided by HIT, including the use of a thermal tank loading machine on which the shape memory polymer was tested. When ideas presented by IREE students required new materials, HIT was eager to find the material and obtain it for the research project.

Testing and implementation of strategies were carried out jointly with the HIT mentors; all samples and sensors were constructed or implemented by the IREE students under guidance and direction by the HIT mentors. Bi-weekly meetings with Dr. Li were held with each student to discuss research findings and plans for future action based on current results. Related research groups, such as the two groups working on the wind turbine blades, met more often on their own schedules to discuss project progress. These groups included a number of other HIT students who provided assistance in testing procedures and experiment design. Interaction also occurred on a personal level between the international researchers and the team members as visitors. Commonly, we had lunch and/or dinner with fellow visiting students, graduate students working in the same lab, and the advising professors. During these times we discussed each other's research experiences and shared ideas. The project concluded with project presentations open to the entire department of civil engineering at HIT.

For the wind turbine project, the goal was to investigate theoretically and then experimentally validate the use of available fiber Bragg gratings and piezoceramics for structural health monitoring of low-cost, small-scale glass fiber reinforced polymer (GFRP) wind turbine blades for use in electrical power generation. The project drew on previous experience of team members in fiber Bragg gratings and piezoceramics, and supported HIT's efforts to start a research push in the topic of wind power. The FBG sensor data from the failure test were consistent with linear strain curves, until the failure point when the blade's laminated layers de-bonded and slipped apart allowing the blade to fold. The goal of the research project remained constant throughout the duration of the visit, although the research plan had to be modified when the availability of appropriate turbine blades proved to be less than anticipated. The best blades available within the HIT-specified budget were hand-made, and had no technical specifications to accompany their purchase. Because of this limitation, one originally planned task to build a finite element model of the blade was not appropriate because repeatability between blades could not be assumed, and the material properties could not be established. The advisors at HIT were helpful in adapting the research plan and an effort began to design the next round of experiments so better results could be expected.

During the research trip, Michael completed extensive background learning on fatigue-induced degradation of GFRP material, and the use of optical waveguides with FBGs for GFRP strength monitoring on both a local and macro scale. Michael designed two experiments for testing the wind turbine blades: one static failure test and then a procedure for fatigue testing based on the strength measurement results of the first test. Michael helped direct the static testing procedure. The study of the deterioration mechanisms of wind turbine blades will lead to improved reliability in manufacturing. The necessity of clean energy sources is rising in the global consciousness, and China and America will both benefit from advancements in the area.

In the research project, we were able to develop a basic theoretical framework and working principle from which to design our self-heating concrete system novel system. At HIT, Christiana characterized electrical and thermal properties of different forms of CNF papers and learned a number of techniques to instrument the material for testing. Time-based heating information was collected and analyzed to relate power input with attained surface temperatures. An integrated self-heating concrete system and its characterization and optimization will lead to cost-effective solutions for de-icing and frost prevention of high priority transportation infrastructure, such as bridge decks and airport runways.

BROADER IMPACTS OF THE INTERNATIONAL COOPERATION

By beginning a number of joint projects, the IREE experience has helped begin a series of collaborations between UH and HIT, including, but not limited to, a number of researcher and student exchanges. Since the IREE travel period in 2008, UH has been host to two Masters students and one doctoral student from HIT. It is believed that the IREE travel will bring more student exchanges and UH and HIT becomes more familiar with each others' specialties and expertise resulting from the collaborative project work conducted. Currently, resulting from the SHM sensor research conducted at HIT, future collaborations in acoustic emission sensing and structural composites monitoring are planned. Both UH and HIT will progress with SHM of composite wind turbine blades, offering further exchange of techniques and findings, as well as the opportunity for collaboration in designing more integrated SHM systems. Furthermore, in addition to HIT, partnership agreements were discussed or agreed upon during the travel, such as the partnership resolution between UH and Shenzhen Polytechnic University.

The international perspective team members gained from the experience is invaluable and multi-faceted. It is common knowledge that industrially driven economies are emerging outside the US in various places including China and India, but on this trip we saw first-hand the incredible effort China is putting into educating the next generation of industrial and academic leaders in engineering. This perspective motivated one of the students of the team to commit to earning a PhD in Mechanical Engineering so he will be competitive for employment and so he can contribute to the field of mechanical engineering in the United States.

Additionally, the cultural experiences from the IREE travel has helped to broaden the students' cultural perspectives. The language barriers and cultural exposure will also be an asset to the team members. For some students, immersion in a foreign language was a new experience that will help them be adaptable in their future careers. Being immersed in a culture so different from America's made the students in this research trip aware that culture runs much deeper than language and food. Exposure to the Chinese language was first facilitated through music; music sharing and singing was engaged with local students who were willing to teach the UH students Mandarin Chinese during the students' stay at HIT. With these local students, UH students were lead through a diverse tour of Chinese culture, attending Dragon Boat races, eating traditional, local cuisine, and explaining unique aspects of student life in booming Chinese cities. The students found that through there are similar pressures to succeed, the sources of these pressures are different for the Chinese and American students and that the ways students relieve stress is very different, given the financial burdens Chinese and American students carry.

Most importantly, we were brought into a lab instrumental in the structural health monitoring movement in China, putting us in contact with the foremost trends in sensing and data processing techniques in civil infrastructure. In research practice, the exposure of real-world implementation of SHM techniques and sensors has given a more concrete perspective of the student's lab work and its use in full scale projects. In our interactions with the local students, it was found that a better understanding of each others' culture was needed to facilitate a better understanding of each others' work styles and common research practices. This is an ongoing process that will see fruition as the students increase their international experience.

The IREE allowed students from a diverse university to travel and exchange culture and research with their foreign peers. This award allowed two minority students, one of which is female, to travel to China to further their goals of continued academic careers. The cultural exchange aspects of the travel program also helped the students become more aware of cultural differences between them and their Chinese peers and to be more aware of culture and diversity on the international research stage.

DISCUSSION AND SUMMARY

The research accomplishments include studying the durability of glass fiber reinforced polymer wind turbine blades, characterizing the performance of specimen blades through static tests, and planning for future dynamic durability experiments. Also, the basic conceptual framework for a self-heating concrete system was developed; to support this concept, preliminary characterization of materials was conducted and feasibility proved. Team members developed communication and interpersonal skills in collaboration with students and professors of a foreign institution on research projects relevant to China and the United States.

The most significant accomplishment of the research experiment was the solidification of partnership between UH, DUT, and HIT for further international exchange programs. Since, a number of HIT students have come the UH for their graduate academic careers. In the near future, more structural health monitoring (SHM) and composite project collaborations are planned, allowing UH students to gain hands-on, real-world SHM implementation opportunities. The IREE experience has given us the insights needed to make these future collaborations successes.

Mandatory cultural and language (when applicable) course programs should be undertaken by students and supporting staff on both sides of the collaboration to minimize the adjustment time when the students arrive at their hosting institute. Students should be made aware of politically or culturally sensitive areas of discussion in the region of travel. Also, more detailed research plans should be drafted prior to the IREE travel period to maximize the use of time at the institute. Goals should be defined with the inputs from the student participants and materials acquired in advance to minimize loss of time and difficulty in acquiring the correct materials due to availability or language barriers with suppliers.

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BRIEF BIOGRAPHIES OF RESEARCHERS

Christiana Chang is currently a graduate student studying mechanical engineering at the University of Houston. She received her bachelor's degree in the same department in the Spring 2008. Her current research topics focus on the use of carbon nanomaterials to improve damping and thermal properties of composites. In the following year, she will participate in a new program pairing graduate students with science teachers in public schools to develop research relevant activities to encourage more students to pursue technical fields.

Michael Fernandez is a senior mechanical engineering student at the University of Houston. After graduating at the end of the Spring 2009 semester with the Bachelor of Science degree, he plans to earn a Ph.D., also in mechanical engineering. He is currently evaluating several offers and will soon decide which program will best support his research interests in controls and robotic systems.