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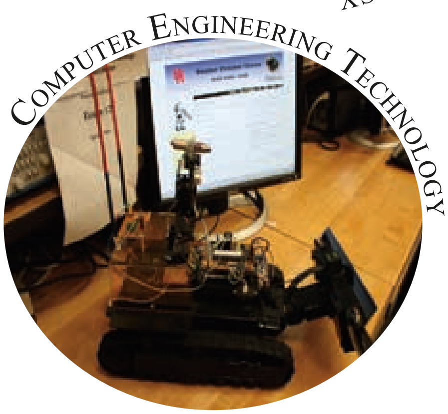

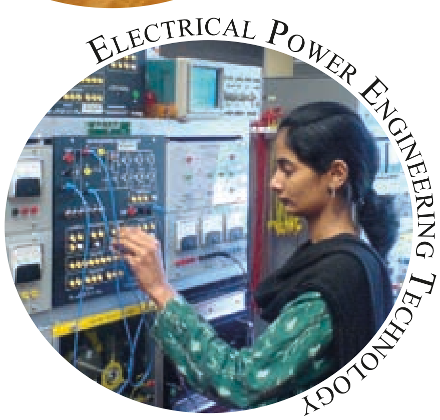

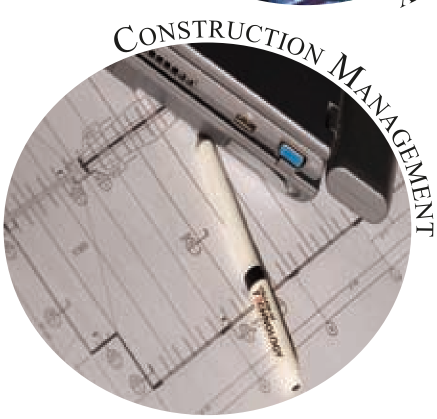

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IJERI is published twice annually (Fall and Spring issues) and includes peer-reviewed research articles, editorials, and commentary that contribute to our understanding of the issues, problems, research associated with the engineering and related fields. The journal encourages the submission of manuscripts from private, public, and academic sectors. The views expressed are those of the authors, and do not necessarily reflect the opinions of the IJERI or its editors.

EDITORIAL OFFICE:

Mark Rajai, Ph.D.
Editor-In-Chief
Office: (818) 677-5003
Email: mrajai@csun.edu
College of Engineering and
Computer Science
California State University
Northridge, CA 91330-8332

THE INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH AND INNOVATION EDITORS

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EDITOR'S NOTE: THE INAUGURAL ISSUE OF THE INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH AND INNOVATION

Mark Rajai, IJERI Editor and IAJC President

The great success of the 2008 IAJC-IJME International Conference and the broad topics of the published articles was the motivation for the International Association of Journals and Conferences (IAJC) to launch its second official and flagship journal to meet the growing demand. On behalf of IAJC board of directors, it is my pleasure to present the inaugural issue of ***International Journal of Engineering Research and Innovation (IJERI).***

The aim of the journal is to emphasize the use of research and innovation in all engineering fields and to strike a balance between research and application as well as decimation of information to both researchers and practitioners. The journal encourages submission of innovative and original articles in all fields of engineering and applied sciences. The new journal follows the same successful platform of its sister journal, IJME.

The *International Journal of Engineering Research & Innovation (IJERI)* is now the official and second flagship journal of the IAJC. IJERI, like IAJC first official and flagship journal, *International Journal of Modern Engineering (IJME)*, is a highly-selective, peer-reviewed print journal which publishes top-level research work from all areas of engineering research, innovation, and entrepreneurship.

IJERI is steered by IAJC's distinguished board of directors and is supported by an international review board consisting of prominent individuals representing many well-known universities, colleges, and corporations in the United States and abroad.

To maintain a high-quality journal, manuscripts that appear in the IJERI Articles section have been subjected to a rigorous review process. This includes blind reviews by three or more members of the international editorial review board, followed by a detailed review by the IJERI editors.

IAJC, the parent organization of IJME and IJERI, is a first-of-its-kind, pioneering organization acting as a global, multilayered umbrella consortium of academic journals, conferences, organizations, and individuals committed to advancing excellence in all aspects of technology-related education.

Inaugural Issue

IJERI's current issue includes nine high-quality papers selected from our 2008 IAJC-IJME international conference. If you have any comments or suggestions, please feel free to send them to me at mrajai@csun.edu or Dr. Sohail Anwar, Associate Editor-in chief at sxa15@psu.edu. We hope you enjoy this inaugural issue and continue to support our new journal and its parent organization, IAJC.

INTERNATIONAL ENGINEERING RESEARCH COLLABORATION ON GALLIUM-NITRIDE (GAN) LASERS AND LIGHT EMITTING DIODES (LEDS)

Xiaomin Jin, California Polytechnic State University, USA; Bei Zhang, Peking University, China;
Fei Wang, California State University, Long Beach, USA; Jason Flickinger, California Polytechnic State Universtiy, USA;
Sean Jobe, California Polytechnic State University, USA;
Tao Dai, Peking University, China; Guoyi Zhang, Peking University, China

Abstract

We established a long-term International Engineering Education and Research Collaboration Program between California Polytechnic State University (Cal Poly), United States, and Peking University (PKU), Beijing, China, on GaN light emitter research in the past three years. We focused on GaN laser diode (LD) research for the first year. GaN light emitting diode (LED) research was added during the second year. The project began by having faculty members work in PKU for one summer. The collaboration in the rest of the period was done through teleconference and e-mails. Cal Poly graduate students were grouped with graduate students in PKU and worked closely on certain projects. Through this project, our students obtained experience in collaborating with foreign partners, especially awareness of cultural differences, without traveling abroad. The work distribution between U.S. students and foreign students was clear, yet closely related. Our students focused on device simulation, and foreign students worked on GaN device fabrication. Exchanging results was necessary for progress on both sides, which encouraged them to actively communicate with each other. The result of this collaboration was successful from both a research and education point of view. We published four technical papers on GaN-laser research in the past year. Student comments on both sides confirm that they obtained a better understanding about foreign cultures and that they thought it was helpful for them if they chose to pursue a career in a multinational firm.

Motivation

Nowadays, U.S. industry and educational institutions face a new set of challenges [1, 2]. Because of rapid technology development, competition among companies is globalized and intensified. To succeed, a company must manage to face this competition. Cost reduction is always the first priority for companies to survive. To reduce operational cost, many U.S. companies have already moved part of their manufacturing and R&D centers overseas, and they plan to continue the outsourcing process. Southeast Asia, most notably China, is among the top choices for U.S. outsourcing because of its fast developing speed, boosting economy, and educated engineering workforce. To make this business transition smooth, there is an urgent need for our engineers, engineering students, and instructors to have direct interaction with their international counterparts [3]. It has been noticed by industries, governments, and institutions that university graduates in the United States are inadequately prepared for the challenges brought by industrial globalization. Therefore, we are obligated to introduce this globalization trend to our students and provide necessary training for them to successfully compete in this environment. A direct solution is for us to establish collaboration among faculties and students between U.S. and overseas partners.

In supplement to the study abroad program that has been offered for years at Cal Poly, we initiated a collaborative research/education program with institutions in China. This is the one of the international programs in Cal Poly that focuses on both research and educational aspects. Our international partner is the School of Physics at Peking University in Beijing, China. The educational goals of this program include the following:

- Improve student's ability to work in a multi-cultural environment.
- Improve student's critical thinking skills and independence by involving them in an open-ended research project.
- Improve student's technical competence by letting them work on cutting-edge research topics.

The major objectives of this cooperative project include the following:

- Establish a long-term collaborative research relationship in the form of telecommunication, instructor exchange, and student exchange.
- Establish routine but powerful simulation, fabrication, and characterization methods.
- Optimize design to achieve high performances of photonic lattice-based Gallium-Nitride epitaxial materials and optoelectronic devices.

Introduction of PKU and Cal Poly

Peking University (PKU) is one of the most prestigious higher education institutions in China. The university is a research-oriented institution that is ranked No. 1 in almost all ranking systems in China. PKU is located on the northwestern side of Beijing, where universities, high-tech companies, and international corporations accumulate. The university currently has three campuses and offers programs in science, engineering, business, liberal arts, law, and medicine. The university is one of the first two schools in China that is funded by China's strategic development plan in science, technology, and engineering. PKU has 110 years of history and has a long tradition in international collaboration. Fluency in English is a requirement for both undergraduate and graduate students in PKU. This removes the language obstacles for this collaboration.

California Polytechnic State University (Cal Poly) is one of the 23 campuses making up the California State University system. Cal Poly offers programs in engineering, science, business, and liberal arts, and the college of engineering is the largest college at the campus. Cal Poly offers bachelor's and master's degrees and is categorized as a teaching-oriented institution. However, to prepare our students with the most advanced technology, most of our faculty is actively involved in advanced research, especially those in the college of engineering. The collaboration with PKU is certainly moving us one step further in that direction. In the Electrical Engineering department, an individual design/research project is required for a BS degree and a thesis project is required for an MS degree. Students that are involved in this research collaboration include both undergraduate and graduate students.

Technical Merit and Research Plan

Recently, many efforts were made on the research of Gallium-Nitride (GaN)-based optoelectronic semiconductor devices, due to their vast promising applications, such as solid state light sources, and ultraviolet light emitters for high-temperature electronics [4, 5]. In some applications, they become irreplaceable. However, GaN-based semiconductors have different optical and electrical properties when compared to other materials [6–9]. Researchers can make light emitters, such as laser diode/light emitting diode (LD/LED) out of GaN-based semiconductors, but the mechanism for their operation has not been fully understood yet. This research covers several fundamental issues of GaN-based LED/LDs including 1) the study of device surface structures that closely associate with light extraction; and 2) the investigation of the effects that influence power transition efficiency.

For the technical content of this project, a five-year research plan was laid out. In the first year, we investigated the optical transverse-mode distribution in the GaN LDs and their basic lasing characteristic. In the second year, we studied the application of nano-photonic structure (photonic lattice or photonic crystal) in the design of GaN devices. At the same time, we evaluated and compared the confinement factor of the gain models in various GaN device structures and optimized the anti-guide layer design. In the next three years, we will optimize the structure to design high power lasers or LEDs, define some design rules for GaN-based opto-electronic devices, and reveal some of their underlining physics.

Cal Poly and PKU both have advantages and disadvantages in terms of facilities necessary for this project. The students at Cal Poly are strong in terms of employing different software models to perform simulations. The research group, led by Dr. Jin at Cal Poly, acquired several cutting-edge simulation packages over these years, which made the detailed modeling and simulation possible. The group in PKU, led by Professor Bei Zhang, is strong in fabrication and characterization. In fact, as a well-funded research university, PKU possesses advanced fabrication and characterization facilities that are not available at Cal Poly. Therefore, students at PKU will prepare some characteristic tests of the GaN-based photonic-lattice structures. These photonic lattice structures become more and more important in the GaN-based optoelectronic devices.

Project Outline

The collaboration started with an initial meeting between research groups in PKU and Cal Poly. Dr. Jin represented Cal Poly and visited the research labs in Peking during the summer of 2006 (sponsored by Wang's Faculty Fellowship). The innovative idea of this project was to have students experience international education training without traveling abroad, which is less expensive for both groups of students. Research collaboration and communication can be done remotely using Internet and teleconferences. This idea has worked well. Some of the key elements of this collaboration include the following:

- Professors from both sides should be the leaders of the project.
- The project needs to be mutually beneficial and supported with complementary capabilities.
- At the beginning, the faculty needs to work at the international institution for a sufficient period of time to demonstrate U.S. research capabilities and to gain mutual trust.

- Because of the current communication technology, teleconference calls, the Internet, and e-mail can be used to facilitate a productive research relationship.
- A one-to-one student relationship should be built. The first year, a master's student from Cal Poly partnered with a Ph.D. student in PKU.
- Build "student-mentor" relationships focusing on the research topic.
- Each year, focus on different tasks of GaN LED and GaN LD development.

Detailed Activities

To obtain necessary research skills for this international project, Cal Poly students need to take EE403/443 (Fiber Optic Communication and Laboratory), EE418/458 (Photonic Engineering and Laboratory), EE335/375 (Electromagnetic Fields and Transmission and Laboratory), EE402 (Electromagnetic Waves), and EE524 (Solid State Electronics). Waveguide and photonic device concepts are addressed in those courses. Basic training through a senior design project is provided to students before they get involved in the collaboration project.

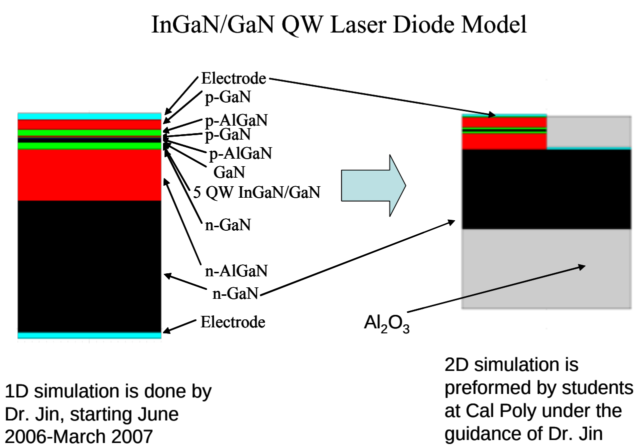

Figure 1. The GaN Quantum-well Device Simulation Research

A 1D GaN LD simulation model for design optimization (Figure 1) was developed during the initial visit to China. This model reasonably considered the optical fields in the devices. However, this model has not included the lasing action simulation. Therefore, the project activities in the first year of collaboration were: 1) to improve the 1D model, 2) to develop a 2D model GaN LD model, and 3) to compare of the enhanced 1D model and 2D results. Three Cal Poly students and two students in PKU were involved in these activities. Communication between faculty advisors and students on both sides was important to the success of this project. As mentioned earlier, students in Cal Poly were in charge of model development. The initial results were transferred to students in PKU, which provided guidance for their fabrication and characterization of the devices. Characterization results were transferred back to Cal Poly, where students improved the model based on the physical data. Figure 2 shows the flow chart of the student-mentor (two-level) communication between the two institutions on the research topics. The final results are the device designs.

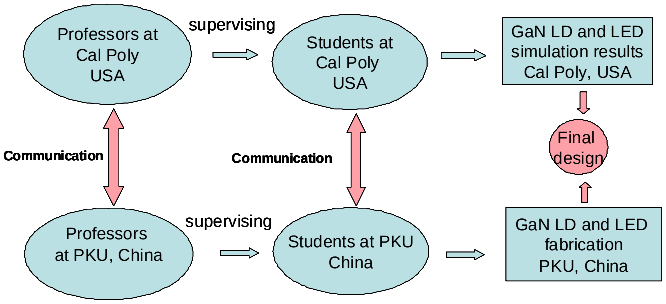

Figure 2. The Joint Research Team at Peking University and California Polytechnic State University with the Two-level Communication

Phase One: The GaN-based laser diodes (LDs) have attracted attention in recent years as short wavelength light sources. However, high threshold current and short lifetimes are the main problems with these lasers. One of the major reasons for these drawbacks is the anti-guided behavior of the waveguide mode associated with the n-GaN buffer layer. The Cal Poly group calculated the transverse mode distribution of InGaN/GaN laser diodes, which was demonstrated at PKU. We found that the n-GaN buffer thickness is an important parameter in the lasing-mode design and pointed out that the maximum optical-confinement-factor variation was due to transverse mode coupling. Our calculation also proved that the current design was close to an optimal design but still had more room to increase the optical confinement factor to reduce the lasing threshold and to further improve laser performance, such as lifetime and far-field patterns. We published four papers [10–13] on this research topic.

Phase Two: Advancements in GaN-based LED technologies have been growing fast. But a common problem still exists in conventional LEDs. Photons are trapped in the device and limit the amount of light extracted. Photonic lattices are one of the proposed solutions of the problem. Photonic lattices are complex arrays of microstructures in a solid dielectric material that can control and radically influence the propagation of light in different directions. They represent a new engineering discipline, combining the principles of electromagnetism with the concepts of solid state physics. Photonic lattices have numerous applications in optics and optoelectronics particularly to GaN-based LEDs. The second phase of collaboration concentrates on the simulation, design, and characterization of the GaN-based photonic lattices and related devices. Because of the impact of the behavior on photonic lattices of pillars or holes with different symmetries, periods on the performances of GaN-based light emitters will be mainly calculated at Cal Poly. Approximately six to eight more undergraduate and graduate students will be involved with this project. A variety of photonic lattice structured on GaN-based light emitters will be fabricated at PKU by different methods, such as ion beam lithography, FIB, ICP dry etching, and nano-imprint technique. Some of the characteristics of the structures and devices will be measured by both groups.

Key Elements of the International Research Collaboration

Previously, because of the lack of communication, international professional groups working on similar research projects did not exchange ideas before publishing their research results. Therefore, some of the research was developed redundantly, which wasted resources. The development of telecommunication in the past decade opened unprecedented opportunities for international scholars. Researchers, leading student-scholar teams around the world, can use each others' knowledge and work together on a project in a timely fashion, leading to what we call international research and education collaboration. However, there are no universal models for international collaboration. Each case has a unique character. In our project, the key elements and obstacles of building the international research collaboration are discussed below (some of those items are closely related to each other):

- ***Trust:*** The leaders of the project should have trust and understanding. This is the first and most important aspect. Even with the traditional international partnerships, trust is still required for effective international collaboration. In early 2006, we started talking about this project. After the first year of work, in July 2007, we signed the collaboration contract for the next four years.
- ***Regular communication and teamwork:*** The first year is critical to set the foundation for future collaboration. Each team leader needs to respond fast to the requests of the other side. Frequently holding teleconferences with the entire group (including both U.S. and foreign teams) is important for both students and faculty to connect with each other, not only on technical issues, but also on working habits and culture differences. Regular communication is also essential to build the trust bond.
- ***Management skill***: The management skill of the professors from both sides is critical throughout the project. Research work needs to be distributed based on each party's strength. In our case, Cal Poly possesses an advanced design environment, and PKU has cutting-edge fabrication clean rooms. Therefore, Cal Poly is in charge of design validation and improvements, while PKU is in charge of design realization and testing.
- ***Research element:*** Another important purpose for this project is to team-up our students (undergraduate teaching university) with a foreign research university and to expose them to an advanced research topic.
- ***The student-mentor team and two-level communication:*** The direct discussion between foreign and U.S. students served as an important agent for inserting an international dimension to the research effort. However, the discussion between the students should be supervised by professors to control the technical aspects of the projects. The students from both sides also need to present their work to each other and to the two groups of professors for discussion.
- ***Mutually beneficial topics:*** This is an important motivation for the project. Good research topics and project goals should be carefully selected by professors from both sides. Complementary capabilities of both sides will produce mutual benefits for the research and strengthen collaboration in the future.
- ***Financial independence:*** It is difficult to receive funding from other countries. We decided to fund research independently. We are in charge of software development funding, and PKU funds their fabrication facility. As for the research visits, the sending country pays the international airfare, while the host country pays for the expenses related to a short visit.
- ***Low financial burden on the students from both sides:*** For students, spending a period abroad is costly. Students also have to plan carefully to make their curriculum flexible enough to allow them to be away long term and not fall behind in other courses. Our project allows the students to get international experience without having to deal with interruptions in their regular course sequence. The short international visit is only an option and enhancement of the collaboration, but it is not a necessary component.
- ***Foreign-born U.S. scientists:*** The international research bridge is built up by international students from China and foreign-born U.S. scientists and engineers. The foreign-born U.S. scientists are the greatest asset in promoting international collaboration. We need to recognize international talent, which lies at the center of the cultural diversity needed for the global environment.
- ***Data accessibility around the world*** (***spontaneous global communities):*** The development of computers, the Internet, the World Wide Web (WWW), and fiber

optical communication systems transforms international research and education into a global scientific enterprise. The current technology allows the formation of spontaneous, international learning communities. We can share information in textual, graphic, and multimedia formats across the world. This shrinking world provides our students a low-cost international education environment. It can be called "Spontaneous global communities."

- ***The consciousness of foreign countries:*** The consciousness of foreign countries is improved throughout the project, which also improves U.S. students' global understanding.
- ***International co-authorship for the research results:*** This is an important outcome of the international educational and research partnerships.
- ***Annual visit:*** Any level of annual visits benefits the international research project.
- ***English:*** English is the basic language for communication. However, U.S. students are also interested in learning a little Chinese besides research in GaN LDs and LEDs. Chinese students are offered an unusual learning opportunity of presenting and defending their projects using technical English terminology. Students from both sides are working toward eliminating the linguistic barrier.

In general, this project builds an international virtual research laboratory, which develops and enhances students' awareness of humanity and the world around them. The future implementation of international projects will depend on growth and sustenance of these relationships.

Future Work

This collaboration is well established. We are continuing it and moving it to a higher level. In the summer of 2008, Dr. Jin will be a visiting professor at PKU supported by "Chun-Hui" exchange research fellow, Educational Department, Chinese government, to promote further interconnection.

In the long run, the participants of both sides will exchange visitors during the period of this project. Faculty in the United States will visit PKU to discuss and adjust each year's research topics in the summer. The participants of the PKU group will bring some of the samples to Cal Poly to perform characterizations at appropriate times.

In summary, the following are Cal Poly's milestones for the next few years on the international research and education collaboration:

- Students from the two universities will make presentations to each other through the Internet.
- Undergraduate students will be involved in the research, which will be a challenge because of the short period of time available for undergraduates.
- We will seek funding to send students to China in future summers to immerse them in an international environment.
- We will seek research projects with research laboratories of U.S. or China-based companies. Initial contacts have been made between Cal Poly and some globalized corporations, such as Agilent Technologies. Although there are more hurdles in the university-industry research collaboration, such as intellectual property (IP), both parties still believe a mutual beneficial agreement is possible.

Results and Conclusion

In July 2007, a formal collaboration contract was signed by professors from both sides, indicating their agreement to a long-term collaboration for the next four years until August 2011. The result of this collaboration is successful from both a research and education point of view. From the research point of view, the collaboration combined the strength of Cal Poly and PKU. As a clear indicator of technical successfulness, we co-published four technical papers on GaN-laser research in the past year. To assess the outcome of educational merit of this project, we collected comments and suggestions from students. Student comments on both sides confirm that they obtain better understanding about foreign cultures and they think it is helpful for them if they decide to pursue a career in a multinational firm. Up until now, six students who were involved in this project finished their degree, among which two graduated and are working at companies and four pursued graduate study. All students commented that their experience of multi-culture research helped them in job interviews with large corporations. The open-ended research project gives students the opportunity to act as an investigator, while instructors serve as a facilitator. All students commented that their critical thinking skills were improved and that they are more confident now to work independently.

Acknowledgments

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Biographies

XIAOMIN JIN received her Ph.D. from the University of Illinois, Urbana-Champaign, in 2001. She has worked in the research laboratories at Corning Lasertron, Inc., W. L. Gore and Associates, and Optical Communication Products, Inc. She is currently an assistant professor at California Polytechnic State University. Her research focuses on fiber optical communication and optoelectronic devices. Dr. Jin may be reached at xjin@calpoly.edu

BEI ZHANG is a Professor of Physics in the School of Physics, Peking University. She graduated from the Department of Physics, Peking University, in 1962. Recently, her research is focused on the photonic lattices-based GaN system light emitting devices (laser diode and LEDs). Dr. Zhang may be reached at beiz@water.pku.edu.cn

FEI WANG received her Ph.D. from the University of Cincinnati in 2005. She joined California Polytechnic State University as an assistant professor in 2005. She is currently an assistant professor at California State University, Long Beach. Her research focuses on electronic materials and devices. Dr. Wang may be reached at fwang3@csulb.edu

GUOYI ZHANG is a professor in the School of Physics and Director of the Research Center for Wide-band Gap Semiconductors, Peking University, China. His research focuses on MOCVD techniques and GaN-based materials and devices. His recent research projects include GaN short wave length laser diodes, GaMnN dilute semiconductor, and polarized LED. Dr. Zhang may be reached at gyzhang@pku.edu.cn

AN ANALYSIS OF THE ENERGY REQUIREMENT FOR THE IMPROVED MECHANICAL PROPERTIES OF A POLYMER-CLAY NANOCOMPOSITE

Rex C. Kanu, Ball State University; Dennis Weldishofer, Jacobs Engineering

Abstract

Because of their perceived primary benefits over those of traditional composites, polymer-clay nanocomposites (PCN) have generated much interest in the field of science, technology, and engineering. These benefits include efficient reinforcement, thermal endurance, flame resistance, improved barrier properties, improved abrasion resistance, reduced shrinkage and residual stress, and altered electrical, electronic, and optical properties.

Polymerization of monomers in the presence of clay particles and incorporation of the clay particles into a molten polymer matrix (melt compounding/blending) are two preferred methods for preparing PCN. Melt blending presents a thermodynamic mixing problem if the polymer matrix is hydrophobic, such as polypropylene, and the clay particles are hygroscopic. To solve this problem, a compatibilizer is employed to improve the interaction between the polymer molecules and the clay particles. Another important problem with the melt blending process is that the clay particles exist naturally as layers of platelets. To achieve optimal PCN properties, it is important for the platelets to be separated from each other (a process also known as exfoliation) and uniformly dispersed in the polymer matrix. Dolgovskij et al. [1] have shown that exfoliation of clay particles depends on a combination of shear rate and residence time in the mixer. Moreover, other studies have shown that the relationship between shear intensity and the degree of exfoliation is not linear. Our study seeks to correlate the degree of exfoliation to the energy requirements associated with the improvement in PCN properties such as tensile strength and modulus. The ultimate goal of this work is to determine if the gain in PCN properties justifies any increase in energy usage. A twin-screw extruder will be used as a mixer in compounding the PCN.

Introduction

Stewart's featured article in the April 2006 edition of the *Plastics Engineering Journal* was titled, "Nanomaterials: Still Climbing the Steep Curve of Material Development." Justifying the title, the author explains, "While most people can appreciate the increased strength, lighter weight, improved barrier properties, and other benefits offered by nanomaterials in plastics applications, nanocomposites are still perceived by many as too expensive and too difficult to process successfully with conventional equipment" [2]. Since this statement was made in 2006, there appears to be no significant development in the preparation of PCN to change the status quo. However, this is not attributed to a lack of research efforts in PCN, for many researchers have been diligently working on the commercialization of PCN. Some researchers, such as Okada and Usuki [3], have approached the subject through the polymerization of PCN, while others chose the melt blending method [4, 5, 6]. The melt blending method is preferred to the polymerization method because it does not use the expensive solvents required in polymerization, nor is it limited to specific polymeric materials. Thus, it appears that the melt blending method is more versatile than the polymerization method. In spite of their differences, both methods utilize clay particles as reinforcing agents. But since the clay particles exist as layers of platelets, as shown in Figure 1, their separation from each other (exfoliation) and uniform dispersion in a polymer matrix is necessary to realize optimal benefits in the properties of PCN. To achieve this goal, the experimenter uses process equipment, such as twin-screw extruders, to affect the breakup of the layered platelets of the clay particles, while simultaneously incorporating the individual platelets into the polymer matrix to form a polymer-clay nanocomposite.

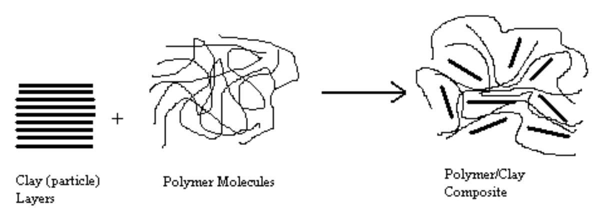

Figure 1. Schematic diagram of the melt blending process

Many studies have examined different aspects of the melt blending method of PCN, but there appears to be no study that has evaluated the additional energy required to break up and incorporate the clay platelets into the polymeric matrix to improve the mechanical properties of PCN. In this study, the authors examine the incremental energy requirement associated with the improved tensile strength and modulus of a PCN to determine if any increased energy usage justifies the gain in the named properties

Experimental

Polypropylene (PP) homopolymer resin (Pro-fax® 6524 from LyondellBasell Industries) was melt blended with organoclay nanoparticles (Closite 20A from Southern Clay Products) and a compatibilizer, maleic anhydride grafted polypropylene (MA), specifically Polybond® 3200 from Chemtura Corporation. The organoclay (density of 1.77 g/cm^3), a powder with a mean particle size of 9 micrometer (μm), the MA, and the PP resins were premixed in gallon paint cans with a paint shaker for approximately 20–30 minutes. This resulted in individual PP resin being coated by the clay particles. PP/MA/Clay mixtures of 96/2/2, 94/3/3, and 90/5/5 wt% were premixed. These mixtures were subsequently melt-blended with a 42-mm Brabender counter-rotating twin-screw extruder at 204 ºC. A screw speed of 40 rpm was used. Neat PP, used as the control material, was similarly processed with the twin-screw extruder. Extrudates from the extruder were air-dried and pelletized with a Killion pelletizer at 30 rpm. During the melt blending processes, the A/C current usage by the extruder was recorded. The neat PP and PCN pellets obtained from the Killion pelletizer were dried and subsequently injection-molded into tensile test specimens with a 60-ton Sandretto injection molding machine. The following temperature profile was used in the injection molding process: mold temperature = 38 ºC, injection machine rear barrel = 182 ºC, middle barrel = 193 ºC, front barrel = 199 ºC, and nozzle = 204 ºC. Tensile test specimens were tested with the Instron test instrument at room temperature, according to ASTM D 638.

Results and Discussion

Since the mean size of the Closite 20A clay particles was 9-μm, and given that each platelet was 1 nanometer (nm) thick, a clay particle would have approximately 3, 000 layered platelets. In this study, the authors used the modified Halpin-Tsai equation, proposed by Brune and Bicerano [7]. Zhang et al. [8] used the same equation to determine the extent of exfoliation of the clay particles in the three PP-Clay nanocomposites studied. It should be noted that an alternate definition of exfoliation is given by Dennis et al. [6]. They describe exfoliation as a process where polymer molecules move into the spacing between platelets, causing the spacing to increase to 8 nm or greater. Both definitions of exfoliation will be considered with the modified Halpin-Tsai equation expressed below.

$$\frac{E_{composite}}{E_{matrix}}\left(\frac{E_c}{E_m}\right) = \frac{1+2A_f'\eta'\phi'}{1-\eta'\phi'} \qquad (1)$$

where $$\eta' = \frac{E_r'-1}{E_r'+2A_f'},$$

$$A_f' = \frac{A_f}{\widehat{N}}\left[\frac{1}{1+\left(1-\frac{1}{\widehat{N}}\right)\left(\frac{s}{t}\right)}\right]$$

$$E_r' = E_r\left[\frac{1}{1+\left(1-\frac{1}{\widehat{N}}\right)\left(\frac{s}{t}\right)}\right]+\left[\frac{\left(1-\frac{1}{\widehat{N}}\right)\left(\frac{s}{t}\right)}{1+\left(1-\frac{1}{\widehat{N}}\right)\left(\frac{s}{t}\right)}\right]$$

$$\phi' = \phi\left[1+\left(1-\frac{1}{\widehat{N}}\right)\left(\frac{s}{t}\right)\right]$$

$$\widehat{N} = N+\left(1-N\right)\left(\frac{s}{t}\right)\left(\frac{\phi}{1-\phi}\right)$$

$E_r =$ ratio of the platelet modulus (1.7 GPa) to the matrix modulus (1.1MPa)

$A_f =$ aspect ratio of the platelet

$\phi =$ volume fraction of platelets in the composite

N = number of platelets per stack. $N = 1$ for completely exfoliated platelets

$s/t =$ ratio of platelet spacing to platelet thickness

Using equation 1, an average platelet aspect ratio of 100 was assumed given that the platelets aspect ratio ranged from 70–150 [9]. Figure 2 shows that at a spacing of 2 nm between platelets, the number of platelets per particle was reduced from 3,000 platelets per clay particle (stack) to between 15–50 platelets per particle, suggesting that some exfoliation of the clay particles took place during the melt blending process. Figure 3 shows that at 30 platelets per stack, most platelets had spacing of 2 nm $\left(s/t\right) = 2$, rather than spacing of 8 nm or greater. These results suggest that most exfoliation of the clay particles occurred by the breakup of the layered platelets as opposed to the movement of the polymer molecules into the particles spacing, thereby increasing the separation between platelets, as suggested by Dennis et al. [6]. Figure 2 shows that the degree of exfoliation was greater for the PCN with 2 and 3 wt% clay particles than for the PCN with 5 wt% of clay particles. This trend was also observed by Zhang et al. [8] in their work.

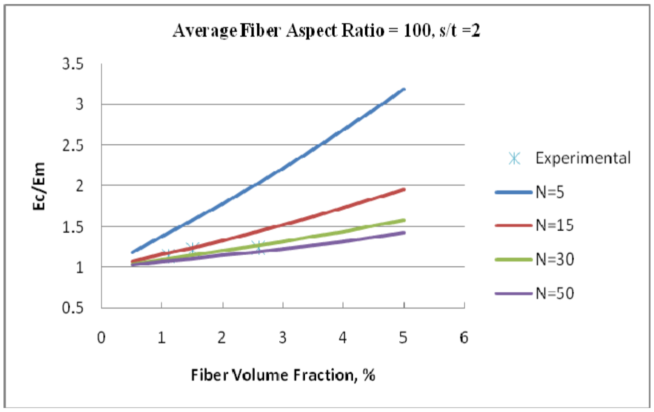

Figure 2. Exfoliation of platelets

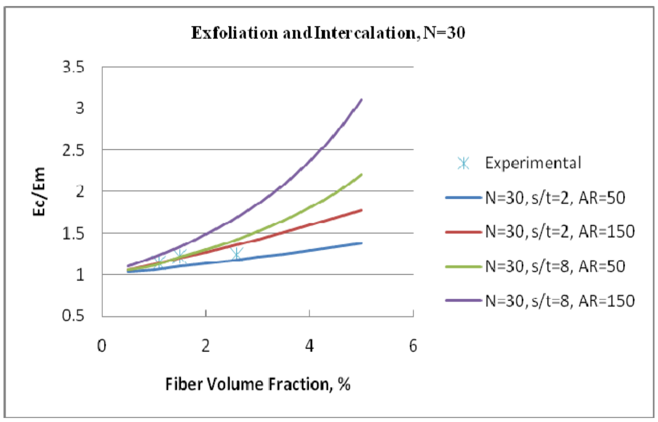

Figure 3. Exfoliation of platelets by break up of layered platelets

Table 1. Tensile properties of PP and PCN

Material	Tensile Strength at Yield (psi)	
	Measured	% Change
Neat PP	4688±49	--
PP/MA/Clay 96/2/2 wt%	4918±37	4.9%
PP/MA/Clay 94/3/3 wt%	4980±23	6.2%
PP/MA/Clay 90/5/5 wt%	4975±20	6.1%

Material	Tensile Modulus (psi)	
	Measured	% Change
Neat PP	101578±4414	--
PP/MA/Clay 96/2/2 wt%	114922±6009	13.1%
PP/MA/Clay 94/3/3 wt%	122529±5928	20.6%
PP/MA/Clay 90/5/5 wt%	124864±5101	22.9%

Material	AC Current Usage (amp)	
	Measured	% Change
Neat PP	4	--
PP/MA/Clay 96/2/2 wt%	4.3	7.5%
PP/MA/Clay 94/3/3 wt%	4.6	15%
PP/MA/Clay 90/5/5 wt%	4.5	12.5%

Table I shows the tensile strength at yield, tensile modulus, and the associated current usage for preparing the PCN. The extruder had current supplied at 208 volts. Shown also are the percent increases of these properties over that of the neat PP, which was used as the control material. Figure 4 shows the ratio of percent increase in tensile strength at yield to percent increase in energy usage, while Figure 5 shows the ratio of percent increase in tensile modulus to percent increase in energy usage. The results in Figure 4 suggest that on a one-to-one basis, the marginal increase in tensile strength at yield is not justified by the increase in energy usage, assuming that tensile strength at yield is the sole property of interest in the PCN. However, Figure 5 shows that with the tensile modulus, the results appear favorable because the ratios are greater than one.

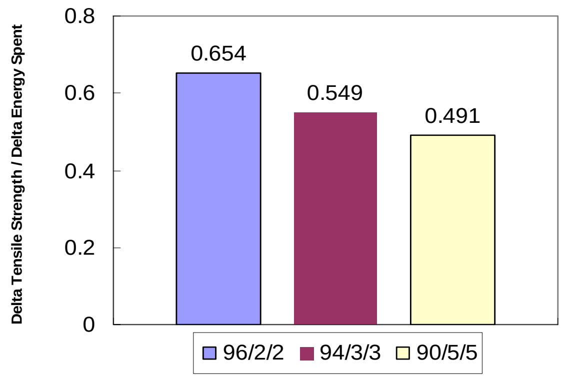

Figure 4. Change in tensile strength per unit change in energy usage

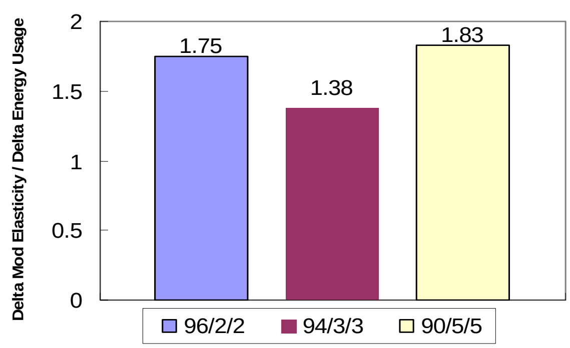

Figure 5. Change in tensile modulus per unit change in energy usage

This implies that if tensile modulus is the primary PCN property for which improvement is desired then the gain in the tensile strength is justified in terms of the incremental energy usage.

A question that this study seeks to address is, "How does the degree of exfoliation affect the mechanical properties of the PCN?" As results in Figure 2 and Table 1 indicate, this may not be an easy question to answer. This is because, as Figure 2 shows, the PCN with 2 wt% (volume fraction = 1.1%) and 3 wt (volume fraction = 1.5%) clay particles tend to show a higher degree of exfoliation than the PCN with 5 wt% (volume fraction = 2.6%). However, Table I shows that the PCN with 5 wt% of clay particles had the highest percent increase in tensile modulus of the three PCN. This suggests, as was remarked by Zhang et al. [8], that the degree of exfoliation of the clay particles may not be the only factor responsible for the improved mechanical properties of PCN; orientation of the exfoliated particles may be an important contributing factor. It is generally known that the orientation of fibers in materials, such as wood, is responsible for their anisotropic properties.

Conclusion

In this study, the authors found that exfoliation of clay particles happens mainly through the breakup of the layered platelets structure of the particles. Little evidence was found that exfoliation occurred by increasing the platelets spacing from 2 nm to 8 nm and greater. The PCN with 2 and 3 wt% of clay particles exhibited higher degrees of exfoliation than the PCN with 5 wt%. However, the difference in the degree of exfoliation was not reflected in the tensile modulus of PCN because the PCN with the 5 wt% of clay had the highest tensile modulus. Based on the observation, it is proposed that exfoliation may not be the only factor responsible for the improved mechanical properties of PCN; orientation of exfoliated particles may be a contributing factor as well. It was observed that of the two mechanical properties examined, the gain in tensile modulus was proportionally greater than the energy employed to achieve the improvement. This was not so for the tensile strength at yield; its gain or improvement was proportionally less than the amount of energy used for the improvement.

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Biographies

REX KANU is an Assistant Professor in the Department of Technology at Ball State University. He is currently the Coordinator of the Manufacturing Engineering Technology program. rkanu@bsu.edu

DENNIS WELDISHOFER graduated from Ball State University in May 2006. He is currently with Jacobs Engineering. He has passed the Fundamental Engineering Certification exam (FE/EIT). Dennis.Weldishofer@Jacobs.com

IDENTIFYING PREVENTION METHODS TO REDUCE CTS INCIDENTS: BASED ON ANALYSIS OF EMPLOYEE PERCEPTION AND BY UTILIZING THE STRAIN INDEX

Gabriel C. Smith, John Deere Dubuque Works; Mandara D. Savage, Southern Illinois University Carbondale

Abstract

Carpal tunnel syndrome (CTS) incidents occur predominantly among manufacturing assembly operations in the United States. The purpose of this study was to establish a methodology to reduce CTS incidents by utilizing the strain index (SI) to assess hazardous operations that contribute to CTS; identify methods to reduce CTS incidents at the hazardous operations with the help of upper management; and seek employee feedback on how successful the identified methods to reduce CTS will be over time. Forty-three employees exposed to hazardous operations were surveyed to determine if the proposed prevention methods would be successful over time. The survey results were analyzed by the chi-square goodness-of-fit test, and the employees significantly agreed that all of the proposed prevention methods would lead to fewer CTS incidents over time, which was verified by the level of significance shown by the chi-square goodness-of-fit test.

Introduction

Work-related carpal tunnel syndrome (CTS) incidents occur predominantly among manufacturing assembly operators in the United States [1]. Occupational risk factors associated with CTS are repetition, force, awkward posture, and vibration [2]; [3]; [4]; [5]; [6]. Researchers recently developed the strain index (SI) to identify hazardous operations that contribute to work-related CTS [7]. The SI has been validated in numerous studies as a state-of-the-art risk assessment tool for analyzing CTS risk [7]; [8]; [9]; [10]; [11]. However, few studies have focused on using a risk assessment similar to the SI as a mechanism to establish and monitor the effects of CTS prevention methods over time. Therefore, the purpose of this study was to establish a methodology to reduce CTS incidents by using the SI to identify operations that have high CTS risk, to identify prevention methods to reduce CTS risk at the hazardous operations, and to seek employee feedback on how successful the identified CTS prevention methods will be over time.

Methods

The methods for this study consisted of the following:

1. Analyze assembly operations for CTS risk with the SI.
2. Obtain SI rating values for each observed operation.
3. Define operations that have high risk for CTS.
4. Inform upper management about the identified hazardous CTS operations and ways to prevent CTS.
5. Identify prevention methods to reduce CTS at the hazardous operations.
6. Seek employee feedback on the proposed prevention methods.

Manufacturing assembly operations were analyzed in a compact disk manufacturing facility. The operations analyzed were from the manual packaging line, manual bulk packaging line, and hand boxing station. A video recorder was used to record employees' hand and wrist movements while conducting an operation. Each task was videotaped for approximately 10 cycles to allow SI evaluation.

The SI rating values for intensity of exertion (IEM), duration of task per day (DDM), efforts per minute (EMM), duration of exertion (DEM), speed of work (SWM), and hand/wrist posture (HWM) were obtained using the SI procedures established by the authors [7]. After each SI rating value was obtained for each parameter, the next step consisted of obtaining the SI score. The SI score was found by taking the product of all the SI rating values.

Once the manufacturing assembly operations were assessed with the SI, the next step consisted of classifying operations for the level of risk for developing CTS. For this step, an operation was considered hazardous for CTS risk if it had a SI score of five or greater. If an operation had an SI score of less than five, the operation was considered safe. This rule for differentiating between hazardous and safe operations for CTS risk was consistent with previous research studies on the SI [7]; [8]; [9].

After the SI was used to classify safe and hazardous operations for CTS risk, the next step consisted of meeting with upper management to discuss hazardous CTS risk operations and ways to prevent CTS. This step involved informing upper management about how the SI works, operations identified with high CTS risk by the SI, and administrative and engineering controls commonly used to prevent CTS.

After upper management was informed of operations with high CTS risk and common CTS prevention methods, the next step consisted of proposing prevention methods to reduce CTS incidents at the hazardous operations. The prevention methods to reduce CTS were determined by upper management reviewing the hazardous CTS operations and discussing feasible prevention methods.

Since CTS is a cumulative trauma disorder that may take months or years to develop in the hand, it is difficult to determine how successful CTS prevention measures will be over time. However, it was possible to ask employees exposed to hazardous CTS operations if the proposed prevention methods identified by upper management would lead to less CTS incidents in the future. This step surveyed the employees' affected by the hazardous operations and asked their opinion on whether the proposed methods to reduce CTS would lead to fewer cases of CTS in the future. The chi-square goodness-of-fit test was used to determine if employees significantly agreed that a proposed prevention method would lead to fewer CTS incidents in the future.

Results

Twenty-four employees from two different shifts voluntarily participated in the videotaping to analyze 27 operations for CTS risk. Twelve operations were analyzed from the manual packaging line, 11 operations from the manual bulk packaging line, and four operations were from the hand boxing area. Tables 1–3 contain SI results obtained from each area where the 27 operations were investigated. By using the SI criteria, a total of 19 operations were identified as hazardous for developing CTS, while eight operations were considered safe.

Table 1. SI Results from the Manual Packaging Line

Operation	IEM	DDM	EMM	DEM	SWM	HWM	SI
1. Case disassembly	3	1	3	3	1	1.5	40.5
2.Inlay folding	3	1	1	2	1	1.5	9.0
3. Insert inlay	1	1	3	2	1	1.5	9.0
4. Sleeving	3	1	2	1	1.5	1	9.0
5. Traying	3	1	1.5	1.5	1	1.5	10.1
6. Disking	1	1	3	3	1	1.5	13.5
7. Booking	3	1	1.5	2	1	1	9.0
8. CD placing	3	1	3	2	1	1	18.0
9. CD packaging	3	1	1	1	1	1.5	4.5
10. Box assembly	3	1	0.5	1.5	1	2	4.5
11.Close CD case and align	3	1	3	2	1	1.5	27.0
12. Case alignment	3	1	3	2	1	1.5	27.0

Table 2. SI Results from the Manual Bulk Packaging Line

Operation	IEM	DDM	EMM	DEM	SWM	HWM	SI
13. Place plastic lid on spindle	1	1.5	1.5	1	1	1	2.3
14.Transport empty spindles	9	1.5	1	1	1	1	13.5
15. Pick up bulk CDs from spindle and place in box	13	1.5	1.5	1	1	2	58.5
16.Fold down box lid	3	1.5	1	1	1	2	9.0
17.Push full box of CDs onto rollers	6	1.5	1	1	1	3	27.0
18.Stack full box of CDs onto pallet	3	1.5	1	1	1	1.5	6.8
19.Transport CDs on spindle from shelf to counter	3	1.5	1	0.5	1	1	2.3
20.Transport	3	1.5	1	1	1	1.5	6.8

CDs from spindle to counter							
21.Transport CDs from counter to larger spindle	3	1.5	1	1	1	1.5	6.8
22.Transport CDs on larger spindle to conveyor	3	1.5	1	0.5	1	1.5	3.4
23.Bulk CD sleeving	1	1.5	0.5	1	1	1	0.8

Table 3. SI Results from the Hand Boxing Area

Operation	IEM	DDM	EMM	DEM	SWM	HWM	SI
24.Assemble box on table	3	1.5	1	1	1	1.5	6.8
25. Place 20 cased CDs in box	3	1.5	1	1	1	2	9.0
26. Fold down box	3	1.5	0.5	0.5	1	1.5	1.7
27. Push box forward	3	1.5	0.5	0.5	1	1.5	1.7

After discussing the CTS hazardous operations and methods to prevent CTS within their company, members of upper management proposed the following ideas to reduce CTS incidents at the hazardous operations:

1. Have workers conduct frequent exercises of the hand and wrist.
2. Allow workers to conduct more tasks that would allow variation in hand and wrist movements.
3. Rotate workers between jobs every one to two hours.
4. Redesign the workstation to prohibit hazardous operations.
5. Allow workers to alternate hands when conducting a task.
6. Train employees about proper ergonomic procedures.
7. Provide assisted lifting devices to employees.

Once the proposed prevention methods to reduce CTS were established, a survey instrument was developed to seek employee input on how successful upper management's CTS prevention methods will be over time. The following questions were developed from upper management's feedback to survey employee perception:

1. Which area(s) do you work within the plant (for example, manual packaging line, bulk packaging line, hand boxing area, other)?
2. Do you believe frequent exercising of the hand and wrist will lead to less incidents of carpal tunnel syndrome? (Yes/No)
3. Do you believe that splitting tasks among workers will lead to less carpal tunnel syndrome incidents (for example, one worker will do three tasks instead of one task)? (Yes/No)
4. If workers are rotated between jobs every one to two hours, with each rotation requiring different muscular contractions, will carpal tunnel syndrome incidents decrease? (Yes/No)
5. Do you think that a better designed workstation would result in less carpal tunnel syndrome incidents? (Yes/No)
6. Would alternating hands (for example, switching from the left to the right hand) while performing a task reduce carpal tunnel syndrome incidents? (Yes/No)
7. Would training employees about using ergonomics lead to less incidents of carpal tunnel syndrome? (Yes/No)
8. Do you believe that assisted lifting devices could be used to reduce carpal tunnel syndrome cases? (Yes/No)

Approximately 43 out of a possible 85 employees voluntarily filled out the survey. A chi-square goodness-of-fit test was used to determine if employees significantly agreed/disagreed that a proposed prevention method would lead to fewer CTS incidents. Each survey question had one degree of freedom and was analyzed at a 95 percent significance level (alpha = 0.05). Employees who participated in the survey served in some capacity at the hazardous operations that were classified by the SI (as identified in question 1 of the survey).

Table 4 contains a descriptive analysis of the number of "yes/no" responses obtained from collecting data on each question of the 43 respondents and illustrates the results for each question from the chi-square goodness-of-fit test. For question two, 42 out of 43 subjects responded. The results showed that employees significantly agree that frequent exercises of the hand and wrist would reduce the frequency of CTS incidents over time (chi-square = 13.714). Question three had 42 out of 43 subjects respond, with the results showing that employees significantly agreed that task variety could help reduce the frequency of CTS cases (chi-square = 7.714). For question four, all 43 respondents answered the question, and employees significantly agreed that rotating jobs every one to two hours could reduce CTS incidents (chi-square = 22.349). Question five had 38 out of 43 subjects respond, which may have indicated that the question was unclear. However, employees significantly agreed that a better designed workstation could lead to less CTS cases in the future (chi-square = 10.526). All 43 subjects replied to question six, and employees significantly agreed that alternating hands while conducting a task could reduce future cases of CTS (chi-square = 3.930). Question seven had 42 out of 43 subjects respond, with the results showing that employees believed that ergonomics training could lead to fewer incidents of CTS over time (chi-square = 21.429). Question eight had 42 out of 43 subjects respond, and employees significantly agreed that assisted lifting devices could reduce future CTS cases at their workstations (chi-square = 16.095).

Table 4. Chi-square Goodness-of-fit Test Result for Each Survey Question

Q	R	E	Y	N	Chi-Square	P-Value
2	42	21	33	9	13.714	0.000
3	42	21	30	12	7.714	0.005
4	43	21.5	37	6	22.349	0.000
5	38	19	29	8	10.526	0.001
6	43	21.5	28	15	3.930	0.047
7	42	21	36	6	21.429	0.000
8	42	21	34	8	16.095	0.000

Where:
Q = Question Number
R = Number of Respondents
E = Expected Frequency
Y = Observed "Yes" Responses
N = Observed "No" Responses

Conclusion

A prevention methodology was developed to reduce CTS incidents at hazardous manufacturing assembly operations. This method was conducted by using the SI to assess manufacturing assembly operations, proposing CTS prevention methods with the help of upper management, and analyzing employee perception on how successful the proposed CTS prevention methods will be over time. The results of the survey showed that according to employee perception, all of the proposed CTS prevention methods identified by upper management will lead to fewer CTS cases over time.

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Biographies

GABRIEL C. SMITH is currently a Supplier Quality Engineer at John Deere. He graduated with a Master's of Science in Manufacturing Systems from Southern Illinois University Carbondale in 2007. He is certified by the Association of Technology, Management, and Applied Engineering as a Senior Technology Manager and by the American Society for Quality as a Certified Quality Engineer. Mr. Smith may be reached at smithgabrielc@johndeere.com

MANDARA D. SAVAGE is currently a Professor and Chair of the Department of Technology at Southern Illinois University Carbondale. His research interests include machine tool dynamics, manufacturing systems and processes, and lean manufacturing systems design. His additional research interests include occupational safety and health, as well as musculoskeletal disorders. He serves as the National Safety Division President for the Association of Technology, Management, and Applied Engineering. Dr. Savage may be reached at msavage@engr.siu.edu

EDUCATIONAL INSTITUTION STRATEGIES TO INCREASE U.S. INNOVATION

Matthew E. Elam, Texas A&M University-Commerce; Jerry D. Parish, Texas A&M University-Commerce;
Ben D. Cranor, Texas A&M University-Commerce

Abstract

In a paper titled "Global Trends in Patenting" (Proceedings of the IAJC-IJME International Conference, 2008), the authors cited data indicating the United States' leadership position in the issuance of patents is being threatened. They also cited references stating that patents are an indication of a country's innovativeness and that innovation leads to technological development. This paper addresses educational institution strategies to increase U.S. innovation. Specifically, it explores creativity and innovation as essential characteristics of engineers and scientists. It also investigates approaches to instill these characteristics in college and university students. Finally, it addresses the shortage of science and engineering graduates. A national agenda to promote, implement, evaluate, and improve efforts to recruit and prepare students to be inventive scientists and engineers will increase U.S. innovativeness and patent output.

Introduction to Creativity, Innovation, and Critical Thinking

Creativity brings into existence an idea that is new, and innovation is the practical application of creative ideals [1]. All people have some level of creative ability, particularity at a young age, and that creative level can be greatly enhanced throughout life with continual education, knowledge development, and practice [2]. Engineering and scientific creativity, as well as innovation, require specific knowledge in mathematics; design and engineering theories and principles; problem-solving principles; and logical (critical) thinking. This type of knowledge can be taught within the educational system. To fully develop one's creative and innovative abilities requires educators to develop curricula that promote the creative, innovative, and critical thinking skill sets.

If the United States is to lead the world in the research and development of high-technology products, services, and industries, the workforce must possess the ability to solve problems and to make creative decisions. Evans [2] stated, "Problem solving and decision making in today's global social and business environments have become complex tasks. The uncertainty of the future, the nature of the completion, and the nature of social interaction increase the difficulty of managerial decision making. Because knowledge and technology are changing rapidly, new problems with little or no precedents continually arise. Thus, one cannot rely on existing methods and approaches to solve such problems. Truly creative approaches are becoming a necessity." Educational programs in engineering and technology are challenged with the task of preparing their students for tasks and jobs that may not currently exist; therefore, they must develop curricula that will educate students to be successful without knowing the specific job requirements. If the student's creative, innovative, and critical thinking abilities are enhanced to a high level, chances are the student can become a successful problem-solver and inventor in his/her technical career. "Students of innovation at the beginning of the 21st century are likely to conceive of this critical activity rather differently than did scholars some 30 years ago. At that time, innovation was seen as essentially synonymous with the linear progression that was thought to characterize research and development. Today, we are apt to recognize that successful innovators—whether individuals, teams, or companies—are engaged in a sequence that is highly variable and interactive rather than linear" [3].

Engineers, inventors, technologists, and scientists of the future need a greater ability to think critically. Therefore, educators need to understand how to teach this skill effectively. To think critically, students require the following:

- A high degree of knowledge in the discipline or area
- An attitude of questioning and suspended judgment
- Some application of the methods of logical analysis or scientific inquiry
- The taking of action in light of the analysis, reasoning, and outcomes [4]

Additionally, the principle of shared learning or cooperative learning must be put forward. In this process, the students are taught to work in teams or units and to assist and encourage each other in the mastery of required knowledge and skills. Effective interpersonal and social skills are necessary for collective groups to develop harmony and to achieve high levels of success. Ruggiero [5] stated, "Much of our education was built on the idea that thinking can't be taught or that some subjects teach it automatically. Modern research has revealed the error of both ideas. Thinking can be taught—not to just gifted students but to all students. No course teaches thinking automatically, but any course can teach it when the teachers make thinking skills a direct objective." Students must also be knowledgeable of world cultures and the impact culture plays on the creative and innovative processes from nation to nation.

Successful global companies of the 21st century and beyond will continue to use creativity, innovation, and critical thinking as major tools in their competitive advantage toolbox. Therefore, it is imperative that the educational process of today and the future places more emphasis on the development and enhancement of these skills in students. The United States is losing market share in the high-technology industries and will continue to do so if it does not place more emphasis on inventor-type skills in engineering, technology, and scientific disciplines.

Challenge to Higher Education in the United States

The previous sections established the terminology for and need to teach creativity, innovation, and critical thinking skills in higher education in the United States. This section presents approaches for incorporating the teaching of these skills into college and university curricula. The approaches may require the need for higher education institutions to partner more effectively with K–12 educational institutions and industry. It may also require higher education institutions, as well as state and federal governments, to place a renewed emphasis on education of students through quality teaching, instructors, and partnerships reflected through increased resources for this purpose.

Amabile [6] presented three components of creativity: expertise, motivation, and creative-thinking skills. Expertise is a person's knowledge and ability in his or her work [6]. Teaching expertise is a traditional strength of higher education institutions. Motivating students is not, in general, a focus of higher education institutions. Students are motivated by different things. One way to determine students' motivations is to administer personality tests. Individualized and/or team assignments can help specifically address each student's motivation. However, team assignments may be more beneficial for instructor time requirements and student learning. As mentioned previously, the principle of shared learning or cooperative learning must be put forward to address creativity, innovation, and critical thinking skills development. In this process, the students are taught to work in teams or units and to assist and encourage each other in the mastery of required knowledge and skills. Effective interpersonal and social skills are necessary for collective groups to develop harmony and to achieve high levels of success. The third component of creativity, creative-thinking skills, determines how flexibly and imaginatively students approach problems [6]. This also is not, in general, a teaching focus of higher education institutions. This is probably best taught toward the end of a course when students have most, if not all, of the tools they need to discover solutions to problems. This is where industry can play a role. Industry representatives can present problems for the students to solve using tools learned in the course. This can be accomplished individually, but working in teams may be more beneficial.

As previously mentioned, innovation is the practical application of creative ideals [1]. Peters [7] developed a circle of innovation that includes the following elements:

- Distance is dead.
- Destruction is cool.
- You cannot live without an eraser.
- We are all Michelangelos.
- Welcome to the white-collar revolution.
- All value comes from the professional services.
- The intermediary is doomed.
- The system is the solution.
- Create waves of lust.
- Tommy Hilfiger knows.
- Become a connoisseur of talent.
- It is a woman's world.
- Little things are the only things.
- Love all, serve all.
- We are here to live life out loud.

The creative descriptions for these elements are typical of Peters' [7] writing style. However, he explained in detail his meaning behind them [7]. According to Peters [7], if people and organizations study and practice these elements, the ability to proceed from creativity to innovativeness will increase. It is possible to incorporate at least some of these elements into higher education curricula. Peters' [7] interesting approach in presenting them contains information that can be used to do this. Some interesting quotes from Peters [7] regarding innovation and design follow:

- "The only sustainable competitive advantage comes from out-innovating the competition" (p. 29).
- "Wealth in the new regime flows directly from innovation, not optimization; that is, wealth is not gained by perfecting the known, but by imperfectly seizing the unknown" (p. 29).
- "Fifteen years ago, companies competed on price. Today it's quality. Tomorrow it's design" (p. 429).

Another approach to help students discover innovation is through empathic design. Its foundation is observation—watching consumers use products and services in their own environment. Its five-step process is observation, capturing data, reflection and analysis, brainstorming for solutions, and developing prototypes of possible solutions [8]. These can certainly be taught in higher education curricula, especially if industry is involved.

As previously mentioned, students require the following to think critically:

- A high degree of knowledge in the discipline or area
- An attitude of questioning and suspended judgment
- Some application of the methods of logical analysis or scientific inquiry
- The taking of action in light of the analysis, reasoning, and outcomes [4]

The requirement of a high degree of knowledge in the discipline or area is the same as the expertise component of creativity from Amabile [6]. Again, higher education institutions do well with this requirement. To develop an attitude of questioning and suspended judgment, instructors can apply the team concept of brainstorming to the classroom. Brainstorming is an open, energetic, and positive exchange and discussion of ideas. Once the brainstorming session is complete, student knowledge and expertise can be employed to pare down the ideas to those believed to have the highest chance of success and meet resource requirements. This will also involve elements of the third requirement to think critically, which is some application of the methods of logical analysis or scientific inquiry. These are more general, subject-independent skills that will require institute-wide initiatives to ensure they are employed in as many courses as possible. The fourth and final requirement to think critically is also one that higher education institutions currently address. The traditional teaching process is to present content, work examples, and assign problems for the students to work. Students working problems constitutes this final part. Problems requiring knowledge from larger portions of a course and having industry participation can only help with the development of the fourth requirement to think critically. Industry will be able to provide less structured and more open-ended problems for the students.

Shortage of U.S. Science and Engineering Graduates

A national agenda to promote, implement, evaluate, and improve efforts to prepare students to be inventive scientists and engineers would have shortcomings if it did not address the growing shortage of U.S. science and engineering graduates. U.S. innovativeness and patent output will increase if efforts to recruit and prepare students to study science, technology, engineering, and mathematics (STEM) disciplines are included in the agenda.

As the 21st century begins, the demand for an abundant, diverse, and talented STEM workforce remains strong. Continued growth in national productivity requires a continuous supply of professionals who are highly competent in the STEM disciplines and who are adaptable to the needs of a rapidly changing profession. While overall employment in STEM disciplines is expected to increase during the 2000–2010 period, STEM degrees over the same time period are expected to remain stable. The number of 18–24 year olds will grow by three million by 2010; and African Americans, American Indians, and Hispanics will make up almost 60 percent of the population increase over that time period. The consensus among leaders in the STEM community is that the necessary increase in the STEM labor supply will come about only through the development of a more diverse workforce [9].

DeReamer and Safai [10] also stated that employment opportunities in the United States requiring STEM expertise are growing rapidly. From 2000–2010, growth is expected to increase about three times faster than the rate for all other occupations. However, the available domestic STEM labor supply has not and will not be able to satisfy this growth because of the long-term trend of fewer students entering STEM programs in college, thus threatening the ability of U.S. businesses to compete in the global marketplace. The situation is so dire that the National Science Board has stated that the federal government and its agencies must step forward to ensure the adequacy of the U.S. STEM workforce, and that all stakeholders must mobilize and initiate efforts that increase the number of U.S. citizens pursuing STEM studies and careers.

May and Chubin [11] mentioned that the STEM workforce, despite years of efforts to diversify it, remains overwhelmingly white, male, and able-bodied, and the available pool of talented women, minorities, and persons with disabilities remains significantly under-utilized. If individuals from these underrepresented groups were represented in the STEM workforce at the same percentage as their representation in the total workforce population, the shortage in the STEM labor supply would largely be filled. Also, currently underrepresented groups are projected to increase from about a quarter of the workforce to nearly half by 2050. This suggests that the United States must cultivate the STEM talents of all of its citizens, not just those from groups that have traditionally worked in STEM fields.

The fact that women and minorities are underrepresented in the STEM labor force has led to the formulation of the following questions:

- What are the psychological mediators of both gender and ethnic group differences in entry into and persistence in the STEM labor force?
- What are the family and school forces that underlie the gender and ethnic group differences in these psychological mediators?
- How do experiences in tertiary educational settings and in STEM work settings influence gender and ethnic

group differences in entrance to and persistence in the STEM labor force? [12]

Many efforts have been established to answer these questions and to increase the percentage of underrepresented populations in the STEM workforce. These efforts have included special college and university freshman courses and programs, summer and after-school programs for high school students, and the integration of STEM applications into high school curricula. One proven technique is from George and Burden [13]. These authors described a Youngstown State University effort to improve the mathematics skills of freshmen entering their technology program. One part of this effort was the development of a freshman-level course titled Technical Skills Development. The approach in this course was to teach the necessary skills according to the precepts of contextual learning. Groundwork was laid on orienting students to engineering as a problem solving activity, algebraic equation and unit manipulation, composite shape usage, engineering graphic techniques, hypothesis formulation and testing, and the entire engineering lab writing process. The second part of this approach involved students taking an elementary algebra course simultaneously with the Technical Skills Development course. In the elementary algebra course, a mandatory lab component was instituted, a supplemental computer and drill assessment was introduced, off-hour Web site tutoring was offered, and mathematics based simulations were used. Analyses showed a statistically significant improvement in the pass rate of high risk students.

Lam, et al. [14] described a part of the University of Akron's approach to improve its STEM graduation rate where, during the academic year, students attended a series of career workshops at local manufacturing companies and research facilities. These activities were designed to inform students about the STEM professions. They also included one-on-one discussions between the engineers and the students.

Gilmer [15] described a Bowling Green State University effort where, starting their first academic year, students were awarded a four-year academic scholarship of $1,500 that increased annually by $500 increments if they remained in good standing. This meant a student remained in a STEM major and showed academic success by achieving certain GPA levels after the first three years of college. Gilmer [15] stated that participating students exhibited pride in earning annual incremental increases and tended to work harder and smarter to ensure that they received the increases.

Popular and successful efforts to introduce STEM topics to high schools include the Infinity Project [16] and Project Lead the Way [17]. The Infinity Project is a national award-winning high school and early college math- and science-based engineering and technology education initiative that helps educators deliver a maximum of engineering exposure with a minimum of training, expense, and time. It is a software-based curriculum that includes a state-of-the-art curriculum; an easy-to-use, yet powerful classroom technology kit; and best-in-class professional development and teacher support for science, mathematics, and technology teachers [16]. Project Lead the Way's equipment-enhanced curriculum makes mathematics and science relevant for students. By engaging in hands-on, real-world projects, students understand how the skills they are learning in the classroom can be applied in everyday life [17].

Conclusions

Efforts to recruit and prepare students to study STEM disciplines must continue. Recently, organizations have started to address innovation. Marquette University's College of Engineering will offer a graduate certificate in engineering innovation starting in the fall 2008 semester. Lehigh University's engineering and applied science magazine, Resolve, recently focused on innovation as it relates to research in Lehigh's P.C. Rossin College of Engineering and Applied Science [18]. The American Society for Engineering Education's (ASEE) 2008 Annual Conference and Exposition had exhibitors whose presentations focused on their innovations.

Progress is being made to promote, implement, evaluate, and improve efforts to recruit and prepare students to be inventive scientists and engineers. A more organized and fully-resourced national agenda to do this will be more effective in increasing U.S. innovativeness and patent output.

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Biographies

MATTHEW E. ELAM, Ph.D., is an Associate Professor of Industrial Engineering in the Department of Industrial Engineering and Technology at Texas A&M University-Commerce. He teaches industrial engineering courses and has research interests in short-run statistical process control and mathematics, statistics, and engineering education. He is also an ASQ Certified Quality Engineer. Dr. Elam may be reached at Matthew_Elam@tamu-commerce.edu

DR. JERRY D. PARISH is a Professor of Industrial Engineering and Technology and Associate Dean for the College of Business & Technology at Texas A&M University-Commerce. His teaching and research interests are in technology management. He has published in The International Journal of Agile Manufacturing, Journal of Industrial Technology, the Technology Interface, and the journal of Epsilon Pi Tau. Dr. Parish may be reached at Jerry_Parish@tamu-commerce.edu

BEN D. CRANOR, Ph.D., is an Assistant Professor of Industrial Engineering and Technology at Texas A&M University-Commerce and Associate Director of the Center for Excellence, whose mission is to promote the concept of global competitiveness. His teaching and research interests are in technology management. He holds U.S. Patent No. 4,358,668. Dr. Cranor may be reached at Ben_Cranor@tamu-commerce.edu

FAILURE ANALYSIS OF GAS TURBINE BLADES

M. Tofighi Naeem, K.N.Toosi University of Technology, Iran; N. Rezamahdi, K.N.Toosi University of Technology, Iran;
S.A. Jazayeri, K.N.Toosi University of Technology, Iran

Abstract

The failure analysis of a gas turbine blades made of nickel-base alloy was carried out in two discrete sections:

- Mechanical analysis
- Metallurgical analysis

Using ANSYS 11.0 –Workbench software (Advanced CFD section), a steady state gas flow analysis was carried out and the pressure and temperature distributions and velocity vectors and streamlines were delineated. Then by mapping of these results on the other section of it (simulation section), equivalent stresses and total deformation were determined.

The metallurgical investigation was carried out using visual examination, photographic documentation, non destructive testing (NDT), optical microscopy, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The surfaces of the blades are diversely colored. Also, these blades suffered both types of corrosion and erosion.

A detailed microstructural analysis of all elements that had influence on the failure initiation was carried out. Namely, micro-cavities were found on fracture surfaces that served as an origin of creeping failure mechanism (the appearance of the fracture surfaces in the failed blade resembles a dimple-like fracture); decreasing of alloy ductility and toughness due to carbides precipitation in grain boundaries (formation of continuous films and dispersed particles of carbides); and degradation of the alloy γ' phase (irregular growing of γ' particles). It is found that the cracks in the coating act as an initiator for the thermal fatigue crack. The substrate intergranular crack initiation and propagation were due to a creep mechanism. Also, due to operation at high temperatures, many annealing twins were observed at different regions.

Introduction

Blade failures can be caused by a number of mechanisms under the turbine operating conditions of high rotational speed at elevated temperatures. In general, blade failures can be grouped into two categories: (a) fatigue, including both high (HCF) and low cycle fatigue (LCF) [1-6]; and (b) creep rupture [6-8]. Researches on evaluating the thermomechanical behavior for turbine blade materials that are made up of Ni base superalloys have garnered increasing interest in recent years. These superalloys are the standard material for hot stages of gas turbines were vanes and blades are subjected to high mechanical stresses and aggressive environments [9-23]. In Ni base superalloys the presence of chromium is essential to assure high-temperature oxidation resistance, whereas other alloying elements are important to guarantee high-temperature strength, especially creep resistance. Other elements, such as aluminum and titanium, enable the precipitation of the γ' phase $(Ni_3(Al,Ti))$ during heat treatment, which strengthens the face centered cubic matrix (γ phase) [24-27]. Another kind of phase is also very important for the mechanical properties of nickel base superalloys (carbides). These particles are present in these alloys because it is very difficult to remove carbon during refining and because carbon is added on purpose to form carbides, which improve creep properties [24, 27].

The aim of this work is to evaluate the creep-fatigue properties of the first and second stage blades under cycling duty. To identify this, a complete metallurgical investigation with mechanical analysis was carried out.

Background

The blades used in a gas turbine were damaged in servicing. The accumulated service time of the blades is more than 10 years. The blades material is specified as IN738LC alloy (Cr: 16; Co: 8.5; Ti: 3.4; Al: 3.4; Fe: 0.3; Mo: 1.75; W: 2.6; Ta: 1.7; Si: 0.1; balance: Ni). Figures 1, 2 show the rotor and stator of this turbine, respectively. The first stage blades were badly damaged while the second stage blades remained relatively whole.

Visual Inspection

The macroscopic features of the blades were observed by visual examination and photographic documentation. These inspections showed the different regions on the surface of the blades at the convex and concave sides.

As can be seen from Figure 3, in the vicinity of the platform both sides of the blades were rough and exhibited diverse colors especially reddish, greenish and dark brownish regions. Using X-ray diffraction (XRD) and X-ray fluorescence (XRF), Khajavi et al. found that these colors represented the presence of iron oxides, Cr_2O_3 and NiO, as well as Na and S [28-31]. Loss of materials and thickness (that may have been caused by interaction of different mechanisms such as hot corrosion (or erosion) and creep or fatigue [30]) was observed at the whole of the blades. Also, dye penetrant inspection (DPI) testing found that there was a crack on both sides of the failed blade coating.

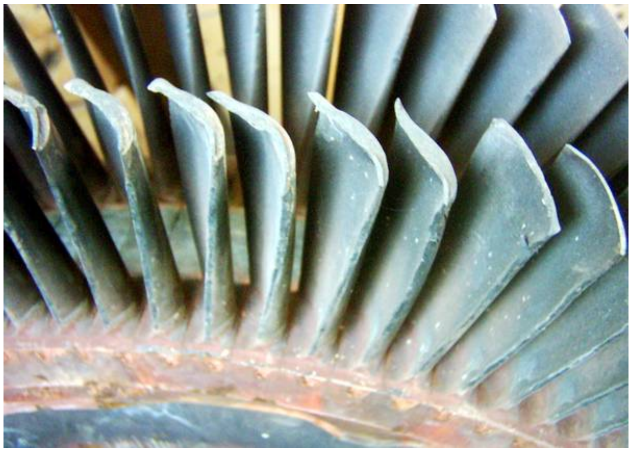

Figure 1. Deformation of Rotor Blades

Figure 2. Failed Stator Blades

Experimental Procedures

The chemical composition of the material was determined by energy dispersive spectroscopy (EDS). The microstructure of the blades was observed by optical microscopy and scanning electron microscopy (SEM). For these investigations we prepared several longitudinal and transverse sections from the blades. These specimens were polished by standard techniques and were etched by solution of 5ml $\mathbf{CuSO_4}$, 50ml $\mathbf{H_2O}$ and 50ml HCl.

Microstructural Evaluation

Metallographic prepared sections were initially examined in an optical microscope and subsequently evaluated in a scanning electron microscope equipped with an EDS spectrometer.

Figure 4 shows the coarsening of grain boundary precipitates in the top section of the service exposed second stage blade because of creeping degradation that was taken by optical microscopy.

Figure 3. The Rough Surface Shows Diversely Colored

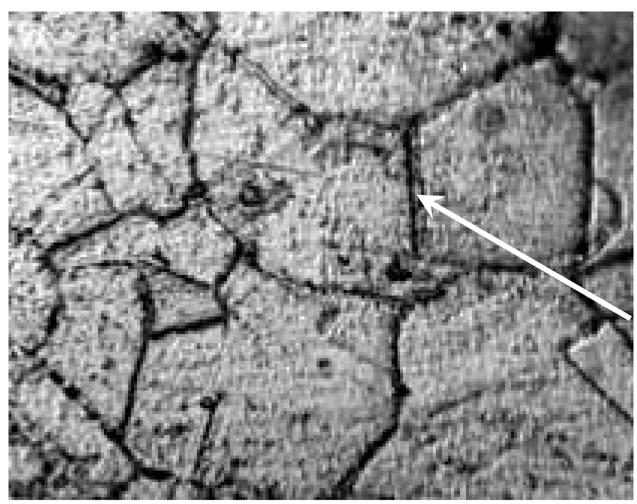

Figure 4. Coarsened Grain Boundary Precipitates ($200\times$)

The distribution and morphology of strengthening phase γ' precipitates in the top section of the second stage blade is shown in figure 5. As can be seen from this figure, the coarsened γ' size is in the range of 0.5-2 μm in this section. Moreover the large size coarsened γ' precipitates are surrounded by γ' denuded zone (darker regions) devoid of secondary γ' precipitates. Figures 6, 7 show carbides precipitation in grain boundaries that is represented in the formation of continuous films (include 39.8 percent Cr) and dispersed particles (include 9.6 percent Ti) of carbides, respectively. Carbides precipitations result in decreasing of alloy ductility and toughness.

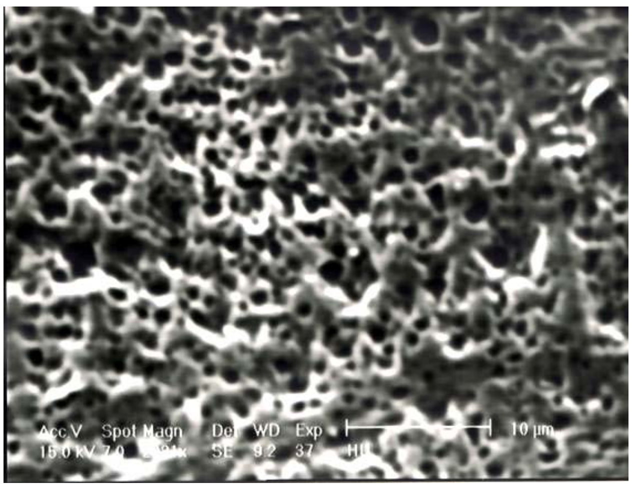

Figure 5. The Large Size of Coarsening-Coalescence of γ' Phase

Figure 6. Continuous Films of Carbides Precipitates

Crack Evaluation

There were a large number of cracks at different regions of blades because of operation at high temperatures and stresses over a long period of time. Some of these cracks are shown in Figures 8-11. In figure 8 we observe an intergranular crack on fracture surface. The appearance of the fracture surface in figure 9 resembles a dimple-like fracture. The dimple-like appearance can be attributed to the microcavities which could be related to intergranular decohesion of carbides [29, 32]. These microcavities serve as the origin of a creep failure mechanism [29, 33, 34].

Figure 7. Dispersed Particles of Carbides Precipitates

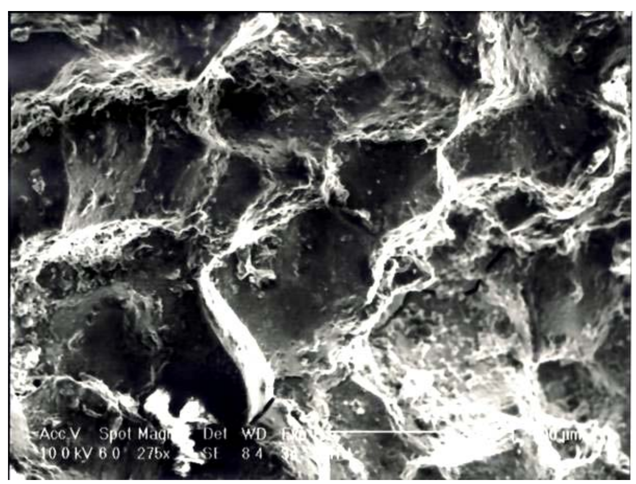

Figure 8. Intergranular Fracture Morphology (There is a crack on fracture surface)

Also we observed an intergranular crack on the first stage blade coating (Figure 10) and several intergranular cracks that were located on transverse section of the blade surface

(Figure 11). The coating crack initiation was probably due to a thermal fatigue mechanism as a result of high thermal transient loads (i.e., trips, start-ups and slow-downs), and crack grain boundary initiation and propagation in the substrate by a creep mechanism (high steady state loads) [33].

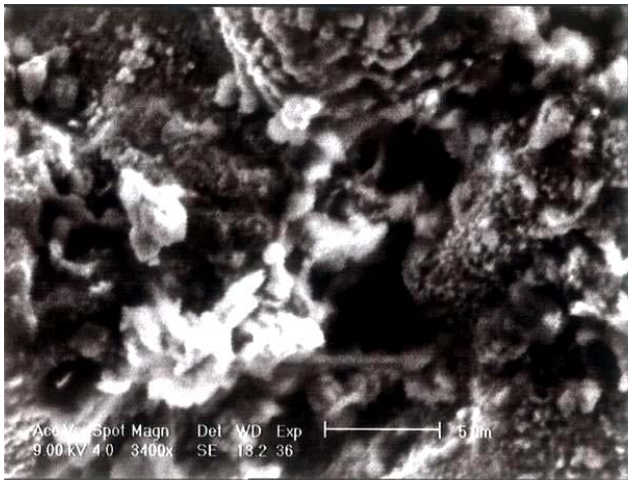

Figure 9. Dimple-Like Microcavities were found on Fracture Surface

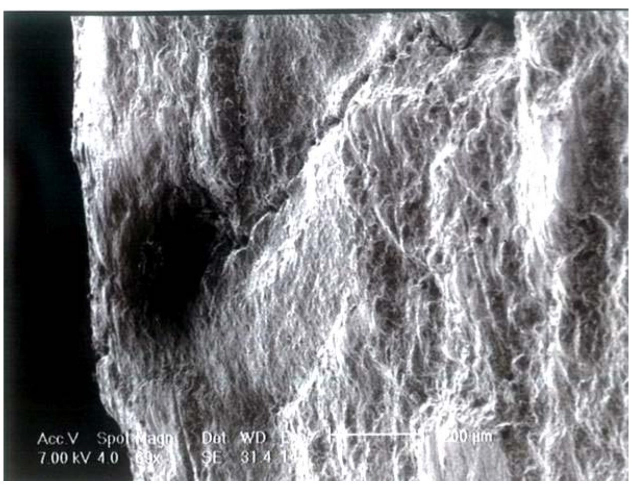

Figure 10. Intergranular Crack on the Coating

As the other result of the creep failure mechanism we found grain detachment in the second stage blade that is shown in figure 12. As seen in this figure, there were several macrocracks on grain boundaries.

One of the important deformations in metals is the process known as twinning. Twins may be produced by mechanical deformation or as the result of annealing following plastic deformation. The first type is known as mechanical twins and the later are called annealing twins [35]. In this study many annealing twins (Figure 13) were observed at different regions.

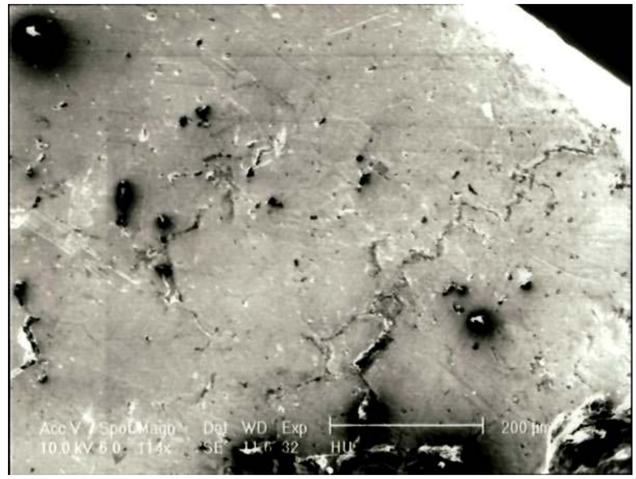

Figure 11. Several Intergranular Cracks on Transverse Section of the Blade Surface

Figure 12. Several Macrocracks on Grain Boundaries due to Creep Mechanism

Mechanical Analysis

A steady state gas flow analysis was carried out by means of Advanced CFD, which is a section of the ANSYS Workbench 11.0 software; then by the mapping these results on the simulation section, the stress analysis was carried out. Since the rotor and stator of this turbine had 83 and 76 blades, respectively, a complete modeling solution took a long time, so we modeled 2 blades of rotor and stator with consideration of correct boundary conditions. Temperature and pressure contours showed a good consistence with real conditions (Figures 14, 15, 16 and17). Note that at these figures, the stator and rotor blades were located left to right, respectively.

Figure 13. Annealing Twins taken by Optical Microscopy ($200\times$)

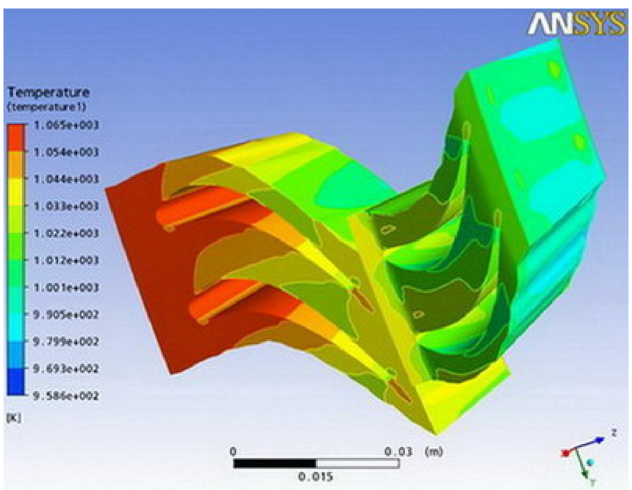

Figure 14. Fluid Flow Temperature distribution around the First Stage Blades

Figures 18 and19 show the magnitude and direction of flow velocity by use of velocity vectors and streamlines, respectively. The stress analysis simulated the steady state behavior of the rotor first stage blade under service conditions where the centrifugal load, gas pressure load and thermal expansion are present. The equivalent stresses and total deformation plots for a blade are shown in figures 20 and 21, respectively. The peak stress of the blade occurred at the bottom firtree, not at the top section of the blade where failure occurred. It is, therefore, unlikely that blade failure was directly related to centrifugal and gas loading.

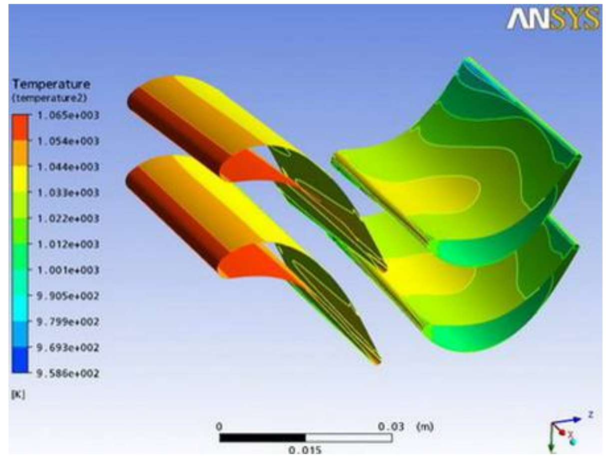

Figure 15. Fluid Flow Temperature distribution on the Stator and Rotor Blades

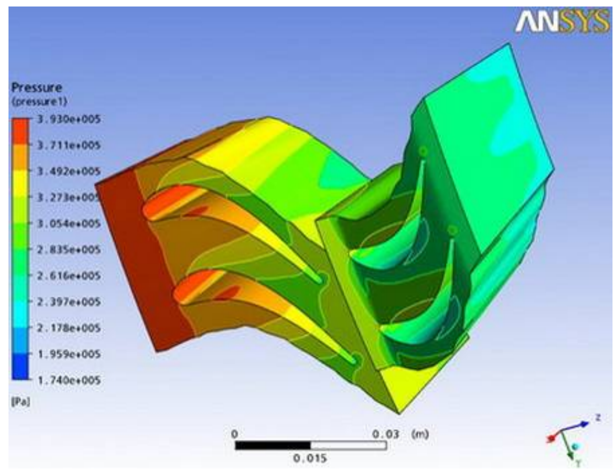

Figure 16. Fluid Flow Pressure distribution around the First Stage Blades

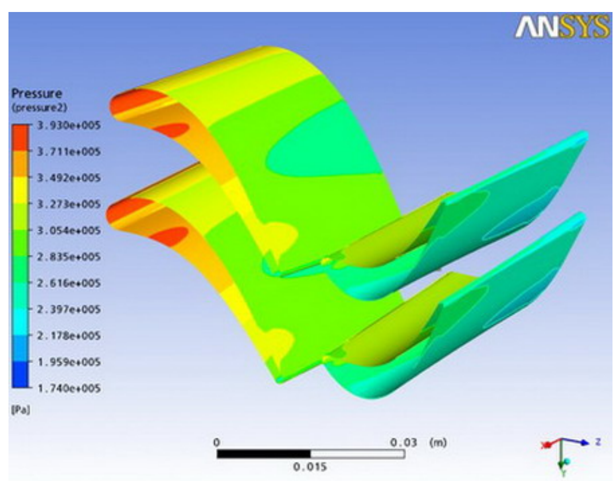

Figure 17. Fluid Flow Pressure distribution on the Stator and Rotor Blades

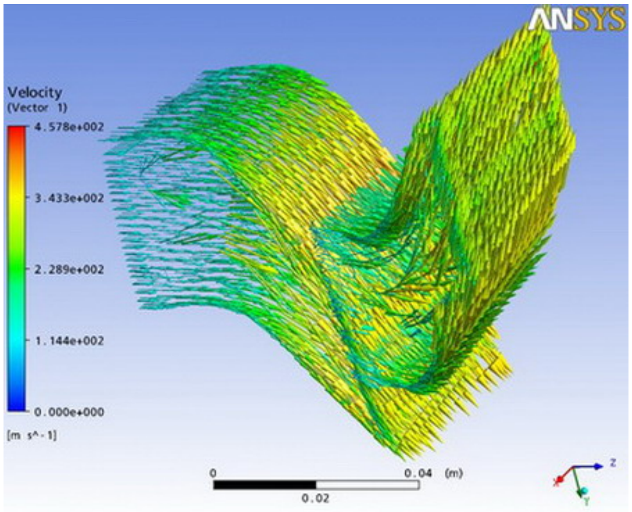

Figure 18. Fluid Flow Velocity Vectors

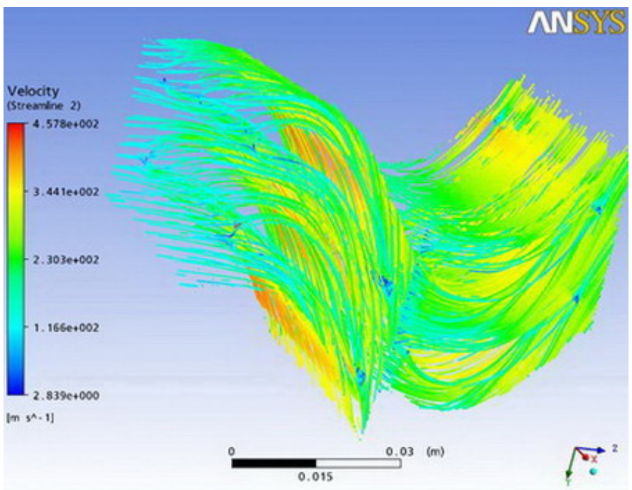

Figure 19. Fluid Flow Velocity Streamlines

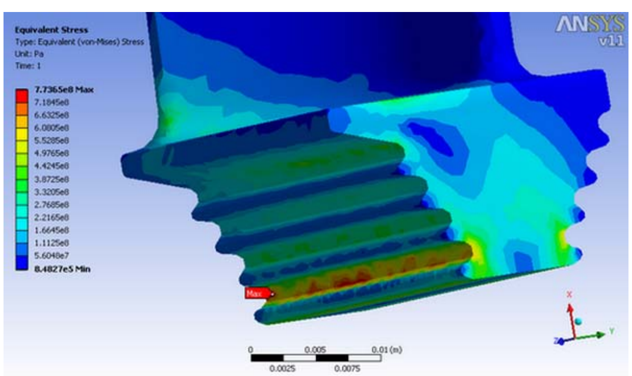

Figure 20. Resultant Stress Distribution for the Rotor Blade

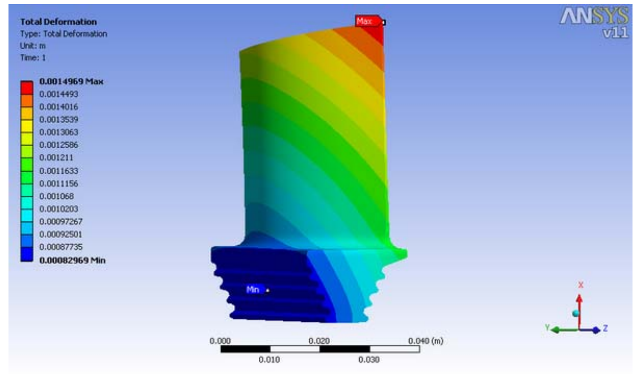

Figure 21. Total Deformation of the Rotor Blade

The cause of the rotor blade failure may be increases in blade length and contact between blade tip and casing as a consequence of creep after an extended period in service.

Conclusion

The failure analysis of a gas turbine with first and second stage blades made of nickel-based alloy was investigated. The accumulated service time of these blades is more than 10 years. This investigation was carried out by mechanical and metallurgical analysis.

After visual examination and photographic documentation, it is found that the surface of the blades exhibit diverse colors that may have represented the presence of iron oxides, Cr_2O_3 and NiO, Na and S. Also, in the vicinity of the platform both the convex and concave sides of these blades were very rough and appeared to have corrosion and erosion. The microstructural investigation of the blades revealed the presence of continuous and dispersed films of carbides in grain boundaries and coarsened γ' precipitates resulting from exposure to extreme temperatures and subsequent operation. There were a large number of cracks at different regions of blades because of operation at high temperatures and stresses for a long period of time. An intergranular crack was found on the failed blade coating; there were some micro-cavities on the fracture surface that served as the origin of a creep failure mechanism; there were several intergranular cracks on transverse section of the first stage blade surface. Also, due to operation at high temperatures, many annealing twins were observed.

A steady state gas flow analysis was carried out by means of Advanced CFD which is a section of Workbench ANSYS 11.0 software. Then by the mapping these results on the simulation section of this software, the stress analysis was carried out. Temperature and pressure contours and the magnitude and direction of flow velocity showed a good consistency with real conditions. It is found that the blade failure was not directly related to centrifugal and gas loading. Finally, it is thought that the cause of the rotor blade failure may be increased in blade length and contact between blade tip and casing as a consequence of creep after an extended period in service.

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Biographies

M. TOFIGHI NAEEM received the B.S. degree in Mechanical Engineering from the Guilan University, Guilan, Iran, in 2005, the M.S. degree in Mechanical Engineering from K.N.Toosi University of Technology, Tehran, Iran, in 2008, respectively. His research areas include Turbomachines and Fracture Mechanics. The author can be reached at m.tofighinaeem@gmail.com

N. REZAMAHDI received the B.S. degree in Mechanical Engineering from the Guilan University, Guilan, Iran, in 2005, the M.S. degree in Mechanical Engineering from K.N.Toosi University of Technology, Tehran, Iran, in 2008, respectively. Her research areas include Turbomachines and Fracture Mechanics. The author can be reached at nesa.rezamahdi@gmail.com

S.A. JAZAYERI received the B.S. degree in Mechanical Engineering (Lon), the M.S. degree in Mechanical Engineering (Bath), and the Ph.D. degree in Mechanical Engineering (UVic), respectively. Currently, He is an assistant Professor of Mechanical Engineering at K.N.Toosi University of Technology, Tehran, Iran. His teaching and research areas include fluid mechanics, automobile especially diesel engines and combustion. The author can be reached at jazayeri@kntu.ac.ir ; sajazayeri@hotmail.com

THE DESIGN AND IMPLEMENTATION OF MULTIPLE PROCESSORS IN CONTROL OF MULTIPLE HIGH POWER DC MOTORS

Steve C. Hsiung, Old Dominion University; Anthony W. Dean, Old Dominion University

Abstract

Small microcontrollers are popular and easy to use in all kinds of applications. On the other hand, they are also limited in their capabilities of I/Os, internal peripherals, and external interfacing. To better extend the capabilities of the pre-developed modules using these small microcontrollers is to link those individuals through a central control format to accommodate a complex project needs. A serial link between all the modules that uses well defined protocols is essential to the success of project implementation in an efficient and economical way.

Using microprocessor/microcontroller in various control applications is not only one of the major topics in Technology curricula, but also of interest in industry applications. The control of multiple high power DC motors in the range of 10 Amps or above with multiple small microcontrollers poses an interesting and challenging task in the design. The implementation and test of the design is also demanding. The solutions to serially link multiple microcontrollers and their control of high current to drive power DC motors are the focus of this article

Introduction

An assignment was given to the authors while doing an application project that was sponsored by private industry out side of the university. The assignment is to design an automation control circuit that uses microprocessor/microcontroller to control multiple high power DC motors (10 DC motors running at 10A-15A) with user selectable options in various motors' actions. The project goal is keep the control simple, independent, and low cost in manufacturing.

The approach is to modulate the design that uses a popular 8 bit PIC16F84A [7] microcontroller to control a DC motor and link each module through specialized protocols between the modules and central command controller that is responsible for communication between the system and the end user.

A high power DC motor control circuit is also the focus of this project that has a special heat sink design and noise suppressor circuit to minimize the noise contamination while running these DC motors in high speed and continuous formats. The test and selection of proper components to minimize the noise contamination is also implemented.

Multiple Processors Connections

To achieve the low cost and simple solution to the control of multiple high power DC motors, the simple PIC 16F84A [1], [8] microcontroller is chosen to meet this goal. The first step is to design a modular circuit that uses minimum resource of this processor to control a DC motor's speeds and directions. This module has to be fully tested and proven effective in control a single DC motor. The second step is to design a protocol link that uses available resources on the controller to handle necessary communications between different modules that controls associated motors with a variety of actions. The third step is to test the integrity of the communication protocols and make sure there is no miscommunication and unanticipated behavior in the controlled motors.

Although the hardware design appears complex, it has a lot of duplications due to multiple CPUs in the system. There are four major parts in this design: (1) the single master that handles the user's commands and communications via keypad and LCD module, (2) the multiple slaves that actual generate the PWM signals to drive the motors, (3) a simple three wires serial links between a single master and multiple slaves and two wires framing controls, and (4) the multiple motor driver board circuits that have special heat sinks for handling the high current and filters for suppressing the brush DC motors' noise contaminations.

Master Control Circuit

The master interface circuit has a standard 4x4 keypad, a LCD module, a shift register, and three software controlled I/Os for the serial interface buses to the slave CPUs.

The keypad is direct interfaced to PORTB RB0-RB7 with eight 10K pull up resistors [1], [7]. RB0 (IO_1) and RB1 (IO_2) are dually used for the slaves' serial communication framing I/O controls. These two logic lines will generate four different states that are used as guidance to the slaves to follow the predefined protocols. RB2 (MA_E) is also used as a control of the slave's de-multiplexer enable that serves as an alarm condition for master to shut down all the motors when an emergency condition is encountered.

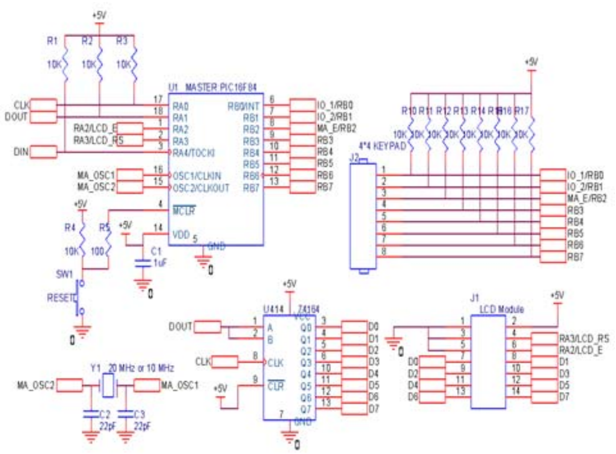


Figure 1. The Master Hardware Circuit

The LCD module is connected to a 74164 shift register [12] in a parallel format, but its interface to the CPU is in a serial form. This is needed because of the limited number of available I/Os on the master CPU. RA2 (LCD_E) and RA3 (LCD_RS) are used for E and RS controls on the LCD display module [3].

The entire serial interface is done through PORTA. RA0 (marked as CLK) is used to generate the clock, RA1 (marked as DOUT) is the control data output from a master to the slaves, and RA4 (marked as DIN) is a return data line from the slaves to a master. RA4 is an open drain I/O, its required pull up resistor (10K) connection makes it the best choice for this type of interface communication [1], [7]. There are three serial communication lines that are not only used in master-slave, but also in CPU-LCD interactions. There is no unused pin on the master circuit. Figure 1 presents the master hardware circuit design.

Slave Control Circuit

The serial communication interface is implemented on PORTA where RA0 (CLK) is used to accept the clock signal from the master, RA1 (DOUT) is used to read the command bytes from the master, and RA4 (DIN) is used to send the ACK to the master. The PWM signal is generated from the TMR0 timer via interrupt control on RB0 pin [7], [8]. It is used to control the de-multiplexer output that eventually is used to regulate the energy to the DC motor. The PWM signal is generated constantly since it is an interrupt driven event. To gate this PWM to a proper channel (either forward or reverse control of the motor), RB3 (marked as SLX_E) is used as an enable control. Both RB1 (marked as SLX_RB1) and RB2 (marked as SLX_RB2) are used as channel select on the 74138 3-to-8 decoder that is functioned as a de-multiplexer [12]. The X on SLX stands for the number of the motor in the circuit.

There are two position sensors on each slave. The signals are monitored on RB4 (SLX_SENSOR1) and RB5 (SLX_SENSOR2) pins to provide feedbacks on the motor's position. The framing logic states are monitored on RB6 (IO_2) and RB7 (IO_1), which controls the slave's communication protocols sequences. There are two unused I/O pins, RA2 and RA3 on the slave circuit design. The multiple slaves are duplications of the following slaves' circuits that have two slaves as presented in Figure 2.

The High Power DC Motors Controls

The motor driver circuit is a standard H-bridge design. These bridge on-off controls are made through an IRFB260N power MOSFET that can easily handle 10A-15A DC current [4]. The circuit can control a motor in either forward or reverse direction depending on the PWM signal that is coming in at its P_F_1 or P_R_1 terminal. Two position sensors have a RS latch debounce circuit to produce a clean signal as a feedback to the slave CPU. This motor circuit design is presented in Figure 3. Home Sensor (SWX_SENSOR1) and Ext Sensor (SWX_SENSOR2) are the position sensors that provide the positions of either full contract or extension. The X on SLX and SWX stands for the number of the motor in the circuit.

These I/O signal is connected to SLX_SENSOR1 and SLX_SENSOR1 pins to each slave processor module. Based on the digital logic of this DC motor control H-bridge design, the logic power (+5V DC) has to be in place before the motor (+VCC) to keep the gate control off the power to the MOSFET as a default state. Care must be taken on this required sequence, if the motor power (+VCC) is supplied before the logic power, the power MOSFET will be turned on by the +VCC that causes direct short to the motor circuit.

The allowable combinations of motor controls are: (a) single motor running forward or backward, (b) two motors running forward or backward, (c) three motors running forward or backward, and (d) the speed controls applies to all the motor combinations. The standard mounting of the power MOSFETs that are soldered on a PCB with an attached head sink device is not sufficient for this high current application. To accommodate the high current needs, the use of European terminal blocks on the PCB and soldering 14 gauge wires between the blocks and MOSFETs that are mounted on heat sink is the design solution. The power supply made by Cherokee International, CAP1000 [2] that provides 24 VDC, 50A max is used to drive all 10 different DC motors operating combinations for this application.

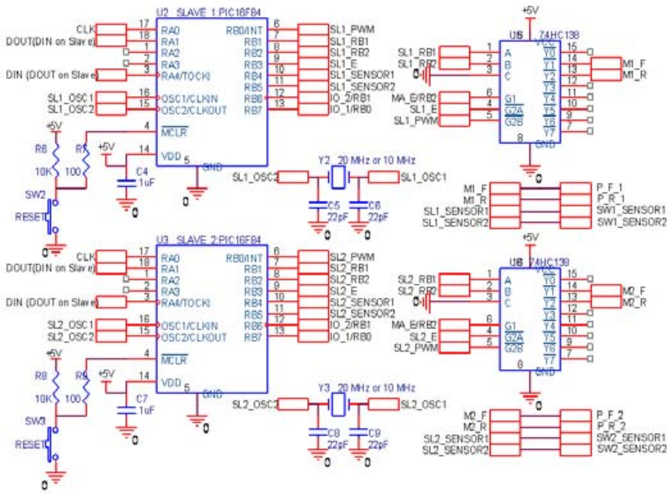


Figure 2. Multiple Slaves Hardware Circuit

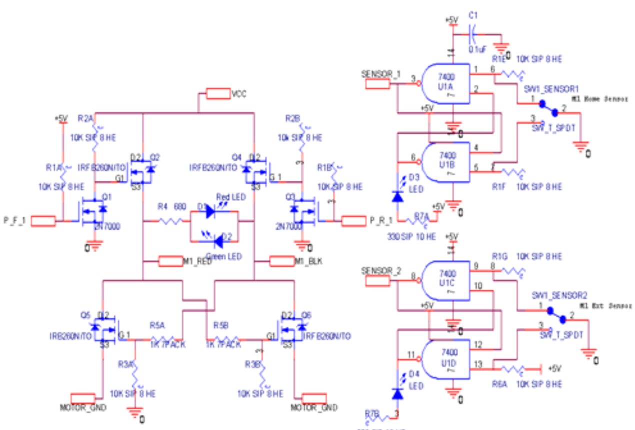


Figure 3. The DC Motor Control Circuits

The Communication Protocols

There are basically three I/O lines (clock (CLK), data in (DIN), and data out (DOUT)) used in this communication [6]. These are all shared as a serial bus between a master and multiple slaves [6], [10], [11]. In each action of the serial communication bits streams, there are total of five bytes either transmit or receive between a master and any particular slave CPU. The pre-defined bytes are: (1) address byte, (2) slave acknowledges byte, (3) speed byte, (4) direction byte, and (5) time period byte.

There are several set of rules for this communication [5],[9],[10]: (1) only one master is allowed in the system, (2) only the master can generate the clock, (3) only the master can start/stop the communications, (4) only the master is responsible for the framing I/O bits, (5) there are multiple slaves allowed in the system, but each slave shall have a unique address recognizable by the master, (6) the slave can only monitor the framing I/O bit for communication responses, (7) the slave is required to respond to its address call by sending an ACK byte, (8) after the initiation of a start from the master, every slave has to read the address that master broadcasts, (9) the slave is not permitted to respond if its address is not called, and (10) the only time that the slave sends a byte is when it is required to ACK.

To ensure the safety of the system performance, an alarm condition is implemented in the event of violation of the protocol. The alarm condition is defined as: when the master sends a legitimate address to the slaves and does not receive an ACK or the ACK is not recognized for any reason. As soon as the master detects this alarm condition, it will disable the de-multiplexer that is used by the slaves to activate the motors.

At the beginning of the protocols testing stage, it was difficult to keep the master and slave synchronized with each other. Therefore, the protocol rules mentioned above were introduced and the framing I/Os were added. These two additional I/O pins were developed to frame the states of the communication bytes to fix the problem. They are the states that the master controls and slaves poll during each action. The framing I/Os are inputs to the slave. They are used to indicate to the slaves that the master is ready to do the next set of instruction. There are four different states (00, 01, 10, 11) the master sends to the slaves. Since the slaves don't perform as much work as the master, these states let the slaves recognize where the master is in the communication sequence. "00" informs the slaves as a start that the master is getting ready to send the first byte (address). Following the first byte, the master sends a "01" to notify the slaves it is ready to receive the ACK. When the I/O pins switch to "10", the slave knows that the master has received the ACK and is about to send the last three bytes. Finally, the master will send an "11" through the I/O pins, indicating it is done with the transmitting action.

The synchronous serial communication shares the same clock [5], [9], [10] and every party relies on the clock edges to either read or write the bits. The framing implementation resolves the timing issues and differentiation of the start, end/stop, address, and command bytes. The presentation of the protocol bytes and associate framing I/O is presented in Figure 4. Picture 1 presents the real sample communication bits streams on clock (CLK), data out (DOUT), and data in (DIN) lines that were captured by a logic analyzer.

Tested Solutions to Noise Contaminations from DC Motors

The above circuits were tested with Pittman [5], GM92334C212-R3, 24VDC motors that running at 2.7A without any problem in controlling all the required sequences with various combinations. When the identical setup upgraded to high power brush DC motors testing, there were several noise contaminations that caused all kinds of strange behavior on those DC motors and eventually short the IRFB260N power MOSFETs. The contaminations were sometimes so bad that they even generated smoke during several attempts to start the motors.

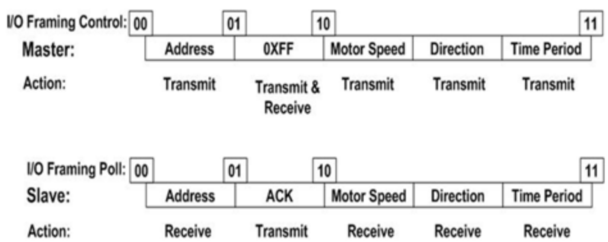
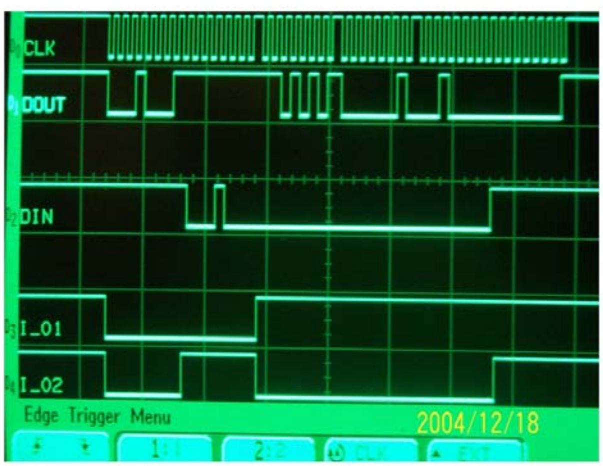


Figure 4. Master & Slave Protocols



Picture 1. The Sample of Serial Communication Signals

Different test parameters were investigated to address the problems and to minimize the various noise contaminations. The tests were done on (a) adding surge protection diode placed between the drain and source on every power MOSFET, (b) adding special 1µF protection capacitors between the power and ground lines in the processors and control logics, (c) adding 1 µF capacitors between the power and ground of all the serial communication signal lines, and (d) adding different combination of capacitors and inductor coils between the DC motor power terminals (MX_RED and MX_BLK). After numerous tests, the last method seems to have the most effects on reducing the noise contaminations.

Table 1 shows the test results of different combination of capacitors and coils that added to the terminals on the DC motors.

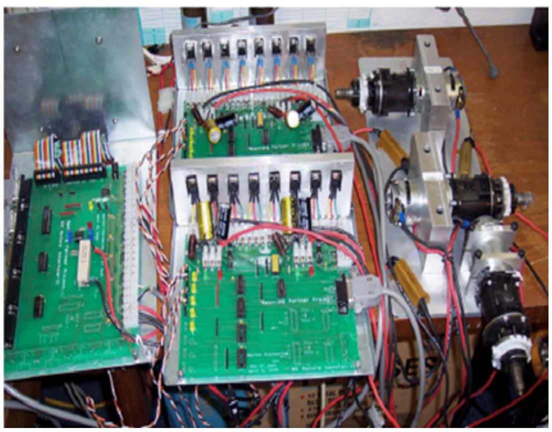
Table 1. Capacitors and Coils Combination Test Results

Capacitor	Coil	Time Delay between Motor Direction Change and Motor Activation	Note/Comment
100 µF * 2	Small (0.14 µH, 1KHz)	Several seconds	This combination has little effect on noises.
220 µF * 2	Small (0.14 µH, 1KHz)	Several seconds	This combination has improvement on motor performance
1000 µF * 2	Medium (0.35 µH, 1KHz)	One to Two Seconds	This is improved but needs long time delay
2200 µF * 2	Medium (0.35 µH, 1KHz)	Above one second	Needs long time delay
4700 µF * 2	Medium (0.35 µH, 1KHz)	Around one second	Need long time delay
2200 µF & 6800 µF	Medium (0.35 µH, 1KHz)	Less than ½ second	This combination has the best improvement and acceptable time delay between motors performances.

Since the motors were controlled through the H-bridge that runs current in either direction on motors' terminals, the non-polarized capacitors are needed. The elimination of electrolytic capacitors' polarities is to connect them back to back serially. That is one capacitor's – connected to the other's – terminal and the coil is placed on either side of the + terminal the capacitor, both sides of the +s are then placed on to the motors' power terminals. In doing so, this will place the electrolytic capacitors in combination with a coil to accept either directions of the current flow and suppress the surges from the power supply and counter electric magnetic field (CEMF) effects from the motors' coils.

The starting current of a motor on average can get up to 5 - 6 times of the operating current. Running these brush motors under constant changing of the motor directions and speeds poses another difficulty. The current limit power resistors with heat sink were added to the test circuit to reduce the high starting current spikes. To compensate the performance of the motors, a 0.5Ω, 50W power resistor made by DALE [13] was chosen to connect in series with each motor supply current path. This modification did improves the high current spikes and not sacrifice much of motors' performances.

The use of shield wire with added 1μF capacitors between +5V power and ground on all the position sensors circuit is also needed to reduce the noise problem. Picture 2 presents the testing of hardware circuit boards and 3 high-power DC motors.



Picture 2. The Hardware Systems under Test

Conclusions

Engineering Technology is the application of science, technology, and mathematics. It is vital to the economic growth and success of the nation's future. Microprocessor/microcontroller technology is a significant part of modern engineering and important subject matter in the Electrical and Mechanical Engineering Technology curriculum.

Using multiple microprocessors/ microcontrollers in automatic control applications is not new, but it is rarely implemented in classroom teaching environment. The process of designing application programs starts from the individual module development through extensive testing, verification, and modification. Applying these developed modules in a useful manner requires the links and integrations that lead to the practical project implementation. Frequently, in students' senior project designs and faculty's research plans, the microprocessor/microcontroller resources become scarce or cause conflicts during the modules' integration stage.

To accommodate the shortfall of the resources and resolve any conflict state, several choices must be considered, such as the need to revise or totally rework the module, or apply the module with additional circuit design. This article presents a proven concept that implements the simple serial communication protocols in a multi-processor environment, which aims to keep the pre-developed modules intact with the least possible modification when they are integrated into the project. This integration of the existing concept in a custom-made application that brings real-life applications into classes, has served one the important missions of the ET education: applied engineering.

There are lessons learned in designing and developing of the high power motors control circuits. The DC brush motor is a very noisy device and the CEMF during the start and reverse direction manipulations are particularly troublesome. First, it is very difficult to predict and measure the noise contamination level. Second, the noise changes along with different control pattern. Third, the locations of the noise contamination vary with the wiring, board layout, and location. All these variables make the implementation of the hardware and software designs difficult and they have to be tuned and modified stage by stage while linking the electrical and mechanical designs together. Table 1 presents the resulting test data that fits the actual performance criteria. Certainly, there are limitations with this project and further research and experimentation is needed to further reduce, or eliminate, the noise contamination. Using optical isolators between the motor and control processor circuits will be addressed in future research as possible solutions to reduce the noise contamination.

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Biographies

STEVE C. HSIUNG is an associate professor of electrical engineering technology at Old Dominion University. Prior to his current position, Dr. Hsiung had worked for Maxim Integrated Products, Inc., Seagate Technology, Inc., and Lam Research Corp., all in Silicon Valley, CA. Dr. Hsiung also taught at Utah State University and California University of Pennsylvania. He earned his BS degree from National Kauhsiung Normal University in 1980, MS degrees from University of North Dakota in 1986 and Kansas State University in 1988, and PhD degree from Iowa State University in 1992. Dr. Hsiung may be contacted at shsiung@odu.edu

ANTHONY W. DEAN is Assistant Professor of Engineering Technology at Old Dominion University. He received his Ph.D. in Engineering and a B.S. in Engineering Technology from ODU. Additionally, Dr. Dean also holds a Master of Business Administration from the College of William and Mary. Prior to his appointment, Dr. Dean was Director of Operations and Business Development, and a Senior Project Engineer, with Clark-Smith Associates, P.C. and served as an Electrician in the U.S. Navy aboard the USS South Carolina and the USS Enterprise. Dr. Dean may be contacted at adean@odu.edu

Facing Idea Engineering Roadblocks

La Verne Abe Harris, Purdue University

Abstract

This exploratory paper discusses some of the challenges facing the creative thinking process leading to technological innovation. It presents various idea engineering approaches that have been successfully implemented in American innovative companies, specifically those that benefit technologists, designers, and engineers.

Introduction

The United State's economy has been in a tail-spin the last several years. The standard of living has decreased because of the loss of jobs, the housing market, and the rising cost of gasoline and food. The United States is faced with the challenge of remaining a competitive global player. The new reality for prosperity is innovation and that is only possible with successful idea engineering. In order for the United States to maintain the competitive edge, technology and engineering companies are well aware that employees must be able to think creatively, since this leads to innovation. United States university graduates have been lacking creative thinking skills for many years [1, 24].

In the next decade, 90 percent of an engineer's knowledge will be accessible on the computer [2]. Many technical skillsets will be outsourced. So what will make the future technologist and engineer in the United States valuable? It will be his or her ability to innovate [3]. The attributes of the

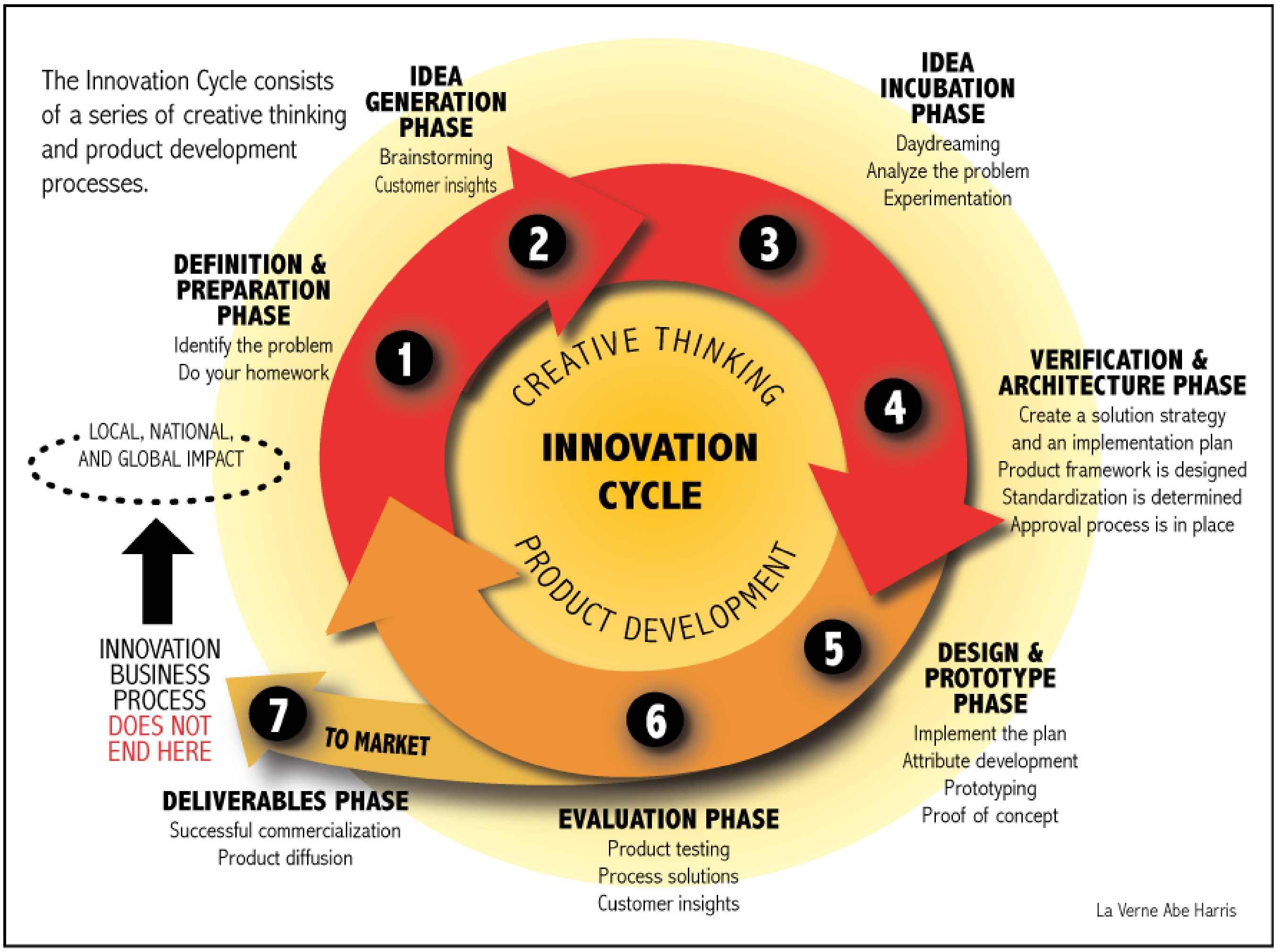

Figure 1. Innovation Cycle

technologist and engineer of the future include practical ingenuity and creativity. The terms "creative technologist" or "creative engineer" are often viewed by those who are not technologists or engineers as oxymorons. Creative thinking is often ambiguous, and ambiguity is "gray." Technologists and engineers are often viewed as traditionally "black and white" thinkers, because they get too focused on the limitations of design. Innovation and problem solving cannot occur without creative thinking, because "creativity is at the heart of innovation" [4]. Technologists, designers, and engineers invent new products, improve the usefulness of objects, and use product design or technical processes to solve problems, make things faster and more cost effective. The key factor of this research is understanding creative thinking, and exploring how successful companies have challenged the roadblocks that prevent technological innovation.

Methodology

This paper is explorative in nature and uses an investigative study, rather than theory-testing academic research. For this research study, creative thinking and the process of innovation will be the focus. Even though there is plenty of research on how individuals can be taught to think creatively, specific techniques on how to do so are not within the limits of this paper. This creativity research also excludes artistic endeavors, and instead, focuses on the applied process for the target market of technologists, designers, and engineers.

Discussion

Major roadblocks to creative thinking in the innovation cycle

Creative thinking is prone to roadblocks in the Innovation Cycle [1]. This includes the following phases of the Innovation Cycle: (1) definition and preparation, (2) idea generation, (3) idea incubation, and (4) verification and architecture *(Refer to Figure 1).* These are the phases that need unblocking in order for successful product development to occur.

It is important to identify the roadblocks that prevent the engineering of ideas in a company, because these roadblocks lead to restrained thinking and jeopardize the creative process that leads to innovation. There are several roadblocks to creative thinking that center around negative attitude. How to change these attitudes that block creativity in individual employees is not within the limitations of this study. This research is based on the bigger picture of researching the creative thinking process in innovative companies. These negative attitudes, however, can apply to the organizational culture. After researching case studies of organizational cultures that have supported innovations in the past, such as 3M, Hewlett Packard, Intel, Apple, Canon, General Electric, Google, Johnson & Johnson, and IDEO, a design consultancy, a number of challenges to roadblocks were found that will be presented.

Challenges to Roadblock #1: Lack of visionary leadership

Technology and engineering companies lacking organizational vision, have heavy workloads, reward crisis management instead of crisis prevention, and do not typically foster creative thinking [5]. Dean L. Kamen, an American entrepreneur and inventor from New Hampshire, states that "innovation requires leadership, but management kills it" [8]. 3M believes that if you want people to be innovative, the one thing you do not want to do as a visionary leader is to micromanage your employees [6].

After examining case studies of innovative companies, the most important challenges to Roadblock #1: Lack of visionary leadership is the hiring of the right people. This in turn sets up an environment conducive to creative thinking and balances creativity and efficiency.

Challenges to this roadblock begin at the top — the hiring of the Chief Executive Officer (CEO), who takes on the role of the "innovation champion" and who inspires every senior manager in the company to commit to the vision. This allows the creative thinking process to take root [8]. Companies are successful at being innovative when the organizational culture is receptive to creativity and "… shaping corporate culture is an executive responsibility" [7].

The innovative companies in this study overcame this roadblock by selecting a CEO who is a visionary leader. They also have team leaders, who are visionaries in the creative thinking process or someone else to champion their cause. Marissa Mayer, the director of consumer Web products at Google, says that it is imperative for company leaders to "act like a venture capitalist" if you want to be successful [8]. A visionary leader is a technical champion who knows how to get things done informally, understands the working dynamics of the organization, is not afraid to put his or her career on the line once in a while, is passionate about the projects and what is being done, and can deal with the constraints of bureaucracy. This person's charismatic personality inspires loyalty.

It is not just the correct selection of the top management that makes a company innovative. Intel says that you need to go a step further and also select the right people to solve the problem — the "transformative employees" [9].

Research has found that creative thinking and innovation can be nurtured by believing in people and expecting success. This empowers employees, opens up communication, gives people freedom, and accommodates their needs. This is what a visionary leader at all levels does. So in summary, it is the people who are central to the creative process [1]. Innovation begins with understanding human beings, especially during the creative process.

Another way to confront creative thinking obstacles is to balance creativity and efficiency, since there is an internal struggle between efficiency and creativity in many companies [11]. It is a balance that is reached by innovative companies, such as Apple Computer, who approach creativity and efficiency as symbiotic entities. The successful creative process makes the entire company more efficient [12].

Steve Jobs, CEO of Apple Computer, focuses on making "insanely great" products (Burrows, 2005). Apple Computer's philosophy on innovation is to have the vision of making great products, not on making a profit or becoming the biggest company [12].

The goal of Hewlett Packard's (HP's) Innovation Program Office is the business impact – getting the product into the hands of the customer. They understand that it cannot be done without creative thinking, so Phil McKinney, the Chief Technology Officer (CTO) of HP's Personal Systems Group, runs an incubation program to analyze and experiment with solutions to problems [13].

Being open to associating unrelated ideas and visualizing new realtionships between concepts sets a creative environment. Intel likes to establish an environment that gives researchers both "freedom and direction" [9]. Other innovative companies, such as 3M, have a deliberate creative environment which enabled the invention of the Post-It note. In spite of the fact that this particular invention was labeled "accidental," it could not have happened without the proper creative setting [11].

Another way to unblock the roadblock is to follow 3M's "15% rule" in which technologists and engineers spend 15% of their company time initiating and developing their own pet projects. This rule resulted in over 60,000 products in 3M by the early 1990s [11]. Google also adopted this rule in their organizational culture; however, they allocate one day a week for the pet projects [8]. This is also a way of rewarding employees.

Challenges to Roadblock #2: Resistance to change or to the idea

An environment that resists change, is bureaucratic, hierarchial, and cautious, is most likely not to be conducive to creative thinking. Unsuccessful initiatives that have been funded and staffed continue in environments that do not foster creativity. The status quo is maintained, which in turn supports the political agendas [5].

Innovation is about embracing new ways of thinking. It is not "pie-in-the-sky." It is about survival for a company in today's post-industrial world. Innovation begins from the top down. It begins by getting rid of those who are resistant to change.

Three challenges to Roadblock #2 are: (1) identifying the correct problem to be solved, (2) not always settling on the first solution, and (3) being open to ideas with a systematic incubation period and experimentation.

A problem to be solved is identified when one can discriminate between what exists now and what you want that is better [15]. Intel says that many times creative activity is wasted on trying to solve the wrong problem [9]. Jobs of Apple says that his company is succussful at innovation because they focus on select problems to be solved and "say no to 1,000 things" [12].

Part of what makes innovation so intriguing is that the solution to the problem may be only the beginning of many more improvements. Just because something works, does not mean it cannot work better. Often noteworthy changes occur by associating unrelated ideas and visualizing new relationships between concepts during the incubation period. Product improvements in cost, quality, and time-to-market are not only incremental steps, but also significant steps of innovation.

Phil McKinney, Vice President and Chief Operating Officer at Hewlett Packard (HP), fosters innovative ideas by being receptive to anyone's ideas in the company who has a sponsor and an advocate. Innovation does not just happen in R&D. It must be a companywide process. HP approaches resistance to the idea by having systematic goals and milestones during the incubation period of the idea [13].

Jim Collins and Jerry I. Porras, authors of the book "Built to Last," stress the importance of experimentation and "purposeful accidents" in the creative thinking process [16]. They believe that in the success of a visionary organization, it has a priority higher than strategic planning. 3M suggests that successful ideation revolves around the persistence of new and unique ideas, and implementation of many inexpensive and small experiments [6]. The experimental part of the incubation phase focuses on the goal of solving problems, not implementing a specific solution. Keep shifting solution paths until one works means that in order for innovation to occur, one must not make the mistake of being overly committed to one solution.

One technique that Michael Lopp, senior engineering manager at Apple, uses is to require their designers to produce 10 design mock-ups in comparison to the typical three produced in other design departments. The designer selects the top three and commits months on the three in order to reduce the choice to one. Lopp states that there is more time spent on the initial design time, but this saves time in the production phase, because less time is spent making revisions and figuring out ambiguity [17].

Challenges to Roadblock #3: Fear of failure and anxiety

One of the major roadblocks to creative thinking and prolem solving is fear of failure and the anxiety that accompanies it. Failure should be expected as a part of the process and should be viewed as educational, as well as evidence of action. Two challenges to Roadblock #3 are: (1) establishing a risk-free organizational culture, and (2) teaching people how to think differently.

Elimination of fear is how creative breakthrough thinking occurs. Not being afraid to make mistakes opens one up to creativity and innovation. This cannot be accomplished without a risk-free organizational culture. "Failure is our most important product," states R. W. Johnson, Jr., former CEO of Johnson & Johnson [18]. In it's 107-year history, this company has never posted a loss. It is not afraid to make mistakes and has many failed ventures; however, the ones that are successful are highly successful.

Just like Johnson & Johnson, 3M understands that failure is part of the creative process. They advise companies to accept their mistakes, learn from them, and move on [21].

Research indicates that when people face huge and complex problems, they habitually gravitate in their thinking to familiar and narrow potential solutions [34, 35, 36]. This results in failing to notice up to 80 percent of potential solutions. What is more surprising is that they are totally unaware of their behavior [37, 38]. People can learn to think differently through learning creative thinking techniques. Higher education is in the business of teaching people how to think, so the responsibility of teaching creative thinking for future technologists, designers, and engineers should rest with universities [3].

Challenges to Roadblock #4: Difficulty dealing with criticism

Another roadblock to creative thinking is difficulty dealing with criticism. Ideas are often criticized because they appear childish or not feasible. In order to deal with criticism, all members of a critique must harvest an open attitude that may link a viable solution to the most outlandish idea. Remember that constructive discontent is necessary to challenge the status quo. Five challenges to Roadblock #4 are: (1) cultivating creativity, (2) changing the way brainstorming is implemented with energy and rigor, (3) brainwriting, (4) concept mapping, and (5) synetics.

"It is easy to destroy creativity through discouragement and other means; cultivating creativity requires a significant, disproportionately higher degree of effort" [25]. For an organization to be innovative it would have to undergo a cultural transformation by having an avenue to express ideas without rejection or consequences. Always following the rules, selecting the first idea that comes into our head, being quiet for fear of failing or believing there is only one best answer are sure ways to fail at creative thinking.

IDEO is a design firm based in Palo Alto, California. IDEO's ideation sessions begin with homework. Participants are asked to research the problem to be discussed the night before. They often begin by playing a zippy word game to set the stage for creative thinking. An ideation facilitator is used to guide the discussion and know when to change the focus. The focus is on one problem to be solved at a time. They come up with "wild ideas" and plenty of them [26]. When "wild ideas" are being presented in a brainstorming session, one person speaks at a time, judgment is deferred, and ideas are presented visually and physically, as well as verbally. The goal is to come up with 100 ideas per hour. Many ideas are built upon others. White boards, Post-It notes, foam core, tubing, duct tape, hot glue guns, and other tools are on hand at IDEO to sketch, diagram, and make rough prototype models [26].

The early stages of ideation, often referred to as the "fuzzy front end," involve decision making associated with ambiguity [14]. Revolutionary thinking stems from believing that in the brainstorming session, no idea is a bad idea, because brilliant solutions are often discovered in the oddest ways. Creative thinking sees beyond the obvious and uses the imagination to repurpose an idea. Taking two good ideas and combining them into one is another method for creative thinking. Being open to changing directions is important, so that there is no overcommitment to a particular solution, when the focus should be on finding the best solution to the problem.

Successful ideation in innovative companies is rigorous and disciplined, as well as creative. Energy expenditure is high in cultivating creativity. Richard P. Carlton, Former CEO, 3M Corporation, states that 3M has "stumbled onto some of its new products. But never forget that you can only stumble if you're moving" [11].

For example, Google has eight brainstorming sessions each year with 100 engineers. Six top concepts are pitched for 10 minutes each. The goal is to have one idea per minute built upon the idea [8]. Some companies have Yes! Meetings in which every idea is greeted with an encouraging "Yes!" to let the ideas flow freely [10]. Apple Computer has paired design meetings (production and brainstorming), and management meetings (pony meetings) each week, and produces more than three times the idea mock-ups than other design departments. IDEO's brainstorming session has the goal of 100 ideas for the hour session.

A brainstorming technique called "brain-writing" is a successful option to an open verbal forum. It is often referred to as the "6-3-5 method" (six participants, three ideas each, and five times around the table). It has been proven successful, especially with introverted technologists and engineers. Ideas are sketched out or written on a worksheet, Post-It notes or index cards and passed out to a team of six participants. The papers are passed around about five times and additional drawings and notes are added to the idea sketches. Usually a feasible design will result from this session [4].

Concept mapping, which was developed by Joseph D. Novak and his Cornell University research team in the 1970's, is another visualization technique to generate and organize ideas. It is based upon the learning movement of constructionism and the cognitive theory of assimilation, which builds upon prior knowledge. The main concept is placed on the blank map and other related ideas are linked as nodes by lines [27].

In the 1960s an alternative to the unstructured chaos that resulted from traditional brainstorming was founded – "synetics." Because it is set up as "controlled brainstorming," it eliminates the discomfort that often arises for the technologists and engineers, when placed in a typical spontaneous brainstorming setting. It also controls the dominance of some people, and formalizes the recording of idea generation. The creative thinking process begins with the client asking a specific problem to be addressed. The team comes up with over a dozen "I wish" or "What if" statements that are read out loud with no criticism. Each member is asked how he or she originated the idea, what will be accomplished, the feasibility of the idea, and questions about the target market. The ideas that are not feasible are eliminated and the list is downsized. The ideas are then organized in categories. The client has the choice to take notes and select any feasible idea.

Challenges to Roadblock #5: Running a company with no reward system

Only 16% of companies give some type of incentive to employees who offer ideas for improvement of company products [28]. Establishing an incentive plan is a management responsibility. When employees do not receive some type of reward for their ideas, they lack initiative and do their job and nothing more. Rewards for innovative behavior and "disincentives for lack of results" should be in place in an innovative company. Compensation structured to reward innovation would create an organization of employees who are motivated [3]. Incentives such as recognition, empowering employees to do the things they enjoy, and money, will inspire loyalty, increase morale, and increase profits. Things get done that are rewarded, so it is important that management makes sure they are truly rewarding the behavior they want repeated.

Jack Welsh, past CEO of General Electric, overcame this roadblock by putting a compensation plan in place that were not only "rewards for the soul," but were "rewards for the wallet." Intel overcomes this roadblock by linking rewards to performance. More than 70% of employees can purchase stock options. In additon to stock options and bonus plans, Canon offers recognition, promotions, and non-monitary rewards, such as thank yous and vacations.

Challenges to Roadblock #6: Lack of resources

Organizational roadblocks limit a company's ability to initiate design and apply new value-added ideas. A lack of resources is one of the roadblocks to creative thinking. Resources in a company are time, space, human capital, and money.

Openers to Roadblock #6: Lack of resources are: (1) commitment by visionary leaders to commit to investing in time, space, human capital, and money, and (2) commitment to research and development.

3M overcame this obstacle by committing to resources, because they value experimentation. Just like 3M, companies wanting to be innovative need to commit to investing in resources for experimentation, because creativity and innovation do not happen by accident [6].

Hewlett Packard (HP) has resources, but their policy is to remain selectively lean. In HP, the decision on whether to continue an idea to the next phase – the Go/No Go milestone – is a final decision. Once the decision is accepted, the process moves quickly to completion, because it is then that resources are dedicated to the project [13]. The faster to "Go/No Go," the better.

If you look closely enough in organizational cultures who do not foster creativity, you will see that the entire responsibility of innovation is given to Research and Development and taken out of the hands of the other employees [5]. Buxton [7] states that innovation cannot be "ghettoized" in R&D, since it should be an organizational culture issue.

In a prior study that was conducted by the author with industry leaders from Motorola, Intel, Boeing, and Honeywell [3]. participants stated that the research and development department needs innovation training the most. The majority of the participants see the need for employees to learn to think more inventively in their organization.

Apple Computer believes in the importance of not cutting R&D resources; however, Intel suggests that confronting the problems between R&D and manufacturing is a key to innovation success [9].

Challenges to Roadblock #7: Poor internal communication

Companies with poor internal communication lack in decision making and effective creative thinking. One of the top ways to address poor internal communication is to focus on conducting efficient and effective meetings.

Industry leaders suggest there is a need to run more efficient and effective meetings in most companies in order to expedite the creative process. The biggest problems with meetings are that they are not well facilitated, not well planned, and there are too many of them with no purpose. The successful companies have "short meetings that are to the point" [3].

The Six Thinking Hats process, introduced by Edward deBono, is a technique used in the workplace in order to conduct efficient meetings [29, 30, 31, 32, 33, 34, 35, 36]. Wearing one hat at a time when considering solutions to a problem allows the problem to be approached through six different perspectives — logic, emotion, cautiousness, speculative-positive, creative thinking, and control. IBM reported a reduction of meeting times to one quarter of what they were once they applied this technique [30].

Apple Computer conducts two types of meetings each week — a "paired design meeting" and a "pony meeting." The paired design meeting — a production meeting and a brainstorming meeting — are opposite in nature and are conducted for designers and engineers. In the production meeting, idea logistics are determined and clarified. The "blue sky" brainstorming meeting is for discussing all possible ideas [17].

Michael Lopp, senior engineering manager at Apple, believes that even if company leaders say "I want a pony," they need to be heard, since they are the ones funding the projects. Lopp incorporates management input in the design process through the pony meeting in which the best ideas from the paired design meetings are presented to the company leaders. He reserves the right to either accept or block their input. In either case, this enables him to get an understanding of what they are thinking and prevents "nasty mistakes down the line" [17].

Challenges to Roadblock #8: Anxiety of external global partners

General Motors (GM) and IBM paved the way for outsourcing to India and other countries (McDougall, 2007). Outsourcing should not be something that American workers fear; however, outsourcing is often perceived as a practice of cutting American operations in lieu of less expensive labor in other countries. Many American workers fear having their company collaborating with external global partners because of outsourcing. What this translates to many American workers is the fear of losing their jobs with their jobs going overseas. How can this roadblock be turned around? Research suggests that openers to "Roadblock #8" are: (1) selective outsourcing, and (2) collaboration.

Companies such as Apple, HP, and Google address this roadblock through selective outsourcing. Steve Jobs depends on outsourced design manufacturers (ODMs) for Apple product manufacturing, but unlike many of his competitors, the key design decisions are not outsourced. He keeps the software engineers, the industrial designers, and the mechanical engineers in-house in California. Yes it is more costly initially, but the cost-savings of outsourcing design decisions are not worth what is lost in the creative process [37].

HP reduces operating costs associated with technology management by taking a collaborative approach to global outsourcing. HP spends less time on everyday information technology (IT) operation issues by outsourcing it. This allows them to concentrate on innovative projects and core competencies [38].

Several years ago Google outsourced their billing, collections, and credit evaluations for webmasters, individuals, and other corporations [39]. This enabled them to allocate their resources to what they do best.

Hewlett Packard addresses this roadblock through internal collaboration. Critiques are open to all at different levels [40]. For an organization to follow this model, it would have to undergo a cultural transformation by encouraging collaboration, and form cross-functional, interdisciplinary teams.

Vint Cerf, the chief Internet evangelist at Google since 2005, says that "the Internet's ability to enable collaboration will be the key to breakthrough innovation" [41]. The answer is to embrace scientific research, business, and education on a global scale and use it to your company's advantage.

Conclusions

The goal of this study was to identify roadblocks that stand in the way of the creative thinking process leading to technological innovation, and discuss ideas that can improve the process. Eight roadblocks have been identified: (1) Lack of visionary leadership, (2) Resistance to change or to the idea, (3) Fear of failure and anxiety, (4) Difficulty dealing with criticism, (5) Running a company with no reward system, (6) Lack of resources, (7) Poor internal communication, and (8) Anxiety of external global partners. Roadblocks, such as resistance to change or to the idea, fear of failure and anxiety, and difficulty dealing with criticism, are centered around negative attitude. Those that focus on organizational culture include roadblocks such as lack of visionary leadership, running a company with no reward system, lack of resources, poor communication, and outsourcing. Research of case studies of organizational cultures that have supported innovations in the past, such as 3M, Hewlett Packard, Intel, Apple, Canon, General Electric, Google, Johnson & Johnson, and IDEO, have lead to findings about people, the creative thinking process, the creative environment, and product innovation.

People

Creative thinking starts with human capital. Higher education should have the responsibility to develop visionary leaders in technology and engineering, along with visionary technologists, and engineers. This begins by teaching people how to think. Teaching people how to think is the role of the university.

Creative thinking process

The balance between efficiency and creative thinking is a tenuous tightrope, but it is the very balance that leads to innovation. With a focus primarily on efficiency, products get delivered, but it is status quo and usually slight modifications of the old. With a focus primarily on creativity, the process gets out of control and nothing feasible gets done.

Creative environment

The creative process cannot be changed without having a receptive environment. A creative environment cannot be formed without creative people working for the company. Without a visionary leader, creative people cannot be free to innovate. With the people, process, and environment in place, the products will become more innovative. Then creative thinking will lead to technological innovation.

Product innovation

Some ideas lead to big inventions and breakthroughs, while some lead to incremental improvements on original products or finding a new approach to doing old processes. The successful ideas of technologists, designers, and engineers are the result of creative thinking and innovation.

In summary, non-visionary companies who are stagnant, centralized, bureaucratic, autocratic, who commit to policies that discourage entrepreneurship, and who have no incentives for successfully engineering ideas, are not innovative. Creative thinking is not unorganized chaos. It is a process that can be systematic and can successfully challenge idea roadblocks. It is not just about finding solutions to problems and producing a product. It is about change in an organization that is transformational. It is change in how people think and how people approach work [6]. The bureaucratic environments of large organizations are not always conducive to out-of-the-box thinking; however, many large companies, as well as smaller companies, have been successful innovators for our society. They need to continue to successfully challenge these idea roadblocks in order to contribute to the sustainable economic growth of American businesses in the 21st century.

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Biography

La VERNE ABE HARRIS is an Associate Professor of Computer Graphics Technology at Purdue University and Director of Purdue's IDEA Laboratory, a creative thinking, interactive media, and animation research and development laboratory. She received her Ph.D. from the University of Arizona in higher education with an emphasis in sociotechnology, and a minor in media arts. She received her Master of Technology degree in graphic communications technology and her BA in art education/commercial art from Arizona State University. The author can be reached at harris1@purdue.edu

CURRICULUM INNOVATION: TECHNICAL SALES

Peter W. Klein, Ohio University

Abstract

An excellent career choice for Engineering, Engineering Technology (ET) and Industrial Technology (IT) graduates is the technical sales profession. Given the technical curriculum combined with opportunities to complete business/management coursework, graduates have a solid foundation that has proven to be quite successful in the sales of products and services. The addition of sales training and credentials during their baccalaureate experience further increases the graduate's success in a sales career. This paper will discuss a unique curriculum innovation for engineering and IT students to earn a Technical Sales Certificate during their undergraduate course of study.

Introduction

Each year, an increasing number of graduates from engineering and IT programs enter the field of technical sales: "In many high-tech sectors—medical devices, computer hardware and software, and manufacturing equipment and controls, for instance—more and more engineers and other specialists are being called out of their cubicles and into sales meetings with customers" [1]. Between August 2006 and 2007, the term "sales engineer" had a growth of 17 percent in job postings on CareerBuilder.com [2]. These professionals hold positions as sales engineers, applications engineers, technical sales representatives, and account managers. They determine how products and services could be designed or modified to suit customers needs, and they may also advise customers how to best use the products and services provided. They typically focus on client's problems and show how their product or service will solve the client's problems. They are also commonly involved after the sale in areas such as installation and training, as well as serving as the liaison between the client and their company. Many technical sales professionals provide turnkey solutions to their client's needs. This requires a broad understanding of the complete "system" and may involve many products from various sources [3].

Technical Sales Training

There are currently 27 universities in the United States offering sales programs; 11 have academic centers focusing on sales training that are recognized by the University Sales Center Alliance. Nine of these offer sales certificates upon completion of a particular set of criteria [4]. At this time, only one university, Ohio University, offers a certificate directed specifically at technical sales. The centers are typically located in a College of Business and tied to a Marketing Department, providing specific emphasis on professional sales training.

The Sales Centre at Ohio University

The Sales Centre at Ohio University was formally established by the Ohio University Board of Trustees as an Academic Center in 1997. In October 2005, the Board approved the addition of the Technical Sales Certificate in partnership with the Russ College of Engineering and Technology. This is now one of six certificate programs offered through the Centre. Other certificates include: Professional, Retail, Media, Financial Services, and Sports Management. A key focus of the Technical Sales Certificate is to prepare candidates to meet the needs of manufacturing firms and industrial suppliers who sell materials, equipment, ingredients, and services business-to-business (B2B) [5]. The first Technical Sales Candidate graduated in spring 2008.

Technical Sales Certification

The Technical Sales Certificate requires 20 credit hours (quarter hours) outside of the major in specific coursework. This includes three advanced marketing courses, one advanced communications course, and a 300-hour internship in technical sales. The descriptions for the courses are seen below [6]:

MKT 358 – Professional Selling Techniques – This course combines personal selling theory with actual practice. Students learn skills needed for successful careers in sales and marketing.

MKT 425 – Business-to-Business Marketing – This course introduces the field of B2B marketing. The course answers the questions: What is business marketing? In what markets does it occur? Topics include: organizational buyer behavior, methods of assessing business market opportunities, and business marketing strategies.

MKT 458 – Sales Management – Principles and practices in planning, organizing, and controlling the sales force including: selection, training, compensation, supervising, and stimulating salespeople. The analysis of sales potentials and costs is also included.

MKT 498 – Internship – 300-hour internship in sales applicable to the student's certificate area.

Select one of the following:

COMS 206- Communication in Interpersonal Relationship – Provides maximum experience in communication in social interaction. Exploration of communication variables and skill development of message generation in one-to-one informal settings.

or

COMS 310 – Information Diffusion – This course provides an understanding of information diffusion theory, which seeks to explain the process through which new ideas (innovations) spread over time via communication channels among the members of a social system.

In addition to the coursework, students are expected to participate in other various learning activities, including Signature Learning Events such as Professional Development Day [7].

Although the Department of Industrial Technology identified the need for this certificate program, it is available to all majors in the Russ College of Engineering and Technology, including Civil Engineering, Chemical and Biomolecular Engineering, Industrial and Systems Engineering, Industrial Technology, Mechanical Engineering, Electrical Engineering, Computer Science, and Aviation. Acceptance into the Technical Sales Certificate program is competitive and has limited enrollment. Numerous criteria are assessed, including GPA, sales experience, communication, and interview skills [8].

Opportunities for Sales Training

Of the 27 universities identified by HR Chally (June 2007) as offering sales programs, 19 also offer accredited programs in engineering, engineering technology (ET), or industrial technology (IT) [9, 10]. These universities are listed in Table 1, along with their accredited degree designations.

Table 1: Schools Offering Sales Training with Engineering, ET, or IT Programs

School	ABET Engineering	ABET ET	NAIT IT
Ball State		X	X
Baylor	X		
Bradley	X	X	
Georgia Southern		X	X
Illinois State			X
Indiana University	X	X	
College of New Jersey	X		
Northern Illinois	X	X	X
Ohio University	X		X
San Diego State	X		
Univ. of Akron	X	X	
Univ. of Conn.	X		
Univ. of Dayton	X	X	
Univ. Houston	X	X	
Univ. of Louisville	X		
Univ. of Toledo	X	X	
Univ. of Wash - Seattle	X		
Western KY Univ.	X		X
Western Mich. Univ.	X	X	

There are a total of 16 schools with ABET accredited engineering programs, 10 with ABET accredited ET programs, and 6 with NAIT accredited IT programs. There may be opportunities for these engineering, ET, and IT programs and their students to participate in the sales programs at their universities to further develop the area of technical sales.

Alumni Survey

The Technical Sales Certificate provides a new opportunity for students that are interested in sales to better prepare themselves for this career. The Department of Industrial

Technology was eager to gain input from alumni currently holding positions in technical sales to better understand how to improve the curriculum to meet the needs of current and future students that may choose sales as a career. The following are results from an e-mail survey to IT graduates that are currently in the technical sales profession. A total of 23 alumni responded. None of these alumni participated in the new Technical Sales Certificate program, but all responded that training in sales would have been helpful for their careers. The order of the responses to each question was randomly sorted for anonymity. A summary of findings is included, following the survey results. "(X2)" indicates that there were two identical responses. "(__ Corp)" indicates the location of the corporate office. The results of this survey are being used to evaluate the current IT curriculum and provide input to the sales training program to better meet the needs of technical sales professionals in the future.

Survey Results

Your Company Name & Location?

Antibus Scales & Systems Inc., South Bend, IN (Fort Wayne, IN, Corp)

Bayer Material Science, LLC, Pittsburgh, PA

Captive Aire Systems, Inc., Denver, CO (Raleigh, NC, Corp)

Captive Aire Systems, Inc., Columbus, OH (Raleigh, NC, Corp)

Flowserve Corp., Ashland, KY (Irving, TX, Corp)

HAAS Factory Outlet, Tampa, FL

Honda Lock Inc, Marysville, OH

Lincoln Electric Co., Buffalo, NY (Cleveland, OH, Corp)

Wittmann Inc., Maumee, OH (Torrington, CT, Corp) (X2)

Superior Equipment Solutions, Springboro, OH (X2)

Owens Corning, Toledo, OH

Parker Hannifin Corp., Pittsburgh, PA (Cleveland, OH, Corp)

Parker Hannifin Corp., Cleveland, OH (X2)

Parker Hannifin Corp., Jacksonville, AL (Cleveland, OH, Corp)

Parker Hannifin Corp., Marysville, OH (Cleveland, OH, Corp)

CVG Global Truck – Commercial Vehicle Group, Dublin, OH

Staffco, Cleveland, OH

JH Bennett & Co., Inc, Novi, MI

Square D Company, Schneider Electric Company, Columbus, OH

Wisco Piston, Inc., Mentor, OH

Your Job Title?

Analytical Marketing Manager
Applications Engineer (2)
Branch Sales Manager
Director, Sales and Distribution
Lead Sales Engineer
National Sales Manager
President/Owner
Product Manager
Regional Sales Manager (X2)
Sales Executive
Sales Engineer (X3)
Sales Manager
Senior Sales Engineer
Technical Sales
Technical Sales Representative
Territory Manager (X3)
Vice President, Sales

Describe the product or service you have been responsible for selling.

Centrifugal pumps and mechanical seals

CNC machine tools (sales and service) (X3)

Commercial kitchen ventilation and fire systems (X2)

Electrical distribution equipment to contractors -120V to 38KV

Fluid handling systems

Fluid power components (pneumatic, hydraulic, vacuum, etc.)

Fuel, air, oil, and coolant filtration systems

Hydraulic components (X2)

Hydrostatic transmissions and variable piston pumps
Industrial scales for industry, aggregate, agriculture, and business
Insulation for commercial and industrial use

Key cylinder sets and door hardware (mirrors, handles, latches, etc.)

Manufacturing components (electronics, electro-mechanical devices, LCD screens, plastics sheet and resin, wire and cable, etc.)

Manufacturing services (metal stamping, plastics molding, composites processing, etc.)

Plastics injection molding equipment, including support equipment

Precision aluminum forgings for the motorsports industry

Raw materials for the paint and coatings industry

Robotics and automation

Welding products

Are you selling a product or service built by your company, or are you a manufacturer's representative?

Products manufactured by my company (X13)
Products and services produced by my company (X2)
Manufacturers' representative/distributor (X7)

Approximately what percentage of your job involves direct sales?

Range: 3–100%
Average: 60%

What percentage of your job involves inside sales and outside sales?

Inside Sales – Range: 0–100%, Average: 25%
Outside Sales – Range: 0–100%, Average: 65%
(Note: nine respondents indicated 100 percent outside sales)

When in your career did you begin having sales responsibilities? (following graduation)

Immediately (first job) – (X10)
Three months after graduation
Six months (X3)
Eight months
One year after graduation
Two years after graduation (X2)
Four years (X2)
Five years
13 years

What type and length of sales training was provided within the company?

On the job – no specific training period (X2)
Two weeks product focus and ongoing (X4)
Three to four weeks
Six weeks
10 weeks
Several months shadowing (X3)
Three months
Five months
Six months
Nine months
18 months
One year technical and sales training (X2)
Two years technical on product
Two-year rotation through marketing, accounting, customer service, product, and technical training

What type and length of sales training was provided outside of the company?

One-day Dale Carnegie Cold Call/New Customer Class
Three, one-week courses on value
10-week Dale Carnegie Sales Class (X2)
Several American Machine Tools Distributors Association (AMTDA) technical courses
Ongoing with manufacturers of the products we represent.
Numerous short courses (1–3 days)
No outside training (X16)

How many total years of experience do you have in the area of sales?

Range: 2–33 years, Average: 8 years

Which of the following have you been responsible for during your sales career? (Check all that apply) (23 possible responses)

_18_ Identifying potential customers (lead generation)
_19_ Making the initial contacts with customers
_21_ Making technical presentations or demonstrations about your product or service
_21_ Working with the customer to determine their need for your product or service
_19_ Working with customers after the sale to apply or implement your product or service

What skills and attributes did you acquire while pursuing your BS in IT that have helped you succeed in sales? (Please add other skills below.)

0 = no help in my success, 1 = somewhat helpful, 2 = important, 3 = very important, 4 = critical

Technical Skills
Computer and systems applications
Range: 1–4, Average: 3.0
Manufacturing processes
Range: 2–4, Average: 3.3
Manufacturing materials
Range: 1–4, Average: 2.8
Quality assurance (philosophy, statistics, continuous improvements, etc.)
Range: 1–4, Average: 2.5
Product and process design and documentation
Range: 2–4, Average: 2.8
Power and controls (electronics, power transmission, hydraulics)
Range: 0–4, Average: 3.0
Hands-on application
Range: 3–4, Average: 3.8

Communication Skills
Written
Range: 2–4, Average: 3.6
Oral (public speaking, formal presentations, etc.)
Range: 3–4, Average: 3.3
Graphical (sketching, CAD, etc.)
Range: 1–4, Average: 2.5

Other Skills and Attributes
Problem solving (application of math, science, and technology principles)
Range: 3–4, Average: 3.4
Work ethic
Range: 3–4, Average: 3.9
Personal integrity
Range: 2–4, Average: 3.8
Global perspective
Range: 1–4, Average: 2.8

How important has the minor in business been to your sales career?

Range: 2–4, Average: 3.2

What could be added to our BS in IT curriculum (IT courses or others) that would help future technical sales professionals succeed?

Increased public speaking (using PowerPoint)
Engineering economics
Increased emphasis on business skills including pricing, margins, ROI, contracts, etc.
Logistics
Require project management
Cost accounting
Market-driven management
Making effective, professional technical presentations
Industrial distribution and logistics
Increased perspective on globalization
How to sell class, such as Sales 101 (X3)
Co-op in sales organizations
A product-based marketing class, rather than service-focused
Add selling to the capstone project
Negotiations (X2)
IT was perfect

Summary of Survey Findings

IT graduates hold positions in technical sales in a variety of organizations with responsibilities for selling manufactured products and services, as well as representing others' products to meet client needs. Of the 22 respondents, 17 different job titles were included, indicating the breadth of the technical sales profession.

Approximately 60 percent of the respondents were involved with direct sales to the end-user, with 65 percent of their time involved with outside sales. This means that approximately 65 percent of the time the sales professional is at the client's location. This time also includes consulting on client needs, managing the installation, and training the client on the product or service. Nine respondents indicated that they spend 100 percent of their time in outside sales. Ten of the 22 respondents started their career in sales immediately after graduation, and several moved into sales positions following positions in design, manufacturing, and engineering.

Training was surprisingly short; however, the IT graduate brings to the job a solid technical and business background. Most of the training was done in-house rather than using outside sources. (Sixteen respondents had no outside training.)

Five responsibilities were identified to include in the survey with input from several technical sales professionals. The results indicated that all were part of at least 18 individuals' experiences.

Several skills and attributes were identified from the IT curriculum, and alumni were asked to indicate how helpful these were to their success in the sales profession. Within the Technical Skills section, hands-on application was the most important followed by manufacturing processes.

Within the Communication Skills section, both written and oral communication skills were very important. Although Graphical Skills (sketching, CAD, etc.) are a significant emphasis in the curriculum, they were not rated as very important to the sales professional.

Within the Other Skills and Attributes section, there were three items that rated highly. Work ethic and personal integrity were identified as critical attributes, followed by problem-solving skills.

The results of this survey are being used to evaluate the current IT curriculum and provide input to the Sales Training Certificate program to better meet the needs of technical sales professionals in the future.

Conclusion

Careers in technical sales are an excellent fit for engineering, ET, and IT graduates. These graduates have the necessary foundation in technology to be successful in this area. The additional formal training in business and sales leading to a Technical Sales Certificate discussed in this paper provides an additional advantage to the student in both gaining employment in sales and succeeding in this competitive career. The author of this paper would encourage all engineering, ET, and IT program directors to identify their alumni that are currently employed in technical sales and seek their input as to how to better prepare future sales professionals for successful careers. It is also suggested that these programs work closely with the business schools at their university to collaborate on developing or improving sales training.

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Biography

PETER W. KLEIN is an Associate Professor and Chair of the Department of Industrial Technology in the Russ College of Engineering and Technology at the Ohio University in Athens, Ohio. He teaches courses in manufacturing operations and industrial plastics. He is also the Associate Director of the Schey Sales Centre with emphasis on technical sales for engineering and technology majors. Following extensive experience in industry, Dr. Klein joined the faculty in 1990.

POST-STAMPED MECHANICAL PROPERTIES PREDICTION FOR CAR CRASH APPLICATIONS

Payam H. Matin, University of Maryland Eastern Shore; Ali Eydgahi, University of Maryland Eastern Shore

Abstract

Computer Aided Engineering (CAE) has been widely used by automakers for Crash Simulation of cars during design and development process. Finite Element Method (FEM) is used for CAE Crash Simulation, where motion of elements is determined over short periods of time during the plastic deformation caused by an impact. Mechanical Properties of structural components need to be specified for the FEM-based Crash Simulation software before simulation starts. These structural components are mostly stamped and exhibit very different mechanical properties than those of as-received sheet metal before forming operation takes place. Common practice is to determine these properties at the locations of interest by tension testing of tensile coupons cut out from these locations. There are many difficulties associated with this practice such as recognizing critical locations, marking coupons, efficiently cutting samples from complicated areas, and etc. All these complexities lead to higher cost and longer time of development. To avoid these difficulties, in this paper an analytical model is developed to deliver post-formed mechanical properties of formed structural components. The model takes the as-received mechanical properties of the component and the level of the plastic strain that each element on the component has experienced during forming process, to calculate post-formed mechanical properties for each element on the component. The strain data required by the model can be extracted from forming simulation of the structural component during early stage of die development and can be verified by circle grid analysis of the formed prototype during early stage of die tryout. Trends predicted by the proposed model match well with the experimental evidence. This work provides promising outcomes that significantly reduce the experimental efforts needed for post-formed mechanical properties required for Crash Simulation.

Introduction

Computer Aided Engineering (CAE) has been widely used by automakers for Crash Simulation of new cars during the design and development process. A crash simulation is a virtual recreation of a destructive crash test of a car using computer simulation. Crash simulation is used to examine the level of safety of the car and its occupants. The data obtained from a crash simulation indicate the capability of the car structure to protect the occupants in the event of collision. The important results of a crash simulation are the deformations of passenger compartment and the decelerations felt by the occupants [1]. These values should meet the safety regulations set by the federal government to assure safety of the cars and their occupants. To comply with these federal regulations, auto-manufacturers extensively use crash simulation for different modes of collisions such as frontal impact, side impact and rollover. In the recent years, more advancement has been made since virtual models of crash test dummies and passive safety devices such as seat belts and airbags have been incorporated in the crash simulation models. All these different crash simulations are beneficial since they produce the results without actual destructive testing of a new car. Simulation can be performed quickly and inexpensively giving the opportunity to the design team to modify the design before the actual prototype of the car has been manufactured. Pitfalls and problems can be explored in the early stage of design and development leading to saving of huge amounts of money and time. While simulation provides all these benefits, it may endanger the future of a product if the results delivered are not accurate enough. The importance of accurate results is even more crucial these days as auto-manufacturers highly desire to design lower-weight vehicles to improve fuel efficiency. Thus, the efforts that promise to improve the accuracy of crash simulation would be highly desirable.

CAE Crash simulation is commonly based on Finite Element Method (FEM), where motion of elements is determined over very short periods of time during the plastic deformation caused by an impact [1]. The mechanical properties of structural components need to be specified for the FEM-based crash simulation software before simulation starts. These structural components are mostly stamped or hydro-formed. These formed components show very different mechanical properties than those of as-received sheet metal before forming operation takes place. That is because of strain hardening phenomenon that the components have undergone during the forming operation. The mechanical properties are even different from point to point on each component due to the fact that different levels of plastic strain and consequently different levels of strain hardening each component has experienced at different locations. This non-homogeneity of material properties should be incorporated in the crash simulation model to improve the accuracy. Common practice is to determine these properties at the locations of interest by tension testing of tensile coupons cut out from these locations on the components as shown in Figure 1.

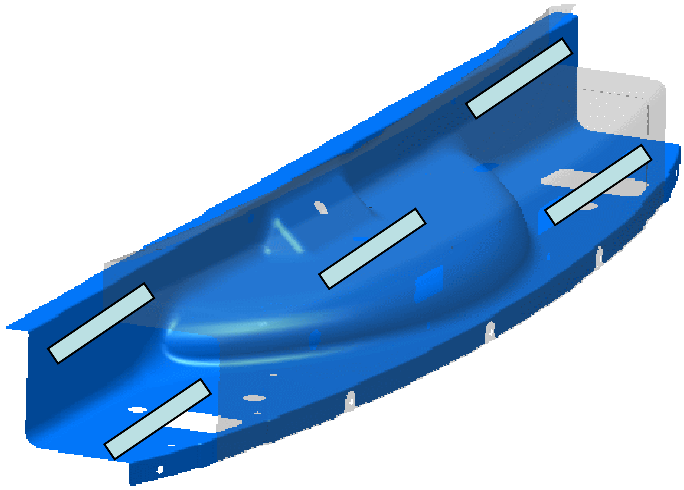

Figure 1. Tensile coupons cut out from the locations of interest for mechanical properties determination

The followings are some of difficulties and disadvantages associated with this common practice:

- For each individual part, it has to be decided at what locations the tensile coupons should be cut out to represent the properties in a corresponding region. Recognizing critical locations may need engineering calls, which may not be straight forward all the time.
- Even if the locations of interest are known, it is not always feasible to cut out a sample. That may be due to the geometry of the part at the location of interest or the space available surrounding the location for the cut out. For instance no tensile sample could be cut out from curvilinear locations on a part.
- So many preparatory efforts need to be taken to have the tensile coupons ready for tension testing. The locations should be accurately marked before the coupons are cut out. Appropriate cutting methods such as laser cutting should be utilized to avoid the undesired material properties change of the metal. Also, the coupons cut should be machined carefully to remove the stress raisers in preparation for testing.
- Tension testing needs to be conducted in such way that the results are accurate.
- One sample from one location on a particular part is not statistically enough.
- Several locations per part need to be tested.
- There are many structural parts that need to be tested with the same process.
- An auto-manufacturer manages many active car programs that need to be supported with similar effort.

All these difficulties and disadvantages lead to higher costs and longer development time. An alternative analytical/computational method is highly desirable to replace these experimental efforts.

In this paper an analytical/computational method/model is proposed for calculating material properties of the formed parts for crash simulation applications. The proposed technique avoids and minimizes the disadvantages associated with the traditional experimental method.

The proposed model takes the as-received mechanical properties of the sheet metal before forming operations along with the level of strain that a particular point on the formed part has experienced to deliver the mechanical properties of that particular point on the part as shown in Figure 2. This process may be repeated locally from point to point to cover the mechanical properties of all points on the part. The calculated properties of the formed part are then inputted into the CAE crash simulation model for more accurate simulation.

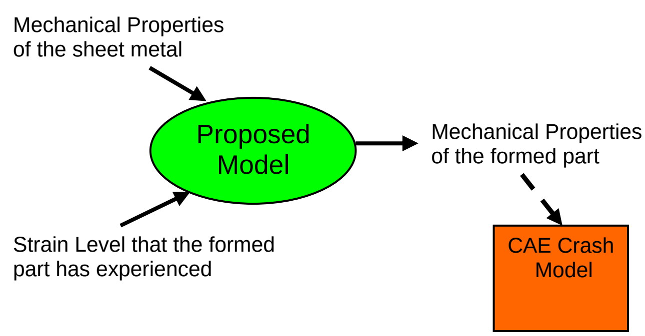

Figure 2. The flowchart of the proposed model

Modeling Approach

The material model of as-received sheet metal before forming operation is shown in Figure 3. Depending upon whether the stress exceeds the yield strength of the material, the deformation can be divided into two different deformation zones that are called Elastic and Plastic deformation zones. As shown in Figure 3, the material model may be expressed as [2]:

$$\sigma = \begin{cases} E\varepsilon & \text{where } 0 < \sigma < \sigma_y \quad \text{(Elastic zone)} \\ K\varepsilon^n & \text{where } \sigma_y < \sigma \quad \text{(Plastic zone)} \end{cases} \quad (1)$$

Where
σ = True stress
ε = True strain

E = Modulus of elasticity (Yong Module)
σ_y = Yield strength of as-received sheet metal (before forming operation)
K = Strain hardening coefficient (K-value)
n = Strain hardening exponent (n-value)

In the elastic deformation zone, the material behaves linearly as opposed to the plastic deformation zone where the material behaves non-linearly.

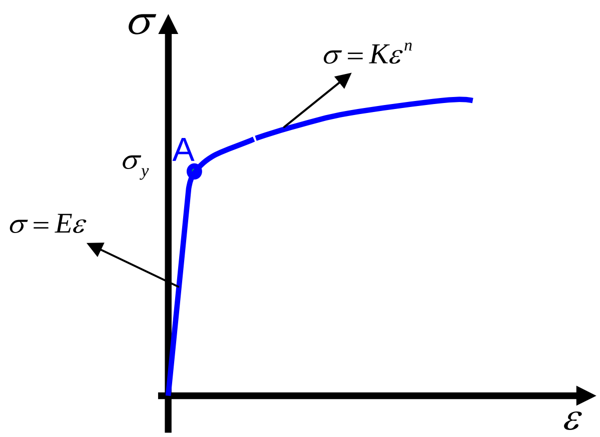

Figure 3. Material model representing elastic and plastic deformation zones

In the Elastic deformation zone, removing the loading leaves no permanent deformation. Conversely, in the Plastic deformation zone, permanent deformation remains after the loading is removed [2].

As shown in Figure 4, when forming operation begins, sheet metal starts to deform linearly in the elastic deformation zone (from point O to point A). As the deformation continues and the stress level increases, the material enters the non-linear plastic deformation zone (beyond point A) and the stress level exceeds the yield strength of the material σ_y. At the end of the forming operation at point B, as the part gets released from the die, the load is linearly decreased to point O', which leaves permanent deformation on the part. This permanent deformation corresponds to a plastic strain ε_p, which remains on the formed part as shown in Figure 4.

Now, if the formed part were loaded as a result of a crash incident, the material would not behave as it used to along the curve OAB. Instead, it would start to deform elastically along load-releasing line O'B, and enter the plastic deformation zone at point B, at some higher level of yield strength σ'_y. Then it would continue to deform in the plastic deformation zone to higher level of stress (such as point C). Increase in the yield strength is due to strain hardening phenomenon; The material becomes stronger as a result of the plastic deformation during the forming process. Now that the material strain hardened, a post-formed material model, which lies down on O'BC should be specified for crash simulation model. It should be noted that the hardened material also becomes more brittle as it undergoes repeated cycles of this work-hardening.

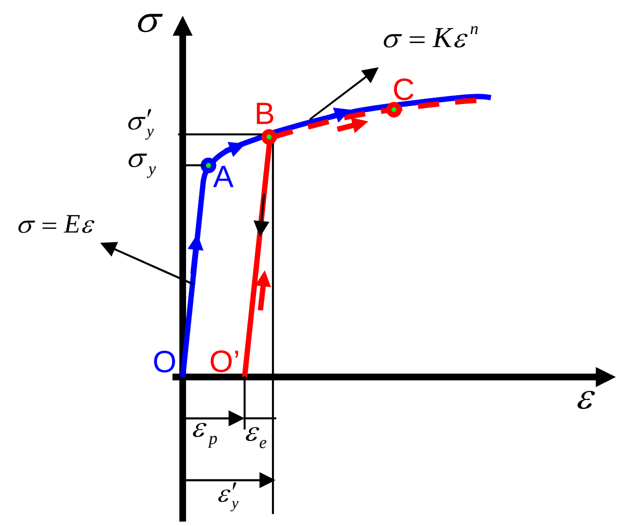

Figure 4. Stress-strain representation of the forming operation and post-formed deformation (such as crash)

To estimate the post-formed material properties, first the new yield strength should be estimated. On one hand, point B is on the plastic deformation zone of the as-received material model, which leads to:

$$\sigma'_y = K\varepsilon'^{\,n}_y \tag{2}$$

or

$$\varepsilon'_y = \left(\frac{\sigma'_y}{K}\right)^{\frac{1}{n}} \tag{3}$$

where

σ'_y = Post-formed yield strength (new yield strength after forming operation)
ε'_y = Total strain corresponding to the post-formed yield strength

On the other hand, point B is right at the end of elastic deformation zone of the post formed material model, which leads to:

$$\sigma'_y = E\varepsilon_e \tag{4}$$

or

$$\varepsilon_e = \frac{\sigma'_y}{E} \tag{5}$$

where

ε_e = Elastic strain corresponding to the post-formed yield strength σ'_y

Also, as shown in Figure 4, the total strain at point B consists of the plastic strain and elastic strain. Thus:

$$\varepsilon'_y = \varepsilon_P + \varepsilon_e \tag{6}$$

where

ε_P = Plastic strain corresponding to the post-formed yield strength
= Plastic strain that the formed part has experienced

Substituting (3) and (5) into (6) leads to:

$$\left(\frac{\sigma'_y}{K}\right)^{\frac{1}{n}} = \varepsilon_P + \frac{\sigma'_y}{E} \tag{7}$$

or

$$\sigma'_y = K\left(\varepsilon_P + \frac{\sigma'_y}{E}\right)^n \tag{8}$$

Equation (8) contains the post-formed yield strength (new yield) σ'_y, material properties of the as-received sheet metal (E, K, n), that are known and the plastic strain that the formed part has experienced ε_P. The plastic strain that the formed part has experienced can be obtained in two ways. One way is through circle grid analysis [3] during the die tryout of the part. The other way, the plastic strain is obtained from the results of the forming simulation, which is available before the die tryout during the early stage of die design and development. Either way, the plastic strain is known. The only unknown is the post-formed yield strength σ'_y. Since equation (8) is non-linear with respect to σ'_y, it should be solved numerically. Since the level of plastic strain ε_P is different from point to point on the formed part, equation (8) needs to be solved for a range of plastic strains to estimate the corresponding post-formed yield strengths σ'_y at different points. Although it is possible to solve equation (8) numerically for σ'_y, there is an alternative solution as proposed below. Equation (8) may be algebraically reorganized in terms of σ'_y as follows:

$$\varepsilon_P = \left(\frac{\sigma'_y}{K}\right)^{\frac{1}{n}} - \frac{\sigma'_y}{E} \tag{9}$$

Equation (9) represents ε_P in terms of σ'_y. Due to strain hardening, post-formed yield strength σ'_y is always greater than original yield strength σ_y. Thus, the min of σ'_y is the as-received yield strength σ_y, and the max of σ'_y is the as-received tensile strength σ_{TS}. To calculate ε_P, we start with σ'_y min and calculate the subsequent ε_P by choosing a sequence of numbers for σ'_y within min-max range of σ'_y. The process is as follows:

$$\begin{array}{lll} \text{Let } \sigma'_y = \sigma_y & & \varepsilon_{\mathrm{p}} = 0 \\ \text{Let } \sigma'_y = 1.1\sigma_y & \text{calculate } \varepsilon_{\mathrm{p}} & \\ \text{Let } \sigma'_y = 1.2\sigma_y & \text{calculate } \varepsilon_{\mathrm{p}} & \\ \vdots & & \\ \text{Let } \sigma'_y = \sigma_{TS} & \text{calculate } \varepsilon_{\mathrm{p}} & \end{array}$$

where σ_{TS} = Tensile strength

Plotting the different values of yield strengths σ'_y versus the different values of plastic strains ε_P, provides the variation of post-formed yield σ'_y with respect to the plastic strain ε_P. An example is shown in Figure 6.

Now that the post-formed yield strength has been determined, the whole new material model should be estimated. As mentioned earlier, a post-formed deformation, such as crash, occurs along O'BC as shown in Figure 4. Although the formed part is pre-strained with the amount of the plastic strain ε_P, any post-formed deformation is considered fresh independent deformation, which starts from zero strain. This means a post-formed deformation treats a formed part as an as-received sheet metal by measuring the strain from the origin as the deformation starts. This implies that the post-formed material model should shift to the left with the amount of the plastic strain ε_P to start the deformation from the origin as shown in Figure 5. A shift to the left with the amount of ε_P coincides the new and original elastic lines O'B and OA, respectively. However, the new yield strength σ'_y is positioned at point B', which is at a higher level than the original yield strength as discussed previously. The shift causes the plastic deformation zone simply shifts to the left with the same amount.

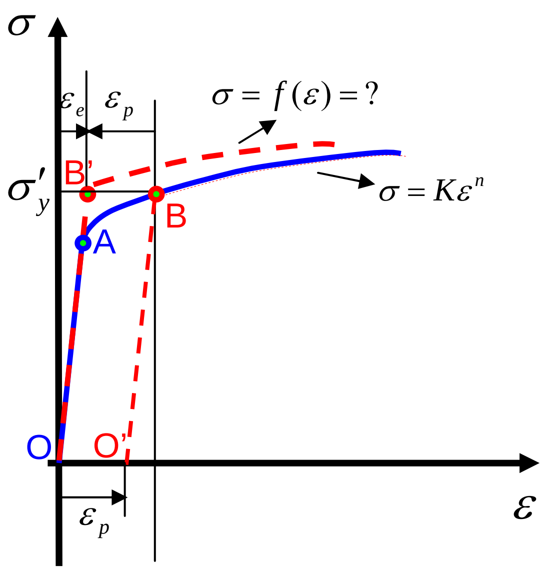

Figure 5. Post-formed material model starting from the origin for crash simulation

Using Figure 5, the material model of the post-formed deformation is achieved as:

$$\sigma = \begin{cases} E\varepsilon & \text{where } 0 < \varepsilon < \varepsilon_e \quad \text{(Elastic zone)} \\ K(\varepsilon + \varepsilon_P)^n & \text{where } \varepsilon > \varepsilon_e \quad \text{(Plastic zone)} \end{cases} \tag{10}$$

where ε_e is obtained from (5), and σ'_y is calculated based on the method explained earlier.

This model should be calculated for different levels of plastic strain ε_P to deliver the material model for each point on the formed part that has experienced such plastic strains during forming operation. An example is presented in Figure 7.

Theoretical Results

A vehicle structural part has been selected to estimate its post-formed properties based on the model proposed. The material is coated medium-strength steel with the following mechanical properties:

$E = 200$ Gpa
$\sigma_y = 216$ Mpa
$K = 600$ Mpa
$n = 0.2$

Using equation (9) and the process explained, the post-formed yield strengths σ'_y is estimated for different levels of plastic strains ε_P as shown in Figure 6. As expected, the model predicts higher amounts of yield strength for higher plastic strains. This is due to the strain hardening phenomenon where higher plastic strains lead to more hardening. The model also predicts no hardening where there is no plastic strain.

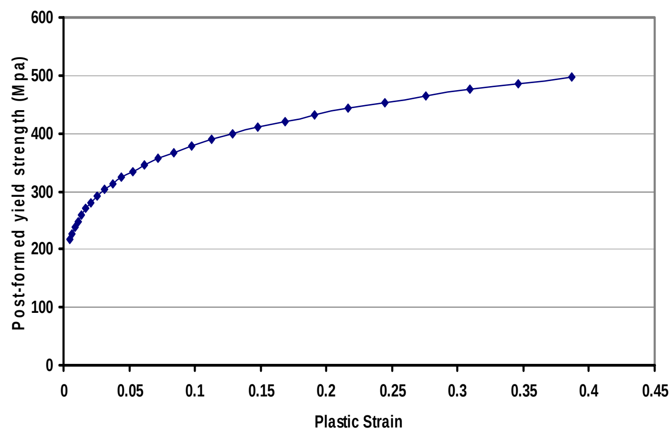

Figure 6. Calculated post-formed yield strength σ'_y as a function of plastic strain ε_P

For the same material, using equation (10) and the calculated function of yield strengths with respect to the plastic strain as shown in Figure 6, the post-formed material models have been estimated for different levels of plastic strain. These results are shown in Figure 7. The curve with 0% plastic strain corresponds to the original as-received sheet metal before forming operation takes place. As shown in Figure 7, for the higher levels of the plastic strain ε_P, the post-formed material models (stress-strain curves) have been shifted to the left exhibiting higher levels of post-formed yield strength. As a trade off, the plastic deformation zone will be smaller for higher ε_P, if it is assumed the material can only sustain up to the maximum stress level that the original as-received sheet metal can sustain [4-8]. These results can be directly fed into the crash simulation model depending on the level of the plastic strain that the formed part has experienced at different points.

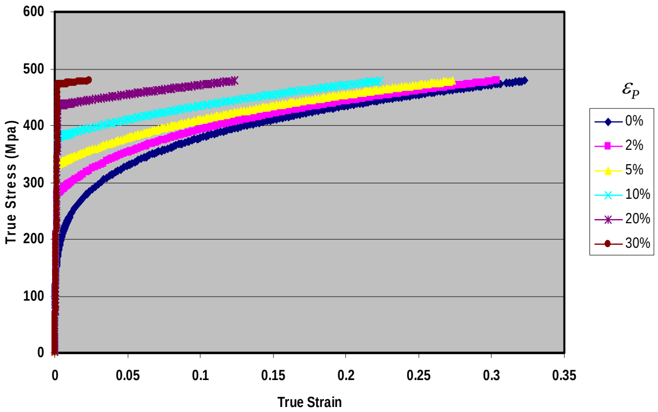

Figure 7. Calculated post-formed material models for different levels of plastic strain ε_P

Experimental Validation

In order to validate the proposed model, we used existing data collected for other experiments. The existing data was available as a result of tension testing that was conducted on the tensile coupons cut out from different locations of the part. These locations have been shown with different numbers on the part in Figure 8. The material is Dual Phase steel with 590 MPa of tensile strength (DP590). The L/H (left-handed) structural part as shown in Figure 8 was selected for experimental validation.

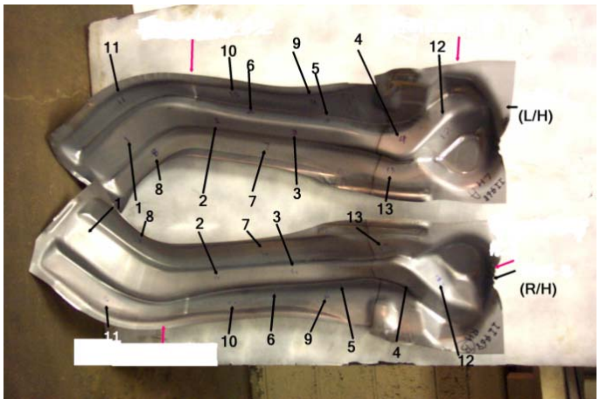

Figure 8. L/H structural part used for testing and validation of the proposed model

The results of the tension testing have been depicted in Figure 9. It represents similar trends as compared to what the model predicted previously. For the areas of the part that experienced less plastic strain (less stretch), lower yield strength and larger plastic deformation zones are observed. These areas are where coupons # 11, #1, and #2 are located. In contrast, for the high stretch areas, where higher levels of plastic strain have been experienced, higher levels of yield strength are observed. As a trade off, the plastic deformation zones have become smaller. Furthermore, it is shown that all the curves are ended approximately at the same level of stress. This behavior is similar to the prediction trends of the proposed model. This validates that the material can only sustain up to the maximum stress level that the original as-received sheet metal can sustain.

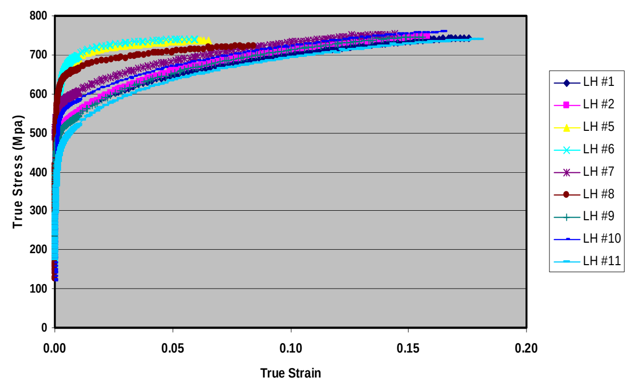

Figure 9. Tension test results conducted on different coupons cut out from a structural part made of DP590 showing similar trends as the proposed model predicts

Another set of existing data have been presented in Figure 10, which follows the trends as it is shown in Figure 9.

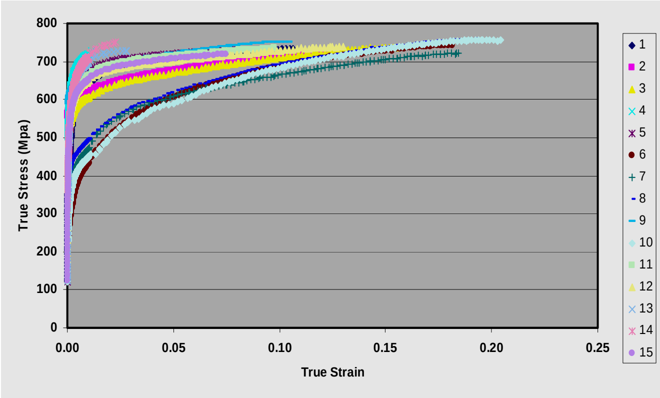

Figure 10. Tension test result on another structural part with similar trends

Conclusion

A model/method has been proposed for prediction of post-formed mechanical properties of structural parts for CAE crash simulation. The model takes the mechanical properties of the as-received sheet metal before forming operation, along with the level of strain that the formed part has experienced during forming, to calculate the post-formed mechanical properties of the part. It has been shown that the trends predicted by the model are similar to the trends obtained by the existing experimental data. The prediction results of the proposed model are promising. The broader impact of the proposed model is minimizing the costly and time-consuming experimental efforts that auto-manufacturers utilize as a common practice to estimate the post-formed material properties for crash simulation application.

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Biographies

PAYAM MATIN is currently an assistant professor at the department of Engineering and Aviation Sciences at the University of Maryland Eastern Shore. Dr. Matin's research interests are materials processing and manufacturing, experimental mechanics, computational mechanics, multi-scale modeling and manufacturing simulation. Professor Matin may be reached at phmatin@umes.edu

ALI EYDGAHI is currently a Professor and Chair of the department of Engineering and Aviation Sciences at the University of Maryland Eastern Shore. Dr Eydgahi is the Director of the Center for 3-D Visualization and Virtual Reality Applications, and Director of the NASA funded MIST Space Vehicle Mission Planning Laboratory. Dr. Eydgahi may be reached at aeydgahi@umes.edu

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Room: JD3317

Northridge, CA 91330