AC 2012-4911: STUDY OF THE BEHAVIOR OF SHAPE MEMORY POLYMERS IN THE ACTIVE DISASSEMBLY PROCESS

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Abstract

This paper reports on a research experience for a teacher in researching the behavior of shape memory polymers. The use of active disassembly using smart materials (ADSM) can be an alternative, with the potential to enable a broad range of electronic devices to be actively disassembled at the same time, reducing the cost of the manual labor or machine operation needed to disassemble the products. Shape memory polymers (SMP) are promising materials for this application. The main aim of the present study was to create SMP snap-fits and analyze the effect design parameters on the disassemble time. Six sets of snap-fits with different design parameters were manufactured from a commercial SMP Veritex. They were tested and the disassemble time was analyzed. According to the results, design parameters showed to have a slight influence in the disassemble time during the active disassemble process.

A learning module based on the legacy cycle concept is being developed and it challenges students to think through new applications for the shape memory polymers. This learning module will be introduced into a high school mathematics class during the 2011-2012 school year. Assessment of the student’s performance will be carried out and reported.

Overview of the 2011 Research

During the summer 2011 I had the opportunity to participate in the Research Experience for Teachers program at the Texas A&M University-Kingsville. This program was a total learning experience, in which I had the opportunity to develop a high level scientific research project. I also got a chance to get to know ten other educators that were selected the same as I to participate in the program. Throughout the six weeks of the summer that this program lasted, I was working on a research project titled “Study of the behavior of Shape Memory Polymers in the Active Disassembly Process” under the supervision of Dr. Hua Li. This project focused on active disassembly using smart materials (ADSM) as an alternative, with the potential to enable a broad range of electronic devices to be actively disassembled at the same time, reducing the cost of the manual labor or machine operation needed to disassemble the products. One of the main aspects of this project that excited and motivated me the most was to be working with smart materials such as Shape Memory Polymers (SMPs). These materials have the characteristic of automatically changing form when stimulated by externally trigger, such as heat. Due to this characteristic, the SMPs are promising materials for several applications, such as the Active Disassembly process.

The main aim of the research project was to create SMP snap-fits and analyze the effect of the design parameters on the disassembly time. Six sets of snap-fits with different design parameters were manufactured from a commercial SMP called Veritex. The design parameters to manufacture the snap-fit prototypes in their release position were chosen according to various factors analyzed during a pre-test process. The pre-test consisted of heating the material to different temperatures (75, 85, and 95 °C) and bending it to a desired angle. For experimentation,
a testing device that simulates a housing case was design and built. For the test a spring was attached to the center of the case, and the walls were machined in order to attach the snap-fits. Four pieces simulating recesses were manufactured and screwed to the cover. The active disassembly tests were carried out in three stages. The first stage was to train the material, in other words, modify its original shape to a temporary shape (assembly position). The second stage of the tests consisted in assemble or close the testing device by means of the snap-fits joints. Finally, during the third stage the testing device was placed inside the oven at 85 °C to activate the snap-fits and release the snap-fit joint. When this happens, the spring ejects the cover disassembling the device. We define as a successful disassembly when all the snap-fits recover its original shape and the cover was ejected by the spring force. During the test, the testing device was monitored every 30 seconds by visual inspection through a 4 inch diameter window on one side of the oven. The disassembly time for each experiment was recorded. Three repetitions for each set of snap-fits were done. According to the results, design parameters showed to have a slight influence in the disassembly time during the active disassembly process.

In my opinion, the most significant accomplishments of the research experience were:

**Development of snap-fits using SMP**

A state of the art technology was first developed starting with my designs on pen and paper and then materialized into real components using a CNC machine. The CNC machine grew a spark of interest in me during this project which motivated me to research its functionality in detail. At the spike of my interest were various projects’ that came to mind to implement with my students in my math class using a CNC machine.

**Development of the testing device**

This took place in a short amount of time which included the design and manufacturing of a functional testing device. During the manufacture of this device I learned a lot in the workshop. My original designs of the testing device were evolving little by little. I have never had the responsibility of manufacture something by myself. In this project, I had the opportunity to participate actively on the manufacture of the components for the testing device working in the workshop and using equipment such as milling machine, lathe, drill, band saw and also precision measuring equipment. This testing device, besides being a key piece for our experimentation, also remained in the hands of the University for future research on this topic.

**Experimentation process**

During the experimentation, I had the satisfaction of proving my own designs, both snap fits and testing device. Regardless of the outcome of the experiments, the experience of seeing my designs working was priceless.

**Research paper and poster presentation**
Writing a scientific research paper for disseminating the results of the experiments was a challenge due to the short period of time to complete the project. More than a research paper, I see it as a mini thesis. However, authoring a research paper and see your own work expressed on paper to be shared with others is an indescribable experience that makes me proud. I think that to share this experience through a research paper or a poster presentation can be very motivating for many students, which can result in the courage that many of them need to embark on the great adventure of the world of the science and technology.

**Background of the Legacy Cycle**

A component of the RET experience was the development of a Legacy Cycle inquiry lesson unit intended to connect the teacher’s research to high school mathematics curriculum standards. The legacy cycle that I developed during the summer 2011 called “Smart Materials in Action” is planned to be implemented with my students during spring 2012 at PSJA High School.

PSJA High School is a public school in San Juan, Texas and is one of the four PSJA district’s high schools. It educates over 2,500 students. Pharr-San Juan-Alamo Independent School District is a district that caters to over 31,000 students in the tri-city area in Texas. PSJA ISD houses students from three different cities, who come from similar backgrounds and way of life. The student body at PSJA ISD is 98.97% Hispanic, 85.37% economically disadvantaged and 73.16% at risk due to low socioeconomic status. With the district’s proximity to Mexico, 41.36% of the students are considered Limited English Proficient (LEP) with Spanish being the language spoken at home. Despite those figures, PSJA ISD has maintained a culture of pride and excellence. Known for its “children first” environment it has actively taken those challenges and has helped motivate students to pursue an education beyond high school.

The “Smart Materials in Action” Legacy Cycle will be implemented with 70 students approximately from two Algebra I classes and two Algebra II classes, including 40 freshmen and 30 juniors respectively. As part of a Dual Language Program one of my Algebra I classes is lectured in the Spanish language.

According to the experience and the knowledge learned during the research project in the summer, I designed the Legacy Cycle, "Smart Materials in Action" which will challenge students to think of an existing application and enhance its functionality by means of a new component produced from an SMP, taking advantage of the fact that it can change shape by itself when heat is applied. The new prototypes will be tested on scale models and from the experiments, students will receive and record information such as temperature, strain and time.

Before I began the Legacy Cycle, I obtained a grant from the RET program to purchase the materials needed for implementation. The detailed list of materials is showed below:

*Shape memory polymer*

For the Legacy Cycle, 4” x 6” and 12” x 12” 3-ply Veritex Shape Memory Composite Sheets were acquired to manufacture the new components. We have previous knowledge on this material since it is the same that was used during the summer.
CNC Router

Due to the impact of the CNC machine in my project to make the snap-fits with great precision and speed during the summer, it was almost impossible not to include a device like this in my Legacy Cycle. Due to the high cost of an equipment such as CNC machine at TAMUK, I was looking for different alternatives through a web quest and I found the CNC routers, which are equipments that operate under the same principles of CNC machines but unlike these, they are used by hobbyists to make pieces from softer materials such as wood, acrylic and aluminum. Since the material used in this legacy cycle is a polymer, I do not hesitate to acquire one of these equipments. However, this task was somewhat complicated, I came across many different CNC router machines on the market, for which I had to choose between many characteristics such as size of the work-table, number of axles, power, operating system, CAM software, etc. According to the needs of my project and the available budget, the best option was to purchase a Probotix FireBall V90CNC router. The details of this equipment are described in detail on Appendix C.

Heat Gun

Since shape memory polymers are activated by heat, during the summer an industrial furnace located in a TAMUK laboratories was used for the experiments. This can be considered a disadvantage for the Legacy Cycle, especially when experiments need to be performed in the classroom. However, as an alternative heat source, a heat gun with variable temperature (Ryobi HG500) was bought, which results to be a small, safe, easy to handle and inexpensive heat source to perform experiments in the classroom, following all the required safety standards. With this heat gun hot air can be directed at a specific area, in this case to the new component.

Model construction systems

We must not forget that students are still adolescents. Therefore, to simplify the task of designing the prototype or scale model (which one of its components will be replaced by a new one manufactured from SMP using the CNC machine) an in addition, to add more fun to the Legacy Cycle, Model construction systems (Meccano Sets) were acquired. These construction sets have all the parts needed to build scale prototypes. These construction systems include small metallic parts, which can withstand the temperature (85 ° F) to be submitted to the new component made of SMP, especially closer parts. Details of the equipment acquired to implement the Legacy Cycle are shown on Appendix A.

Smart Materials in Action will challenge students to use their imagination to design new components and parts (exploiting the characteristics of the SMP) and learn concepts related with engineering, such as Computer-Aided Design (CAD) in two dimensions and CNC manufacture devices as well as their operation. In addition, students will conduct experiments that will have to prove the SMP components previously manufactured and collect information such as temperature, time and deformation.

One of the most important objectives of this legacy cycle is that students have to interpret data collected during experiments using the concepts that they have acquired through their math
classes. Students will be formally assessed and will be required to complete a data analysis report and the final report (mini essay, 5 to 8 paragraphs).

This legacy cycle will be taking as a review of the Algebra I and Algebra II classes since it will cover a vast array of standards included in these two classes. Since Algebra I class cover most of the objectives studied Algebra II, the legacy cycle activities are based in the Algebra I standards, aligned to the State of Texas Assessments of Academic Readiness (STAAR). The standards addressed in the legacy cycle can be found in the Appendix B and the standards related to specific activities in the legacy cycle are listed below.

A.1.A and A.1.B, students will be able to, from the acquired data (time, temperature and deformation), organize it in two tables (temperature vs. time and deformation vs. temperature) and describe the independent and dependent quantities justifying their answers.

A.1.D and A.2.D students will represent relationships among the quantities (temperature, deformation, and time) using, tables and graphs. Besides, students will be able to make and interpret scatterplots (including recognizing positive, negative, or no correlation for data approximating linear situations.

A.5.A and A.5.B students will be able to determine whether or not the collected data can be represented by linear functions and, if so, they will determine the domain and range for the linear functions.

A.6.A, A.6.B, A.6.C, A.6.E, the students will be able to determine slopes from the graphs and tables (temperature vs. time and deformation vs. temperature) and also interpret its meaning. Students will be able to investigate, describe, and predict the effects of changes in \( m \) and \( b \) on the graph of \( y = mx + b \).

A.11.A, A.11.B, A.11.C, if the information cannot be modeled neither linear nor quadratic functions, the student is expected to use patterns to generate the laws of exponents and apply them in the problem situation. The students will be able to analyze the data and represent it using concrete models, tables, graphs, or algebraic methods.

The experience of developing a research project left me a great learning experience. Participating in this research program has been an unforgettable experience that has left a great mark on my life personally and professionally. For me it was a great motivation to have been selected to participate in the RET TAMUK. I am a mechanical engineer with a master's degree in materials science, I did all my education in Mexico and I never had the opportunity to be at a university in the United States, much less to do something so important. I have one year living in this country and thanks to my background and my passion for teaching math I got a job at a High School not only in English but also in Spanish, because I am part of a program called Dual Language.

Research conducted during the summer had a great impact on my life. It and gave me the opportunity to participate in a high level research project and in addition to meet other teachers and professors from who I learned a lot. In this research project had to create my own hypotheses based on the state of the art and present them as a research question, and participating actively in the design and development of experiments needed to answer that question.
As a result of this experience I feel more confident to express my passion for science and technology to my students in the classroom.

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. EEC-1106529, Research Experience for Teachers in Manufacturing for Competitiveness in the United States (RETainUS). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Bibliography


Appendix A – Smart-Materials in Action Legacy Cycle (Materials)

Figure A.1 Shape Memory Polymer (Veritex)

Figure A.2 CNC Router Probotix FireBall V90
Figure A.3 Construction Model Systems (Prototype)

Figure A.4 Infrared Thermocouple
Figure A.5 Heat gun

Figure A.6 Heating process
Appendix B – Standards Addressed

Algebra I Standards according to the State of Texas Assessments of Academic Readiness (STAAR)

Reporting Category 1: Functional Relationships

A.1 Foundations for functions

The student understands that a function represents a dependence of one quantity on another and can be described in a variety of ways. The student is expected to:

(A) describe independent and dependent quantities in functional relationships;
(B) gather and record data, and use data sets to determine functional relationships between quantities;
(D) represent relationships among quantities using concrete models, tables, graphs, diagrams, verbal descriptions, equations, and inequalities.

Reporting Category 2: Properties and Attributes of Functions

A.2 Foundations for functions

The student uses the properties and attributes of functions. The student is expected to:

(D) collect and organize data, make and interpret scatterplots (including recognizing positive, negative, or no correlation for data approximating linear situations), and model, predict, and make decisions and critical judgments in problem situations.

Reporting Category 3: Linear Functions

A.5 Linear functions

The student understands that linear functions can be represented in different ways and translates among their various representations. The student is expected to:

(A) determine whether or not given situations can be represented by linear functions;
(B) determine the domain and range for linear functions in given situations;

A.6 Linear functions

The student understands the meaning of the slope and intercepts of the graphs of linear functions and zeros of linear functions and interprets and describes the effects of changes in parameters of linear functions in real-world and mathematical situations. The student is expected to:
(A) develop the concept of slope as rate of change and determine slopes from graphs, tables, and algebraic representations;
(B) interpret the meaning of slope and intercepts in situations using data, symbolic representations, or graphs;
(C) investigate, describe, and predict the effects of changes in \(m\) and \(b\) on the graph of \(y=mx+b\);
(E) determine the intercepts of the graphs of linear functions and zeros of linear functions from graphs, tables, and algebraic representations;

**Reporting Category 5: Quadratic and Other Nonlinear Functions**

**A.11 Quadratic and other nonlinear functions**

The student understands there are situations modeled by functions that are neither linear nor quadratic and models the situations. The student is expected to:

(A) use patterns to generate the laws of exponents and apply them in problem-solving situations.
(B) analyze data and represent situations involving inverse variation using concrete models, tables, graphs, or algebraic methods.
(C) analyze data and represent situations involving exponential growth and decay using concrete models, tables, graphs, or algebraic methods.
Appendix C – CNC Router specifications

FireBall V90 CNC Router

FireBall V90 CNC Router is a high performance (computer controlled) general purpose router tool positioning device, suitable for many uses. The machine is constructed of Fiber Board, Acetal, PVC, and Industrial Urethanes. It includes high quality precision linear rails and acme threaded rods for precise and accurate production of parts in wood, waxes, plastics, foam, and many other softer materials. Gantry type routers are not intended to be metal-working machines, but some users have had great success cutting and drilling thin soft metals, such as brass and aluminum.

The machine has a footprint of approx. 25" wide and 27" depth with a height of 17". Dimensions are shown on figure C.1. It weighs about 40 lbs. A motor will extend out from the front, side, and top of this adding about 5 inches and 7-8 pounds.

Figure C.1 FireBall V90 CNC Router dimensions.
There are basically 3 steps needed to get up and running with a small home CNC router like the V90:

- Mechanical Machine
- Electronics, power supply, and motors
- Software

*How It Works*

The Fireball V90 use step motors. These motors are small and powerful little motors that turn the leadscrews precisely and accurately depending on how many pulses the motor receives from the computer. A step motor is different from a regular motor with a free spinning shaft. The step motors used in this machine have 200 positions of 1.8 degrees in a single 360 revolution. Use of "microstepping" can increase the positioning greatly. One pulse from the computer will turn the motor one step.

The small motors combined with the leadscrews provide plenty of power to cut through hardwoods and dense industrial plastics with the appropriate cutting bits.

A design is converted into a regular text file with lines of coordinates, via the use of software. The resulting "G-code" file can be opened and viewed in any text file editor.

The G-code files can be extremely simple or complex for specific commercial or industrial machines. The G-code file is opened in a program that reads the file line by line, such as Mach3 for Windows XP, EMC2 for Linux machines, or Turbocnc for an old DOS machine. The correct number of pulses is calculated (at lightning speed), then the software sends a series of pulses to the "Driver" or "Controller" electronic card/board. The driver board then increases the power of the pulses to the motor to do useful work.

*Specifications*

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