McNair Scholars Research Journal

Volume 1 Article 10

2014

# Morphing Wings Using Macro Fiber Composites

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# MORPHING WINGS USING MACRO FIBER COMPOSITES

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## ABSTRACT

Macro Fiber Composites (MFC) are smart materials that have one or more properties that can be altered by an external stimulus such as magnetic and electric fields, temperature and pH, in order to meet specific requirements or conditions. Today, smart materials are used in a variety of applications in the aerospace industry, locomotives, and in the medical field to generate better performance for its devices. The objective of this paper is to describe an experiment on morphing a wing using MFCs. The materials needed to achieve this project are illustrated in the experimental setup of this paper. Additionally, the author expects to be able to morph the wing of the aircraft and compare its acquired data to that of a general aircraft to determine which one has the best performance.

## INTRODUCTION

Smart Materials are materials that have the capabilities to respond to environmental conditions, and manifest associated functions such as intelligent sensing, processing and actuation. In other words, smart materials are materials that perform both sensor and actuator functions [1]. There are several different types of smart materials; yet, Shape Memory Alloy (SMA) and Piezoelectric are the most common type of smart materials. SMA has its original shape memorized, but when deformed after cooling, it returns to its original shape by the help of external stimuli such as temperature, pH, magnetic and electric field. [1].

Piezoelectrics are a type of smart materials with the properties of transduction, meaning there is a coupling in between the electrical and mechanical properties. There are two different types of piezoelectric effects and they are the Direct and Converse piezoelectric effects. The direct piezoelectric effect is the effect which displays a mechanical pressure and results in an electrical output of the material, whereas the converse piezoelectric effect is the opposite. Therefore, with an appliance of electric field, the material strain is induced which can be used to activate some devices such as morphing wing [2].

Another form of materials based on piezoelectric is piezoceramics. Piezoceramics exists in different configurations such as monolithic piezocermaincs. The most common material made of piezoceramics is the Macro Fiber Composites (MFC) [3].

The MFCs are materials recently fabricated by the NASA Langley Research Center for two major reasons; sensing and actuation for vibration control. Advantages consists of flexibility, durability, reliability, increased strain actuator efficiency, directional actuation and sensing, damage tolerance, and accessible as elongator and contractor [3]. Most importantly, one of its main advantages are its lightweight and its ability to achieve a continuous camber change along the wing for hinged control surfaces, and it can be incorporated directly into the structure of a wing [4]. The MFC has a rectangular shape which contains piezoceramics rods sandwiched between multiple layers of adhesives, electrodes and polyimide films [3]. Additionally, the electrodes are attached to the film in an interdigitated pattern which transfers the applied voltage directly to and from the ribbon shaped rods [5]. The utilization of interdigitated electrodes can be used to manufacture a very high performance, flexible, and durable piezoelectric actuator [3]

MFCs, SMAs, and Piezocermaics have been used in many different applications such as energy harvesting, vibration and shape control, aircraft de-icing and flight control. MFCs are fabricated from thin sheets which are composed of piezoceramic fibers and polyimide electrodes bonded together with an epoxy matrix. The significance of the piezoceramic materials is that they generate a voltage in response to an external stimulus such as stress. As a result, it deforms when voltage is applied. MCF actuators are driven by the piezoelectric effect; and depending on the electrode pattern built into the material, it elongates or contracts in response to a voltage input. MFC actuators have been employed for a diverse array of applications especially in the Aerospace Industry. For instance, NASA has used MFC piezocomposites for alleviating tail buffeting in aircraft, controlling unsteady aerodynamics and noise on helicopter blades, and actively reducing vibrations in large deployable spacecraft structures [5]. Several institutes like Virginia Tech have made successful experiments with the MFCs. Recently, they replaced hinged trailing edge control surfaces of an aircraft with a deformable structure capable of continuous camber change driven by the MFC actuators [4]. Shown below are images of the Virginia Tech research project.

Concerning this research and project, type PI elongator macrofiber composites, fabricated by Smart Materials Corporation, will be utilized to deflect the ailerons on the wing. Additionally, it will also be used to replace aileron servos. When voltage is applied to the PI macrofiber composites actuator that is attached to the structure, the resulting elongation will produce a bending stress and deformation in the structure.

MFC actuators are a better option for this project because they are capable of large, continuous deformations, which eliminate the need for hinged control surfaces [4]. MFCs can also be utilized as a strain gage sensor, which makes them useful for structural health monitoring and vibration and shape control [4]. The proposed research entails fabricating and incorporating MFC actuators into a wing structure.

## THE PIEZOELECTRIC EFFECT

In the year 1880, Jacques and Pierre Currie identified the concept and ideas of piezoelectricity. They discovered that an unusual characteristic of certain crystalline minerals is they become electrically polarized when subjected to a mechanical force. When it is in compression or tension, voltages of opposite polarity are produced which is also in proportion to applied force. If one of these voltage-generating crystals was exposed to an electric field it lengthens or shortens according to the polarity of the field, and in proportion to the strength of the field. Furthermore, these behaviors were labeled the piezoelectric effect and the inverse piezoelectric effect [3]

Piezoelectric consists of two different effect, Direct and Inverse Piezo effect. Direct Piezo electric effect, which is generally referred to as the generator effect, is when mechanical stresses arises as a result of an external force acting on the piezoelectric body induce displacements in the positive and negative lattice elements which manifests themselves in dipole moments [3]. Inverse piezo effect is the application of an electric voltage to an unconstrained piezoceramic body results in deformation. The amount of movement is a function of the polarity of the voltage applied and the direction of the polarization vector. By applying an AC voltage, a cyclical is generated which produces a change in the geometry. However, a mechanical stress or force is produced if the body is clamped and if free deformation is constrained [4]. Piezoelectric effect is common in piezoceramics such as $PbTIO_3$-$PbZrO_3$ synthesized from the oxides of lead, titanium and zirconium. Special doping of these lead zirconate-titanate ceramics (PZT) for example, Ni, Bi, Sb, Nb ions makes it possible to adjust individual piezoelectric and dielectric parameters [3]. Piezoelectric effect is essential in achieving the objective of this project because it gives the author an understanding of how MFC's are influenced by the appliance of electric fields.

## MANUFACTURING OF PIEZCOELECTRIC MATERIAL

Manufacturing of the piezoceramic employs a large number of modern production techniques which makes it possible to achieve an appropriate custom engineered requirements. In the initial phase, the piezoceramic powder which consists of a specific particle is mixed with additives and solvents. The mixed materials are then milled so it can obtain a homogenous suspension. The suspension is then tape casted on a carrier and then dried. The fired tape thickness is between 15-35 micrometers as standard. The green ceramic tape contains a large amount of binder materials which makes the tape flexible and easy to handle. The green ceramic tape is then removed from the carrier foil and then prepared for cutting. The tape is cut into square pieces of same size as the carrier blocks used in the subsequent processes. The piezoceramic are then covered using three repetitive components such as stacking, printing, and drying. Stacking is a procedure where layers of ceramic are placed on the carrier blocks before each print. The carrier-block is placed in a hydraulic press and each new ceramic layer is pressed gently against the ceramic layers underneath so the layers adhere. The printing processes are internal electrodes with predetermined patterns, printed with silkscreen on the top of the ceramic layer of the carrier-block. After, the printed electrodes are dried in a tunnel oven, and upon completion of the drying process, the entire build up procedure is repeated; stacking, printing and drying. The edges of the piezoceramic are then trimmed to the desired size. It is then laminated at a well defined pressure, temperature and time. At this process the layers are firmly laminated and brought in appropriate contact with each other. The piezoceramics are then diced out of the green ceramic blocks. It is critical for the dicing procedure to be accurate because it has to match the pattern of the internal electrodes. The piezoceramic materials are then terminated, which is the external electrodes applied to make connections to the internal electrodes inside the component. Then after, the piezoceramic materials are polarized by aligning the dipoles. After this procedure, the piezocermarics are then packaged into proper components such as plastic trays, plastic bags, and foam.

## TYPES OF SMART MATERIALS

There are several different types of smart materials, such as monolithic piezoceramics, active fiber composites and micro fiber composites. Monolithic piezoceramics are ceramic-based materials which exist in several different configurations. It is the first smart material to be generated, and it has the advantage of being very simple to utilize and very inexpensive to manufacture. However, they are also very brittle and vulnerable to impact with other devices. [3]

Active fiber composites were developed by researchers at MIT as an effort to combat the disadvantages of the monolithic piezoceramics. [3]

 

The image below shows the configuration of the Active fiber composites.

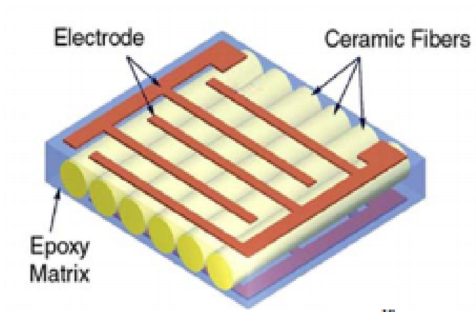


**Figure 1: Active Fiber Composites configuration [5]**

As it can been in the image above the active fiber composites consists of round cross-sectional PZT fibers embedded into a soft epoxy matrix. Each side of the PZT fibers lays a network of interdigitated electrodes which results in a greatly increased in-plane actuation over standard fibers. Some advantages of the active fiber include improved flexibility and increased robustness. And some of its disadvantages consists high cost production, high voltage operating range, and inefficient electric field transfer due to poor surface area connectivity between the flat electrode and round PZT fiber surface areas.

MFCs were manufactured by NASA. It is has a laminate of less expensive rectangular cross-sectional PZT fibers in an epoxy matrix and also uses interdigitated electrodes. It has similar advantages like that of the active fiber composites and it very inexpensive to manufacture. Additionally, it has an enhanced electric field transfer due to increased surface area connectivity introduced by the rectangular PZT fibers.

 

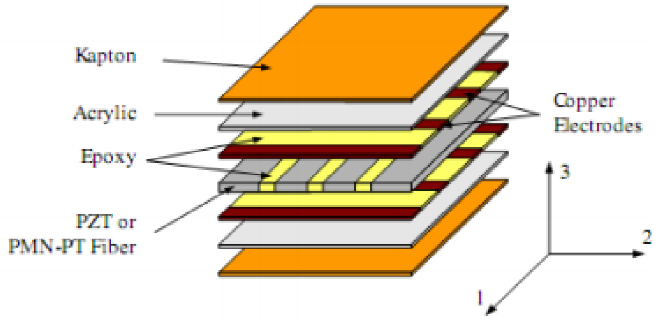


**Figure 2: Micro Fiber Composites configuration [5]**

## LABORATORY AND TESTING FACILITIES

The study was conducted at the ERAU Eagle Flight Research Center (EFRC), which has the necessary facilities and space to perform the actuator development. The research team also had access to the AE Department low-speed wind tunnel, Structures and Materials Laboratory, and Dynamics and Control Laboratory. EFRC researchers currently perform UAV flight testing at several locations in the Daytona Beach area [4].

## EXPERIMENTAL SETUP

The equipment used for this project was property of Embry Riddle Aeronautical University and it is in charge and care of Assistant Professor, Dr. Daewon Kim.

 

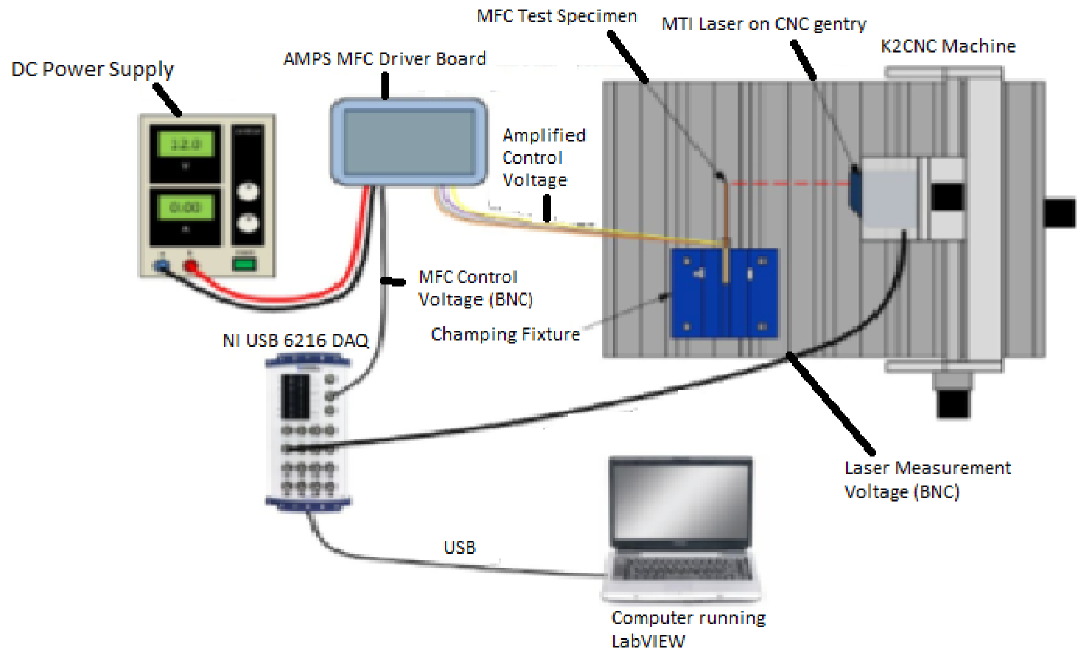


**Figure 3: Experimental Setup [5]**

In the image above, the computer has a software program called the labView and it is used to input values. For instance if the author wishes to deflect the MFC by 5V, then that value is put into the labView, which then sends a signal to the amplifier which also sends a signal to the MFC. And also, you have the laser vibrometer which measures the displacement or bending moment of the MFC and then sends that information to vibrometer control which gives a displacement.

## STRUCTURAL REQUIREMENTS FOR THE PROJECT

The structural requirements for this project are a foam wing, a bimorph MFC, and MFC bonded together with substrate**.**

## PROTOTYPE AND BENCH TEST

In other to fit the MFC into the wing, a CATIA model of a box shape was made and 3D printed. Then the MFC was placed inside the 3D printed box material and tested for bending.

Below is a CATIA model of the MFC and a box

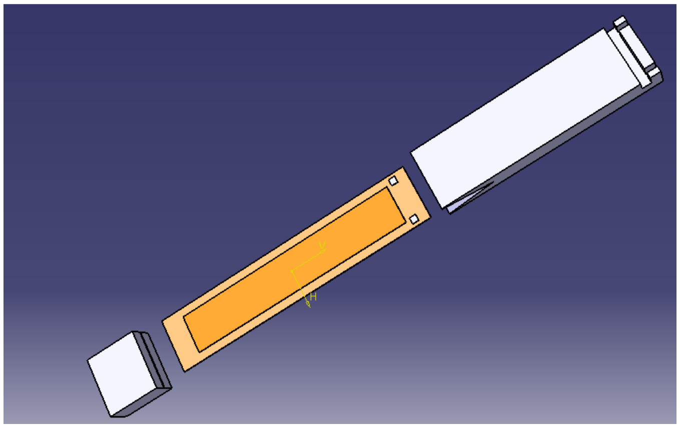

**Figure 4: CATIA model of MFC in a box**

This experiment showed that the MFC can still bend to its maximum deflection but requires for the model to be designed at the appropriate dimensions. Bimorph MFC and MFC with substrate were tested, and data showed that MFC without substrate or bimorph had a better bending deflection or displacement than that of the MFC with substrate. This is because the substrate in the MFC is a stainless steel material with a very high young's modulus or stiffness; and this prevents the MFC to have a maximum deflection. Therefore, it is determined that substrate and without substrate works best

The below images shows the MFC bimorph and MFC with substrate

**Figure 5: Macro Fiber Composite without substrate**

 

**Figure 6: Macro Fiber with substrate**

## IDEAS FOR FUTURE IMPROVEMENT

During testing of the MFC, its bending moment and displacement were determined by experiment. Yet, it is unknown how these devices will perform under certain temperatures and aerodynamic forces. Conducting a Finite Element Analysis, FEA and wind tunnel tests will provide a good comprehension about how MFC will perform under certain pressure and temperature conditions.

## CONCLUSION

MFC, a common smart material has different potential advantages which are essential in this modern generation especially in the aerospace industry. Accordingly, MFCs are a better option for flight control due to the fact that they are capable of both large-scale deformation and high bandwidth. [4]. Recent studies and experiments from reliable sources and universities such as Virginia Tech have shown that the concept of MFC can be integrated into a complex flight control system such as micro or nano air vehicles[1]. It is believed that this idea might be a stepping stone for the possibility for the design and manufacturing of morphing and flapping wing vehicles. The objective of this project is to incorporate MFC into a foam wing and then test its performance. The MFC, which are made of piezoceramics, will be bonded together as bimorph and bonding another MFC's with an epoxy and substrate sandwiched in between. Data collected from testing these two MFC showed that the MFC's without substrate has a better bending deflection than that of a substrate; and this is due to the fact that substrate has a high stiffness property. The aileron section of the wing is replaced by the box MFC and the tools mentioned above such as LabVIEW, laser vibrometer, and vibrometer control is used to determine its displacements and bending deflections. Several tests have proven that MFC's are a good choice for morphing a wing of an aircraft due to its light weight, flexibility, and quick response to voltage input. Even though this project only consisted of a small percentage of the author's Thesis work the results acquired holds a strong foundation to in completing the entire project.

The most significant outcome of this research is that it will help the authors develop a strong conception about smart material and also enable them to extend their knowledge to a more complex structure or projects.

## ACKNOWLEDGEMENTS

Dr. Sathya Gangadharan, Assistant Professor at Embry Riddle Aeronautical University. Dr. Mohamed Camara, Director of the McNair Scholars program and Professor at Embry Riddle Aeronautical University. Ms. Paula Reed, Assistant Director of the McNair Scholars Program Embry Riddle Aeronautical University. The PI, Dr. Richard Prazenica, has extensive experience in the development of guidance, navigation, and control (GNC) algorithms for autonomous vehicles, nonlinear system identification and aeroelasticity, smart material implementations for control applications, and modeling and simulation. Co-PI, Dr. Daewon Kim is an expert in smart materials and structural Health Monitoring. Co-PI Hever Moncayo has extensive experience in the design, implementation, and testing of adaptive fault tolerant control laws for fixed-wing aircraft, and has developed an autonomous UAV simulation and test bed, capabilities that will be leveraged for the proposed research program.

## REFERENCES

[1] Butt, Lauren, Day, Steve, Weaver, Joseph, Sossi, Craig, Wolek Artur., 2010, "Wing Morphing Design Utilizing Macro Fiber Composite Smart Materials," *Virginia Tech, Blacksburg, VA*

[2] American Piezoelectricity 2013. "Piezoelectricity" Retrieved from http://www.americanpiezo.com/knowledge-center/piezo-theory/piezoelectricity.html. 1

[3] Piezotechnology 2013. “Piezo Materials Tutorial: The Piezoelectric Effect,” Retrieved from http://www.piceramic.com/piezo_effect.php

[4] Prazenica Richard, 2013 “UAV Flight Control with MacroFiber Composites” Proposal. Embry Riddle Aeronautical University.

[5] Ohanian, John III, Hickling, Christopher, Stiltner, Brandon, Karni, Etan, 2012. “Piezoelectric Morphing Versus Servo-Actuated MAV Control Surfaces.” *Virginia Tech, Blacksburg, VA*

 