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Active Buckling Control of Composite Plates

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ABSTRACT

The objective of the research project is to investigate the feasibility of using the rapidly growing technology of smart materials in actively controlling the buckling of laminated composite plates. Advanced composite structures are susceptible to structural instabilities under compression loadings, and the proper control of such instabilities is essential to the effective performance of the structures. The focus of the research activity is to perform an experimental study of using embedded piezoelectric materials for enhancing the critical buckling loads of laminated composite plates. The forces induced by the piezoelectric actuators under the applied voltage fields will be used to counterbalance the occurrence of buckling. In order to gain hands-on experience, the test specimen to be examined will be fabricated in the composite material laboratory.

INTRODUCTION

To meet the research objective as described above, the semester's experimentation had to first be divided into smaller, more easily attainable steps. The first goal of the semester was to develop a consistent and unfailing method of producing composite structures. In pursuit of this goal, we first needed to understand how to use the new Dake 75 ton Hydraulic Laboratory Press, which was available in the composite material laboratory, and what were the advantages and disadvantages of the press. After learning to use this press, we further acquainted ourselves with its capabilities by fabricating a composite plate using the conventional method, which will be described later. By constructing this plate, we were able to detect limitations and shortcomings of the conventional fabrication method. After analyzing the limitations of this method, the next goal of our research was to refine the procedures followed by the conventional method to eliminate its faults. Therefore, a mold was designed fabrication. The effectiveness of this mold was verified by using it to fabricate additional composite plates. After a refined method of fabricating composite plates was established and after the method was redesigned to include the embeddment of piezoelectric sensors, then tests for active buckling control of smart composite materials, the final goal of the semester, could be developed for future testing of the composite plates.

USE OF NEW DAKE PRESS

The first goal to meet in our research was to learn how to operate the new Dake 75 ton Hydraulic Laboratory press. The new press, Dake model # 44-806, has two major differences from the older press already available in the composite laboratory. The new press has both a higher operating temperature range and is equipped with a 180 Series Single Relay Output Controller which will regulate the temperature input of both the upper and lower plates. The desired final temperature of the upper and lower plates can be input into the controller as the set point. Another advantage of this controller is that the temperature of the plates can be read easily from the LED display.

To make a composite plate, the press had to have certain features which include both temperature control and pressure control. To aid in the construction of composite plates, the manufacturer of the particular material which we used supplied us with a specified heating-cooling curve to use in the fabrication process. An example of the heating-curve that was used in our research may be seen in figure 1.

HEATING AND COOLING CURVE

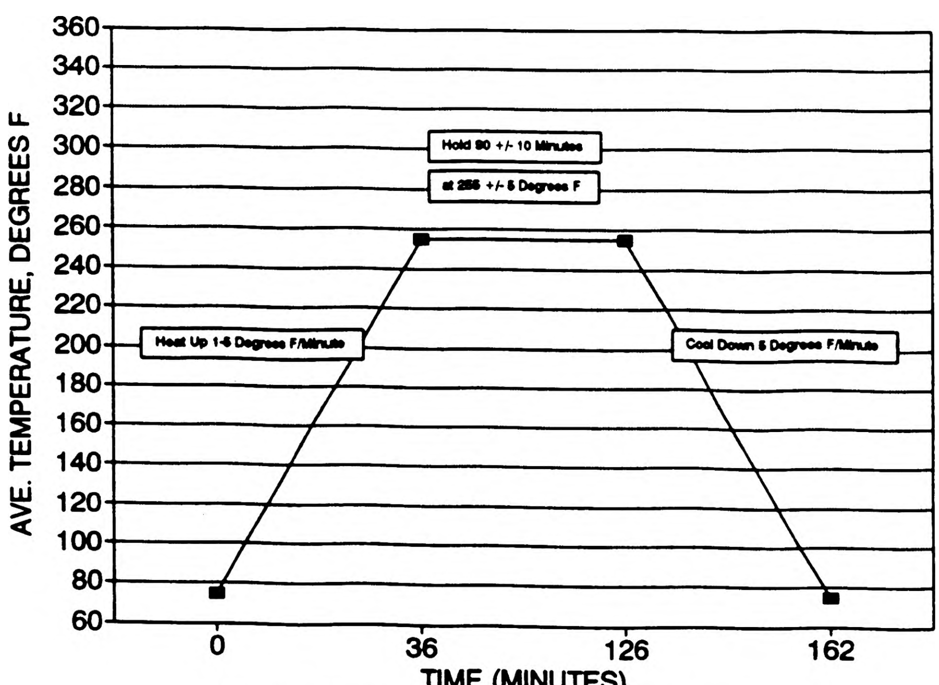

Figure 1: Manufacturer's Suggested Heating-Cooling Curve

The final or desired temperature from the heating-cooling curve can be input into the controller as the set-point. Then the set point of the system can be varied to achieve an accurate description of the curve. After the heating cycle of the sample is finished, the cooling process can be initiated. The cooling of the sample is provided by the platens of the press through the use of the water channel system embedded within the platens. This system allows water to be injected into the platens by opening the water control valve leading to the press.

In like manner, for a given pre-impregnated material, a specific pressure is required which is specified by the manufacturer of the material. Using the designated pressure along with the cross-sectional area of the sample to be fabricated, we calculated the force needed to produce the desired pressure. This force is applied by the platens of the press, which are activated by pushing the pump handle until the calculated force on the composite sample is reached. This force, displayed in tons, can be read off the gauge located in the upper right hand corner of the press.

ANALYSIS OF CONVENTIONAL METHOD

The primary purpose of fabricating the first plate was to get acquainted with the procedures or steps followed in making composite samples using the conventional method. The conventional method consists of using two flat aluminum plates between which the composite sample is placed. The material used for our semester research project was a glass epoxy pre-impregnated tape. The first step in the construction of this composite plate was to sandblast the aluminum plates. This sandblasting was necessary to remove any contaminates on the plates such as old matrix which might have been left from previous fabrications of samples. Next, both of the aluminum plates as well as the tabletop were cleaned with acetone to ensure that impurities would not be embedded into the tape. The cleaned aluminum plates were then coated with Frekote 44, which is a releasing agent. The Frekote 44 is used to prevent the composite from sticking to the aluminum plates. We applied four coats of the Frekote 44 to the plates to try to minimize any sticking problems.

Next, two sheets of 14" square release fabric were cut. This release cloth was to be placed between the sample and the aluminum plates and its purpose was to allow moisture and air to flow out of the composite during the heating-cooling process while not allowing the matrix from leaving the sample. The following step was to cut the glass epoxy pre-impregnated tape to a previously specified size and shape, supplied by the instructor, as well as to layer these sheets with a certain fiber orientation. Our first plate was a 12" X 12", four ply, symmetric cross-ply laminate with a fiber orientation of 0-90-90-0. For the first two layers of laminates, which were 0-90, this means the fiber orientation of the second layer is rotated 90 degrees from that of the first. This type of fiber orientation can also be specified as 90-0-0-90.

The next step is to place the layered laminate on top of the release cloth which lays on the aluminum plate. Then a high temperature sealant, frequently referred to as "tacky tape", is placed approximately 1/8" away form the laminate. This distance is meant to allow for expansion of the sealant during compression which, after being compressed, will hold the sample to the desired dimensions. The sample was then placed into the Dake press and the manufacturer's suggested heating-cooling curve was followed to fabricate the composite.

A first glance of the sample made using the conventional method showed that the matrix of the sample has flown past the sealant at the edges, thus producing an irregular shaped composite sample. Also, this flow of matrix past the sealant makes it difficult to obtain a consistently square plate. This inefficiency of the sealant in holding the sample to the desired dimensions is not only the major problem when using the conventional method but the leakage is magnified when fabricating thicker plates due to a greater amount of matrix in the thicker samples. Another complication encountered in making the first sample was the inability of the Frekote 44 in keeping the composite from sticking to the aluminum plates. As a result of the ineffectiveness of the Frekote 44, the first composite sample has delamination caused by us having to pry the aluminum plates apart to get the sample. Also, there was a problem with using the new press to control the heating-cooling curve to within the guideline given by the manufacturer. In trying to achieve the desired curve, we found it necessary to periodically turn the controller on and off until we attained the desired temperature slope. For example, in the heating portion of the curve, we found that the desired slope could be obtained by turning the controller on for around 10 to 15 seconds and then leaving it off for the next minute. Since we had to heat the sample from room temperature to the set point of 255 degrees F, it was very time consuming to continually monitor the controller's operation during this time.

IMPROVEMENTS TO CONVENTIONAL FABRICATION PROCEDURE

Due to complications encountered in the conventional method, it was first necessary to refine the manufacturing process of making composite plates so that more consistent results could be obtained and better samples could be made for use in the buckling tests. This new fabrication method needed to address, and hopefully eliminate, the problem of matrix flow past the sealant tape. In accomplishing this task, this design must also ensure that the plate kept a consistent shape and thickness.

We believed that new types of aluminum plates could be designed so that the leakage problem would be eliminated. These plates were designed as a type of "mold" that consisted of a top plate that had a ridge around the perimeter and a bottom plate that had a grove around the perimeter. The mold was designed to produce a 12" X 12" composite with a sample thickness up to 0.25 inches. In compressing the plates to the desired pressure, the ridge on the top plate will slide into the groove on the bottom plate. Thus, the ridge on the top plate was devised to give the composite dimensional accuracy by holding the sample to a 12" X 12" cross-sectional area. The groove in the bottom plate is also used for placement of the high temperature sealant which will flow into any voids in the clearance of the ridge and groove when the hydraulic press pushes the mold together.

VERIFICATION OF NEWLY DESIGNED MOLD IN FABRICATION PROCESS

After designing and manufacturing the new mold, composite samples were to made to verify the effectiveness of the new mold in eliminating the problems faced in the conventional method. In all, four additional samples were made. For comparison reasons, the second composite made was fabricated using the same procedures as those of the first plate.

From its appearance, it was evident that the second sample, made using the new mold, was superior to the first sample made using the conventional method. Dimensional accuracy was proven since the plate held its designed 12" X 12" shape. However, we found that the matrix had a tendency to flow past the sealant at the corners of the composite and that the sample was extremely difficult to remove from the mold. This sticking problem proved that the Frekote 44 is not a good releasing agent. For additional verification and for refinement of the manufacturing procedure, three more composite plates were produced each having slight variances in the fabrication process. These variances were conducted to find the most efficient way to eliminate the problems of matrix flow past the sealant and of the composite plate sticking to the aluminum mold.

After analyzing the different composite plates we had made throughout the semester, it was evident that the last plate was the best sample produced. This sample was made with a new type of releasing agent called, Chemlease 41, which helped to solve some of the sticking problems. In addition, this plate was made with a full width of sealant tape in the groove of the bottom plate. Finally, one layer of release cloth was used. However, we cut the corners of the release cloth to try to minimize bunching of the fabric in the corners. This bunching was thought to have been the cause of the leakage of the matrix. This plate had no delamination and a minimal amount of leakage of the matrix past the sealant.

MODIFICATION OF PROCEDURE TO INCLUDE EMBEDDED PIEZOELECTRIC SENSORS

The fabrication process for composite laminates including piezoelectric sensors involves additional parameters from those stated for regular composites. Similarly for this construction, the layout and geometry of the composite and placement of the piezoelectrics are known at the time of fabrication. For the placement of the piezoelectric sensors, the glass epoxy pre-impregnated tape will need to be cut to allow for the placement of the sensors. An example of a laminated plate lay-up with multiple piezoelectric sensors can be seen in figure 2.

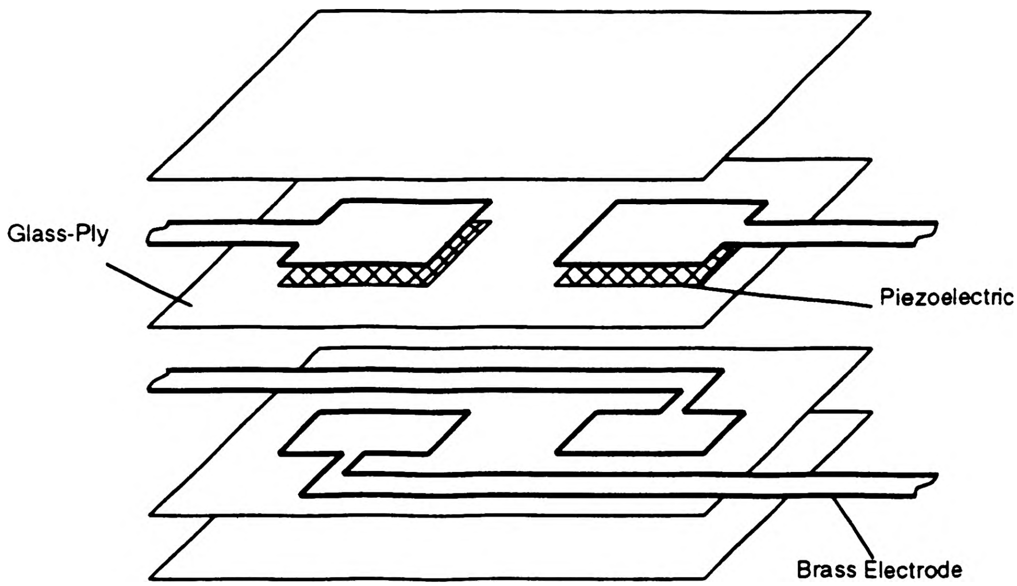

Figure 2: Schematic of Laminated Plate with Embedded Piezoelectric Sensors

It may be necessary to cut more than one layer of tape due to the thickness of the piezoelectric. Also, electrodes need to be attached to the piezoelectric, one on each side of the sensor, and run through the sample out of the mold. Electrodes of brass have been used for previous research in the materials research lab. If smart materials made of graphite epoxy tape were to be fabricated, a layer of glass epoxy would need to be placed on either side of the piezoelectrics and electrodes for electrical insulation purposes. There are two factors that need to be addressed with these electrodes. First, the electrode needs to be bonded to the sensor. The electrodes are bonded prior to placement in the glass epoxy ply by use of a silver epoxy. This type of epoxy is a cold apply epoxy. The electrode can not be soldered directly to the sensor since the piezoelectric properties can be adversely affected if heated above its curie temperature. The next factor that needs to be addressed is that the brass electrodes need to run out of the composite sample since these will be the electrical connection points of the testing apparatus. Therefore, these electrodes need to either run out into the sealant tape, which can be cut away to reveal the electrodes, or the new mold can be redesigned so that there is a way the electrodes can run through the mold itself.

BUCKLING CONTROL OF COMPOSITES

With the fabrication of the smart composite plates, the embedded piezoelectric actuators sensors will be used as force or strain producing devices, or as sensors to detect deflection or strains. A computer assisted control loop connected to these sensors and actuators can then be used for the testing of the composites under buckling loads. Due to the extremely small signal coming from the piezoelectric sensor, the electrical output needs to be magnified for use in the buckling test, or any test. In a buckling test, an axial compressive load is applied gradually to the test sample. During this application, the embedded sensors will generate a particular output that will be received by the control loop. In future tests, the computer assisted control loop will analyze the signals from the piezoelectric sensors and then be able to energize actuators to prevent the occurrence of buckling under the load. In this way, it is feasible to increase the critical buckling loads that the plate or beam can endure.

ACKNOWLEDGMENTS

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