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Fabrication of Composite Laminates with Embedded Pizo-ceramic Sensors and Actuators

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ABSTRACT

The purpose of the research project is to investigate the methods for embedding pizo-ceramic sensors and actuators in a composite (a fiber reinforced epoxy matrix). The importance of these sensors and actuators is vital in controlling the vibration and excessive strain on a structure causing fatigue or failure. With the control of these instabilities by the actuator, proper performance of the structure is achieved. Most sensors and actuators are surface mounted because (1) The sensor can pick up the greatest strain on the surface of a structure. (2) The actuator can create a stronger moment to counter balance the strain when the actuator is further from the central axis of structure. The surface bonding of sensors and actuators work fine when testing in a lab, but when this technology is tested in the environment, the pizo-ceramics need to be protected from damage. This is why research in embedding sensors and actuators is important. The whole goal of the project is to embed the sensors and actuators as close to the surface of a composite structure as possible. This creates better sensing and dampening of strain and vibration while protecting the pizo-ceramic.

INTRODUCTION

The main goal of this research was to develop and improve upon the methods of producing smart composite structures. Throughout the period of research, small goals had to be obtained before the final goal could be reached (producing a smart structure). One of the very first goals was to learn how to use the Dake heated press. This was achieved by laying up a composite using graphite/epoxy prepreg tape and curing the composite in the press. The cure cycle that was used can be seen in Figure1, which was provided by Hercules Incorporated. After the heated press was used and found to be in good working order, there were several problems that came about which prompted a new mold to be made. Finally after months of testing, the composite structures were coming out of the heated press in perfect condition. Now that all the kinks were worked out, the smart structure research began. From this research, new improvements were made to some of the older conventional methods of fabricating smart structures. With some of these new ideas or modifications to old methods, the main goal for the research was completed. Hopefully, from the problems and mistakes that were overcome, future testing for composites and smart structures can be developed with less time and complications.

FABRICATING A CONVENTIONAL COMPOSITE PLATE

When fabricating a composite plate, there are several considerations before placing the composite in the heat press for curing. The configuration of the composite plate is the most important step to be considered from the very beginning. The configuration is the orientation each lamina will have with respect to an arbitrary xy axis. Most composites and smart structures are oriented perpendicular to each other or [0/90]s with the s representing symmetry (i.e. an eight layered plate with [0/90]2s = [0/90/0/90/90/0/90/0]). Another important thing to remember when laying up a composite is not to leave the lamina (the sheet of prepreg tape) out very long because the lamina will start curing at room temperature (this can be seen when the epoxy starts to become very sticky). One of the last things to consider in the fabrication process is the position of the pizo-ceramic sensors and actuators. This will be discussed in detail later.

USING THE DAKE HEATED PRESS

In order to cure a composite plate or a smart structure, the process of high pressure and elevated temperatures are needed. Because the Dake hydraulic press measures in tons, the required pressure found in Figure 1 is converted to tons. To do this, the area of the composite (Ac) is taken in square inches. The required pressure (Pr) is then multiplied by the area of the composite. After this is done, the pounds of pressure is changed into tons by multiplying the pounds of pressure by 1 ton/2000 lbs.. The final equation is (Ac * Pr * 1 ton/2000 lbs.) to find the amount of pressure in tons needed for the curing cycle of the composite. The same process is used for smart structures. Once the pressure is applied, the heating plates on the Dake press are turned on. Then, the temperature gage for the plates are adjusted accordingly to follow the temperature versus time graph represented in Figure 1. As can be seen in Figure 2, the temperature curve for a Graphite/Epoxy follows fairly close to the original. The only problems that need to be considered is the ability to keep both heating plates close to the same temperature. Also, the pressure has a tendency to drop when the epoxy becomes fluid and raises as the composite plate cures.

IMPROVEMENTS IN THE FABRICATION PROCESS

During the first part of research, there were complications. The most important problem was in the curing cycle of the composite. When the composite was being prepared for the heated press, tacky tape was used to keep the epoxy from running out the sides of the composite mold. While twelve ply composites worked really good using the tacky tape, the composite that was less than twelve ply did not cure right on the outer edges. After extensive studying and testing was done on the problem, it was decided that the problem was the inability of the tacky tape to compress to the thickness of the desired ply level. This prompted a new mold to be made where the tacky tape would not be used

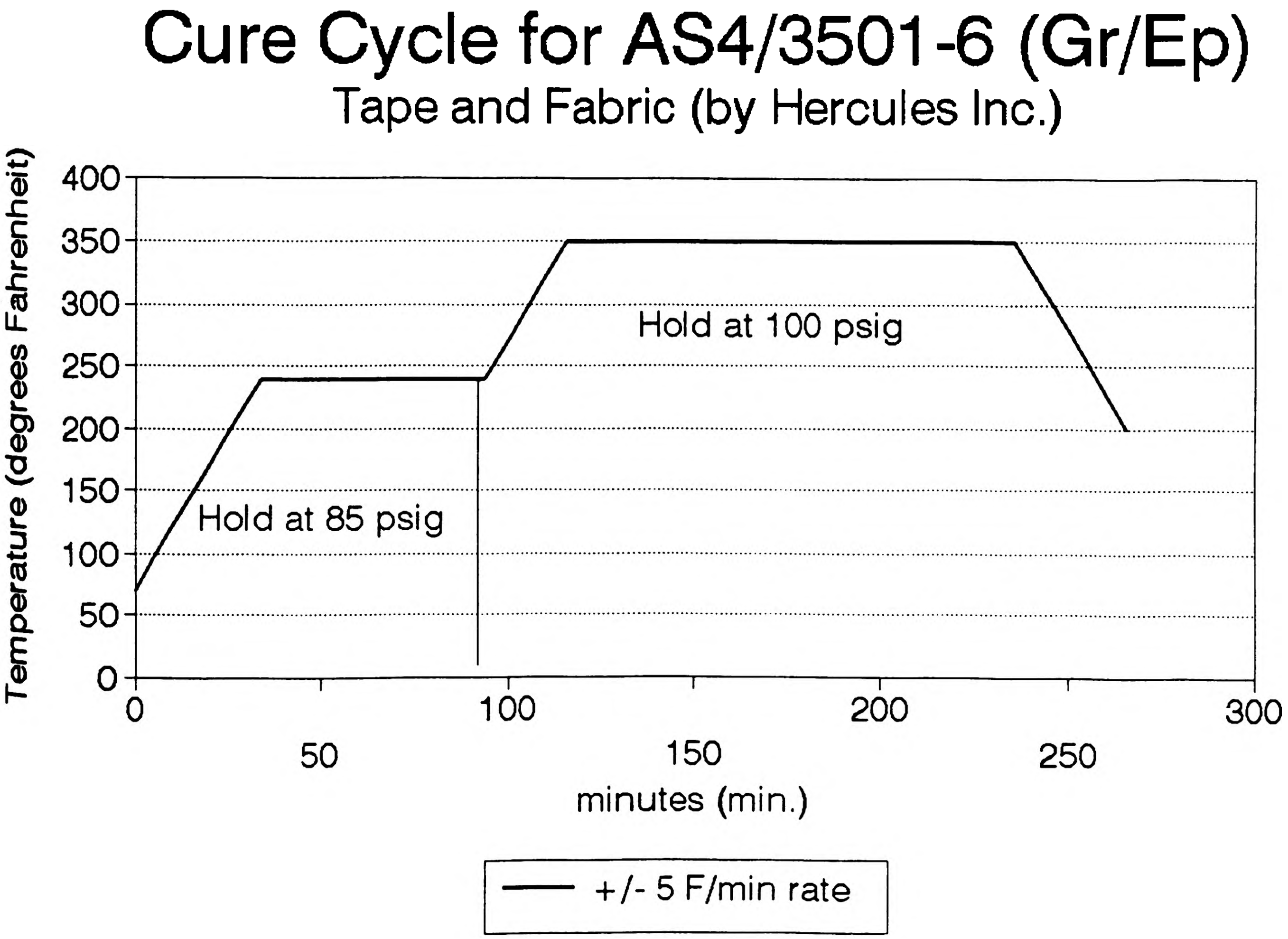

Figure 1: The curing cycle for Graphite/Epoxy from the Hercules Inc.

TABLE I. DATA FROM THE CURING CYCLE OF AS4/3501-6 GRAPHITE/EPOXY

List of date used to plot out Figure #2
Sample #9 Gr/Ep - [0/90]3s 12" * 12" plate
Area of plate = 144 in.^2
for 85 psig = 6.12 tons
for 100psig = 7.2 tons

Time	The plates temperature in the Dake Press						
minutes	top	bottom	average	minutes	top	bottom	average
0	74	74	74	120	266	268	267
2	78	78	78	122	272	274	273
4	82	83	82.5	124	278	280	279
6	88	90	89	126	285	288	286.5
8	94	95	94.5	128	291	293	292
10	100	101	100.5	130	299	300	299.5
12	104	105	104.5	132	307	309	308
14	112	112	112	134	316	317	316.5
16	118	119	118.5	136	324	325	324.5
18	125	126	125.5	138	332	334	333
20	131	132	131.5	140	339	340	339.5
22	139	140	139.5	142	345	345	345
24	149	150	149.5	144	350	350	350
26	157	157	157	159	352	351	352.5
28	167	167	167	174	348	348	348
30	172	173	172.5	189	349	350	349.5
32	180	181	180.5	204	353	353	353
34	188	189	188.5	219	351	352	351.5
36	202	199	203.5	234	350	350	350
38	211	210	211.5	249	350	350	350
40	219	219	219	264	350	350	350
42	223	223	223	266	332	332	332
44	230	231	230.5	268	327	328	327.5
46	234	234	234	270	313	315	314
48	238	239	238.5	272	294	294	294
63	243	242	243.5	274	284	286	285
78	240	240	240	276	271	271	271
93	240	240	240	278	259	260	259.5
108	240	240	240	280	246	250	248
110	240	240	240	282	239	241	240
112	246	248	247	284	234	234	234
114	250	252	251	286	222	220	223
116	254	256	255	288	214	213	214.5
118	260	262	261	290	205	204	205.5

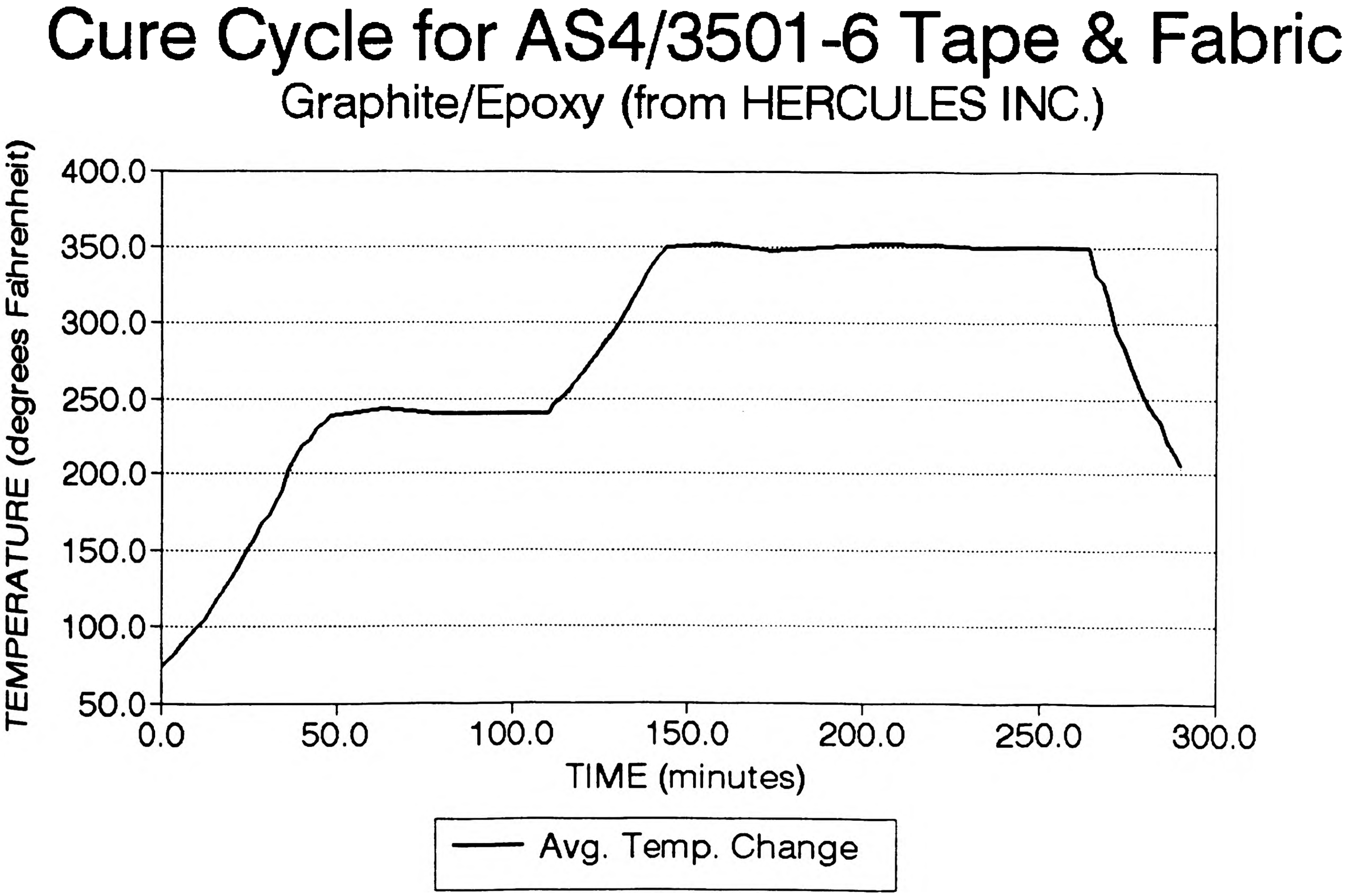

Figure 2: The actual curing cycle done in the lab with the Dake heated press

The mold successfully cured a four ply composite. Also, the mold was designed to make various size composites by adding or removing plates inside the mold.

Another complication that developed during the curing cycle was the temperature variance in the cool down cycle. It was noticed that at the boiling point of water (220 degrees Fahrenheit), the temperature of the top plate would start cooling slower then the bottom plate. The water cooling system for the hot plates seemed to let water flow easier to the bottom plate just below the boiling point. The problem was overcome by allowing the water to remain on all the time at about 210 degrees Fahrenheit while releasing the mold from the compressed state. This allowed the top of the mold to air cool which is very close to the cooling rate of the bottom of the mold. The bottom of the mold was still on the heated plate. At about 150 degrees Fahrenheit, the mold was removed so it could be air cooled. The new compensating process reduced the amount of thermal stress that could be seen in the warping of the composite plate. The new mold and the cooling process helped in producing a near perfect composite plate for testing.

METHODS FOR EMBEDDING PIZO-CERAMIC SENSORS AND ACTUATORS

After the fabrication process for composites was perfected, the attention was turned to the development of a smart structure. The most effective placement of the pizo-ceramic sensors and actuators were on the surface of the structure because it picks up the maximum strain and creates a maximum moment on a structure. For the sensors and actuators to be effective on structures (i.e. airplane wings, stabilizers, and helicopter blades), they should be protected from the harsh environmental conditions. All of the methods that have been researched follow these main ideas.

EMBEDDING PIZO-CERAMICS IN A GLASS/EPOXY

The first smart structure fabricated was a Glass/Epoxy plate with the pizo-ceramic sensors and actuators embedded inside the lamina. Because the Glass/Epoxy plate was nonconducting, the embedded pizo-ceramics can meet all the objectives with no problem. This fabrication process can be seen in Figure 3.

EMBEDDING PIZO-CERAMICS IN A GRAPHITE/EPOXY

The most difficult problem faced in the fabrication of smart structures was the embedding of the pizo-ceramics in a Graphite/Epoxy. Because the Graphite/Epoxy composite was conductive, the embedded pizo-ceramics should be insulated to protect it from short circuiting. Three different method for insulating the pizo-ceramics were developed to help overcome the problem of the pizo-ceramic sensors and actuators from being shorted out.

The first method used for insulating a pizo-ceramic in a Graphite/Epoxy was by using Teflon. Teflon tape was used by wrapping the pizo-ceramic and its leads. Then the inside lamina closest to the surface was cut so the pizo-ceramic could fit inside the lamina (see Figure 4 for the lay up). After the smart structure was cured, the resistance was tested by the leads which were connected to the pizo-ceramics. The resistance, which was tested by a volt meter, was found to be zero. Thus,

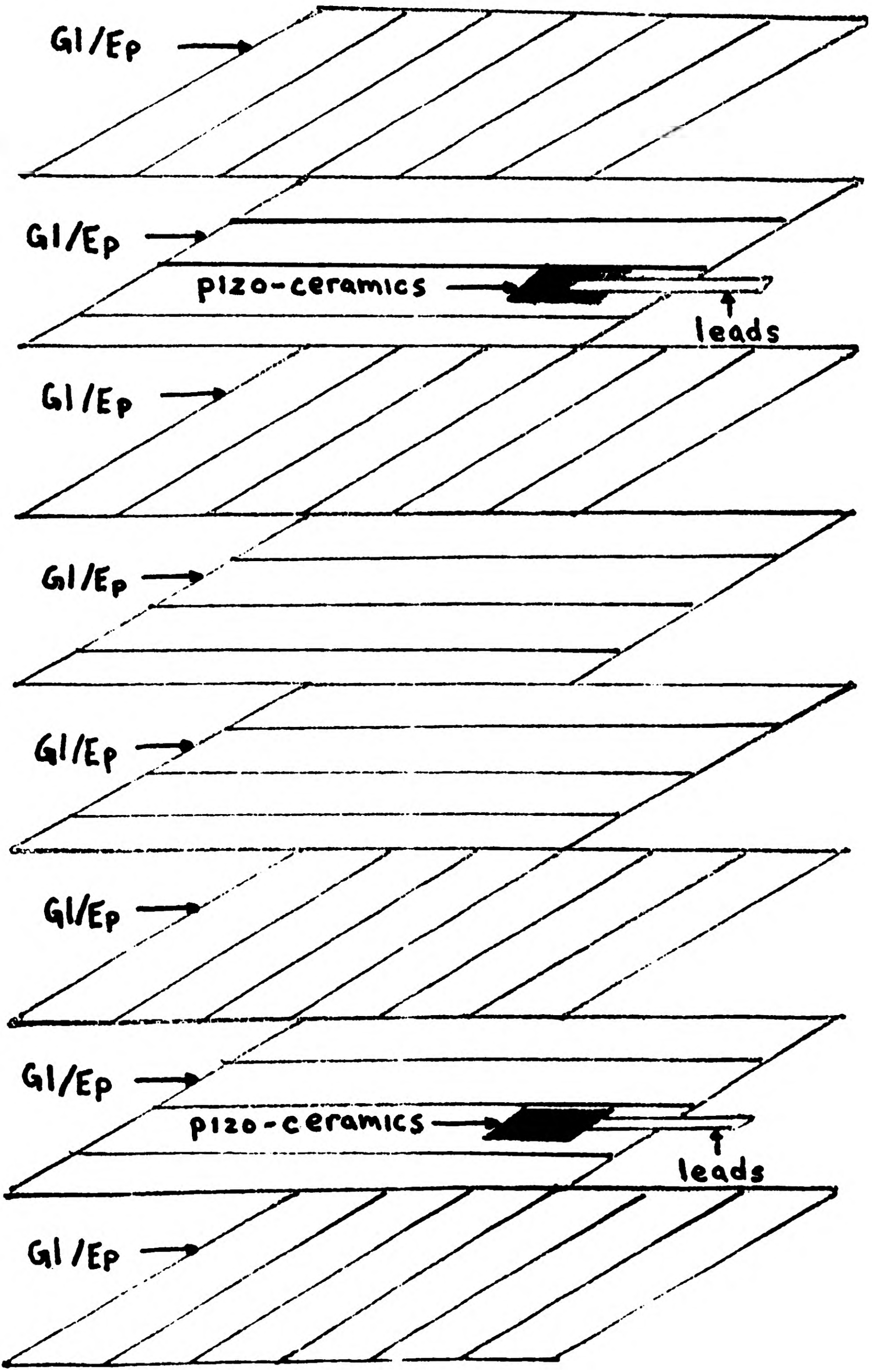

Figure 3: Pizo-ceramics embedded in a Glass/Epoxy (Gl/Ep) matrix

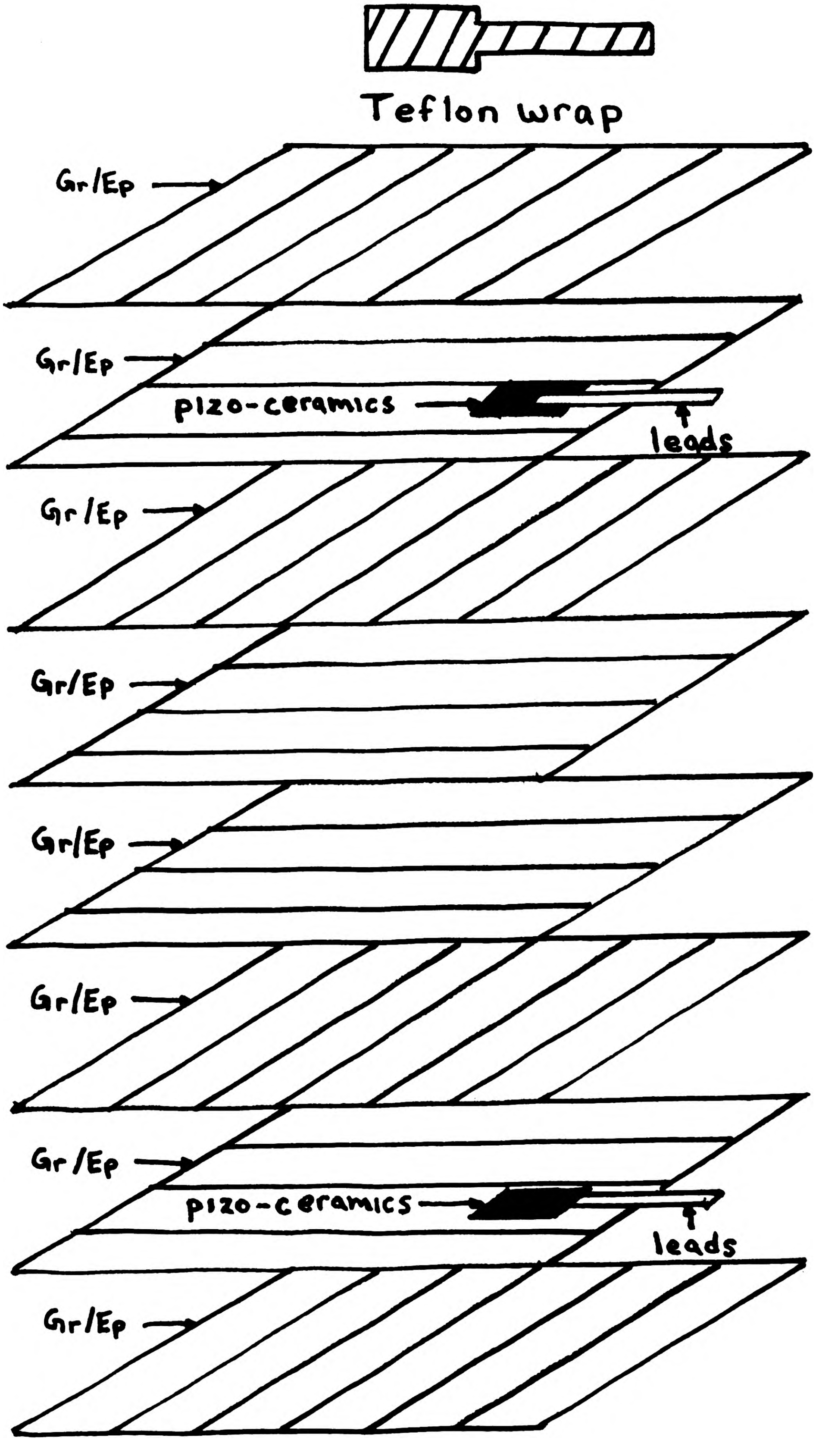

Figure 4: Teflon insulated Pizo-ceramics embedded in a Graphite/Epoxy (Gr/Ep) matrix

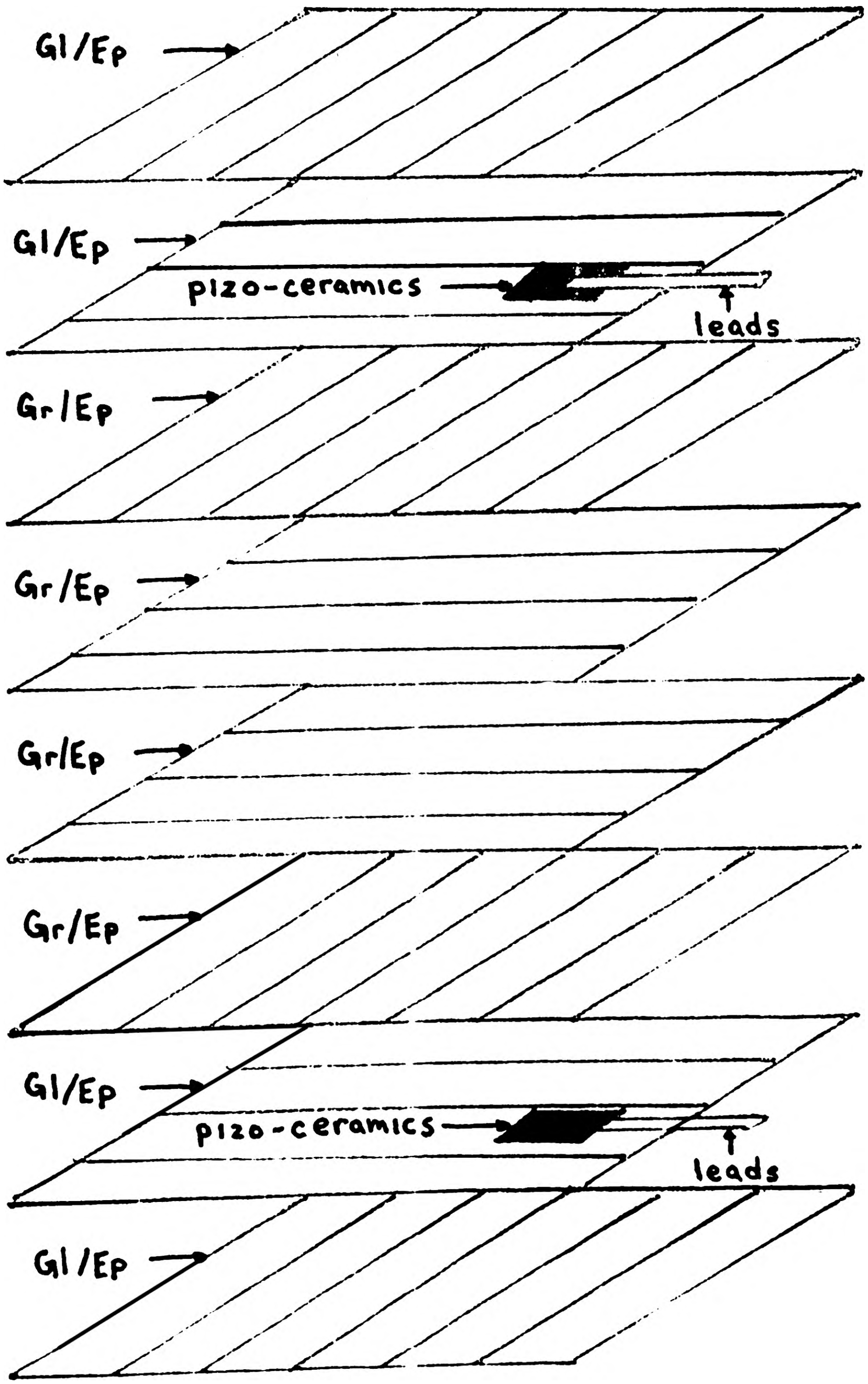

Figure 5: Pizo-ceramics embedded in Glass/Epoxy (Gl/Ep) matrix surrounding a Graphite/Epoxy (Gr/Ep) matrix

the insulator for the pizo-ceramics and their leads worked without any problems from the conductive Graphite/Epoxy structure.

The second method used for insulating the sensors and actuators was the use of polypropylene. This method did not work because the polypropylene had to be heated to 600 F before it would become liquid. Also, the polypropylene liquid was to thick to coat the pizo-ceramics. The last reason the polypropylene did not work was because the high temperature might have caused thermal stresses on the pizo-ceramic. For these reasons, the polypropylene coating of the pizo-ceramics was not used.

The last method for insulation a pizo-ceramic was the use of Glass/Epoxy and Graphite/Epoxy mixed. The Graphite/Epoxy composite was prepared while the pizo-ceramics were being placed between two Glass/Epoxy laminas. After both Glass/Epoxy and Graphite/Epoxy structures were made, the two Glass/Epoxy structures (each structure contained one pizo-ceramic) were placed on opposite sides of the Graphite/Epoxy (see Figure 5). In this way, the pizo-ceramics are protected from the environment and the conductive Graphite/Epoxy matrix.

CONCLUSION

In the end, the new methods developed for fabrication of composites and smart structures will help future research in this area. With this technology, airplanes, helicopters, and automobile are able to preform better and last longer. Also, with the smart structures information on fabrication, fiber optics could be embedded in a composite. A fiber optics grid network could be used to run a diagnostic test on an aircraft to determine damage or the health of its skin.

ACKNOWLEDGMENT

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