Machining Hexcel's Blue Seal Board: Problems Encountered on the CLAS Large Prototype Endplates

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Blue Seal board is a composite, structural material manufactured by the Hexcell Corp. This product contains a 1 in. by .007 in., perforated foil which is corrugate and glued together to form a “honeycomb” with 3/8 in. diameter cells. On the top and bottom of the “honeycomb”, sheets of .020 in. epoxy coated aluminum are fastened with a thermo-setting adhesive. The material is a stock item and is available in 4 ft. by 8 ft. sheets. For it’s weight and thickness it is extremely stiff. For this reason, it was decided to test the Blue Seal board for possible use on the CLAS drift chambers as endplates. 

We decided to have the endplates machined on a tool which would have the capability of machining the “real” endplates measuring approximately 22 ft. by 8 ft. The idea here was to test the capabilities of such a large machine to hold tolerances on hole locations. It turns out that Hexcel has the capability to fabricate and machine single plates of this size. The Hexcel corp. agreed to machine seven, 3 ft. by 3 ft. plates made of Blue Seal with approximately 735 holes (for feedthroughs and wires) drilled in each plate using a CNC milling machine with a 100 ft. bed. We provided the data on a floppy diskette in a format defined by Hexcel. Five of the plates had holes drilled normal to the surface. Of these, two were to be used to construct the large prototype of the region three drift chambers. The other three of the five were to be used as backups and for mechanical testing. The remaining two plates of the seven were drilled with holes 60 degrees to the surface to determine if it was feasible to drill the holes at that angle and maintain the position tolerances that we require.

1The endplates must be stiff enough to withstand the force of the wires strung between them under tension without too much deflection. They must also be light to minimize their deflection due to the force of gravity.
The holes to be drilled were specified as .1875 in. diameter with +.002 in. and -.000 in. tolerance. The hole positions were specified as a “best effort” on the part of the manufacturer with a nominal position accuracy of + or -.002 in. on the surface that the drill first encountered. We were told that on the plates with holes normal to the surface they could hold position to better than .005 in.

Hexcel delivered 8 plates. The extra plate was one with holes drilled normal to the surface which their machinists used to test their process (so we received six plates with holes normal to the surface and two plates with holes at 60 degrees). Initial inspection revealed a large burr on the front surface of the plates. Further inspection showed that most of the holes are oversized and varying in diameter to such a degree that we were prevented from measuring the position accuracy. Our study here will be limited to the hole diameters on the 6 plates with holes drilled normal to the surface. The reason for concentrating on these is that our immediate concern is for the large prototype which would be using two plates of this type.

Figures 0—5 are plots representing the distributions of hole diameters taken from 100 sample holes on each of the six plates that were measured. We began at hole 1 and sampled through hole 100 (in the order they were drilled) on each plate. Figure 0 is the plot made with data from the “extra” plate while Figures 1—5 show the data collected for the five that we ordered. Figure 6 represents the collective data from all six plates.

According to the specifications, most of the data should have fallen between .1875 in. and .1895 in. As you can see, Figures 0 and 5 show the best distributions (but not good enough) of the batch and Figure 3 shows the worst—with two peaks. All of the plots are shifted far towards larger diameters. Even if the machine operator had used a smaller tool to shift the data to the left, none of the samples would have come close to the distribution that we required for the hole diameters. The condition of these endplates would compromise the degree of certainty of the wire locations to the extent that they are unacceptable.

One possible explanation for the poor hole quality is that the material itself is

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2Since the endplates are facing each other at 60 degrees the wires that go between them will have to roll over the inside lip of a feedthrough which protrudes past the inside wall of the endplate if holes are drilled normal to the surface. On the other hand, with 60 degree holes drilled in the endplates, the wire will be allowed to go straight through without touching the feedthrough.

3This surface would become the inside face of the endplate. It is more important for this surface to have the holes accurately placed (for the plates with holes normal to the surface). The reason for this is that the end of the feedthrough on this side of the plate is used to position the wire.
inherently difficult to machine. With the help of Frank Folsom, Ralph Stegman and Doug Tilles we set out to try and understand the problems that the Hexcel machinists might have encountered. The first step was to drill holes through a small piece of Blue Seal using a standard jobbers drill in a chuck mounted on a hand operated Arboga Maskiner milling machine. A feed rate of approximately .3 ft. per minute was used. The idea here was to try and reproduce the results of Hexcel. Figure 7 represents the distribution of 100 of these hole diameters. As you can see, the distribution is wider than that specified but it does fall closer to the nominal values than either of Hexcel's samples. Given these results (using a tool with no special qualities) suggests that variables other than tool selection may have factored into the problem. With this in mind, using the same setup, the feed rate was arbitrarily increased for a small population of holes and we found that the diameters did in fact increase dramatically (and unpredictably). This finding together with the (reproducible) dimpling and raised burrs on the front side that we observed on some of Hexcel's panels implicates feed speed as one of the factors contributing to their poor results.

We also checked to see if the drill was deflected when it encountered the "honeycomb" between the skins. This had been a problem when we used a .125 in. drill on previous tests. With the .1875 in. drill there was some vibration when the walls of the "honeycomb" were encountered but only if the feed speeds were too high. When using a slow enough feed speed, there was no measurable difference in hole diameter for holes going through "honeycomb" walls or holes going through voids.

There was independent consensus between F. Folsom, R. Stegman and D. Tilles on factors which might affect the quality of the holes. These are outlined below.

- Build up of aluminum on the tool can cause the hole to be enlarged. Incorrect feed speed is the most likely cause of this build up. Figure 3 is a most probable representation of this effect. Notice the two peaks. The farthest peak to the right would indicate a build up of aluminum on the tool. The peak on the left is at Hexcel's mean for all holes. Over heating of the tool could also cause build up. Since using a lubricant is out of the question, a viable option could be the use of a venturi/compressed air cooling system.

- If chips are allowed to accumulate on the surface of the plate they may be

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4 Since they gave us no indication of what tool they used we decided that a standard twist drill would give us equally poor results.

5 Lubricant would enter the cavities of the cell structure and be a potential electrical problem if it were to leak out onto the endplate.
picked up and carried by the tool and cause the hole to be forced over size. It is possible on a numerically controlled machine to establish a “pecking cycle” which can cause a chip to be shaken off of the tool (either during or between the hole drilling cycle.

- When using a twist drill, a raised burr on the side you drill from is an indication of feed rates that are too high for the material.

- The shorter the cutting tool is the less the tool will wobble. One should use a tool that is only long enough to go through the material with as little distance from the spindle of the machine to the work as possible. Using a short, centering or “stub” drill is a possibility.

- Drilling the hole undersized and either step drilling or reaming to size might give better results.

- An end mill with a drill point ground on or a simple ball mill could be tried.

- Any tool will become dull after a time causing the holes to be enlarged and more rapid build up to occur. The machinist should determine the lifetime of a tool for the material he or she is working. The most common way is to use a “go or no go” gauge.ª

The next step was to try some of the recommended processes. Some work was done with the multi-stage operations outlined above with promising results. To simplify the investigation, though, we decided to limit the data that we produced to techniques using a one step drilling process. Doug Tilles and Frank Folsom each drilled 100 holes using an off-the-shelf .1875 in. ball end mill. Their respective results are shown in Figures 8 and 9. Notice how closely the two results come to the required five bin distribution that we require. Also note how close they are to each other even though the feed speeds were different and they used different machines.

ªSuch a gauge for our application would be a rod stepped to the dimensions of the lower and upper allowable limits of the hole.
Figure 10 shows data from another set of holes that Frank Folsom made on his CNC machine. The only difference here is that the feed rate is now .4 ft./min. instead of .8 ft./min. The distribution is much narrower and would be acceptable for our endplates if it were shifted .001 in. to the left. This could have been overcome by grinding the tool by .001 in. or more in diameter. One problem with the ball mill, however, is that it can leave rather large burrs on the front and back of the endplate. We are confident that this can be overcome. Perhaps an end mill with a drill point ground on the end would eliminate the burr.

The results that we have shown have been obtained using off-the-shelf tools in less than two man-days. With little more time, we feel it would be possible to machine Blue Seal board to tolerances of .002 in. if some care is taken. Although we do not know the circumstances under which Hexcel corp. machined the samples they sent us, we feel they could have done a better job. We have offered them our assistance if need be.
Figure 0
Hexcel machinist's test sample.
Figure 1
First Hexcel endplate sampled.
Figure 2
Second Hexcel endplate sampled.
HEXCEL SAMPLE 3, 90 DEG., FRONT

Figure 3
Third Hexcel endplate sampled.
Figure 4
Fourth Hexcel endplate sampled.
Figure 5
Fifth Hexcel endplate sampled.
Figure 6
Combined data from all six Hexcel samples.
Figure 7
Doug Tilles' sample using a jobber's twist drill on an Arboga Maskiner hand controlled milling machine. The feed rate is approximately .3 ft./min.
Figure 8
Doug Tilles' sample using a stock ball mill on an Arboga Maskiner hand controlled milling machine. The feed rate is approximately .3 ft./min.
Figure 9

Frank Folsom's sample using a stock ball mill on a Mazak AJV-25/404 CNC machine with M-32 controller. The feed rate is .7 ft./min.
Figure 10
Frank Folsom’s sample using a stock ball mill on a Mazak AJV-25/404 CNC machine with M-32 controller. The feed rate is .4 ft./min.