The Building of a Hexcel Table

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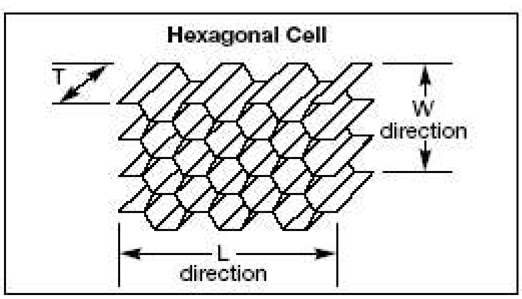
Introduction

This paper describes the methods used by myself and Andres Ghisays in building our latest tables as well as a set of recommendations for those considering doing the same.

Hexcel is a honeycomb material often used by the aerospace industry for making structural panels that are very light but extremely stiff or strong. They're used in aircraft wings, walkways, satellites, Moon-bound spacecraft and can even be found in many cars. Hexcel honeycomb (hereafter just referred to as "Hexcel") as discussed here is a flat panel made out of aluminum in the shape of a honeycomb.



By making the a panel in this way, the final product doesn't bend easily and can bear quite a lot of weight. More information can be found at the Hexcel site referenced at the end of this paper.

In January of 2004 I had begun expanding my cinder block & steel table from 2x4' to 4x4' when Bill McGarvin alerted the members of the Holography Forum to his find of a quantity of Hexcel panels at a nearby surplus yard. I was far enough along in my expansion that it made sense for me to continue working on that while considering the option of building a larger table using Hexcel.

Three primary reasons for making a table out of Hexcel are high stiffness, low weight and low cost.

Stiffness is extremely important in holography where you want the table to deform as little as possible when weight or a force is applied to the table (something causes the table to move). Because of the fringe stability requirements, if there is any movement on the table you need all the components to move as a unit. A person walking by, truck passing outside or someone making some other strong vibration can all cause the table to move. Assuming you have good component holders, the stiffer the table, the more likely you'll see uniform movement. When Hexcel is sandwiched between two pieces of steel, it creates a very stiff panel that isn't easily deformed.

While I don't have exact weight data for the Hexcel I used, I would estimate that the original 3.5'x6.7'x1 1/4" panels weighed about 10 lbs. They were easily lifted up and held by one person. This is a huge difference from the common materials used such as sand, solid concrete or concrete blocks.

The last reason for my using Hexcel was that it was available cheaply through the surplus market. Professionally made holography tables are manufactured with a honeycomb core because of their low weight and high stiffness but usually cost $6,000.00 and more. The tables described here can be built for about $1000.00 depending on the cost of the Hexcel.

The fact that we were able to build a table using Hexcel involved almost equal amounts of luck and planning. Luck in the form of Bill McGarvin and his find of a stack of surplus Hexcel panels. Luck also that Bill was going to be traveling across country and was able to put the Hexcel panels in with the rest of the material he was carrying so that it only cost us a minimal amount of money and a couple of beers for shipping.

While the descriptions that follow are centered around the creation of my table, duplicate methods were used in the creation of the table that Andres Ghisays is using.

One thing to keep in mind is that our labs are in upstairs rooms. In my case this limitation meant that I not only needed to keep the table relatively small since I use the room as an office but also needed to keep the weight at 750lbs or less. The 4' x 4' combination cinder block and steel table that I'd been building prior to hearing about the availability of the Hexcel was coming pretty close to that weight limit.

Planning

Hexcel configuration

The amount of Hexcel I needed was dictated more by economics and space than by stability. I knew that I couldn't move my table into the garage nor could I buy the ideal amount of Hexcel (the amount that would give me as close to 0 deflection as possible, see below for LEOT references) since this was going to be a bit of a science project and I wasn't certain of the outcome.

I started doing some calculations and determined that three 3.5' x 6.7' sheets could be cut to end up with four layers of Hexcel 3.5' x 5' in size. The fourth layer would be a simple composite of the excess cut from the original panels. At $30/panel the initial cost would be $90 and a table 3.5' x 5' could easily fit in my office. I'd need to make a few modifications to extend the existing table canopy over the new table but it was doable.

Figuring how much and what gage steel to use

Figuring how much steel would be required was a simple matter. I'd need a sheet for the top and bottom skin and a sheet between each layer of Hexcel . With that in mind, five sheets would be needed. After consulting with the denizens of the Holography Forum I decided on using 16ga sheets for the skins as a compromise between weight and stiffness. Fortunately Metal Supermarkets has an outlet nearby and I was able to order the steel and have it cut and delivered for $301.00.

Unfortunately I didn't think about making the top skin thicker to enable the use of threaded mounts. If you think you might want that ability, go for something like 12ga or thicker for the top skin. Not only will that allow you to thread the top but will also increase the stiffness of the table.

Something else to consider is the use of epoxy along with fiberglass fabric instead of steel for the inner layers. This should have similar shear characteristics and would keep the weight down. Contact Colin Kaminski through the Holography Forum for more details as this is what he is currently planning on using for his new table.

Figuring what epoxy to use

I was looking for an epoxy that has high shear strength yet wouldn't cause my wallet to explode and based on my initial research considered using JB-Weld or PC-7. According to the manufacturers of those products I'd need a 1/8” thickness to get a strong bond. I couldn't obtain shear data for the JB-Weld or PC7 but knew that PC7 was used to hold down the white road markers along our highways and thus were subject to high forces on a regular basis and that JB-Weld was often used to repair farm machinery.

I went back to the forum to get opinions on what epoxy to use and starting looking at the Loctite products used in the aircraft industry. John Klayer had made some breadboards using Loctite's high-end material and I started looking at Hysol E-20HP due to its having physical characteristics similar to the epoxy he used, but at a relative lower cost. It was expensive overall but only needed a 3-9 millimeter bond gap for a good hold. I decided to order 1L worth to give it a try before ordering enough to finish the job. At the same time I bought some JB-weld locally to test that out as well.

Figuring how much epoxy to use

I knew that I'd need eight layers of epoxy (plus some extra for the bonding of the layer built with the excess cut from each Hexcel panel) with each layer being 17.5 sq/ft. Based on the manufacturers recommendations I figured that in order to finish the entire table I'd need:

2520 ounces or 252 units of JB-Weld

11 Gallons of PC-7

6107 ml or 16 units of 120HP

Any way I chose to go it was going to be an expensive proposition. It was pretty clear that I needed to actually make a layer to verify the theoretical numbers.

Figuring what the table is going to weigh

Weight was pretty easy to estimate. The weight of the steel was supplied by Metal Supermarkets and after cutting was computed to be 191 lbs. The Hexcel was estimated at 5 lbs per panel or 20 lbs total and after adding in the weights from the rest of the table (such as the steel, sand-filled legs, epoxy and plywood) came out to a total table weight of 651 lbs. This was within the limit I'd established for my upstairs office.

Estimating the performance of the table

While gathering materials together I spent a fair amount of time running numbers through the formulas given on the LEOT web site concerning the performance of a honeycomb table. The final result that I got with the materials I used was a theoretical deflection of 7 wavelengths when a 100lb weight is applied.

This calculation is for 16ga (0.0625") steel skin with hexcel core.

$P := 100$ Force in lbs

$L := 5$ Length of the panel in feet $T1 := \frac{0.0625}{12}$

$T := T1 \cdot 5$ Thickness of the skins in feet $T = 0.026$

$b := 3$ Width of the panel in feet

$H := 0.5$ Thickness of the pane in feet

$E := 4.18 \cdot 10^{9}$ Young's modulus for the skin material in lb/ft^2

$G := 1.008 \cdot 10^{7}$ Shear Modulus for the core in lb/ft^2

$WL := 633$ Wavelength in nm

$$TD := \frac{P \cdot L^{3}}{24 \cdot E \cdot b \cdot T \cdot H^{2}} + \frac{P \cdot L}{4 \cdot G \cdot H \cdot b}$$

Total deflection $TD = 0.0000146468$

$$WLd := \frac{TD \cdot 304.8}{WL \cdot 10^{-6}}$$ (convert deflection in ft to mm)

Deflection in wavelengths $WLd = 7.053$

The reason this is important is that environmental movement causes the table to flex or “deflect”. The shear and other material data can be run through the LEOT formula to tell you how much your table will deflect when a point load of 100lbs is applied to the center, assuming the table is supported at the ends.

Material purchasing

Hexcel

The three 3.5' x 6.7' x 1.4” Hexcel sheets used for the first top were purchased from Bill McGarvin. He's on the road a fair amount but can generally be contacted through the holography forum. His web site is http://www.indimensionn.com/page3.html

The material that Bill acquired was *CR III 5052 & 5056 Corrosion Resistant Specification Grade Aluminum 1/8 4.5lb core*.

If you're looking to buy Hexcel from another source (although at the time of writing Bill does have some Hexcel remaining) scour the surplus yards used by the large aircraft manufacturers such as Boeing or perhaps some of the military yards (although I'm told that they typically destroy any material they don't use). There are also a few links below which may get you on your way.

I also recommend contacting Hexcel to see if they have any material available as surplus. They had some available while I was doing the initial research but it was quickly snatched up by someone else.

Epoxy

I initially chose Loctite Hysol E-20HP based on recommendations from John Klayer on the Holography Forum but after epoxying the first layer on the table I determined that was going to be prohibitively expensive since I'd need 36 tubes to complete the project and that would add up to almost $2,000.00 worth of epoxy.

JB-Weld is often used to repair engines for working machinery and it seemed likely that it would do the job more economically. Based on an initial trial layer I calculated that it would take eight units of Industro-Weld (the 10oz version of JB-Weld) per epoxy layer to finish the table for a total of $460.00. That was a number I could more easily handle. With that information in hand I began looking for a source that could supply me with 24 units of Industro-Weld. I called the manufacturer and was told that it would be at least two weeks before I could get it from them but that I might have more luck going through a local distributor.

I was able to find a local auto supply house that had a case and that allowed us to get started on the table. They were later able to supply us with two more cases to complete construction.

Steel

The steel was purchased from Metal Supermarkets - http://www.metalsupermarkets.com but should also be available at any other metal supplier. I chose to use 16ga cold-rolled steel and might have gone with a ferromagnetic stainless top skin if they'd had that available.

Construction

Tools needed: Ruler/bar guide to use when cutting Hexcel, jigsaw with metal cutting blade, sander & 150 grit pads, steel fine-toothed v-notched grout spreader (I used a 3/16" x 5/32" trowel), tube squeezer (pasta maker works great), rubber sheet (those used for opening jars are just right), denatured alcohol, leather gloves, paper towels, mixing bucket(s), mixing sticks, weights and/or clamps, a friend who can help you plan, carry, clean, mix, assemble and put the finished top where it belongs.

Cut your Hexcel to size using the jigs and bar guides. I won't go into detail in this area since it's highly dependent on what kind and size of Hexcel you have. If you have access to a band saw you may be able to use that. A table saw will work as well. Make sure you wear goggles to protect your eyes from flying bits of aluminum.

Find a flat surface to work on. If you can afford (or have access to) a sheet of float glass large enough, use that as your base. We used a concrete floor in the garage. You want as flat a surface as possible so that your table is level and you won't be building any avoidable stresses into the table top.

Spread out a single layer of newspaper to project your working surface from the epoxy and sanding tools. Put a sheet of steel down and clean it thoroughly with denatured alcohol. I recommend wearing leather gloves while doing this as the alcohol is rough on the hands.

Take a break and heat a bowl of water large enough to hold 16 tubes of JB-Weld. I don't have an exact temperature to give you but you should make the water hot but not boiling. Heating the epoxy will make emptying the tubes, mixing and spreading it much easier and doesn't shorten the pot life enough to be a concern. Let the epoxy soak while you finish prepping the steel.

Now that the steel is clean, dirty it up by sanding the steel with 150 grit sandpaper (or larger). Even if you are forced to rent one, use an orbital sander. The job will go much quicker that way. If you do this by hand, you'll be hating your table by the time you do the third or fourth layer of epoxy. The reason for sanding the steel is to aid the epoxy bond. Epoxy works best when there's a good mechanical bond formed and the rough sanding provides a plethora of grooves for the epoxy to settle into and grab once hardened.

Now clean the steel again with the alcohol. Some people may be tempted to skip the initial cleaning step but most cold-rolled steel will be coated with a thin layer of oil to keep it from rusting and why gum up your sander with oil if you don't have to?

Now that the steel is ready, it's time to empty the epoxy tubes. With any luck you've got a pasta maker or you know someone who will let you borrow one (as long as you don't tell them what it's for. Clean it before you return it). Take the first tube out of the water, wrap the tube in the rubber sheet and open the tube cap. Unfold the flat end of the tube, slip it between the rollers in the pasta maker and put the bucket under the tube mouth. Now start cranking the pasta maker and the tube should be sucked into the maker and the epoxy forced out into the bucket.

Once you've emptied all the tubes into the bucket take your stirring stick and stir the epoxy until just before your arms fall off. Warming the epoxy should make it nice and runny and you want to stir vigorously followed by scraping the epoxy off the sides of the bucket and bottom, followed by more vigorous stirring and scraping. If you've ever mixed cake batter, you'll be familiar with the process. If you haven't, I definitely recommend talking to someone who bakes to get the idea. Here's a link supplied by Colin Kaminski which goes into more detail http://www.star-technology.com/epoxymix.html.

Once the epoxy is a good even gray and you don't see **any** streaking, pour the epoxy out onto the steel. You don't need to pour a perfectly even layer but you don't want a big blob of epoxy in the middle of the table either so move the bucket around the table as you pour.

Taking the grout spreader, spread the epoxy out to evenly cover the steel. For more details on the technique for spreading the epoxy, Google for instructions on laying tile or check with your local home center. You want to ensure that you've got an even layer of epoxy all across the sheet of steel.

Now carefully place the first sheet of Hexcel on top of the epoxy. This is where help from a friend or two will really come in handy. As much as you can, you want to place the Hexcel down right where you need it. Try to avoid sliding it around on the epoxy as that will disturb the even layer of epoxy you went to so much trouble to create. If you need to move it slightly to center the panel on the steel though, this is the time to do that.

Now pile all your unused steel on top of the Hexcel and anything else you have handy which will help press the Hexcel down into the epoxy while it cures.

Let the layer cure overnight and then repeat the process with the successive layers of Hexcel until your table top is complete. After you've done a full panel (steel on both sides) you may want to lift the panel off the work surface slightly so that you can clamp the edges while piling weight in the middle.

After you've done a layer or two, you should be tempted to test the top for stability. I highly recommend following this temptation. Get your laser and enough components to create an interferometer and set it up on your top. Put a few inner tubes under the top a with any luck you'll find that the fringes settle quite quickly, although this depends as much on the reliability of the component mounts as it does on the rigidity of the Hexcel panel you've made.

We found that with two layers of Hexcel and a few inner tubes, we could walk around the table with no response and that the disturbance caused by stomping our feet settled out extremely quickly.

Results

After installing the top in my upstairs office we set about testing it with an interferometer. When standing next to the table we could see the fringes move when we moved but otherwise they stayed still, even when running a fingernail lightly across the table top. Tapping the table produced the expected fringe movement but the fringes settled very fast. We were even able to stand quietly on the same joists that the table rests on and not see any fringe movement. Something we couldn't do with my old cinder block table which would still show movement from our heartbeat.

I've been using this table top for nearly a year now and am still very happy with its performance. In fact, I could probably separate the table into two (we built the top as two halves and while I'd planned to epoxy them together once they were carried upstairs, I never have) and get very good performance out of a two double-layer tables.

Things I'd do differently next time

Use 12ga steel for the top. I've thought about the benefits of using a table with tapped holes and have a minor regret that I didn't think of that while planning my current table. I suspect that I'd use the screw mounts less for bolting the mounts to the table and more as a way to re-create successful layouts by putting mounts in the exact same locations so perhaps I'm not missing as much as I sometimes think.

I would likely buy another panel or two of Hexcel or fewer thicker panels to make the table even thicker than it is now. The thicker the top, the more rigid it will be and thus more stable. I might end up with a top that's thicker than absolutely necessary but I don't believe you can have too rigid a table top given the varying loads that it will be subjected to over its lifetime as well as the fact that my table is on an upstairs wood floor and subjected to much more vibration than those found on ground-floor concrete slabs.

A recommendation from Colin Kaminski is to use an odd number of Hexcel sheets so that the shear performance is greatest at the point of greatest load (the center). One of the key factors in designing a table is the sheer modulus of the main material. This is a number that indicates how much the material resists sheer stresses like those present in a holography table that is subjected to varying forces (movement and/or weight on the table top).

More information & references

- For a blow-by-blow account of the building of our first Hexcel table see http://www.dragonseye.com/holography/2004_04.html
- Bill McGarvin – http://www.indimensionn.com/page3.htm The Holography Forum post that started us down the Hexcel road can be found here http://holographyforum.org/phpBB2/viewtopic.php?t=385&postdays=0&postorder=asc
- Holography Forum – http://www.holographyforum.org
- Metal Supermarkets - http://www.metalsupermarkets.com
- JB-Weld - http://jbweld.net/index.php
- LEOT laser tutorial, including table performance calculations - http://repairfaq.ece.drexel.edu/sam/CORD/leot/course06_mod01/mod06-01.html
- Mixing epoxy - http://www.star-technology.com/epoxymix.html
- Alternate cell material - http://support.wwcomposites.com/forum/index.php?showtopic=4
- Hexcel sources - http://www.deltronix.com/public/search/surplus.html
- Definitions of shear and stress – http://www.uvi.edu/Physics/SCI3xxWeb/Structure/ShearStress.html.
- Hexcel home - http://www.hexcelcomposites.com

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