[SQUEAKING]

[RUSTLING]

[CLICKING]

PETER HOUK: I'm Peter. I'm Peter Houk. I'm the program director for the MIT Glass Lab. We're part, of course 3, Material Science and Engineering. And this is Mariel over here.

MARIEL BASS: Hi.

PETER HOUK: Mariel is one of the other senior instructors in the lab.

MARIEL BASS: Meet you guys.

PETER HOUK: So we've done this demo a few times for JJ. And one of the things that we like to do is show you how-- to illustrate different coefficients of expansion that glass can have. So every single glass has a really different kind of formulation. Sometimes they're very close to each other in compatibility or thermal expansion coefficient. Sometimes they're really far away from each other, because I guess you know glass is a pretty big family of materials. Even though it's amorphous, it can be all kinds of things and have all kinds of uses.

So two of the most common glasses are borosilicate glass, or Pyrex, that gets used in labware a lot. What we're going to illustrate is what happens when you put two glasses that have different compositions, and therefore, different coefficients of thermal expansion together-- what happens. And then after that, we'll do another demo about engineered stress in glass. And that includes glass tempering and what I'm going to call hypertempering, which is a Prince Rupert drop.

So this is the furnace where we melt the glass that we have here. Mariel, are you over there?

MARIEL BASS: Yeah.

PETER HOUK: Could you grab a little cullet so we can show them what the raw material. So this is how the glass comes to us. We don't deal with quartz. We don't want airborne silica in this room. So we don't take the batch glass. We don't take the sand and the soda ash and the calcium carbonate, and we don't mix those things here.

This furnace is designed so it has two chambers. On the right-hand side, we throw the glass in, and on the left-hand side, we have all the glass that we use. And the two chambers are divided by a wall. And there's a little hole in that wall so that there can be migration of glass from the charging side of the furnace to the gathering side of the furnace.

So it's a continuous feed furnace, which is good because we use this lab every day. So we can't have a day where we fill the furnace and wait for all the bubbles to come out. We have to have a design of a furnace that can give us good glass every day.

So we have two types of furnaces in here. There's the glass furnace there, where we melt a crucible full of glass. There's about probably 300, 350 pounds of molten glass in that furnace. And that furnace is on all the time. We don't turn it off until we have to rebuild it. So it may be on for five, six years at a time, all day, every day, all night. These furnaces are for reheating the glass, and they're about the same temperature, but we turn these off at the end of the day.

MARIEL BASS: Glass plate is basically [INAUDIBLE] metal [INAUDIBLE] grinders.

PETER HOUK: So I'm heating the two glasses together now. You saw how I put one just right on the side of the other. And I can't really mix them here. I'll never get them hot enough to make them homogeneous. I'm just trying to get everything hot again so we can pull it.

Try to have more or less equal amounts of glass.

OK.

OK. Wow, that really went. I don't think I'm going to give up just yet on that. OK. There's definitely boro in that. Yeah. And you'll see that in The Prince Rupert drop, too.

So this is another way of talking about stress in glass, is to talk about engineered stress in glass. So instead of putting two different glasses together, we're going to take a glass and suddenly chill the outside so the inside remains hot and the outside cools first and it compresses a little bit. And the outside-- or the inside would like to keep expanding, so you have tension and compression in conflict there.

So that there are kind of two reasons to temper glass. One is it's stronger, it makes it stronger. But there's another one, too. When it breaks, what happens? Yeah, into small, little relatively harmless pieces. So if you're driving along on the highway and a rock flies into your windshield and your windshield breaks-- well, first of all, it's laminated usually, too, but it would break into little kind of Chichlet-sized glasses, piece of glass. So if a skyscraper-- bird flies into a skyscraper 60 stories up and breaks the window, you have little pellets of glass raining on you instead of giant shards of potentially lethal glass. So that's the other big reason for tempering glass.

So what I'm going to show you now is an example of tempering glass, but in an even more extreme way. So in the factory setting, they'll use air. So they heat up the glass with natural-- or electricity, usually. So they'll be heating elements above and below the glass that heats the glass very quickly up to the transition temperature of the glass. And then it slides out of that zone on a flat bunch of rollers into another zone where it's being cooled with compressed air above and below quickly so it can induce stress in the glass. And the key is that it's done really evenly, so that there's no-- it's not colder over here than it is over here, or hotter over there.

It's all very hot and then very cold. So because there's no unevenness in the heating or the chilling, the glass can go into even compression and stay very stressed out, but very strong. So we're going to use water to cool glass here. So you probably know water is a much more effective, dramatic, radical coolant than air. So it's going to generate a lot more stress in the glass.

So we're going to take some furnace glass and ask it to cool down from 2150 degrees Fahrenheit to room temperature in a matter of seconds. Oh, hang on a second. Can I give that one to you?

MARIEL BASS: Yes.

PETER HOUK: I made one before you came in. Just in case. So these can be a little hard to make. They don't always cooperate.

So that's just an aluminum tube filled with room-temperature water. And it's long enough that by the time the drop gets to the bottom, it's pretty solidified. So where's that one? This is perfect. All right.

So you can break them. It's hard. You have to really put a lot of force into it. So usually, the way we break them is in this enclosed thing-- anyone else want to try to give it a try? No, you're good? OK. Trust and verify.

All right. Well, so much stronger. Just so you know, this is regular glass unannealed. If we break this with the pliers, that's all it does because there's not too much stress in it. Come closer.

On the other hand, this one, even where it's tiny like this, it was still in the water, so this part got tempered. Got tempered all the way up to there when it came out of the water and I looped it around. So keep your eye on the drop down there. Not what I'm doing, but on the drop, and I'll give you a countdown of 5, 4, 3, 2, 1-- 4, 3, 2, 1.

So just breaking the surface of that compressed layer there makes the entire thing fail at the point of failure at-- how fast?

AUDIENCE: At speed of sound.

PETER HOUK: Fast. Speed of sound in glass, not in air, which is different, I think dramatically different. Something like 3x, 2x.

AUDIENCE: [INAUDIBLE]

PETER HOUK: Yeah. So then the size of the fracture here is an indication of how much stress. If you walk around the street and you see little pieces of leftover glass from where somebody's car window broke, they're about the size of my thumbnail, kind of roughly. But come closer and look at these. Yeah, much, much, much smaller. There's just so much stress in there.

What is the shape of that? This is not the best example, but it's kind of cone shaped, right?

AUDIENCE: Right.

PETER HOUK: So I think what we're looking at here-- so I'm going to do a little chalk drawing on the floor. When the Prince Rupert drop fails, the center of the failure is right down the center, like that. And then you see this kind of thing.

So it's falling down, but at this angle from the center of the axis of the failure. And this is a little artifact of the center and that angle at which the failure is occurring. Why that angle?

AUDIENCE: Maybe it's the shear stress?

PETER HOUK: I'll buy that. [LAUGHS] So that's all the way open. That's all the way cross-polarized. And you can see-- can you see the colors? There's a magenta and a green, and then all these little kind of striations in the glass. Those are all stress signs.

Can you guys see any of the color in there? This is just a single chunk of white color pulled out and then twisted. So you get this kind of variable pitch sine wave here. And then this is more elaborate cane here, with a-- these are the MIT colors. So there's this red and a gray with a sine wave in the middle. And then these little filaments, little canes on the outside.

So we would start with red cane and gray cane, combine them, and then pull it all hot while twisting. So just to show you a simple example of that, I'm going to pull some cane with this gold color. And then maybe we'll make something quick with cane, like a pumpkin or something-- something that can happen fast.

So a couple ladders, please. So this is just fritted glass with colored oxides in it. So this is a transparent gold color that probably has a bit of silver-- silver salts, silver nitrate, probably. Does that sound right, JJ? What would--

AUDIENCE: [INAUDIBLE]

PETER HOUK: We don't mix our own color here, but the colors have a lot of different oxides in them. The blues usually have some cobalt, sometimes copper. The reds can be nanoparticles of gold sometimes, or copper will give you a different red. Chromium makes green. So does copper. Iron will make green, too.

I'll go once more and that's it for the color.

So I'm just trying to melt the color in so it becomes a smooth surface.

And then we'll get one final layer of glass on top, and then we'll pull the cane.

Yeah, I'll take a post after you, after I gather.

Hey, Mariel, we'll go this side.

Ooh, I'm sorry. You all right?

That's good. [HUMMING]

No, thanks.

So it's still kind of hot. You can grab it with the cold tweezers and stock it to break it. So you that cane that we made that had the borosilicate in it started to curve immediately. This remains really pretty straight. That one has a little bend in it, probably more because I didn't pull it all that much. There's very little stress in this glass.

Anyway, this is kind of the way that we make starter cane. Any color that you want to use, you have to first make that color in cane. So this is gold. And then on the very outside of the glass, I picked up several sets-- two sets of eight or nine canes, and then we pull and we twist them.

So yeah, you can heat up a plate. And I'll make something real quick out of this cane so you can see how we take canes and transform them from a bunch of separate objects into a single blown thing. Let's see. We got about 10 minutes.

We'll use the MIT cane. In order to keep the canes from rolling of the plate-- so Mariel preheated this ceramic plate so that we can boost the heat of the canes up so that they don't thermally shock when we go to get them really, really hot. So while the plate is still hot, I'll set up the cane.

We have alternating red and gray and red and gray In? This particular design. There's no real reason other than aesthetic. And then I want you to look at these calipers. So these calipers are two-sided calipers that I can use to measure this length of cane and then divide it by pi and end up with that diameter.

MARIEL BASS: Tray right here.

PETER HOUK: Oh yeah, let's try it.

MARIEL BASS: [INAUDIBLE]

PETER HOUK: Hmm?

MARIEL BASS: It's got glass on it.

PETER HOUK: Oh, I see. That's good. So what I'm going to do is we'll get it hot enough that we can fuse the canes together. I will roll them up into a cylinder, close it off, and it becomes inflatable at that point, so it can be made into a bubble.

So to prepare to make this object-- this is a blowpipe. So it's hollow. I can blow through it and introduce air into any glass I have on this side.

So I have to make something that looks kind of like a donut of glass on the end of this, but it has to still be open so that I can breathe air into it. So I can't just pick up glass and have a closed bubble. It has to be an open bubble. So the way I do that is I'll get a little tiny gather of glass on the end of the blowpipe. Just a very even, small gather. And I hold it up and let the glass fall back onto the pipe.

And then I'm going to put some air in it. Blow a bubble and then pop the bubble back in the furnace. And now I have an open bubble. And I'm just pulling the glass away from the hole, using my calipers now to get in the neighborhood of the right diameter.

A lot of turning and glass blowing, I'm using the centrifugal force to spin the shape. You really learn how to work with gravity when you blow glass. Gravity can be your friend. It can also be your enemy. But under the right conditions, you can get a lot of work done by using centrifugal force and hanging things down. That's probably ready. Ooh, you OK?

MARIEL BASS: Yeah.

PETER HOUK: So timing becomes very important here. Mariel needs to heat up the cane enough that it doesn't shock when I pick it up, but not so much that it sticks to the plate and doesn't want to come of the plate. Meanwhile, I'm kind of watching. I don't want to be too cold here, or too hot.

So I'm watching now and thinking about my timing while I watch how hot the cane is. It looks like it's picking up heat, starting to glow. Mariel will probably squish it a little bit here. Probably at least one more heat.

Yeah, you can get it hotter. There's a bunch of boro in there. Just say another 10 or 15. OK. Can I get it?

MARIEL BASS: Yeah, ready. Bring them over there.

PETER HOUK: Thank you. This is just to get off any dust that might have been on the kiln shelf, because now's the time. Once I start heating it up towards 2000 degrees, anything that's on there will stick to the surface.

So now just a little adjustment to make sure that the canes are all stuck together where I came around and joined. I can't even find it anymore. I think it's there. Yeah, I think you could go up to 4 on that garage. It's not going to overheat anytime soon.

So now those canes are joined along their length in a very kind of provisional way. I can't blow into this yet because it's still open on the bottom. So what I'm going to do is roll all the canes on the steel table here, the marver, to try to increase their surface area at the point of contact so that when I go to blow this thing, it doesn't want to open up at the joint between the canes.

That's one of the first things that beginners learn here, is that if they don't join their canes together enough, you get a hole, and then that's a game over situation. So I'll take a couple of heats and just make sure I'm really joining them together well by rolling and smashing.

OK, you got the torch? We'll do one more roll and smash and then I'll close it up. All right. The next thing I'm going to do is close this off at the end so that it can be blown. No. It's OK. Thanks.

Now it's closed. Probably just use a-- put a clear stem on it, probably.

So I did that because I could tell it was a little colder near the end where the metal of the pipe is, because the metal of the pipe has been acting as a heat sink and taking heat out of that region. So that was a way of evening out the heat, using the torch to point it at that one area where I thought it was a little colder.

And this is-- I'm now using just a foot pedal and compressed air to introduce air into this bubble. We developed this system during COVID so that people could blow glass in here without touching the pipe with their mouth.

MARIEL BASS: First?

PETER HOUK: No, let's do the stem first.

MARIEL BASS: OK, [INAUDIBLE].

PETER HOUK: Yeah, yeah, you can start it up right now. Just a clear one.

MARIEL BASS: Sit there?

PETER HOUK: Yep. So I'll bring this over and you can see how the cane changed as it got mapped onto this much wider surface.

AUDIENCE: Wow.

PETER HOUK: So it's closer to flat than round now.

AUDIENCE: Mm-hmm.

PETER HOUK: So that's something you have to think about when you make cane. What's it going to look like in the end?

So Mariel is getting the stem ready now. And again, I'm paying attention to what she's doing it so that I can control the timing. I don't want that to be added to this when it's too hot or too cold.

OK, I'll take a quick flash when you go in.

AUDIENCE: [INAUDIBLE]

PETER HOUK: Yeah, spinning it because it's still hot enough that the glass could fall off center if I don't keep turning.

Clip. Nice.

All right, Mariel. So I'll torch this, and then you can give that a quick flash and come on over with it. Let me just locate where I want to put it. OK.

So it's done. We'll put it away now.

So to avoid thermal shock, we can't just let this cool as fast as it would like to. We have to cool it down slowly in one of our ovens over there. So we'll load it in the oven, and then tomorrow, it will come out after having ramped down overnight over about eight hours.

So right now, I'll just put a little drop of water where I made the neckline with the tool here. And that water will shock the glass just a little bit in that place so that it wants to come off right there. And then we're just going to melt in the break off so it's not sharp. Do I need to spoon that or-- it doesn't really look like it. OK. And then we put it in the oven.

Seems a little counterintuitive that you would put something in an oven to cool it down, but that's what we do. So you can see that the temperature of that bottom oven is at 884 right now, Fahrenheit. This is at 2100, and that glory hole over there is the same temperature. So for us, things get cold when they get below 1000 degrees Fahrenheit because that's below the transition temperature of the glass.

So that's a good temperature to put the glass in there, because it won't continue to deform at all. It will stay there happily at 1000 degrees, or just below, about 930 degrees, all day long. And then we'll cool it down slowly overnight, and then there won't be any stresses left in the glass if we do it all right. It's a little bit more complex. So maybe where's my piece of chalk? I can draw what the ramp looks like.

So if this is temperature, and this is time, we're going to start at 930, which is our annealing temperature. And we hold there as long as we need to, all day long. And then you have to stay at that temperature so that the temperature can even out within the piece that you're using. So if you put in something that's really thin, you can hold it at 930 for only like a half an hour and it will be OK.

But if you're making the Hubble telescope lens, then you need to anneal that for a year because it's that thick. So there's a geometric relationship between thickness and annealing. So after you've annealed for enough time, then you can go down a little more gradually to 750 over-- this might be an hour, and this might be two hours, to get past the strain point of the glass.

And then you can go down really pretty quickly. This might be another four hours to, say, 300. So this is where you have to be kind of gentle going through the strain-- the strain part of the glass, which is about 100 to 150 degrees below the annealing temperature, generally, of our glass. So that's what the profile looks like. It's about eight hours.