An Investigation into the Effect of Hollowing Printed Investment Casting Patterns to Reduce Shell Cracking in the Autoclave

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Hollow SLA Investment Casting Pattern

QuickCast®

About 2/3 of all printed patterns cast in North America are QuickCast patterns

Advantages

- Accuracy
- Surface finish
- Large size capability
- Durability

QuickCast Patterns

DISADVANTAGES

- Residual ash
- Tendency to crack investment casting shells in de-wax
- Requires modifications to the normal casting process
  - Increases time
  - Increases cost
- Prevents use for production of any volume

SOLUTIONS

- Ash
  - Will require new resins
- Shell cracking
  - Project to improve internal support structures
    - This paper is a report on progress on that project
- If these two issues can be solved, foundries can use the same process to cast QuickCast patterns that they use for molded wax patterns
  - Lower cost castings
  - May make QuickCast patterns viable for low-medium volume production

Development of Hollow SLA Patterns

~1987 - Immediate interest in using rapid prototyping to create prototype patterns for investment casting

- Enabled fast, low cost prototype castings

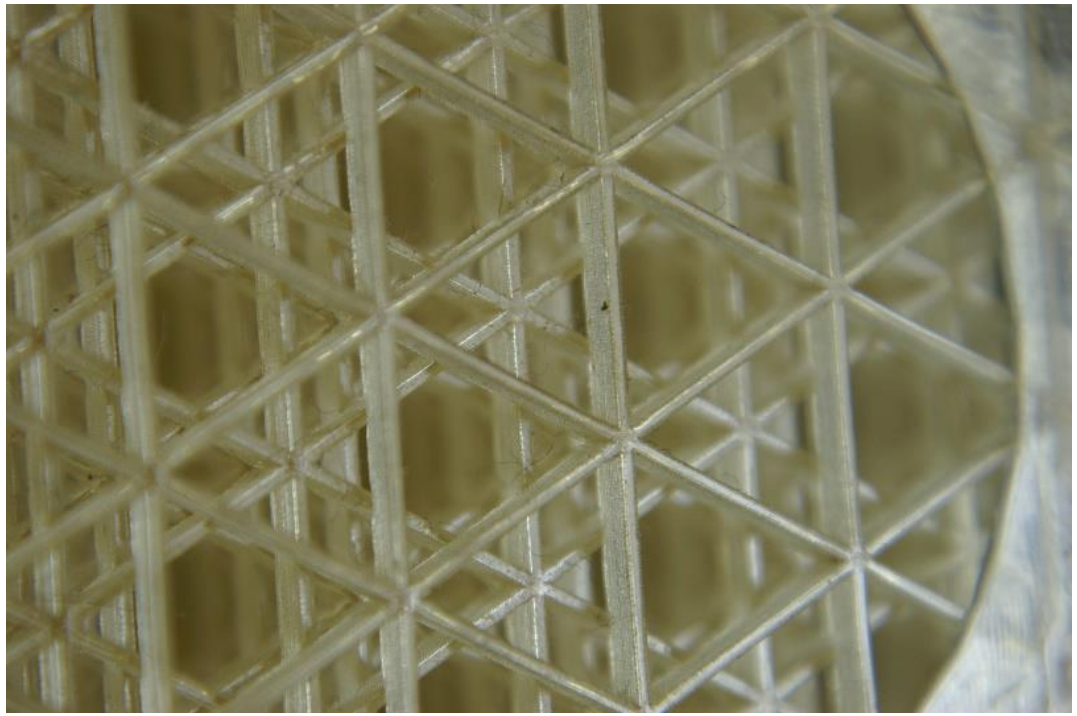
~1989 - efforts with solid patterns

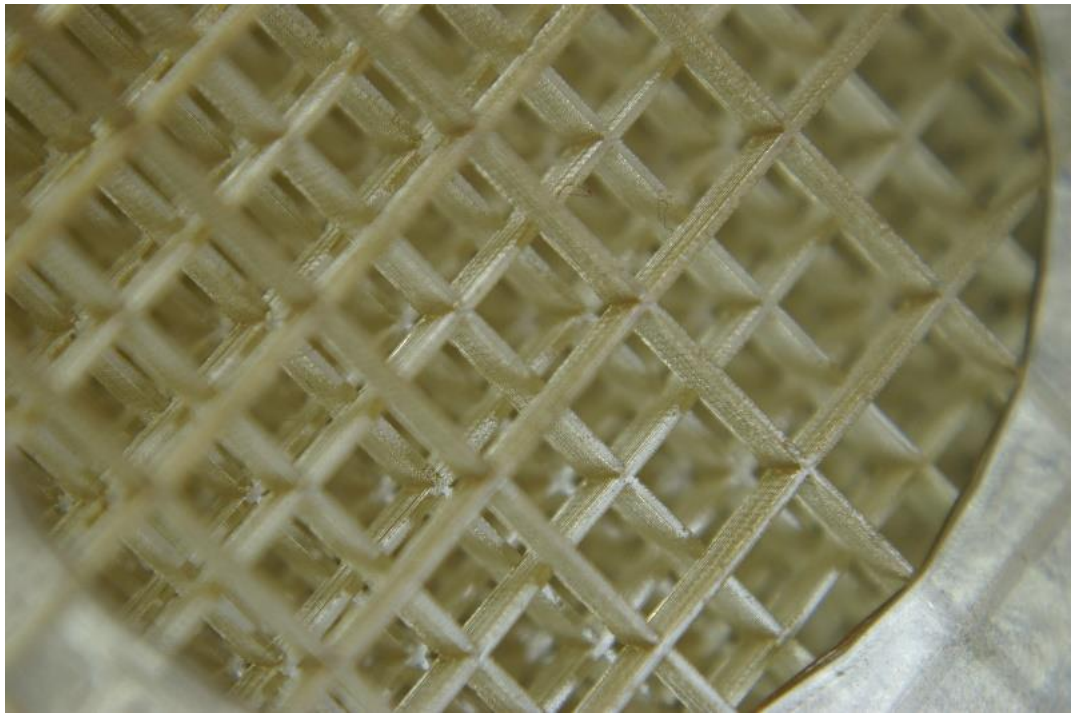
- Roger Swanson: 20% success rate

~1990 – attempts at hollow patterns

- Worked but very fragile

~1991 – initial attempts at internal support structure



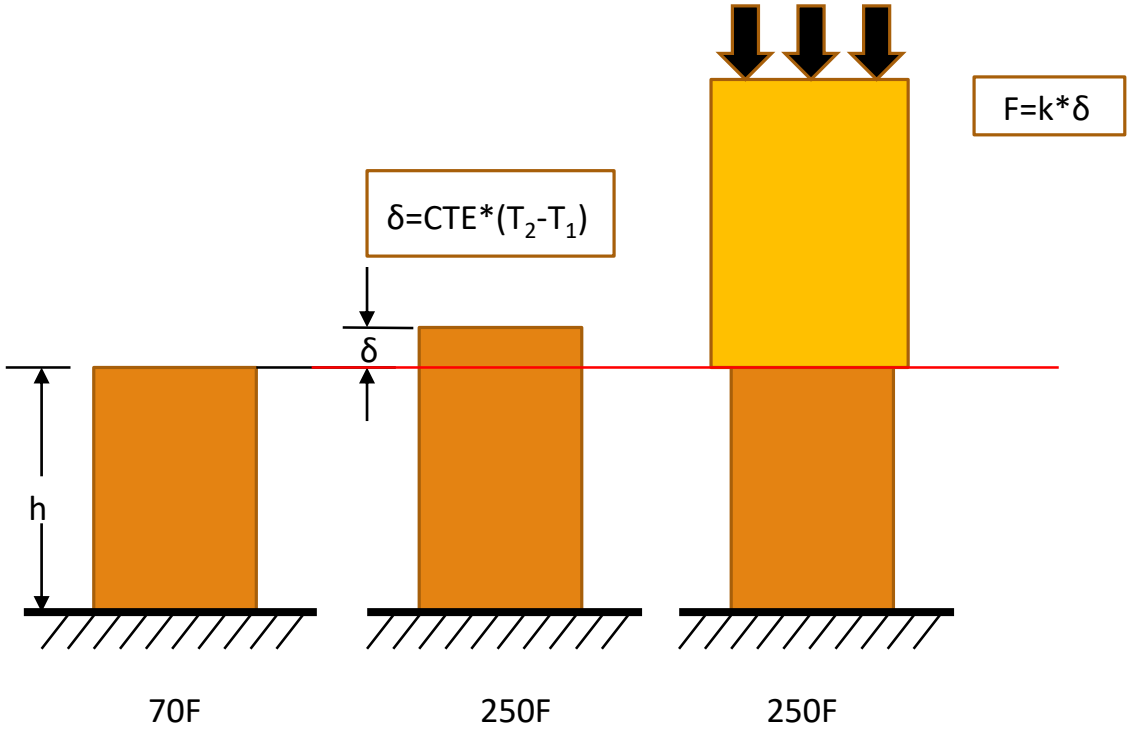


Early Internal Supports

Problems with Early Reinforced Hollow Patterns

Still cracked shells

Effect of Stiffness on Forces on Shell



$F=k*CTE*(T_2-T_1)$

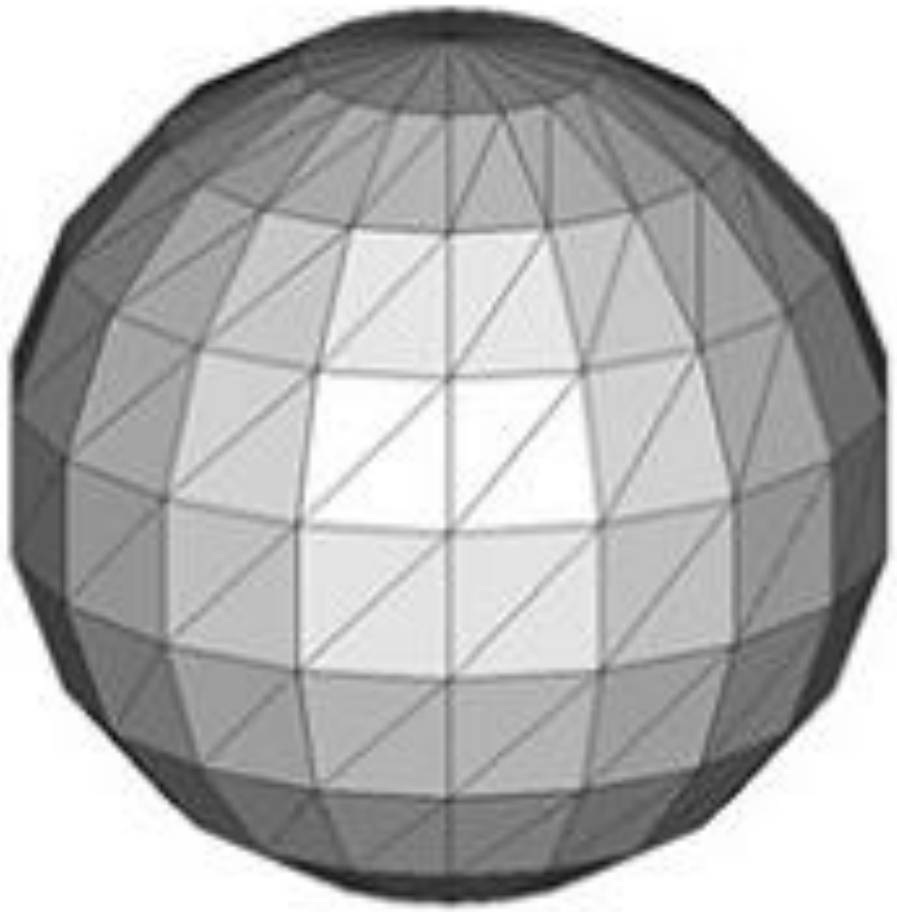
- Stiffness has as much influence as CTE
- Cutting stiffness in half has same effect as cutting CTE in half

Problems with Early Reinforced Hollow Patterns

Still cracked shells

Data problems

- Need to create pattern file
- Increase size of stl files



STL file

Faceted representation of outside surface of pattern

Hollow doubles the number of facets

Each leg in internal support structure adds at least 6 facets

Files sizes go up by a factor of 10 or more

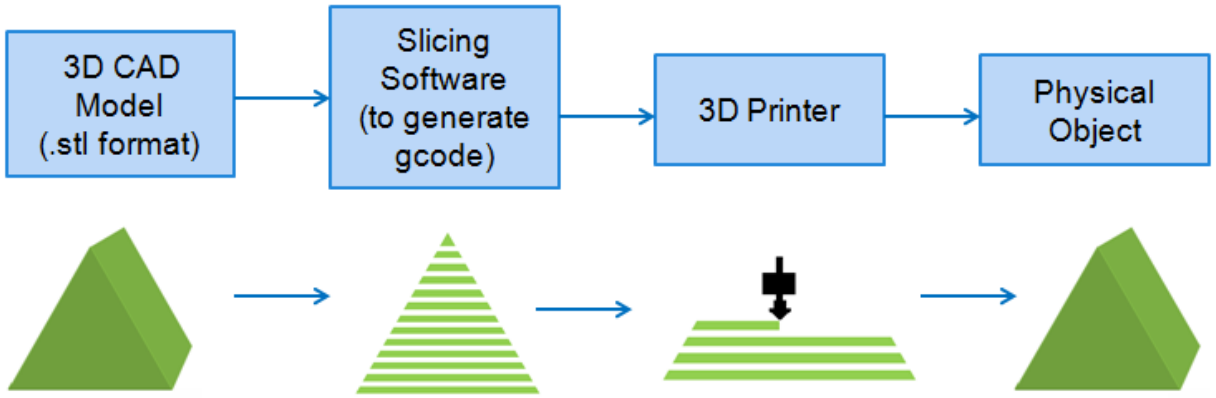
Problems with Early Reinforced Hollow Patterns

Still cracked shells

Data problems

- Need to create pattern file
- Increase size of stl files
- Significant increase in slice time

File Slicing



Number of calculations is proportional to number of intersections between slice plane and facets

Modelled internal structure can increase number of intersections by a factor of 10 or 100 or more

Slice time goes up dramatically

Problems with Early Reinforced Hollow Patterns

Still cracked shells

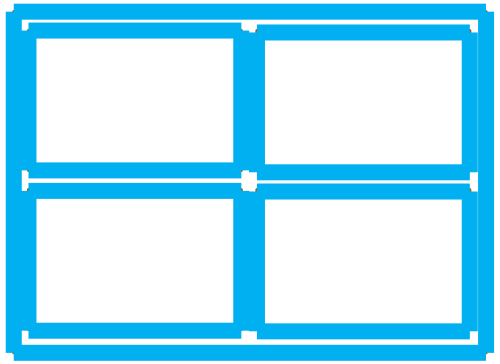
Data problems

- Need to create pattern file
- Increase size of stl files
- Significant increase in slice time
- Significant increase in build time

Speed Issues

Solid Section

Hollow Section with
Internal Structure



Border Vector
Hatch Vector

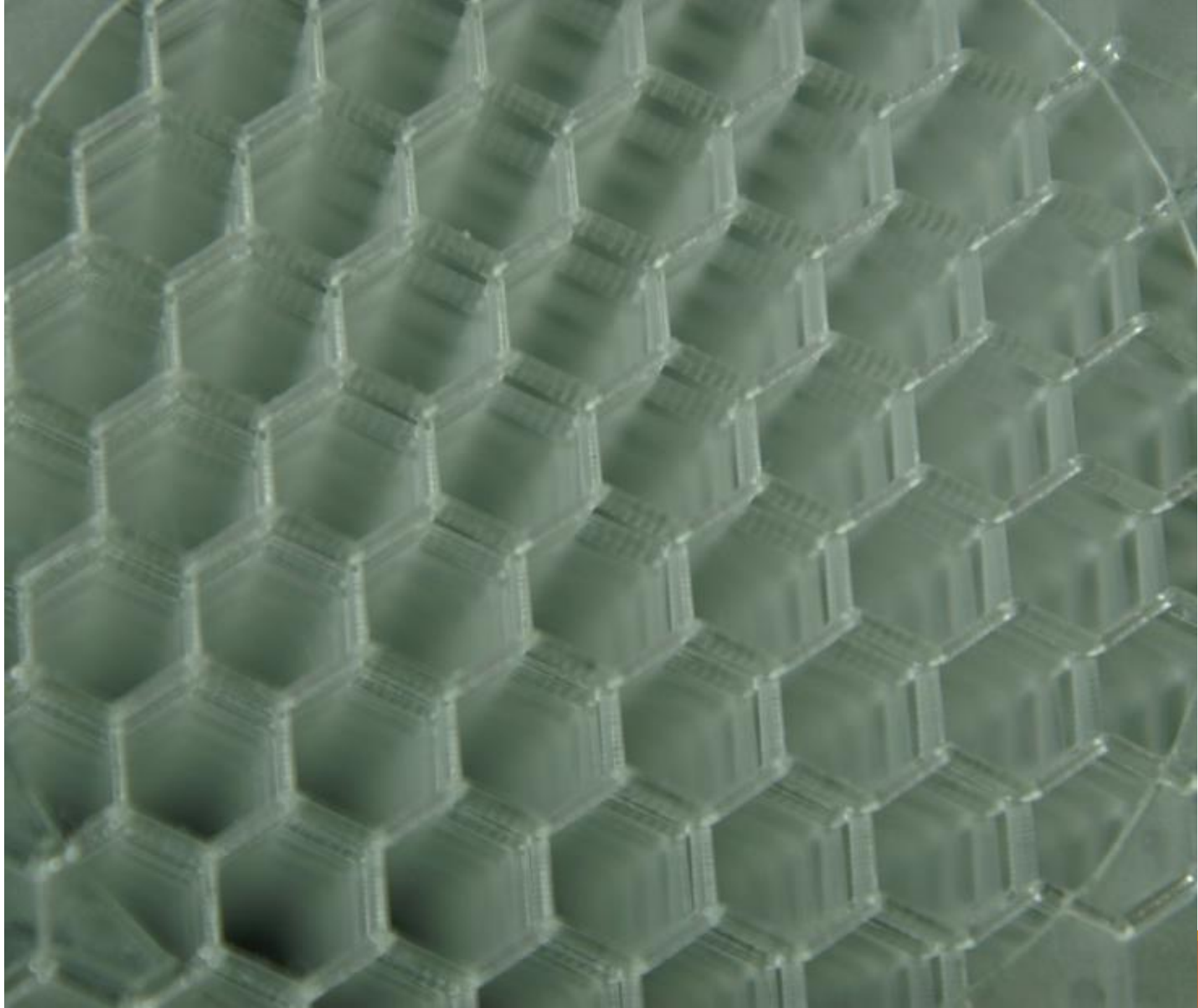
Internal structure can more than double the time required to build the part.

Nearly doubles part cost

An Ingenious Alternative - QuickCast

Developed by Phil Dickens and Richard Hague – University of Loughborough in the UK

Introduced in 1992



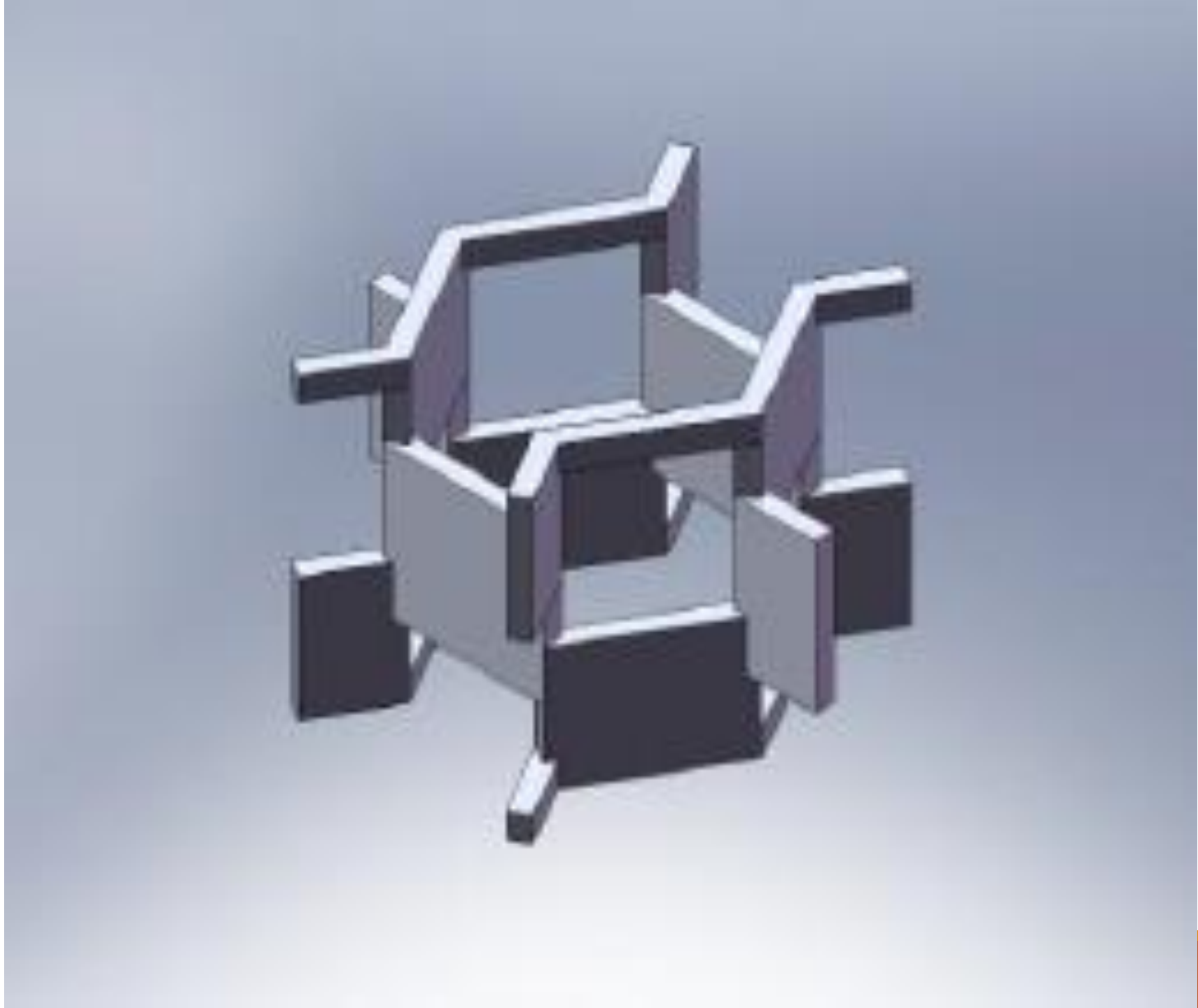
QuickCast Structure

The structure is not a complete hex.

Along most of its length, there is only two sides of the hex present on any one layer.

Allows for drainage from any point in the structure

All created using hatch vectors



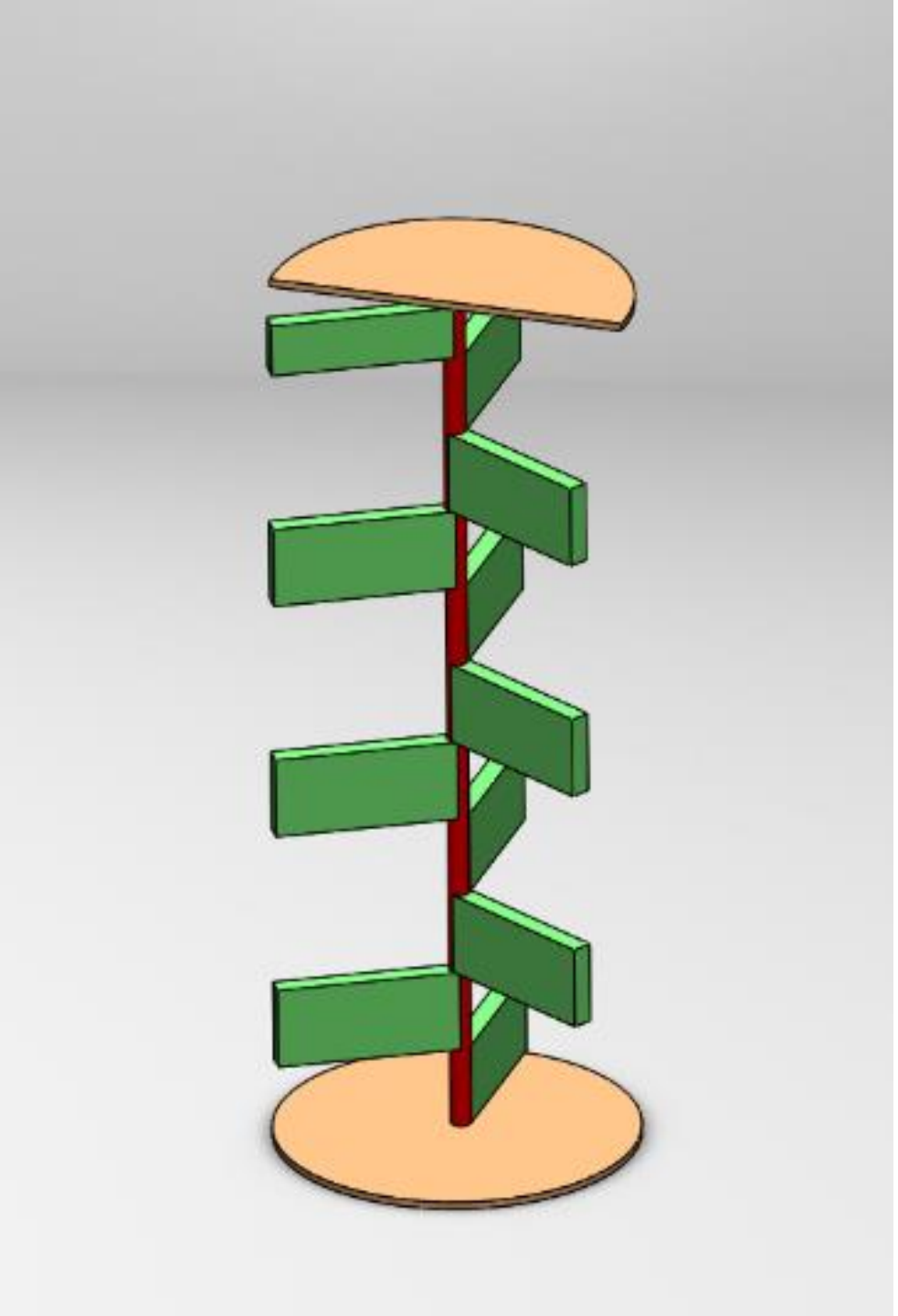
QuickCast Build Style

ADVANTAGES

- Only hatch vectors are used
  - Uses same file as solid part
    - No Structure information in STL file
    - Small file size
  - Simplifies and speeds slicing
  - No borders or skins in internal structure – Faster build
- Good drainage of uncured resin

DISADVANTAGES

Creates a solid post at each corner of hex structure



QuickCast Corner Post

Creates a solid post at every corner of the hex that runs from skin to skin

Supported by hex walls over 100% of its length

Very difficult to buckle – required if pattern is to deflect inward and avoid cracking the shell

Work Around

Add Vents to Pattern

- Spaghetti wax to provide a connection to the outside of the shell
- Poke through the skin under the vent
- Open path to pattern interior before autoclaving
- Allow steam to heat the internal structure quickly upon pressurization – softens the material – allows it to buckle

However

- Adds labor to the casting process
  - Adding vents
  - Opening vents prior to autoclave
  - Cool down after burnout
  - Patch vents
  - Grind vent stubs after casting
- Adds time to the casting process
- Risks Shell integrity
- Stiffness not uniform in all directions
  - Very stiff in Z direction
  - Less stiff in X,Y directions

Objectives for a New QuickCast Structure

Reduced stiffness

Stiffness uniform in all directions

Structure modelling not required

No increase in file sizes compared to solid part

No increase in slice time compared to solid part

No increase in build time compared to solid part

Candidate Internal Structures

Notched QuickCast

Diamond

Notched QuickCast

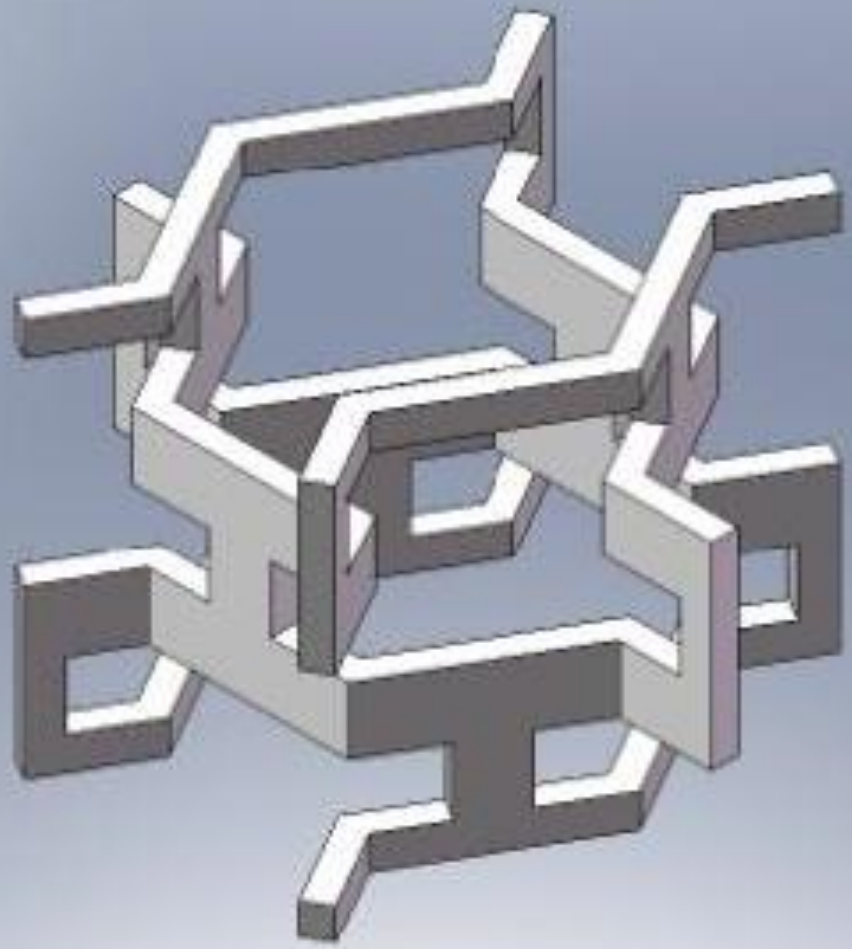
Notch added to short wall of hexagonal structure

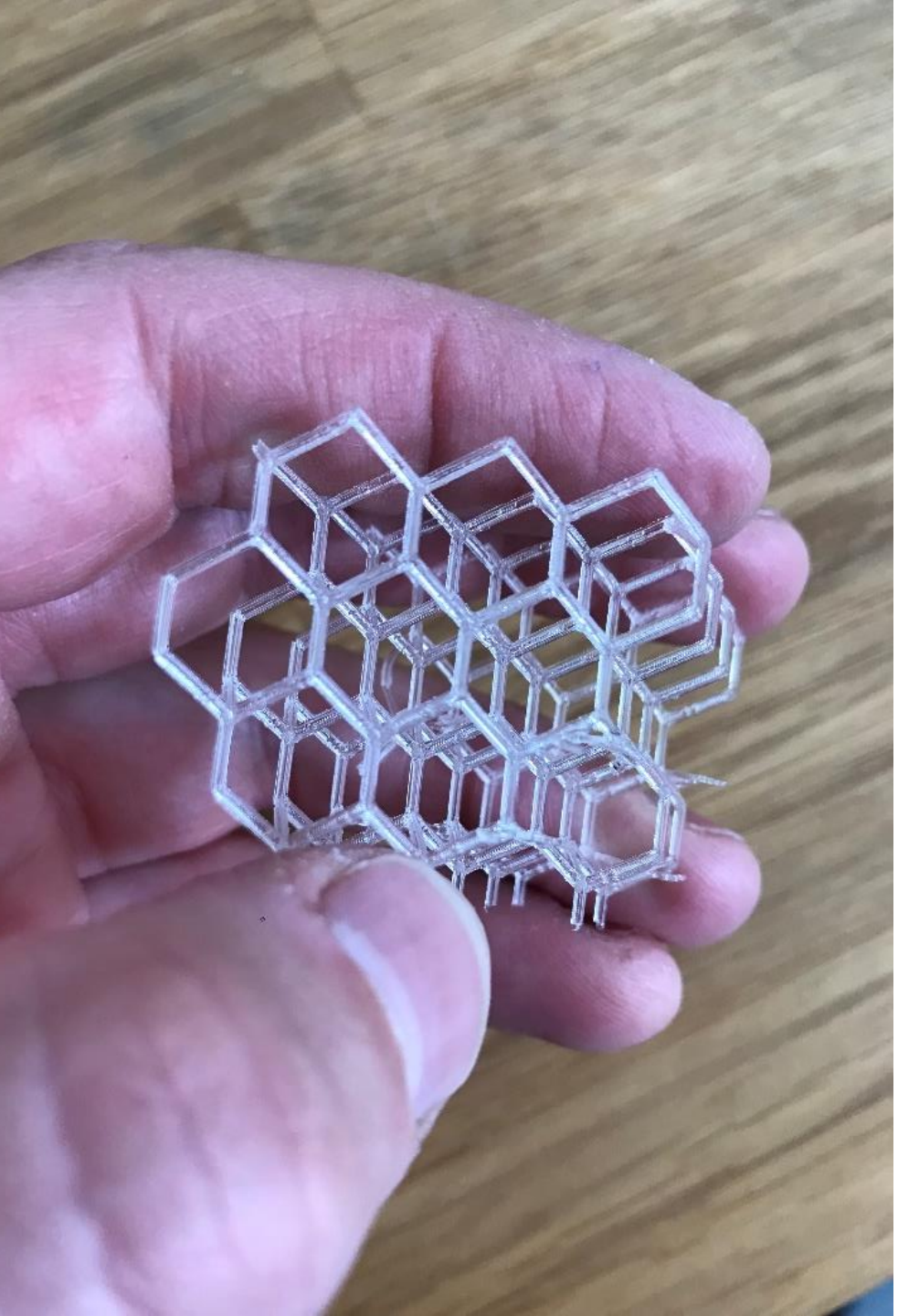
Cuts post in corner of hex at several places along its length

Provides a means for that column to collapse

Reduces stiffness

Stiffness can be varied by varying cell size, notch width





Diamond Structure

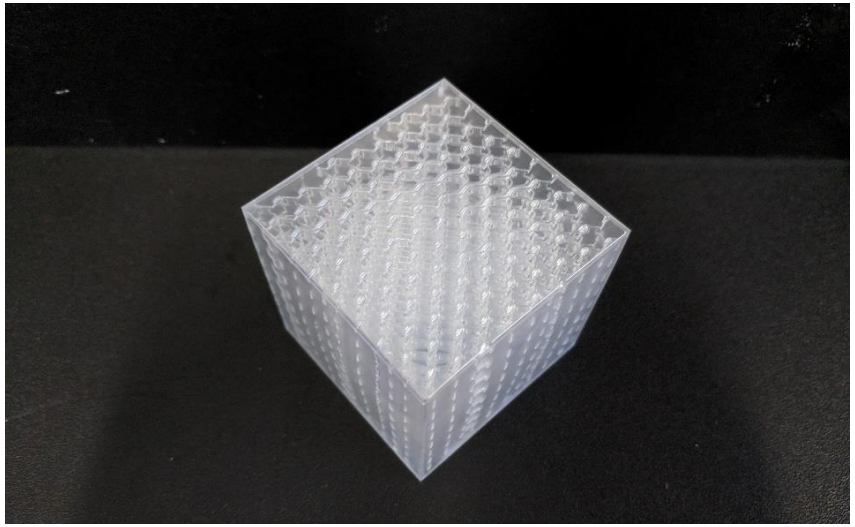
Uses hatch vectors – no internal modelling

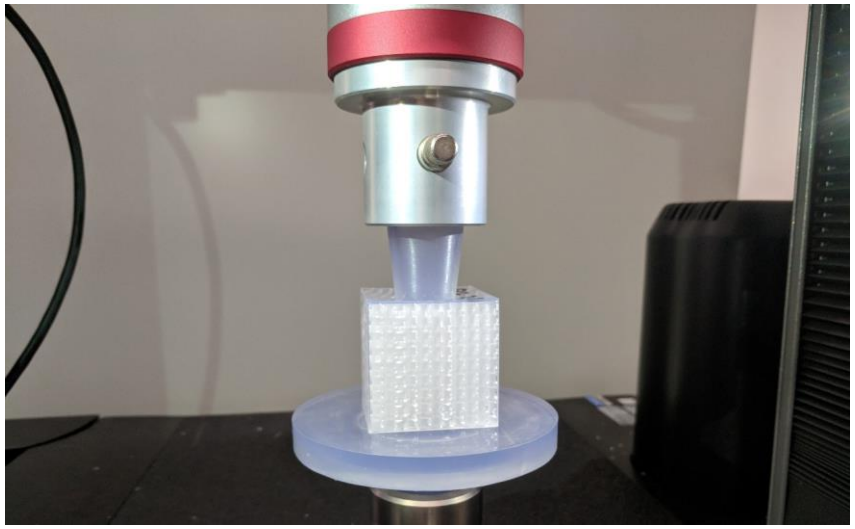
More uniform stiffness in all three coordinate directions

High percentage of void – less mass

- Lower material cost
- Less ash

Stiffness can be varied by varying cell size





Stiffness Test

2 inch cube built for each build style

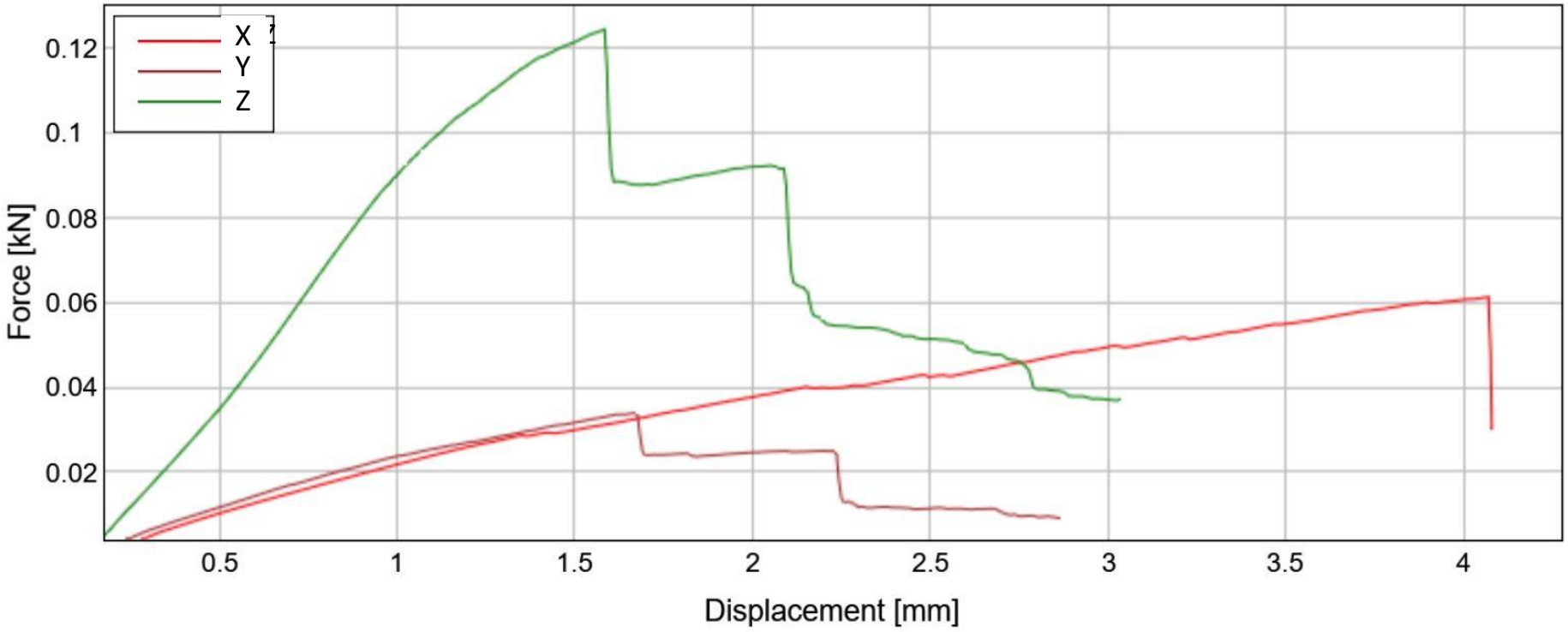
- QuickCast
- Notched QuickCast
- Diamond

Tested in Instron Machine

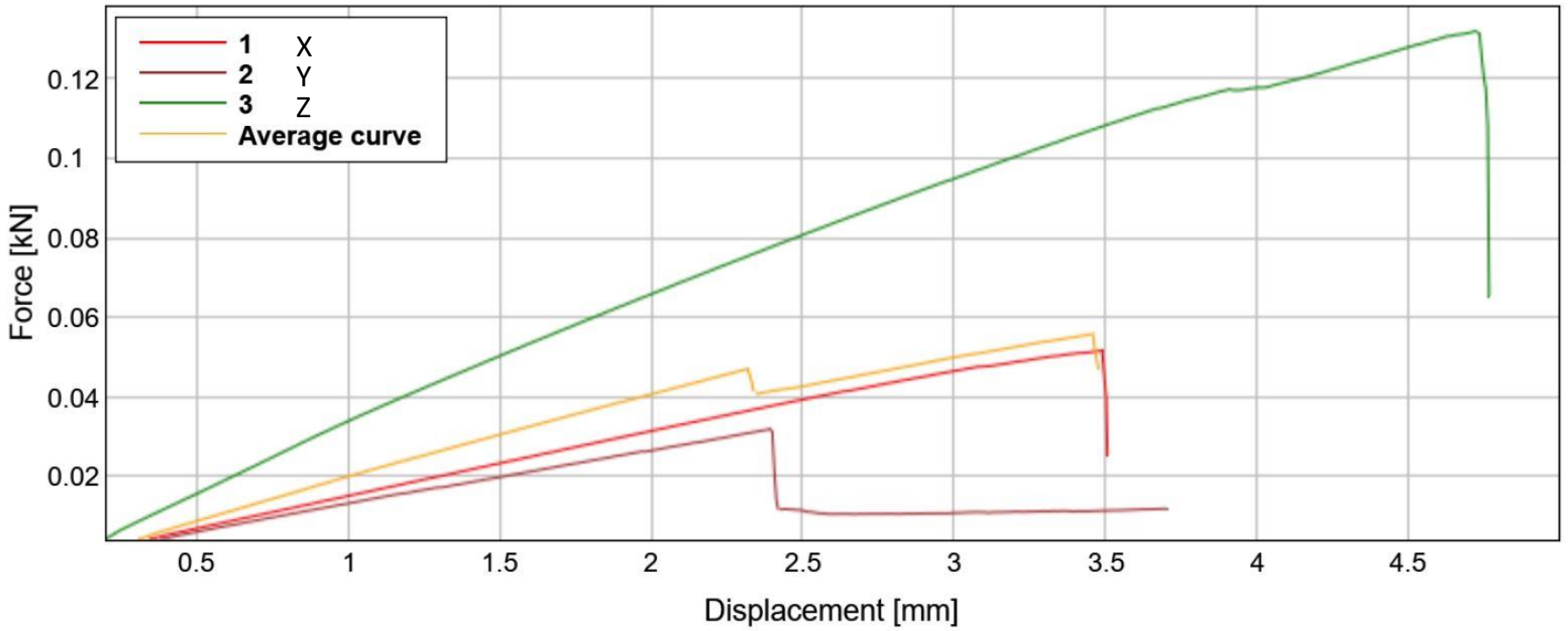
- Slowly increased load
- Recorded force, displacement at small increments of force

QuickCast

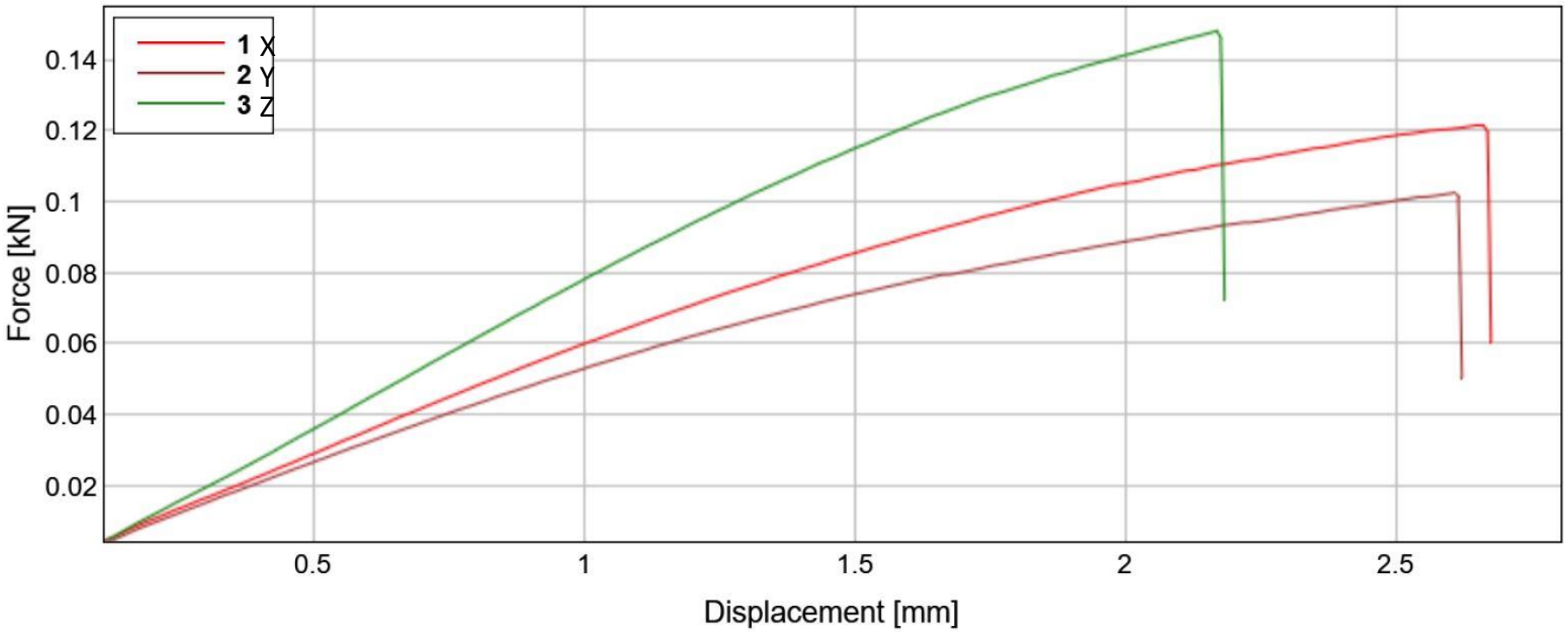
Stiffness is the slope of the curve



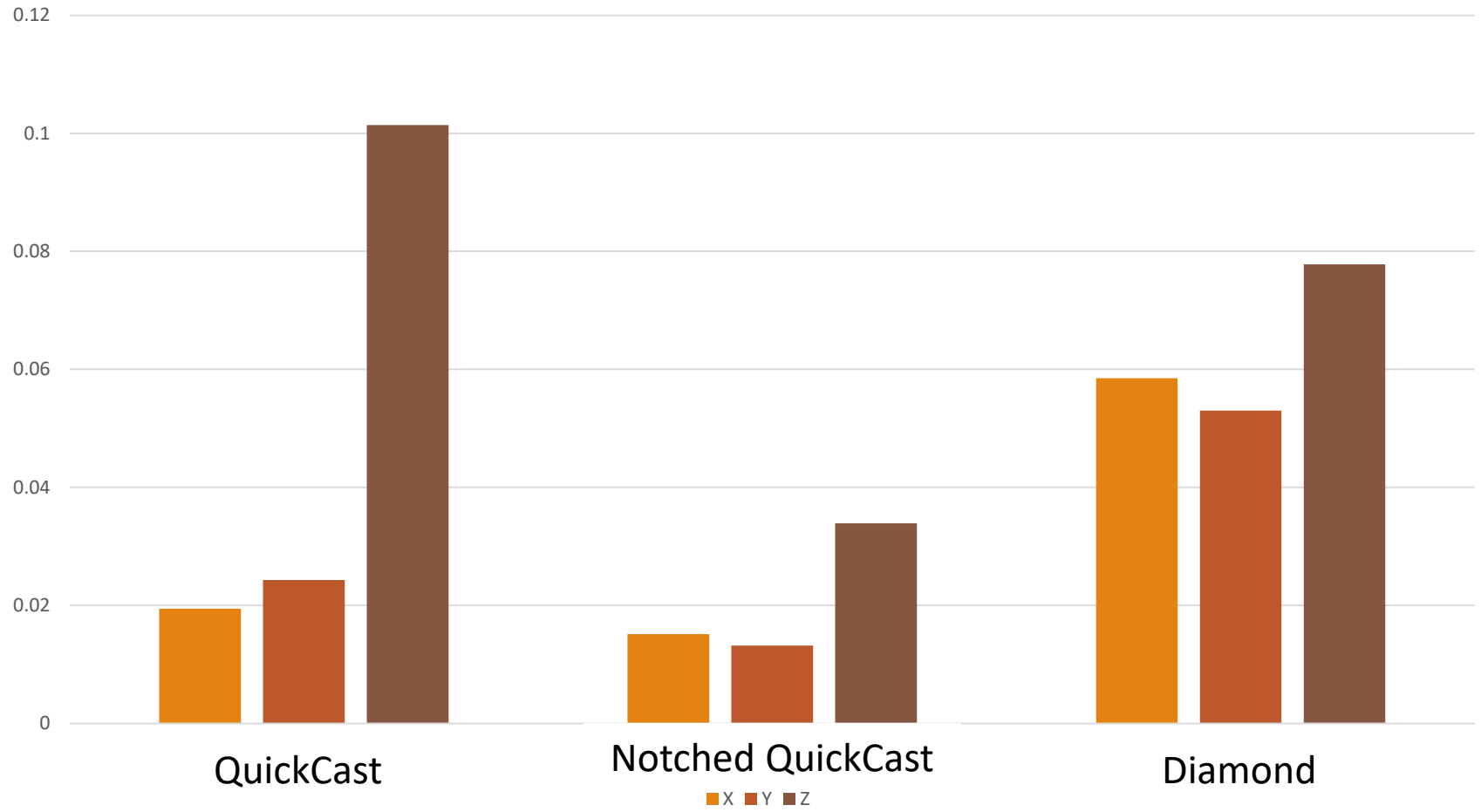
Notched QuickCast



Diamond


1 X
2 Y
3 Z
0.14
0.12
0.1
0.08
0.06
0.04
0.02
Force [kN]
0.5
1
1.5
2
2.5
Displacement [mm]

Force (kN) for 1mm Displacement



Comparison of the Three Build Styles

Objective	QuickCast	Notched QuickCast	Diamond
Reduced Stiffness		✓	✓
Uniform Stiffness		✓	✓
No Structure Modelling	✓	✓	✓
File Size	✓	✓	✓
Slice Time	✓	✓	✓
Build Time	✓	✓	✓

Project Status

FEA to determine cell sizes to control stiffness

Foundry testing to determine optimum stiffness

Foundry testing to verify results

- Does it really reduce shell cracking?

Conclusions

Alternative build styles exist that offer advantages over the current QuickCast build style

- Reduced stiffness
- More uniform stiffness
- Easily varied stiffness
- Maintain other advantages of QuickCast

If alternative build styles reduce shell cracking in the autoclave,

- It will lower casting cost and time
- Increase viability for low-medium volume production

Thank You!

Questions?