3D Printed Sand Casting of Low Density Gyroid Structures

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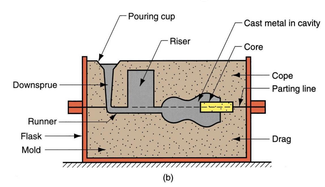
Abstract

Metal casting has been around for over five thousand years; the oldest surviving metal casting is a copper frog, believed to be cast around 3200 BC in Mesopotamia. The earliest recorded use of sand molds were in China in 645 BC.

Recently, additive manufacturing has revolutionized the way parts can be fabricated with this age old technique. By eliminating the use of patterns and utilizing direct-from-CAD production of sand molds, previously impossible geometries can be sand cast while simultaneously reducing lead times. This work demonstrates the ability to cast low density, highly complex lattice structures using 3D printed sand molds – a feat that could not be achieved with traditional sand casting methods.

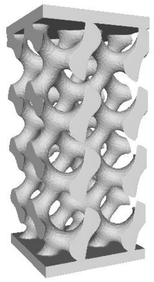


Left: Traditional metal casting process with a flask and pattern
Right: Additively manufactured sand molds

Gyroid Design Process

Low density lattice structures can be used in a variety of applications including lightweighting, energy absorption, and heat dissipation. However, such structures are inherently complex and pose significant challenges to fabrication.

The objective of our project was to design and cast low density structures using 3D printed sand molds. The results of our research demonstrate the feasibility of using 3D printed sand molds to create complex metal castings and represents a significant advance in mankind's oldest manufacturing process.



CAD Model

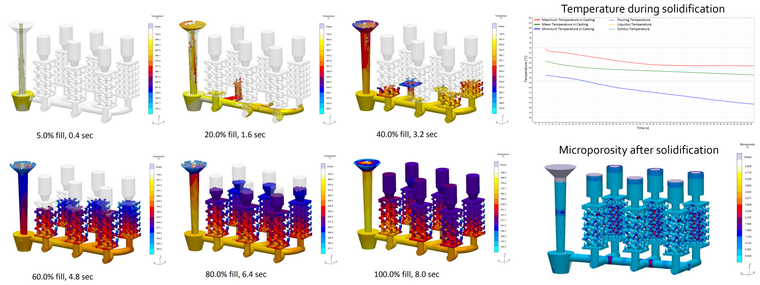
Cast Part

The architecture of the lattice structures used in this work is based on the gyroid triply periodic minimal surface. The gyroid is trigonometric in nature and is a three-dimensional analogy of a complex sine wave, hence it's periodicity. MATLAB was used for processing the CAD models.

MAGMA Casting Simulation

MAGMA is a computer program that has the ability to create 3D castings and simulate their pouring and solidification processes. This software is useful because pour rates, optimal conditions, and freezing points in the casting can be determined before metal hits the sand.

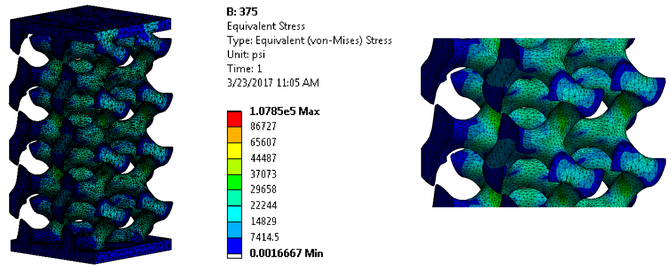
We used this software to create and test multiple gating systems to figure out an optimal pouring rate and determine if there would be any early freezing points in the castings. Below is the casting simulation model during filling & after solidification. This model showed us the micro porosity that would occur and possible problematic areas within the model or the casting.



ANSYS Structural Simulation

ANSYS is a finite element analysis (FEA) simulation program that is used to simulate mechanical testing on parts. This helps us run multiple testing conditions without requiring a physical part to gather data.

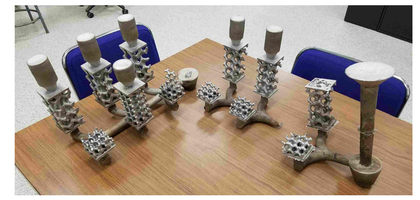
In our research, we compared two geometries with the same mass but different strut sizes (⅜" and ¼") to investigate structural efficiency. We ran a simulation on both sizes of models with a deflection of 0.03 inches (0.5% strain). The stress and strain of the parts were recorded and can be visualized in the figures below. A structurally critical spot on the part was then sectioned out and the maximum stress and strain of the area was used for failure analysis.

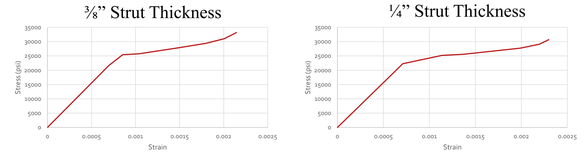


Results

The cast parts were allowed to cool for 24 hr and then manually removed from the sand molds.

Some early freezing was observed, causing half of the specimens to only partially fill. Failures primarily occurred in the smaller strut, higher surface area parts, corresponding to a higher rate of heat transfer and, therefore, faster cooling.

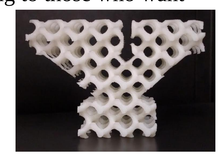




Above: The stress-strain simulations indicate that the ⅜" model is more structurally efficient than the ¼" model.

Future Applications

Low density metal cast structures can be used in load bearing applications. This is very useful for material and weight reduction. This method is also appealing to those who want to produce unique or complex structures. Another advantage of the gyroid architecture is that it can be embedded into existing models and external geometries.



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