Using Boron Nitride to Increase the Thermal Conductivity of 3D Printed Polymer Injection Molds

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Schweitzer Engineering Laboratories (SEL) is currently 3D printing resin molds for polymer injection molding which have large thermal gradients due to low thermal conductivity of the mold material. One additive being investigated as a potential route to improve mold life in FormLabs Rigid10k 3D printing resin is boron nitride due to its high thermal conductivity. The goal is to find an optimal volume fraction of boron nitride to add to the resin to increase the thermal conductivity while not sacrificing mechanical properties or harming the UV curing process.

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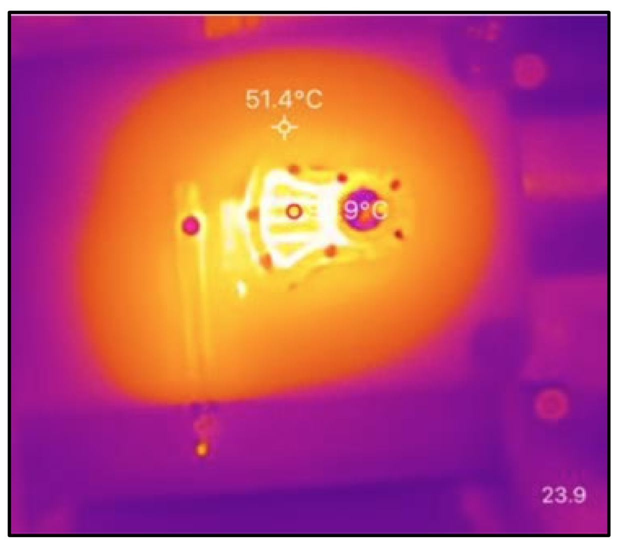
SCHWEITZER ENGINEERING LABORATORIES

Background & Objectives

Motivation:
Thermal degradation of SEL's injection molding molds and **long cooldown times** results in lower lifespans of the molds, frequent reprinting, higher costs, and environmental impact. Finding a **thermally conductive additive** for the 3D printing resin will increase **heat dissipation**, increasing the number of injection molding cycles, resulting in lower costs for the company over time. **Boron nitride (BN)** is a promising additive due to its high thermal conductivity (30 W/mK [2]) compared to FormLabs Rigid 10k resin (0.621 W/mK [1]).



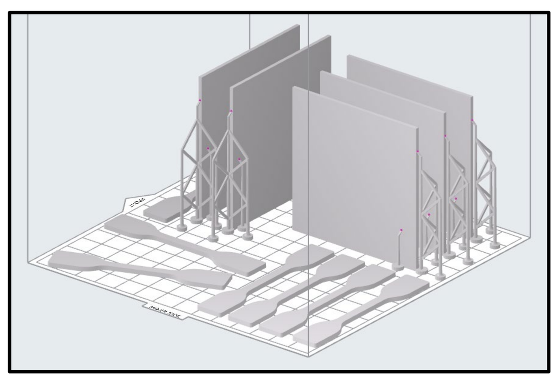
Heatmap of injection molded part showing thermal gradients

Constraints & Objectives:
SEL defined the following constraints and objectives to allow for the final product to function and improve the performance within both the printing and molding environments:

- Inclusion of BN must not affect **UV curing** of final part
- BN particles can't impede **bonding** between printed layers
- New formulation must have similar **mechanical performance** to original Rigid10k formulation
- Maximize **thermal conductivity** of mold system (minimum 15% increase)

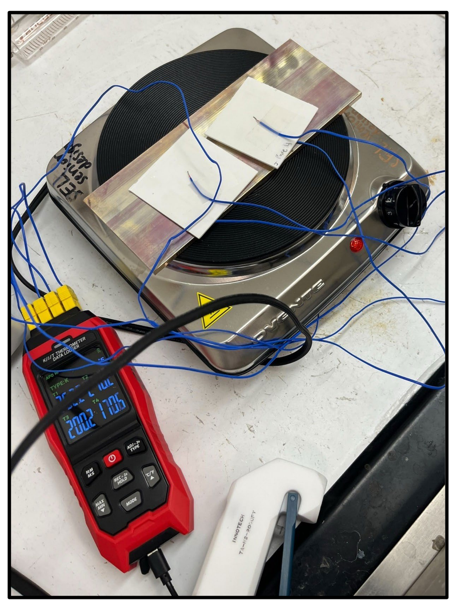
Experimental Methods

Printing:
Stereolithography (SLA) printing is an additive manufacturing method that involves a vat of thermosetting resin that **cures with UV light** onto a build plate, followed by **post-processing** that removes excess resin and completes the curing [3]. Printing was conducted using a FormLabs Form 3 printer. A **FlackTek high-speed mixer** was used to disperse the BN particles into the Rigid10k resin. The novel formulations with adjusted BN **volume fractions** were added directly to the tank of the printer and not to the cartridge to prevent contaminating the tubing of the printer with BN particles.



Printing layout of heat transfer slabs and tensile test dog bones

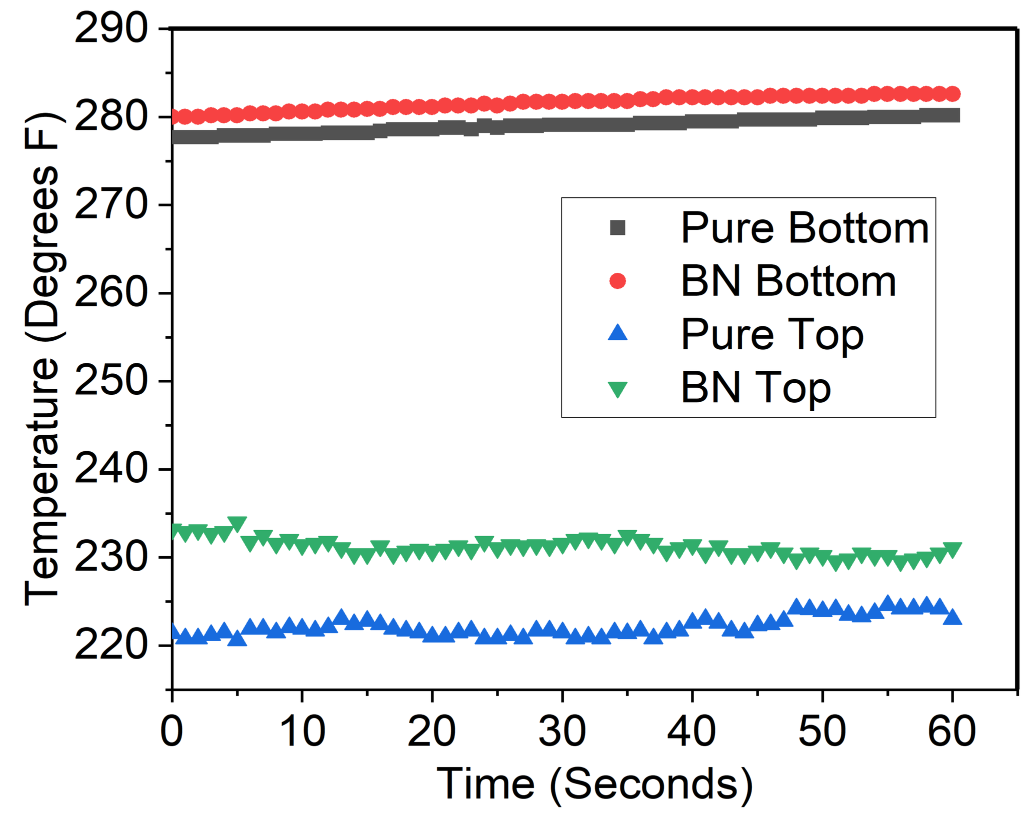
Heat Transfer Testing:
The experimental setup used the following ASTM standards as guides to allow for repeatable and accurate test results: **C518-21, C177-19, E1530-25**. An **isothermal base** was created using a hot plate and a copper heat spreader. Thin slabs were used as the test specimens to **minimize edge effects**. Thermocouples were placed in contact on the top and bottom surfaces, and the temperature difference was measured once the specimens reached **steady state**. One baseline slab and one BN slab were tested on the hot plate simultaneously to minimize error stemming from inconsistent heating rates.



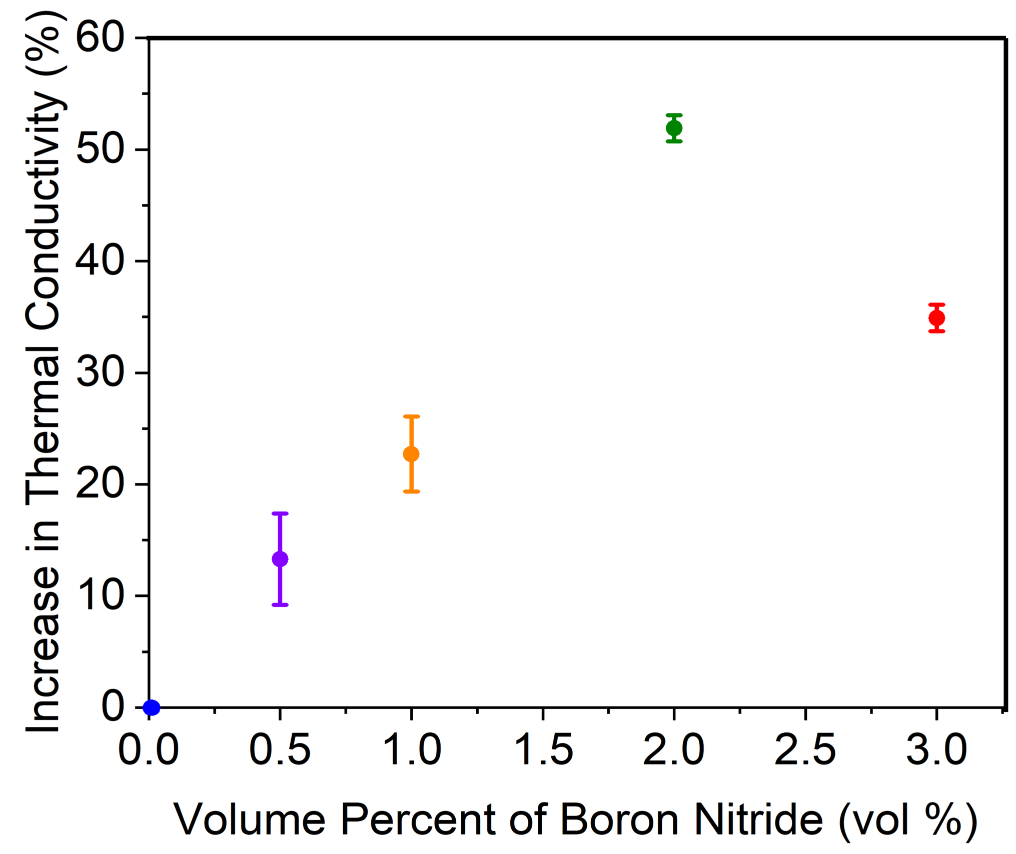
Heat transfer testing experimental setup

Tensile Testing:
Printed dog bone samples were tensile tested on an **MTESTQuattro** load frame according to **ASTM D638** for plastic tensile testing. The pull rate was **0.1 mm/min**. The **ultimate tensile strength (UTS)** of each sample was measured and was compared to the baseline prints.

Results



Thermocouple data collected from a representative heat transfer experiment at steady state.



An increase in thermal conductivity is observed with increasing volume fractions of BN. The lowest volume fraction that satisfies the goal of increasing the thermal conductivity by 15% is the **1.0 vol % BN** formulation.

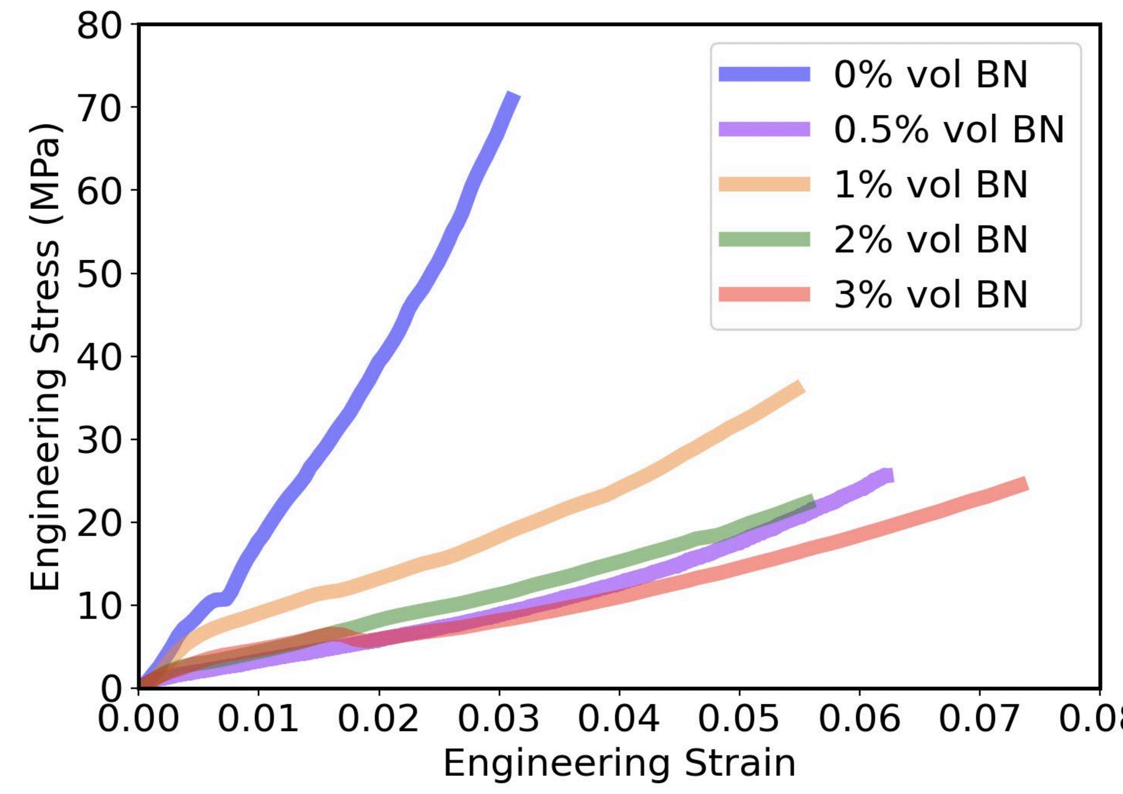
Volume % BN	0	0.5	1	2	3
Thermal Conductivity [W/mK]	0.418	0.459	0.562	0.591	0.568

Measured thermal conductivity values. The literature value for Rigid10k is 0.621 W/mK, so this suggests that there is some error in the heat transfer testing experiment [1].

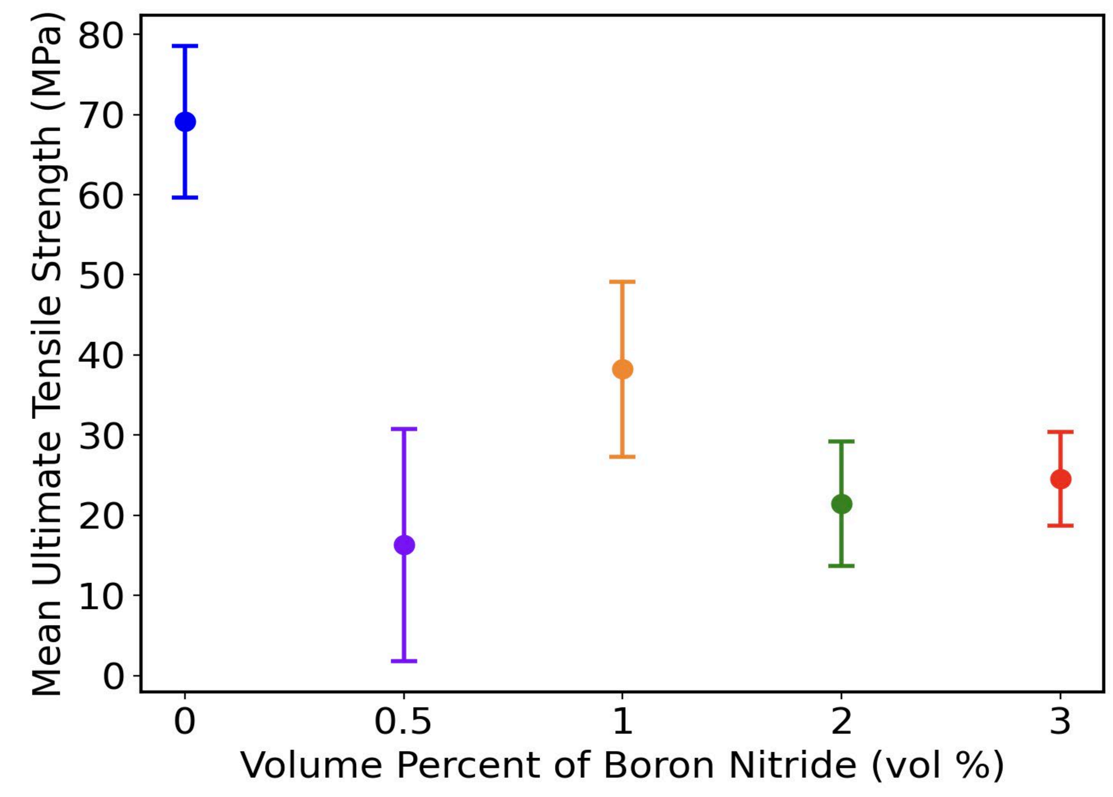
Test	Null Hypothesis	P-Value	Implications
One sample t-test on difference in all means	H_0: The mean thermal conductivity does not change with the addition of BN	0.000036	There is **sufficient evidence** that the addition of BN to Rigid10k causes a difference in the **means** of the thermal conductivity.
Wilcoxon signed rank test	H_0: The median thermal conductivity does not change with the addition of BN	0.000011	There is **sufficient evidence** that the addition of BN to Rigid10k causes a difference in the **medians** of the thermal conductivity.

The completion of a one sample t-test on the difference in means between the pure and BN containing specimens was carried out. This shows that the addition of BN to Rigid10k has a **significant effect on the thermal conductivity** of the material at the α=0.05 level. A Wilcoxon signed rank test was then completed on the differences. This is a non-parametric test that is more robust than a t-test as it does not assume normality. The result was that the addition of BN to Rigid10k has a **significant effect on the thermal conductivity** of the material at the α=0.05 level.

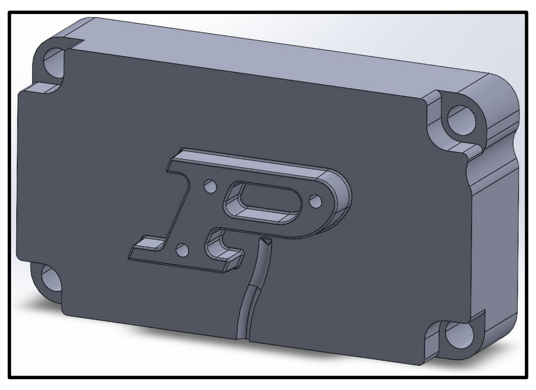
Results Continued



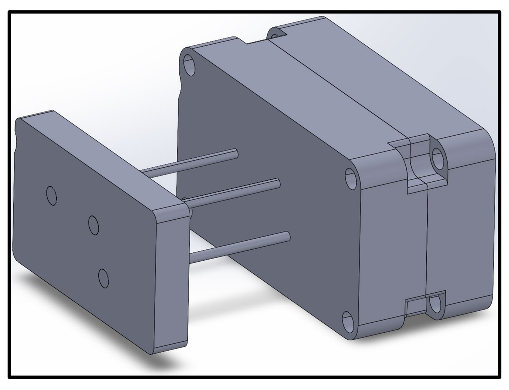
Tensile testing data with one representative curve from each print formulation.



Tradeoff plot of mean ultimate tensile strength versus BN volume percent. There is a decrease in UTS as more BN is in the mixture, possibly due to side effects in curing of the Rigid10K.



Mold Core



Full Mold System

Injection molding mold schematic for printing out of BN resin to produce "Purdue P" shapes out of polycarbonate. The final test is to print a full mold with the most promising BN formulation that meets all the curing, mechanical performance, and thermal conductivity increase objectives.

Conclusions

- BN increased the thermal conductivity of Rigid10k 3D printing resin without harming the printability at low volume percents (< 3 vol %), however the UTS decreased with BN additions
- 1 vol % boron nitride meets the objective of increasing the thermal conductivity by at least 15%, with the lowest decrease in UTS, making it the ideal choice for the first mold print

Acknowledgments & References

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[1] *Rigid 10K Short-run injection molds and inserts Heat resistant and fluid exposed components, jigs, and fixtures Simulates stiffness of glass and fiber-filled thermoplastics Aerodynamic test models.* (2022). https://formlabs media.formlabs.com/datasheets/2001479-TDS-ENUS-0.pdf
[2] *Boron Nitride Thermal Management.* (2022). Kennametal.com. https://catalogs.kennametal.com/infrastructure/Boron-Nitride-Thermal-Management/1/
[3] *SLA 3D Printing: How It Works and When to Use It | Stratasys.* (2026, March 30). Stratasys.com. https://www.stratasys.com/en/resources/blog/sla-3d-printing/

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