Improving Thermal Conditions and Reducing Process Costs for Core Setters in Aerospace and IGT Applications

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In the continuous improvement of investment cast blades for Aerospace and IGT applications, the associated ceramic core technology is also being pushed to new limits. With increased tolerances and intricate geometry, ceramic cores require accurate processing that is consistent and cost effective.

In our previous paper, "Effects and Analysis of Thermal Stresses on Core Setters for Aerospace Applications", we reviewed the benefits of using core setters with matched 3D geometry, to reduce the effects of sintering the ceramic core. We continue with this subject matter as we look at optimal core setter design for thermal consistency, through comparing the thermal profiles for ceramic setters, kiln layout optimization and a discussion of core setter material selection. Our goal is to provide solutions for aerospace foundries and core producers on how to improve yields, generate core consistency, and reduce scrap and energy costs.

Thermal Profiles During Core Sintering and Processes Variances

Having previously reviewed the concepts of sintering (heating) and its effects on ceramic cores; we concluded that these effects can be reduced through the use of a ceramic setter. Additionally, having higher variabilities in the sintering can result in higher stresses and geometric deformation in the ceramic cores, as referenced in Figure 1.

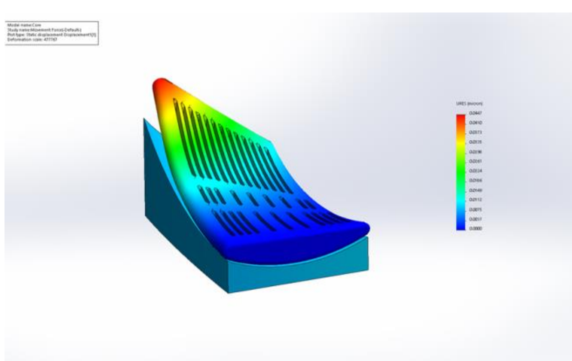


Figure 1: Stress and Deformation of Ceramic Core Under Thermal Load

From this we can theorize that providing more consistent and even heating to the ceramic core during sintering will reduce stresses and improve part consistency.

Our analysis spanned three settering designs: A grog filled sagger, a standard ceramic core setter, and an optimized ceramic core setter.

Figure 2 shows the modelled sagger with grog, representing a simple and common way to set ceramic cores.

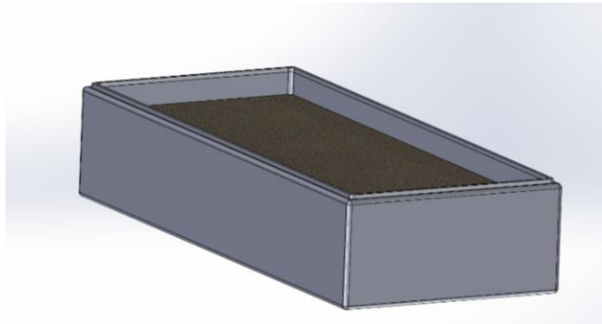


Figure 2: Grog Filled Sagger

Figure 3 models a simple ceramic core setter, a noted improvement over the grog filled sagger, However, this displays an inconsistent wall thickness.

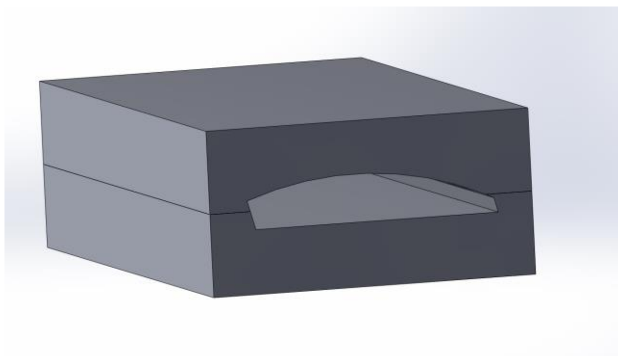


Figure 3: Simple Ceramic Core Setter

Finally, the thermally optimized ceramic core setter is shown in Figure 4, with the thermal mass reduced while still maintaining structural integrity. This allows for a consistency in wall thickness, further aiding in uniform heat transfer.

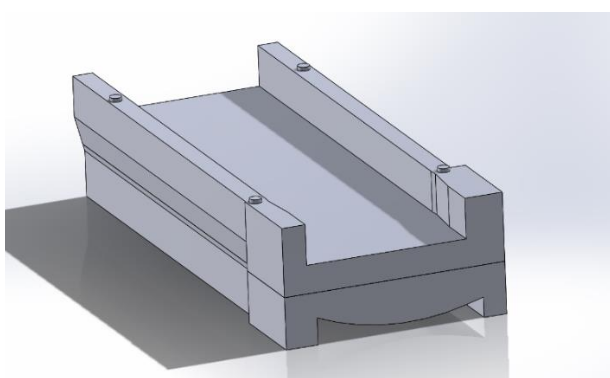
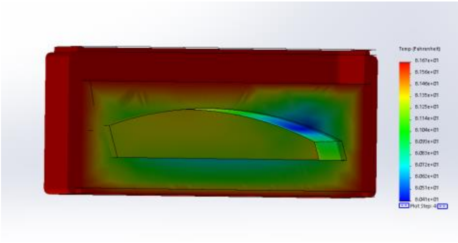


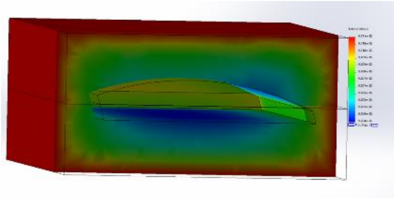
Figure 4: Thermally Optimized Ceramic Core Setter

All three models' overall length, width, height, and material were identical for the studies run.

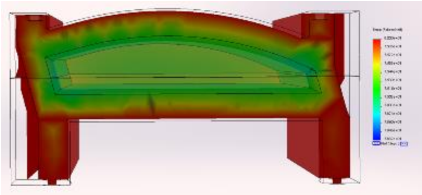
Using thermal modelling in Solidworks' FEA software, we produced a thermal profile under transient heating for our three models, displayed 820 C in Figure 5.



(a)



(b)



(c)

Figure 5: Thermal Profiles of Three Settering Designs at 820 C

At this temperature the core in a core setter with an optimized wall thickness, Figure 5c, has reached a higher internal temperature sooner. This is due to the reduced total mass, requiring less thermal energy to be heated. Also, we see the more uniform thermal temperature profile of the setter around the core. Conversely, we can see the blue spots in areas around the unoptimized setter, Figure 5b, and in the core in sand, Figure 5a. This variance is caused by the relatively uneven thermal mass of these unoptimized setters, which require more heat (thermal energy) in the thicker areas to bring the core up to the same sintering temperature. It is safe to assume an increase in time might be required to allow the setter and core to heat thoroughly.

From this review, we are showing that having the core set into a thermally optimized ceramic core setter, will provide a more even sintering temperature, along with using less thermal energy to get to that planned sintering temperature.

Kiln Loading Optimization

Now that we have optimized the geometry that we are firing the ceramic core in, we analyzed different organization profiles for improving and optimizing the orientation of setters in the kiln used for sintering.

Though not always the case, we will assume that our kiln is evenly heated with no apparent “dead spots” for heating. An example of this even flow is shown in Figure 6.

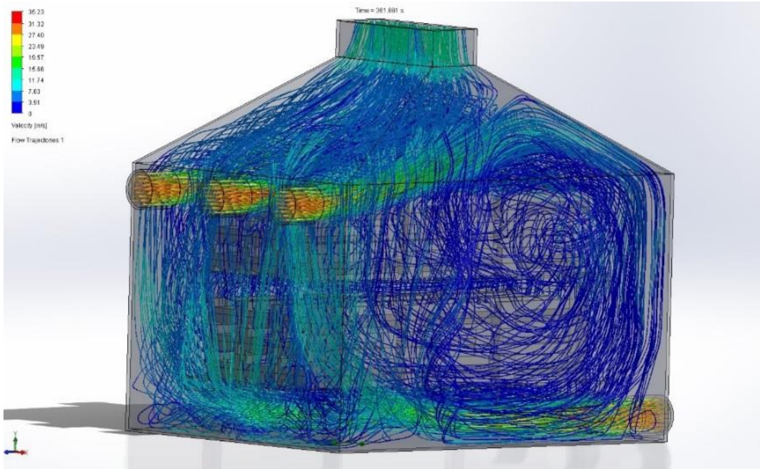


Figure 6: CFD Modeling of Even Flow

Using an evenly heated kiln, we can focus on setting up and arrange setters into the kiln for the best orientation for heating and thermal load optimization.

In Figure 7 we show an example where saggers with sand/grog are set into the kiln tightly packed together.

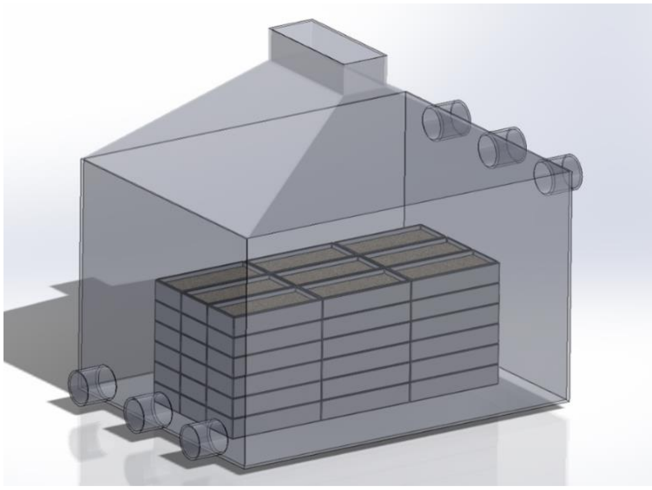


Figure 7: Tightly Packed Grog Saggers in Kiln

With the layout as shown, the heat profile for the large blocks of setters will act as one large object for heating; similar to the thermal model shown for the individual saggars, there are large variants in the temperature distribution and more energy is needed to bring the center saggers up to the required temperature.

Figure 8 shows the kiln load better optimized for heat transfer.

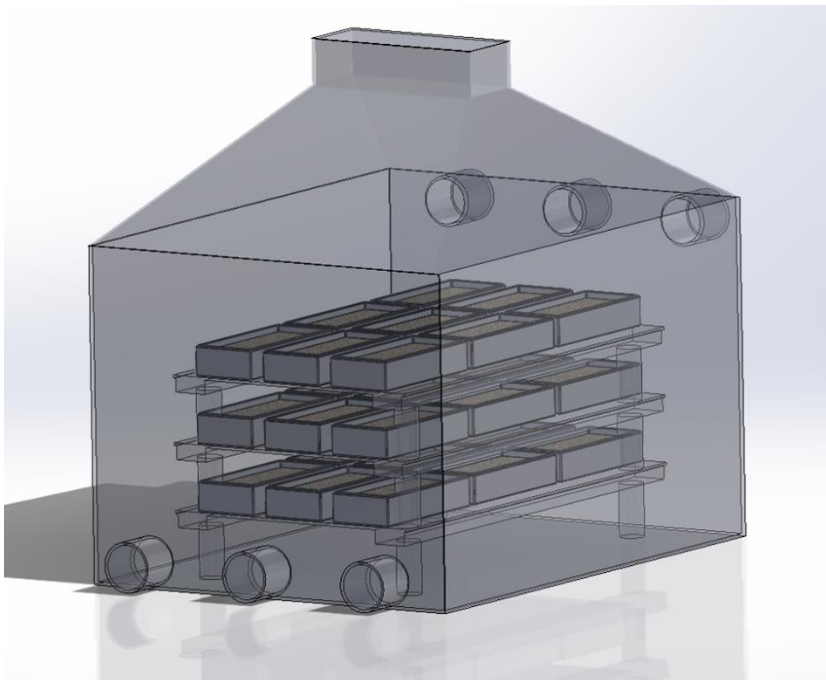


Figure 8: Improved Spacing in Kiln Layout

The saggers are spaced with gaps around them. This is done by using kiln furniture interlocking beams and plates. The kiln furniture structure allows this orientation, and in addition is made from a thermally conductive ceramic with assists in heat transfer.

In this next example, Figure 9 and Figure 10, we show a similar stacked kiln orientation, but now with the optimized ceramic core setter.

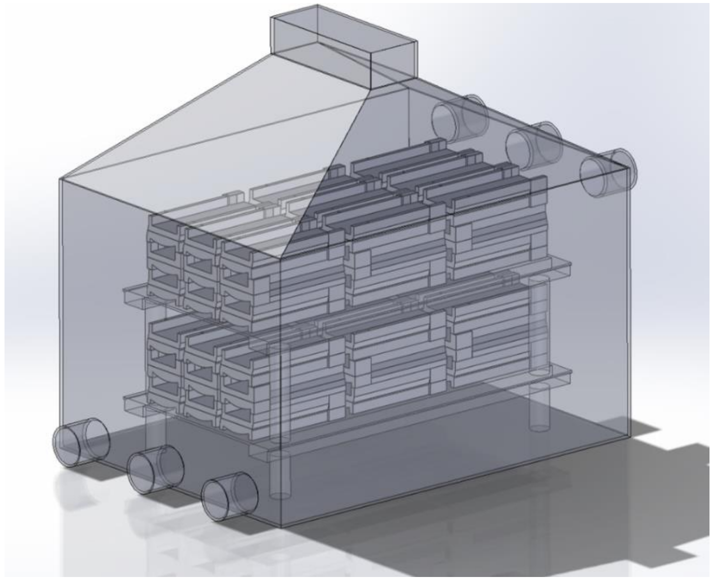


Figure 9: Isometric view of Kiln with Optimized Setters with Optimal Layout

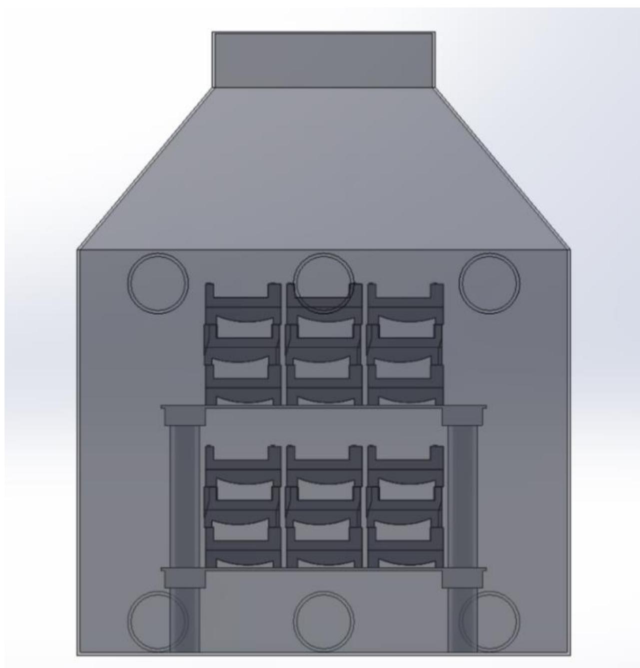


Figure 10: Front view of Optimal Layout

As shown, using the optimized ceramic core setter design, we have integrated stacking capability into the core setter which allows increased heat transfer around the setter and reduces the amount of kiln furniture required to accomplish this. Even spacing can also be accomplished with or to assist with automatic loading and unloading systems.

We see that organizing the kiln using a planned kiln furnace layout and even spacing of setters will allow the ceramic cores to have more uniform heating and allow better thermal profiles for sintering no matter what type of core firing technique is used. Adding design features into the core setter can optimize the thermal profiles even further.

Core Setter Material Selection

Core setter material also plays a vital role in the sintering and consistency of the finished part. Material characteristics that are most crucial to settering include: thermal shock resistance, part geometry tolerance, and ceramic creep resistance.

Thermal Shock Resistance:

The environment of the kiln sintering process requires heat cycling from ambient temperature to 1,200C, so the ceramic must be highly resistant to thermal cycling, called thermal shock.

Part Geometry Tolerance:

As the design of aerospace blades continues to evolve, the cores necessary are increasing in complication and complexity. To provide a matched 3D designed core setter to properly hold the core, high as-cast tolerances are required for the setter to function properly. Cast part tolerances near the range of .005" per inch are needed in the core setter and the forming process for the ceramic core needs to provide for this.

Ceramic Creep Resistance:

As the ceramic core setter thermally cycles potentially hundreds of times, the ceramic needs to resist any movement or change in tolerance through these cycles. This phenomenon can be tested by a three-point bend creep test, Figure 11. In this test, a single point weight is placed on a test bar of material, and is heated for the predetermined cycle. Once cooled the test bar is then measured for movement.

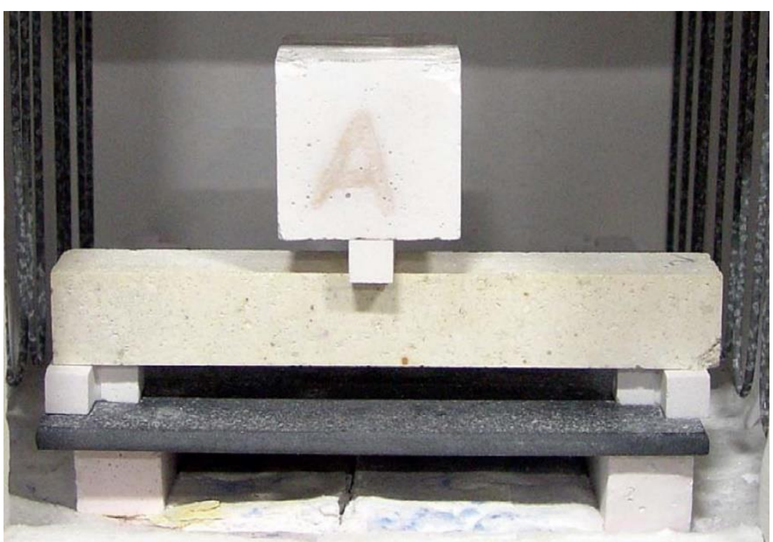


Figure 11: 3-Point Bend Creep Test Setup

As we develop materials for core setters, the creep test is a great developmental tool. Blasch recently developed a new material which was creep tested along with two other materials for reference as shown in Figure 12.

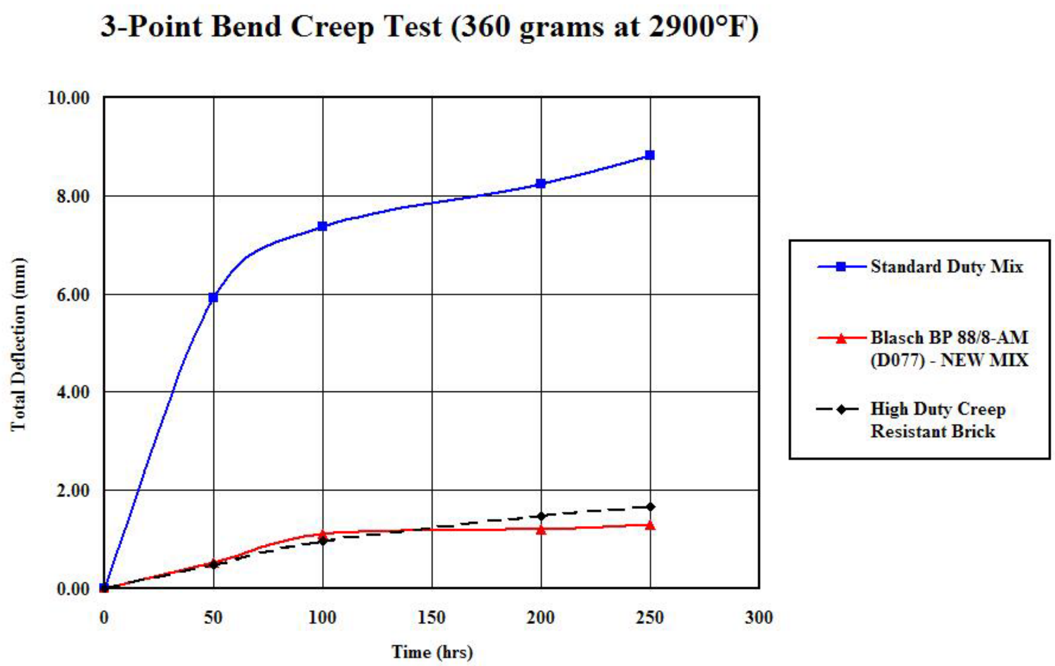


Figure 12: Results of 3-Point Bend Creep Test for Three Materials

We tested three materials: a standard refractory material, an industry standard high duty creep resistant brick material, and a new Blasch developed material. Displayed by total deflection over time (less deflection being better) this newly developed material showed a substantial improvement over a current industry standard creep resistant brick material. Improvement has also been noted in core setter life and tolerance stability over repeated firings with this new material.

The optimal conditions for sintering complex cores are as such: a uniform spaced kiln layout utilizing thermally optimize core setters made from high tolerance, thermal shock and creep resistant material. Blasch has over 40 years in ceramic materials and processes to help improve your foundries core sintering process.