The Impact of Complete Lubricant Removal on the Mechanical Properties and Production of Powder Metal Components

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The greatest hurdle to the sintering of powder metal components has always been the removal of the lubricant from the compact. This lubricant is necessary for the ejection of the compact from the compaction press. Although the industry has worked to reduce the amount of lubricant that is mixed into the powder, there is always a need for some. The problem arises when the compact is to be sintered. The lubricant must be removed from the compact or a carbon residue will form and detrimentally impact the properties of the final product.

Over the years, equipment and processes have been implemented to help in the removal of the lubricant from the compact during the sintering process. Unfortunately, this technology was not successful in removing all of the lubricant nor was it able to stay in step with the advancements in molding technology that continued to increase the density of the part from the press.

Recent developments in the sintering process have resulted in a paradigm shift in the way that lubricant removal is addressed. This new technology is called the Vulcan process. A process and accompanying equipment, the Vulcan has demonstrated the ability to remove all the lubricant from the compact. The result of which is the increase of physical properties of the sintered part and a significant opportunity to reduce the cost of production without compromising quality.

Introduction

The work horse of lubricants used in the production of conventional press and sinter components is Acrowax^{TM} C. This is an N,N' ethylene bis-stearamide-based synthetic wax (EBS) with a melting point between 140^{o}C to 145^{o}C (Lonza Group).

For a long time, it was believed that this lubricant would melt and vaporize early in the process; however, the formation of soot, resultant of the decomposition of the EBS to form carbon, continued to be a problem. The soot causes contamination of the sintering furnace, carbon deposits inside of the part, and variation of the properties in powder metal compact. Many equipment modifications and process changes were made to help this issue; however, the problem remained.

A mechanism for the formation of soot from EBS was proposed by Levenduski and Feldbauer and validated by the work of Powell, Stringer, and Feldbauer (Robert Powell).

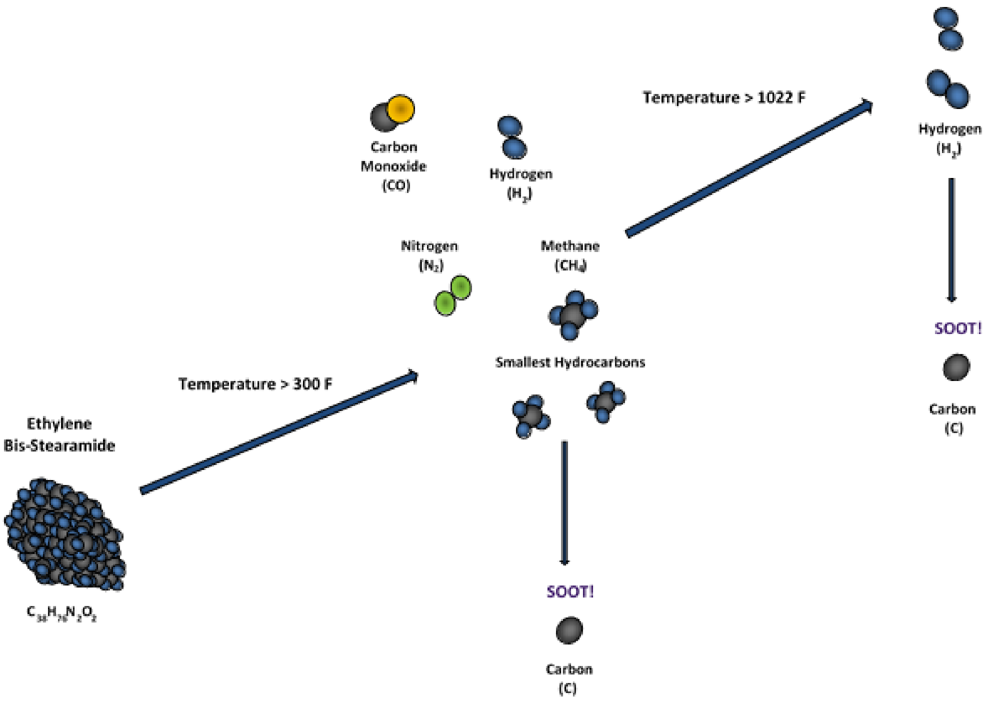

Figure 1. Mechanism of soot formation (Edward Levanduski and Stephen L. Feldbauer)

This mechanism defines the critical temperature range for the removal of EBS as 145°C to 545°C. It is in this temperature range that the EBS with melt and flow out of the compact via capillary action; however, the temperature is not high enough to cause the total dissociation of the EBS to soot and hydrogen.

Although the EBS does not dissociate, the hydrocarbon will break down. As the hydrocarbon "unravels", a small amount of carbon is dropped.

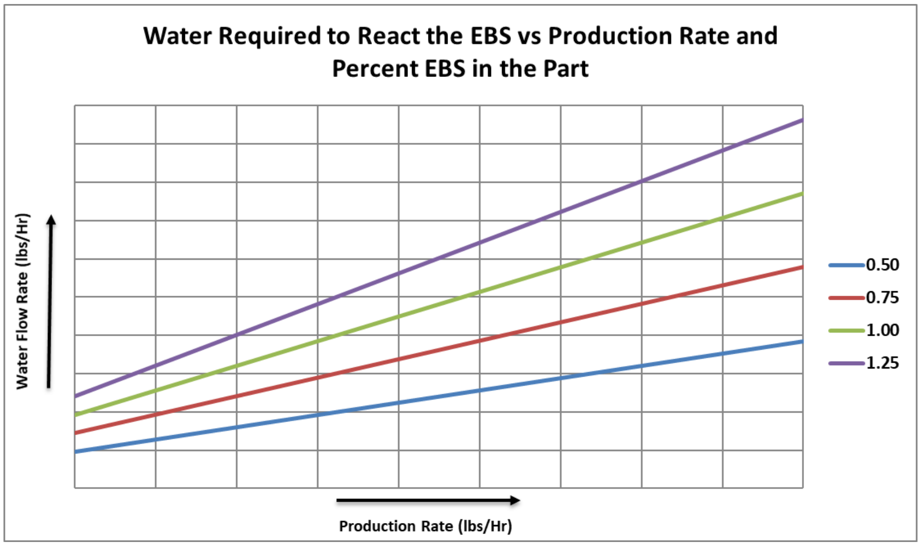

Figure 2. Water flow rate to react carbon during lubricant dissociation. (Stephen L. Feldbauer)

For this reason, Feldbauer goes on to describe the need for a very controlled amount of oxygen in the system to react with the carbon. Moisture is the most controllable form of oxidizing media that will react and remove the carbon. Figure 2 illustrates the wide range of water flow rates that are needed with changing lubricant contents and production rates. (Stephen L. Feldbauer)

In the paper by Powell, Stringer, and Feldbauer (Robert Powell), the time to remove EBS as a function of the green density was measured and mathematical model developed.

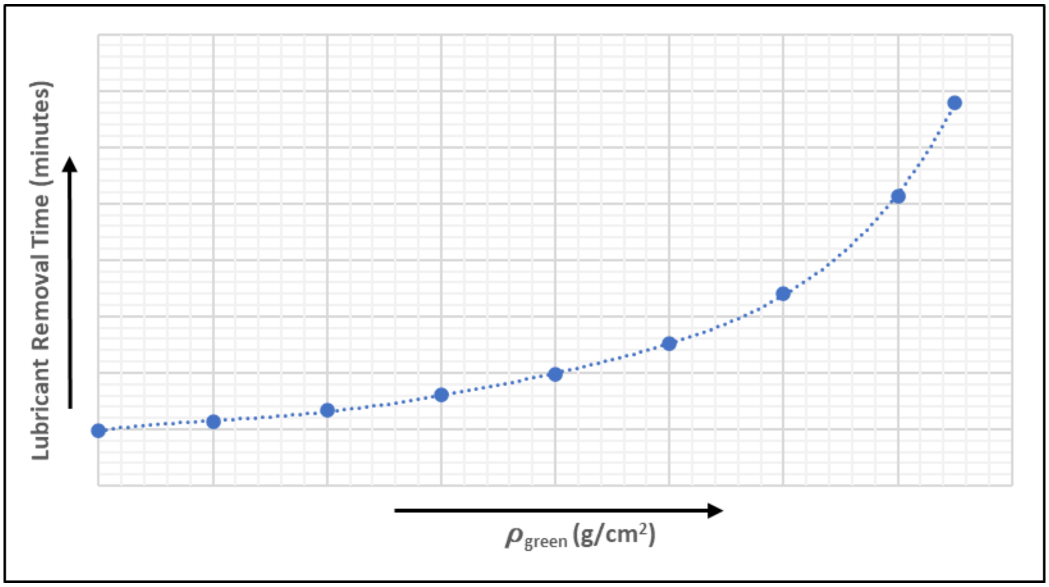

Figure 3. Lubricant removal time as a function of density model. (Robert Powell)

Prior to this work, the “rule of thumb” for the time needed to remove the lubricant from an iron-based compact was 20 minutes. Although Powell, Stringer and Feldbauer demonstrate that a compact with a density of 6.2 g/cc stops losing weight in approximately 22 minutes, the compaction technology has made significant advancements over the past ten years. The typical density of an iron-based powder metal compact today is above 6.8 g/cc and it is now common for producers to compact to densities as high as 7.5 g/cc for some products. The result is a lubricant removal time for EBS that is significantly longer.

An Innovative Approach

Until recently, equipment and processing have not been designed to accommodate the increased densities from continued compaction advancements or the clearer understanding of the temperatures that are critical to the removal of EBS. Traditional equipment and processes have constantly moved toward increasing temperatures to deal with issues of lubricant removal and sintering quality. The opposite of what has been described above. This has led to a continued issue with product quality and equipment maintenance.

Recently, an innovative approach to incorporating this new knowledge has led to a paradigm shift in the way that powder metal components are processed. The process is called the Vulcan. It gets its name from the Roman god of metalworking and incorporates all the research described above.

Figure 4. Vulcan System.

The optimal temperature range for the removal of lubricants is low in comparison to typical sintering processes. A conventional sintering furnace will have difficulty holding the compacts in this range because of the radiant style of heating used. The result is a rapid heating of the product and lubricant that dissociates to form soot, both internal and external to the compact.

This optimal temperature range requires a convective heating source for the initial portion of the Vulcan process. The convective heat transfer coefficient is a strong function of atmosphere chemistry and velocity. (DeWitt) This, along with loading and belt speed, provide a great deal of heating control, which enables the time in the optimal temperature range to be adjusted to accommodate the density, product loading, and mass of the compacts.

The Vulcan uses an independent moisture source that provides fine control of the amount of water that is introduced. The injection location and fine moisture control provide moisture to react with any carbon that is being dropped during the lubricant break-down. Moisture injection in conventional systems is typically insufficient, difficult to control, or influences the thermal control of the system, all negatively influencing the quality of lubricant removal process.

Comparing Performance

To evaluate the performance advantages and impact of lubricant removal on quality, a series of tests were conducted. Transverse rupture strength (TRS) samples were sintered with the Vulcan process and compared to those produced using a conventional sintering process. Samples of an FC-0208 material were molded with EBS lubricant of varying amounts, ranging from 0.30 wt%, 0.50 wt%, and 0.75 wt%. Among these samples, the molded density was varied from 6.8 g/cc, 7.0 g/cc, and 7.2 g/cc. Finally, the samples were sinter in two configurations on both the Vulcan and conventional furnace. Some were processed in a single layer on a ceramic plate. Others were sintered between plates to simulate a double stacked condition.

Figure 5. Photo of TRS samples loaded on the conventional sintering furnace.

The Vulcan and conventional sintering furnace were configured the same. Each has a pre-heat section that is 240 inches long, a high heat section that is 240 inches long, and a 24 inches wide wire mesh belt. Both furnaces contain 8 zones of heating control, 4 zones in the high heat section and 4 zones in the pre-heat section. These zones were set for each furnace to achieve optimal lubricant removal, a sintering temperature of 1135^{o}C, and approximately 22 minutes at the sintering temperature for each system.

The thermal profiles of these two systems demonstrate the paradigm shift in the way that products are sintered in the Vulcan process. Notice that the temperatures and times are much different from what has been considered optimal lubricant removal in conventional sintering. The Vulcan operates at a much lower pre-heat temperature and maintains the product in the optimal temperature range for lubricant removal for a much longer time.

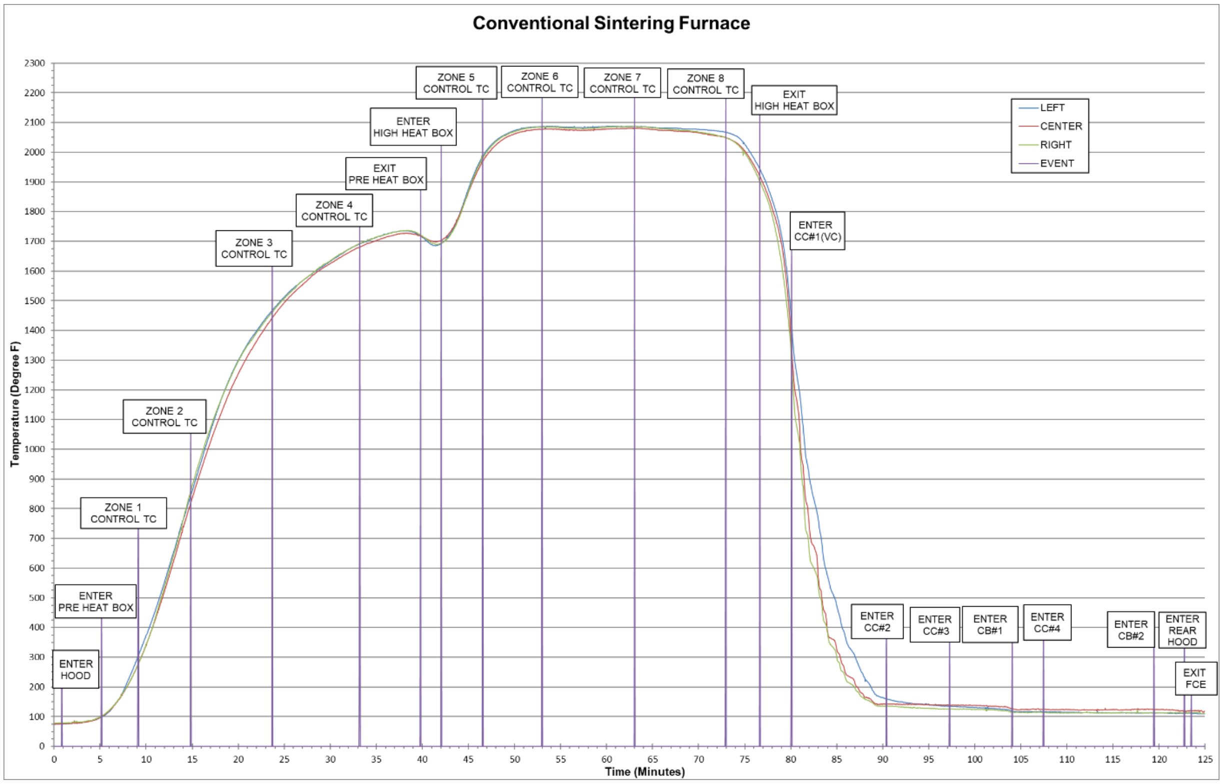

Figure 6. Profile of conventional sintering furnace.

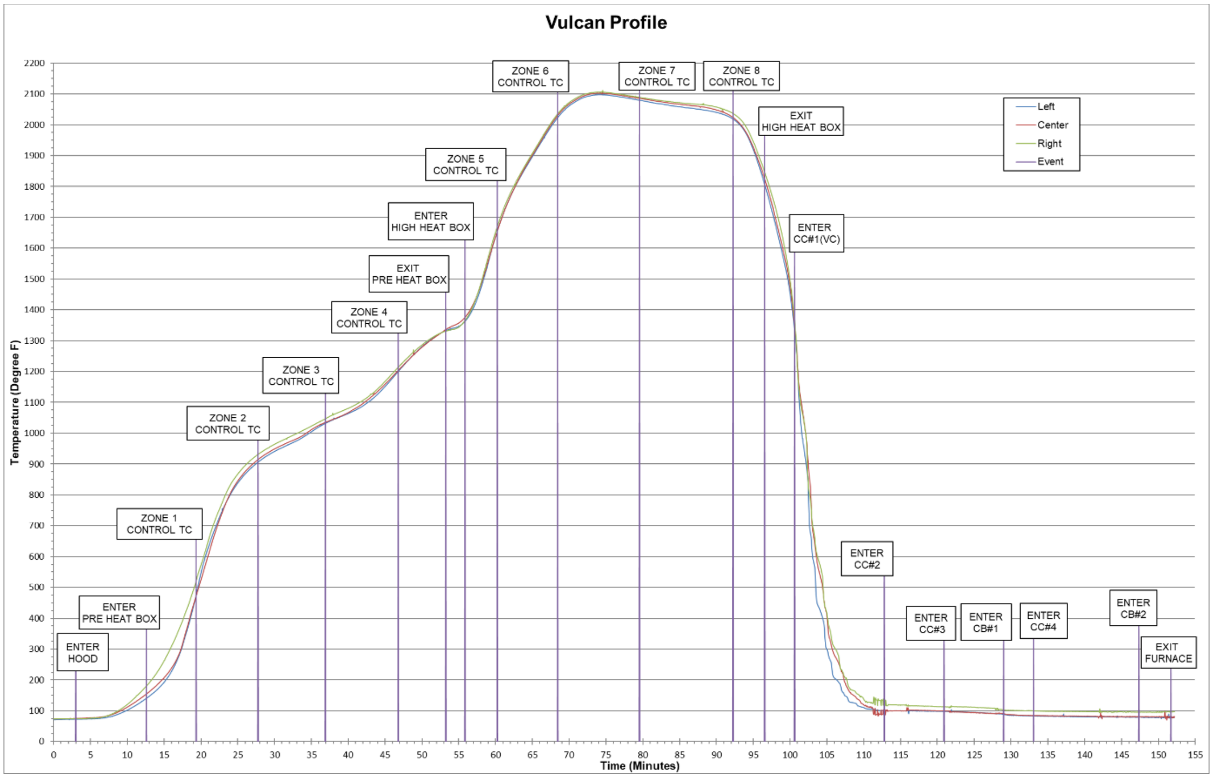

Figure 7. Profile of Vulcan furnace.

Weight Loss

Weight loss was evaluated for all samples. TRS samples were weighed before and after sintering. In all cases, the weight change was greater than the initial amount of lubricant in the sample; however, weight loss has two contributors in its total value, the removal of the lubricant and the removal of oxygen during the oxide reduction step of the sintering process. It is still valid to compare the weight loss because the amount of oxygen in the original powder should be the same for all samples. Hence, a failure to achieve the same level of weight loss under the same conditions can be attributed to a failure to remove the lubricant from the compact.

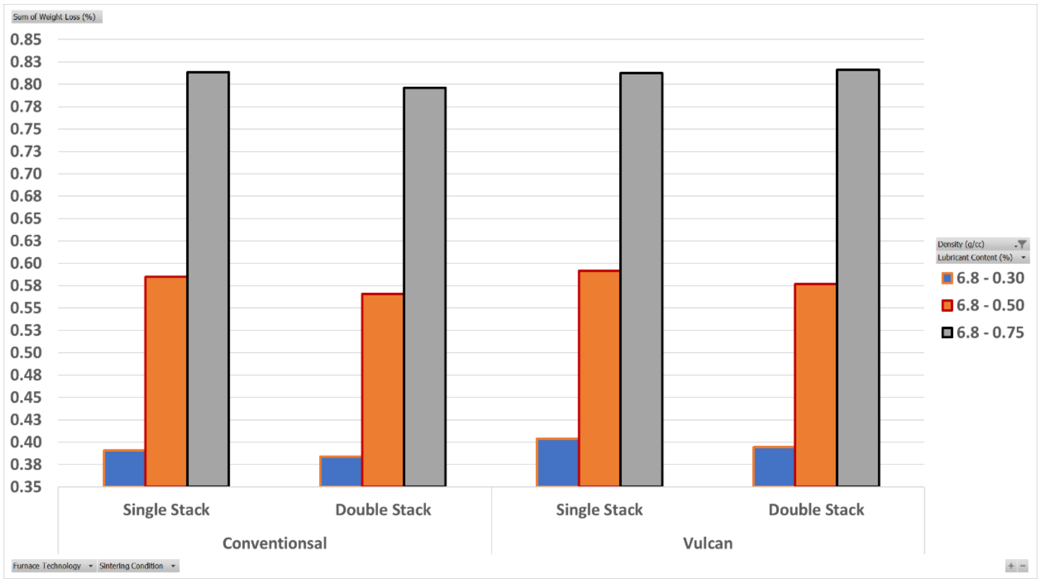

Figure 8. Weight loss for 6.8 g/cc density versus lubricant content.

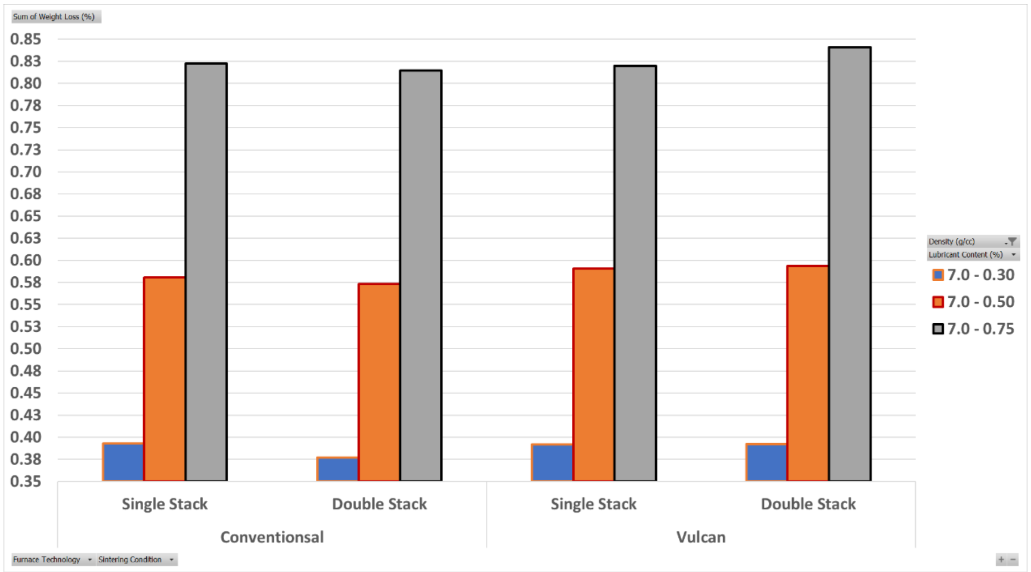

Figure 9. Weight loss for 7.0 g/cc density versus lubricant content.

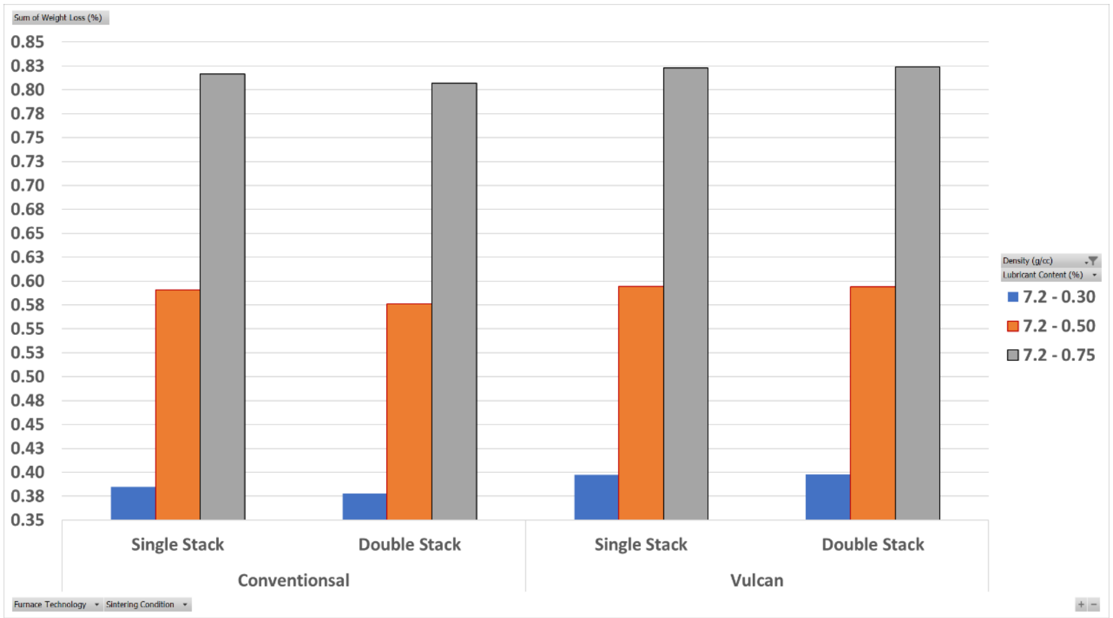

Figure 10. Weight loss for 7.2 g/cc density versus lubricant content.

Although the comparison yields small differences in the total weight loss under comparable conditions, in most cases the weight loss was less in the conventional furnace than in the Vulcan. It is also important to note that the weight loss in the double stacked condition for the Vulcan is often better than the single stack condition in the conventional furnace.

The variation seen when double stacking may be attributed to a couple factors. First, the loading condition impedes the atmosphere flow around the parts. The second is the heating rate. The double stacked condition has more thermal mass. Since the speed was kept the same for the tests, the double stacked load would have heated slower and had a slightly reduced time in the optimal temperature range. The convective heating in the Vulcan helps to minimize the influence of these factors.

Transverse Rupture Strength

Transverse rupture strength data was collected from the sample in each processing condition. The largest difference between TRS results is in the samples molded at 6.8 g/cc. In some case, the samples that were sintered in the single stacked condition on the Vulcan had as much as a 20% greater transverse rupture strength than those of the same condition that were sintered in the conventional furnace.

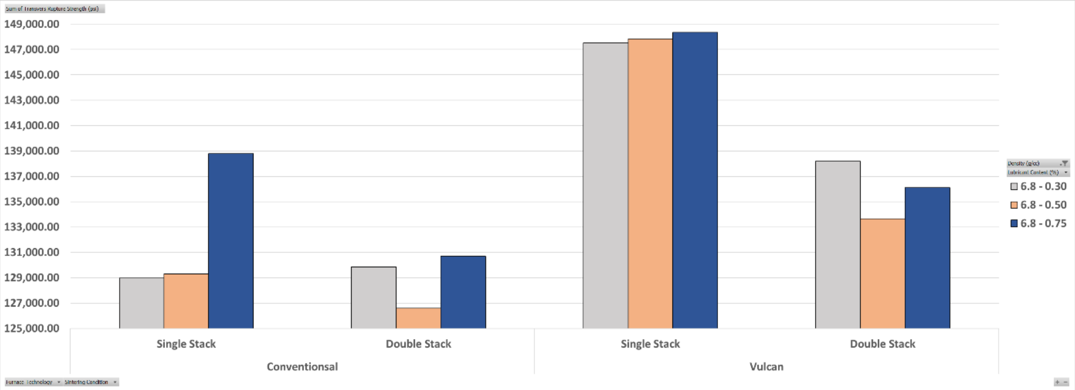

Figure 11. Transverse Rupture Strength (psi) for 6.8 g/cc density versus lubricant content.

The data continues to demonstrate the importance of the lubricant removal. As the molded density is increased, there is a significant improvement in strength for those samples sintered in the Vulcan process.

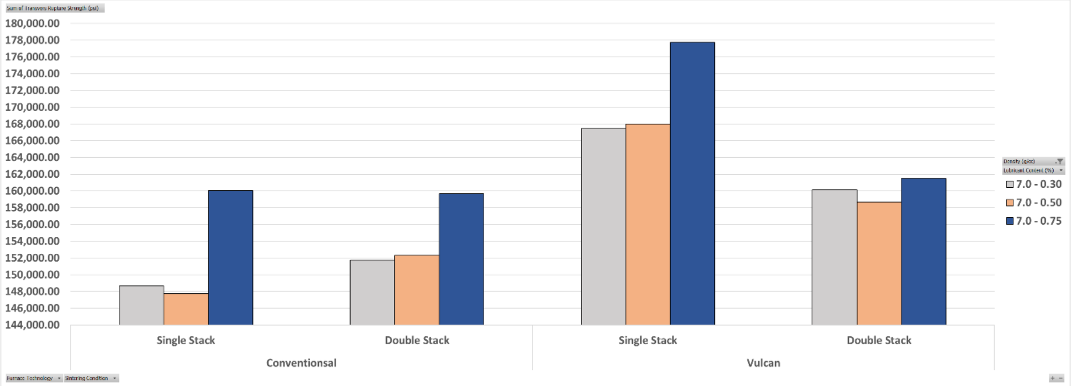

Figure 12. Transverse Rupture Strength (psi) for 7.0 g/cc density versus lubricant content.

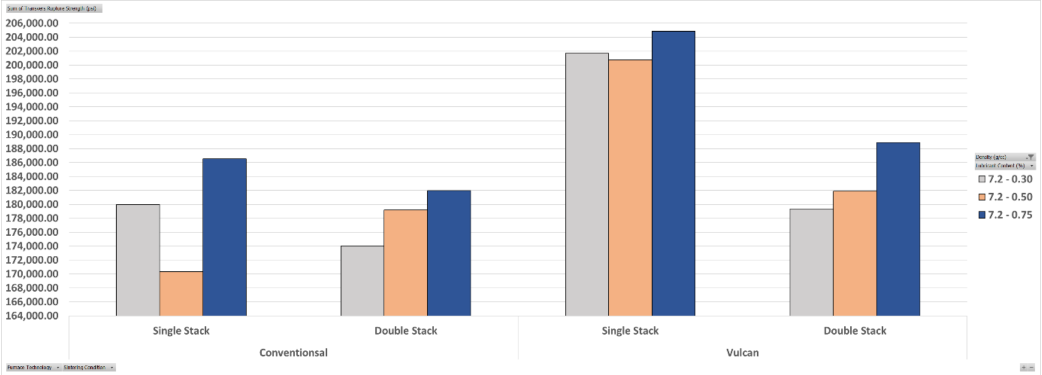

Figure 13. Transverse Rupture Strength (psi) for 7.2 g/cc density versus lubricant content.

At a molded density of 7.2 g/cc, a density that is known to be a challenge for the EBS system, the Vulcan shows a large improvement in the properties of the product.

An important aspect to note, in all cases, the product that was sintered in a double stacked condition on the Vulcan system has strengths that are equal to or better than those sintered in a single stacked condition on the conventional system. This is would indicate that the Vulcan has the potential to produce at twice the production rate and still produce a product that is equal to or superior to one sintered on a conventional furnace.

Conclusion

A comparison was made of the Vulcan process to a conventional sintering process for an EBS lubricant system at various lubricant contents, densities, and loading conditions. In all cases, the Vulcan demonstrated the importance of removing the lubricant and the resultant improvement on the sintered strength.

It was demonstrated that the Vulcan process affords two distinct advantages over the conventional sintering process. The producer has a choice in how to realize these advantages. They can produce a superior quality product, or they can produce a comparable quality product at twice the rate.

Special Thanks

The authors would like to extend a special thank you to Symmco Inc. for granting us access to their laboratory. Without their cooperation, the project would have not been possible.

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