A COMPARISON OF METHODS OF REACHING HIGH GREEN DENSITIES USING ELEVATED TEMPERATURES

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ABSTRACT

It is well known that the properties of powder metal components increase as the density increases. There are many methods of increasing the density of green compacts, including lubricants, warm compaction, and increased compaction pressures. The purpose of this paper will be to describe the properties achievable using elevated die and/or powder temperature to achieve increased green densities. Green densities achieved using elevated temperature processing will be compared to green.

INTRODUCTION

The ability to efficiently achieve high green densities in powder metal (PM) components has been the subject of much research. Reaching high green densities allows higher sintered densities, and subsequently higher material properties. The ability to reach high material properties allows the potential for applications such as high performance gears in automotive, lawn and garden, and hand tool applications. As the performance level is increased, the potential for sales of PM components is also increased[1].

In the field of powder metallurgy, there are many methods of achieving high green densities. These methods include high velocity compaction [2], warm compaction [3], reduced and advanced lubricants [4,5,6], and high compressibility powders [6]. Each of these methods has many advantages and disadvantages associated with it. The purpose of this paper will be to discuss conventional and warm compaction, and introduce elevated die temperature compaction.

Conventional compaction can be used to reach high densities by using elevated compaction pressures (>700MPa (50tsi)), high compressibility powders, or reducing lubricant level [3,4,5,6]. High compaction pressures have theoretical limits when considering part configuration and tooling requirements. The highest compressibility powders are typically pure iron, which is not always suitable for the very high performance applications where increased densities are required [6]. Finally, reducing the lubricant level can be limited by the part configuration, since lubricant is required, especially during ejection [4,5,6]. On the other hand, there is no added cost or complexity to employing enhanced conventional compaction.

By elevating the powder and tooling temperature, warm compaction can reach green densities in up to 0.15 g/cm^3 greater than green densities achieved by conventional compaction [5]. Warm compaction also allows high green densities to be reached in virtually any part configuration. There are also advantages to warm compaction, such as, high green strength, and the possibility to achieve higher densities at lower compaction pressures [5]. Heating the powder and tooling can present an added level of complexity, however.

There is now an intermediate alternative. Warm die compaction utilizes a combination of the properties of warm compaction and conventional compaction. In warm die compaction, Kenolube™ (a commercially available lubricant) is used at reduced levels in combination with high compaction pressures and die temperature in the 140°F range. The result is a method which creates the potential for increasing green densities in some applications.

This paper is divided into two sections: development of the warm die compacting process and presentation of a case study where this concept was successfully applied.

EXPERIMENTAL PROCEDURE PART 1: METHOD DEVELOPMENT

The first portion of the method development was to set up a design of experiment to determine the influence of die temperature, compacting pressure, and lubricant content on achievable green densities. To do this, slugs 25 mm (0.984 in) in diameter x 15 mm (0.60 in) high were pressed using D.AE + 0.3% graphite. D.AE is an atomized iron base (ASC100.29) with 0.50% Mo, 4.00% Ni, and 1.50% Cu diffusion alloyed. The Kenolube™ content was varied from 0.30% to 0.60%, the compaction pressure was varied from 600 – 1000MPa, and the die temperature from 30 - 80°C (86 - 176°F) to determine the relationships between each parameter. A 125 mt Result press installed at Höganäs AB, instrumented for compaction force and ejection force, was used to manufacture the slugs.

Part two of the method development was to use the optimized green density parameters achieved in part one and determine if the ejection forces were acceptable. For this portion of the testing, the same D.AE mix was utilized, however, the tool die was held at 60°C (140°F) and the lubricant level was held at 0.45%.

The final portion of the method development was to determine if the same level of Kenolube™ could be used for all base irons. In order to determine the optimal Kenolube™ content for other materials, Astaloy CrM and Mo were chosen and combined with 0.30% graphite. A die temperature of 60°C (140°F) was selected, and the Kenolube™ content was varied from 0.30% to 0.60%. The achievable green densities were determined, then the ejection energy was also considered to determine the optimized level of lubricant for each base iron.

RESULTS AND DISCUSSION PART 1: METHOD DEVELOPMENT

Initial testing revealed that lubricant content and compaction pressure, as expected, had a significant influence on green density (fig. 1). Lower lubricant content and higher compaction pressure resulted in the highest green densities. What was unexpected, however, was the effect that die temperature had on the results. Increasing the die temperature from 30 - 80°C (86 - 176°F) yielded an increase in green density of approximately 0.07 g/cm^3.

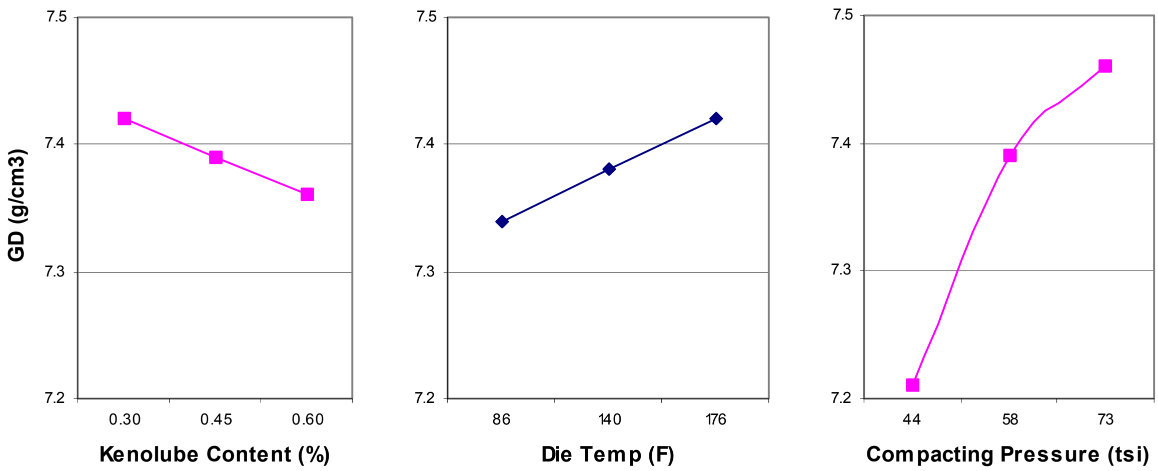

Figure 1: Effect of lubricant content, die temperature, and compacting pressure on the green density of D.AE + 0.3%C

After determining the potential increases in green density, a second trial to determine the ejection forces was completed (fig. 2). The acceptable maximum ejection energy is considered for this experiment to be 30 J/cm^3. Practical experience in the lab at Höganäs AB indicates that ejection energies beyond this level are not acceptable for production. By exceeding the 30 J/cm^3 level, die wear and component surfaces could become unacceptable.

For ejection energy, the amount of lubricant affects the energy required to eject the part. By reducing the lubricant level too low, the acceptable maximum ejection energy level of 30 J/cm^2 can be exceeded. High ejection energies would become more problematic as the surface area or height of a component is increased.

Die temperature also has a large effect on the ejection energy. At low die temperatures, the ejection energy is very high, exceeding the 30 J/cm^2 level. However, as the temperature increases, the ejection energy is reduced. An optimum temperature for ejection energy is reached at approximately 60°C (140°F). This temperature is approximately what could be expected as the die heats to steady state during an extended production run. However, by heating the die initially, all components will have acceptable surfaces and the tool life can be extended.

As the compaction pressure is increased, the ejection energy begins to approach the level. However, the energy reaches a maximum at approximately 800 MPa (58 tsi). Beyond this pressure, the ejection energy begins to drop again. The ejection energy at 1000 MPa (72 tsi) is only slightly higher than that experienced at 600 MPa (43.2 tsi).

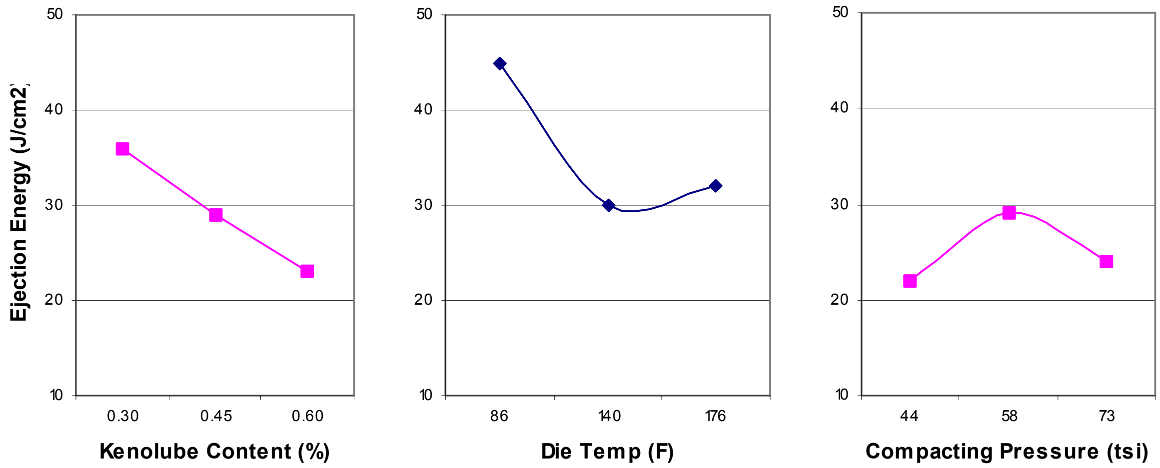

Figure 2: Effect of lubricant content, die temperature, and compacting pressure on the ejection energy of D.AE + 0.3%C

The next portion of the development was to determine if the optimized parameters achieved with the D.AE material would be the same for other materials, particularly pre-alloyed irons. Using the optimized die temperature of 60°C (140°F), green density curves were generated for Astaloy Mo (1.50% Mo pre-alloyed) and Astaloy CrM (3.00% Cr/0.40% Mo pre-alloyed with varying lubricant content. The compaction curves were generated using 0.30, 0.45, and 0.60% Kenolube.

As can be seen in Figure 3, reducing the lubricant level increase the maximum green density achievable. An approximately 0.06 g/cm^3 density increase can be achieved at high compaction pressures and reduced lubricant content. Each material achieves the highest green density with the lowest lubricant content and highest compaction pressure.

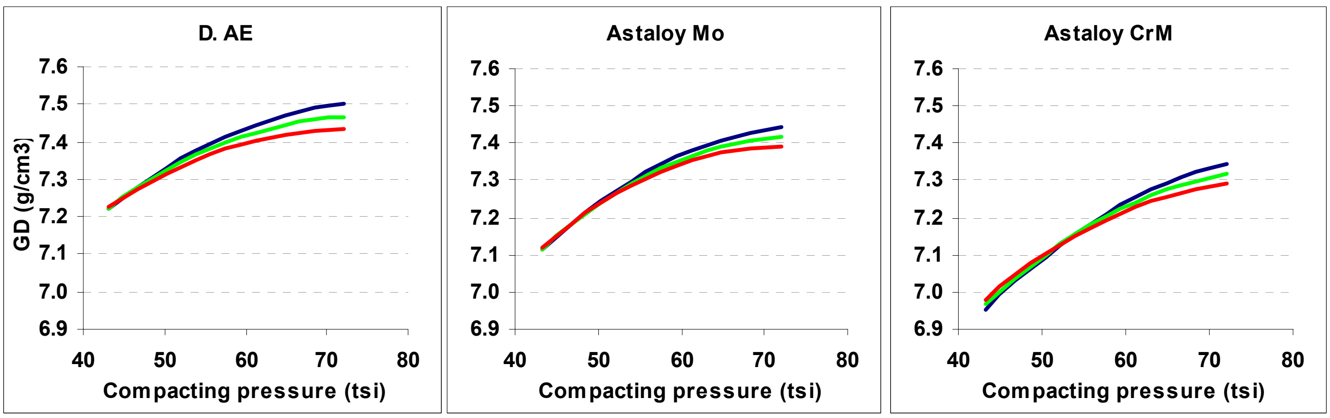

Figure 3: Green densities achievable using a die temperature of 60°C (140°F) and 0.30 – 0.60$^{w}/_{o}$ Kenolube

The achievable green density is not the only parameter that must be considered, however. The ejection energy is also important to the success of the compaction process. As can be seen in Figure 4, not all materials have the same ejection energy under the same compaction conditions. The ejection energy curves generated for each material indicate that the higher the alloying level, the higher the required lubricant content.

For the diffusion bonded material, as seen previously, the ejection energy and green density are optimized for $0.45^{w}/_{o}$ Kenolube and a die temperature of 60°C(140°F). However, for the pre-alloyed materials, this is not the case. Although the die temperature has been optimized, $0.45^{w}/_{o}$ lubricant is not adequate for these materials. The level for Astaloy Mo lies somewhere between $0.45^{w}/_{o}$ and $0.60^{w}/_{o}$. For the Astaloy CrM, $0.60^{w}/_{o}$ would be the minimum acceptable amount to achieve acceptable ejection energies

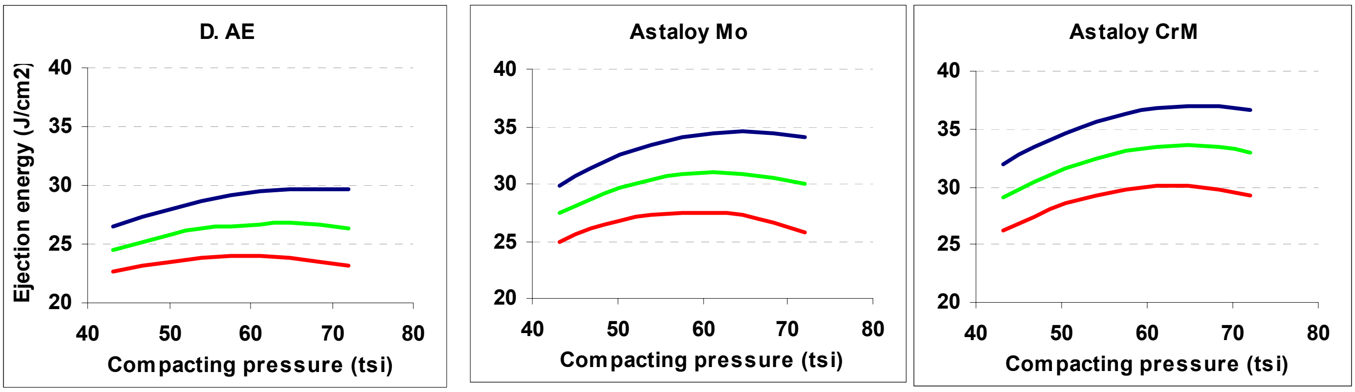

Figure 4: Ejection energies achieved using a die temperature of 60°C(140°F) and 0.30 – $0.60^{w}/_{o}$ Kenolube

As a result of the method development, it can be seen that high green densities are achievable by reducing the lubricant content and elevating the die temperature. However, ejection energies must also be considered for the application to be successful. Therefore, it is important that the lubricant level be optimized for each material and application.

EXPERIMENTAL PROCEDURE PART 3: CASE STUDIES

A case study was undertaken to evaluate the potential of the warm die Kenolube™ process in a production application. For the production simulation, a ring with a 45 mm (1.77 in) inside diameter and a 55 mm (2.17 in) outside diameter was compacted on the Result press at Höganäs AB. The mix composition was atomized iron (ASC100.29) with 2.0% Ni, 0.5% graphite, and 0.5% Kenolube™ admixed. The height of the part was varied between 10 mm (0.40 in) and 25 mm (1.0 in), while the compaction pressure was limited to 930 MPa (65 tsi). The goal of the customer was to achieve a final sintered density of 7.40 g/cm^3 or greater.

RESULTS AND DISCUSSION PART 3: CASE STUDIES

The warm die Kenolube™ process offers the potential for mass production in parts up to 25 mm (1.0 in) high. The surfaces on the components (Figure 5) indicate acceptable ejection energy levels. The green density level of 7.37 – 7.39 g/cm^3 is acceptable to reach a sintered density of greater than 7.40 g/cm^3 based on the shrinkage expected from the 2% Ni material. Based on the trials, the process was acceptable for the customer for their specific application.

CONCLUSIONS

Based on the method development and production trial, the following conclusions can be drawn:

- The die temperature plays a significant factor in achievable green density and ejection energy. A die temperature of 60°C (140°F) was found to provide the optimum combination of green density and ejection energy.
- High compaction pressures in combination with reduced lubricant levels and elevated die temperature provide can provide high green density and acceptable ejection energies.
- The previously discussed optimal parameters do not apply to all base irons. Pre-alloyed irons, such as Astaloy CrM and Astaloy Mo require higher lubricant contents than D.AE in order to maintain acceptable ejection energies.
- Warm die compaction offers the potential for green density increases in the 0.07 g/cm^3 range for some applications.

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