Warm Die Compaction with Reduced Lubricant Levels Promoting Higher Green and Sintered Densities

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Abstract:

Achieving enhanced mechanical properties in ferrous PM is accomplished via attaining high sintered densities with the proper alloy system. Significant experimental work has been done to quantify the lubricant requirements to enable high green densities. Described in this paper is a new multi-component lubricant system engineered to enable PM part production with lubricant levels of 0.25 weight per-cent for components having an overall length of up to 20 mm. This new lubricant system enables green and sintered densities in excess of 7.4 g/cm³ at compaction pressures of approximately 750 MPa. Details of the processing and resulting mechanical properties will be presented. This new advanced premixing technology is currently being utilized in the production of high density automotive and non-automotive ferrous components.

Introduction:

Achieving high densities (>7.2 g/cm³) in powder metallurgy parts can be achieved via double pressing, copper infiltration, die wall lubrication, high pressure compaction, and high velocity compaction. [1] Die wall compaction, high pressure compaction (>1000 MPa) and high velocity compaction are limited because of reduced press speeds, tool breakage issues and inability to produce multi-level components. The traditional PM approach of using admixed lubricants has proven to be the most economical approach for the production of PM parts. However, the traditional amounts of lubricants required, reduce the maximum attainable green density because lubricants have a density of approximately 1.1 g/cm³ compared to iron having a density of about 7.85 g/cm³. [2] This difference in density of the lubricant vs. the iron implies that for every 0.1% lubricant added there is a loss in green density of approximately 0.05 g/cm³. Thus, for an FC-0208 type material with 0.75% admixed lubricant; the maximum attainable green density is 7.10 to 7.15 g/cm³.

Increasing compacted part densities can be achieved by reducing the amount of premixed lubricant; however, reducing the internal lube must be done with caution. Simply reducing the amount of the lube can result in excessively high ejection pressures with a corresponding unacceptable surface finishes. To facilitate reduced lubricants levels, the lubricants used must give the same performance at the reduced level as the traditional lubes and amounts. This paper will discuss a new powder premix alternative that enables the reduction of admixed internal lubes to amounts as little as 0.25 w/o. In addition to promoting higher green densities; this new system demonstrates good lubrication, higher apparent densities in premixed powders and higher part green strengths. Additionally, because there is no need for die wall lubrication; compaction rates are equivalent to lower density PM parts.

Process Development:

Attaining high green density is accomplished via a combination of heating the powder mass and reducing the amount of lubricant. Preheating of the powder mass can be accomplished by direct heating of the powder and die (warm compaction). However, this requires costly capital equipment and the need to maintain a uniform powder pre-heat temperature of + / - 2.5 °C. [3] An alternative to heating the powder is only heating the tooling. [3] This alternative requires less capital equipment and is easier to implement in a PM parts manufacturing environment. Heating of the tooling can be done via cartridge heaters embedded in the stress ring of the die body or via the use of a heated fluid that surrounds the compaction tooling. The temperature of PM tooling will rise as a consequence of ejection stresses; however, this frictional heating of the tooling requires approximately 50 parts to stabilize and is often insufficient to fully activate these advanced lubricant systems.

The recently developed premix described is a 'bonded' premix system which enables consistent flow and apparent density control for production. Presented as Figure 1 are the effects of increasing compaction pressures coupled with increasing die preheat temperature on the green density achieved during compaction. Increasing die temperatures coupled with compaction pressures up to 830 MPa result in green densities up to >7.45 g/cm³ for an FLN2-4405 premix (~ 98% of the pore free density). The physical characteristics of the lubricants must be such that they can withstand these elevated compaction temperatures without excessive melting or degradation.

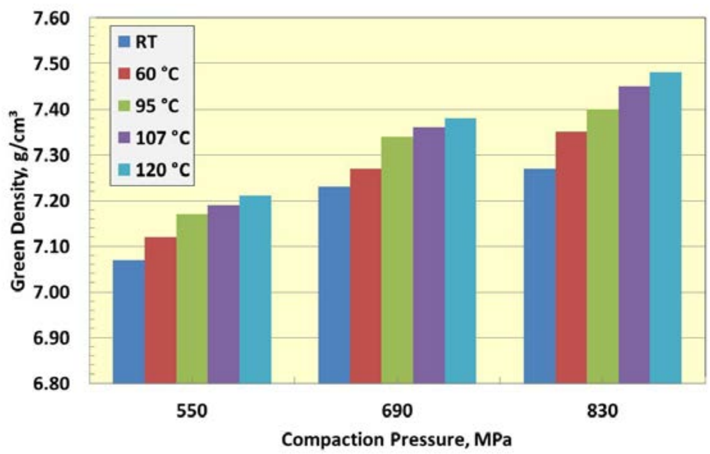

Figure 1: Green density vs. die temperature and compaction pressure

This new premix alternative utilizes lubricant levels as low as 0.25 w/o in combination with warm die compaction (die temperature of ~107 °C) to achieve high green density with acceptable compaction press performance. Shown as Figure 2 is are the attainable green densities and green strengths achieved with this new premix system. In addition to higher green density, additional benefits are reduced green expansion and

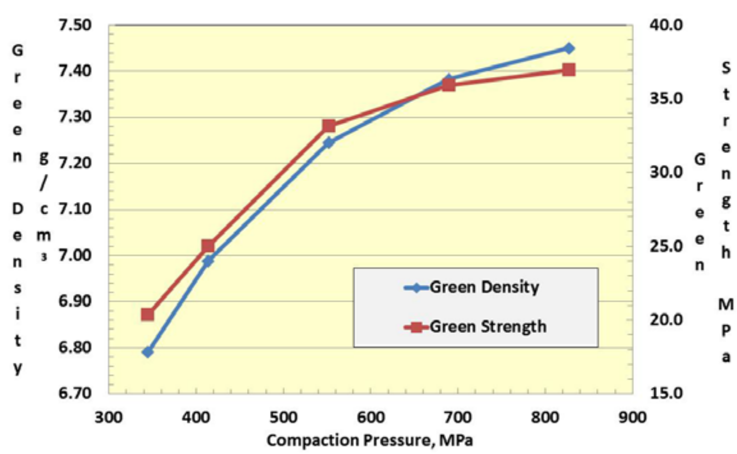

Figure 2: Green density and green strength of new premix at 105C die temperature

higher green strength approaching 35 MPa. The high green strength is advantageous because it lessens the potential for green part damage and enables green machining of the compacted component. Mechanical properties of the resulting PM compacts are equivalent to the properties listed in MPIF Std. 35 for the appropriate material. [3]

This new system was successfully utilized in the production of an automotive component shown in Figure 3. [4] This part has a pressed weight of approximately 500 grams with a minimum green density of 7.25 g/cm³. Production experience showed this weight variability of less than +/- 0.3% with no loss in productivity relative to the conventional processing. Previously produced via warm compaction, this new system offered consistent powder properties of AD and flow. An added benefit of this material system compared with the conventional warm die compaction is the capability to interrupt the production run without the need to re-establish steady state conditions.

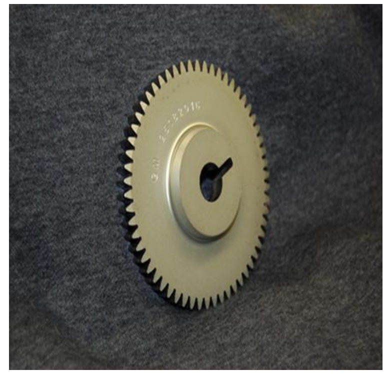

Figure 3: Photograph of automotive gear

An additional benefit observed with this new premix alternative is the enhanced uniformity of green density throughout the compacted part. Figure 4 is an unetched photomicrograph of the cross section of the gear at the 'neutral' zone. It demonstrates the uniformity of density in the body of the gear plus at the gear tips. This gear was compacted to an overall density of ~7.45 g/cm³ utilizing FLN2-4405 material and a lube content of 0.25 w/o. Details of the gear are a major diameter of 18.5 mm with a height of 5 mm and module of ~0.8 mm. Larger components up to ~1000 grams and 45 mm tall have been successfully produced to densities approaching 7.4 g/cm³ (with 0.40 w/o lube).

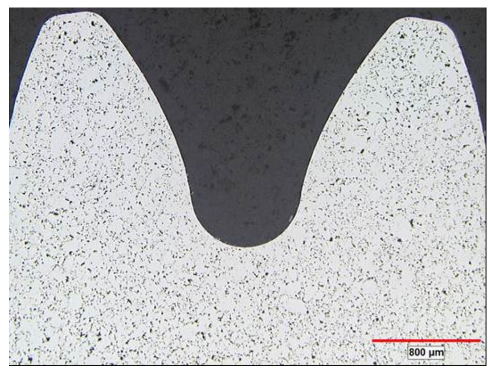

Figure 4: Photomicrograph showing uniform density in gear teeth

Ejection characteristics of this new lubricant system were compared to standard premix lubricant additives. Comparisons were done using a 25 mm tall by 10 mm diameter round slug compacted at 760 MPa. Shown in Figure 5 are the representative ejection characteristics of the new premix alternative compared to existing material systems. This figure shows the new system gives ejection characteristics

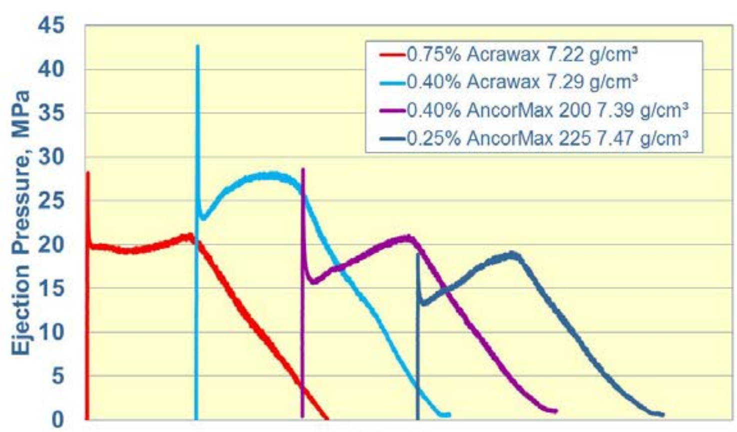

Figure 5: Ejection characteristics of various premix alternatives

equivalent to a standard 0.75 w/o lube addition; yet the new lube compact had a green density of 7.45 g/cm^3 vs. the standard lube having a green density of 7.25 g/cm^3. This equivalency in ejection characteristics result from the engineered lubricant and binder system in combination with warm die compaction techniques. [5]

Summary:

Described in this paper is a new premix alternative that facilitates the reduction of the internal lube from the standard 0.75 w/o to as little as 0.25 w/o. This reduce lubricant level has proven successful in the production of a range of parts up to 1000 grams. This new premixing system gives enhanced green densities and green strengths with part ejection characteristics equivalent to traditional amounts. A key to obtaining good performance is the combination of the bonded premix, unique lubricant system, and warm die compaction (die temperature of ~105 °C). Production experiences have shown this new system gives good weight control throughout the production run. Additional benefits of the reduced lubricant content are the increased the pore-free –density with corresponding benefits of increased green density, reduced carbon emissions during sintering, and the potential for higher green strength. Utilizing a warm die compaction technique offers the potential for reduced green scrap because press interruptions do not necessitate the need to re-establish steady state compaction conditions.

References:

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