Warm Die Compaction of a High Density Crankshaft Sprocket

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ABSTRACT

Original Equipment Manufacturers (OEMs) are demanding higher properties in ferrous PM components as engine sizes shrink and the performance/weight ratio increases. One method to achieve enhanced mechanical properties is to attain high densities along with the proper alloy system. A recently developed lubricant system has been engineered to enable PM part production with lubricant levels as low as 0.25 weight percent and green densities in excess of 7.4 g/cm³ at compaction pressures of approximately 750 MPa. This system has been successfully used in the production of a crankshaft sprocket with teeth density requirements exceeding 7.20 g/cm³, overcoming green part defects present with prior lubricant systems. Details of the processing, microstructure and resulting mechanical properties will be presented.

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 viable 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 signifies for every 0.1% lubricant added, there is a loss in pore free 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 lubricant can result in excessively high ejection pressures with corresponding unacceptable surface finishes. To facilitate reduced lubricants levels, the new lubricants are required that must provide the same performance at reduced level as the traditional lubricants and amounts. This paper will discuss a new powder premix alternative that enables the reduction of admixed internal lubes to amounts as low as 0.25 w/o (AncorMax 225®) . 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. [3] Preheating of the powder mass can be accomplished by direct heating of the powder and the die (warm compaction). However, this requires costly capital equipment coupled with a process requirement to maintain a uniform powder pre-heat temperature of + / - 2.5 °C. [2] An alternative to heating the powder is simply heating the tooling. This alternative is less capital intensive and is less difficult 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. It should be noted, that 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 optimal performance of these advanced lubricant systems.

The recently developed premix described is a chemically 'bonded' premix system which enables consistent flow and apparent density control for production. [4] 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 increases in green density result from lower compressive strength of the iron powder at these slightly elevated temperatures and the interaction of the lubricant to facilitate enhanced particle rearrangement and deformation. The physical characteristics of the lubricants must be such that they can withstand these elevated compaction temperatures with minimal melting and no degradation.

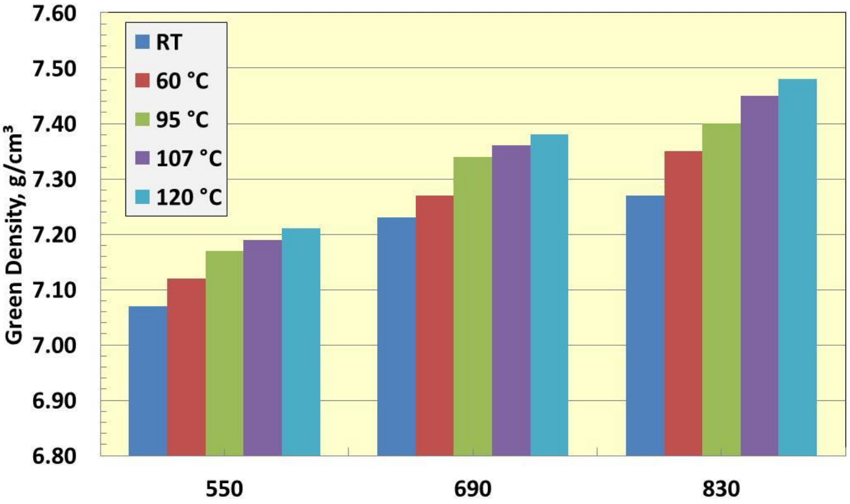

Figure 1: Effect of compaction pressure and die temperature on green density

This new premix alternative utilizes lubricant levels as low as 0.25 w/o in combination with warm die compaction (die temperature of ~105 °C) to achieve high green density with acceptable compaction press performance. Shown as Figure 2 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 higher green strengths exceeding 35 MPa. The high green strength is advantageous because it lessens the potential for green part damage and possibly enables green machining of the as compacted component. Mechanical properties of the resulting PM compacts are equivalent to the properties listed in MPIF Std. 35 for the appropriate material. [3]

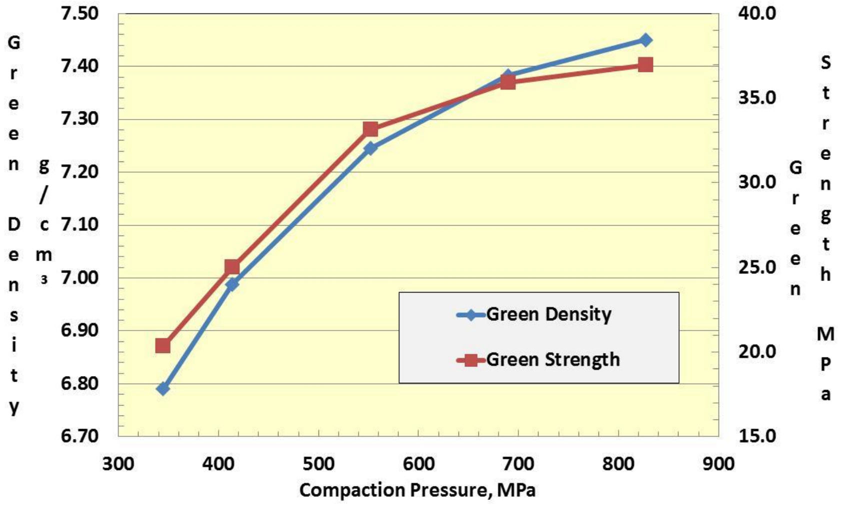

Figure 2: Green density and green strength of AncorMax 225 FLN2-4405

Production Trials

This new powder lubricant system was successfully utilized in the pre-production of an automotive crankshaft sprocket shown in Figure 3. This part has a compacted weight of approximately 400 grams with a minimum overall sintered density of ~7.15 g/cm³ and gear teeth densities exceeding 7.20 g/cm³. A maximum compaction pressure of 580 MPa was specified for the production of this component using an MPIF FN-0208 material with 0.40% of the advanced lube system. Prior to producing the components, the pore free density of this premix was calculated to be approximately 7.5 g/cm³ and the 98% pore free density is > 7.30 g/cm³; thus, no compaction related issues were anticipated. Prototype production experience showed this weight variability of approximately +/- 0.5%. During the prototype development of this part, it was often necessary to interrupt the continuous compaction cycle for sectional density evaluations and overall size verification. One distinct advantage of warm die compaction technology is the ability to interrupt the production cycle without the need to re-establish steady state conditions as is often required for conventional warm compaction.

Figure 3: Photograph of finished crank sprocket evaluated in this study

Shown in Figure 4 is the production sequence for this part. The gear teeth exhibited a sintered density of 7.24 g/cm³ and the sprocket teeth exhibited a sintered density of 7.25 g/cm³. After through hardening of the sprocket the sprocket and gear teeth had an apparent hardness of HRA 71 – 73 with a micro-hardness HV0.1 of 700 – 750.

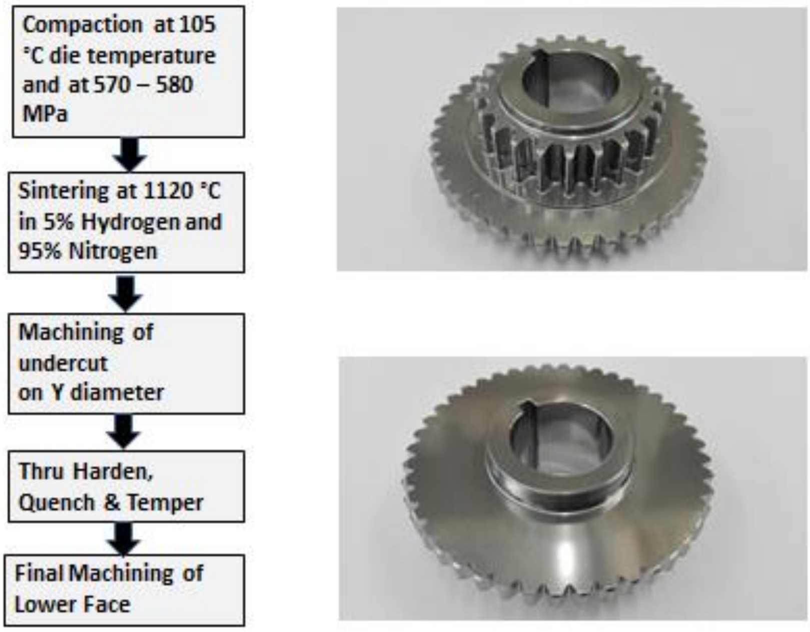

Figure 4: Processing Sequence for the prototype production of the crank sprocket

Previous studies with this advanced lubricant system demonstrated enhanced uniformity of green density throughout the compacted part. Figure 5 is an unetched photomicrograph of the cross section of a small gear at the 'neutral' zone. It demonstrates the uniformity of density in the body of the gear plus at the apex of the gear teeth. 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). [5]

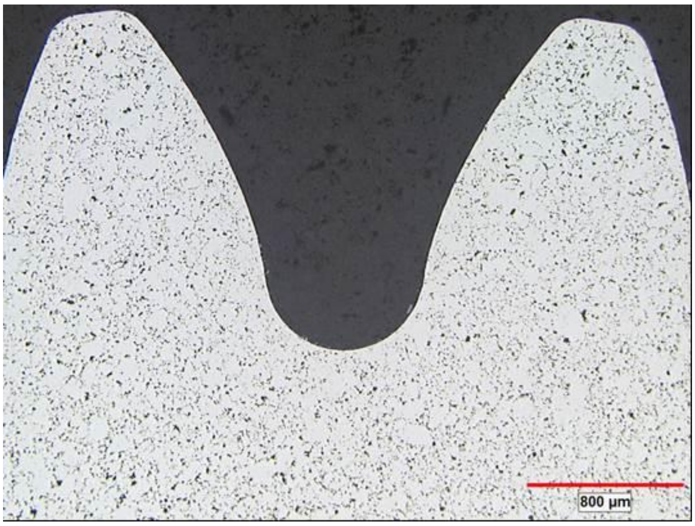

Figure 5: Photomicrograph of 0.80 mm module gear demonstrating the uniformity of density from body of gear to the apex of gear tooth

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 6 are the representative ejection characteristics of the new premix alternative compared to existing material systems. This figure shows the new system gives ejection characteristics equivalent to a standard 0.75 w/o lube addition; yet the new lube compact had a green density of 7.45 g/cm³ vs. the standard lube having a green density of 7.25 g/cm³. This equivalency in ejection characteristics result from the engineered lubricant and binder system in combination with warm die compaction techniques.

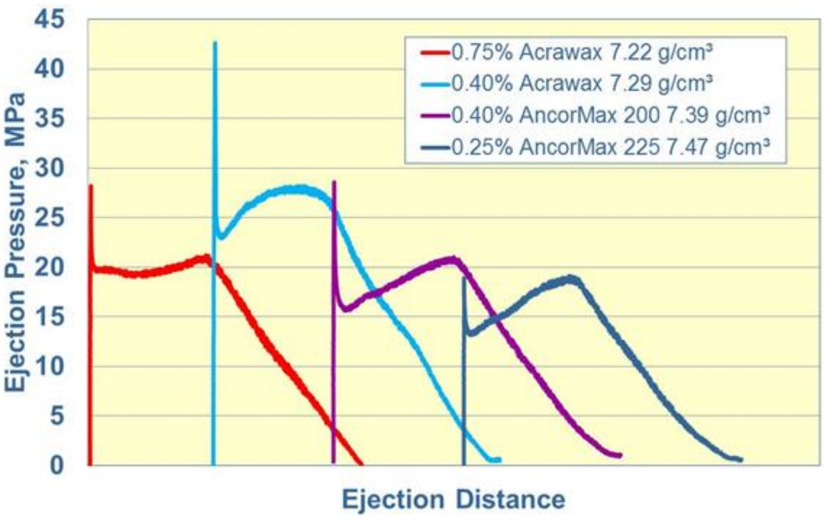

Figure 6: Ejection characteristics of a common lubricant compared to the AncorMax 225 lubricant system, all samples compacted at 760 MPa. The Acrawax® samples were compacted at 25°C, the AncorMax 200 compacted at 93°C, and the AncorMax 225 sample compacted at 105°C.

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 reduced 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 exhibits good weight control in daily production. Additional benefits of the reduced lubricant content are the increased 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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