

High Density via Single Pressing / Single Sintering

Francis Hanejko
Hoeganaes Corporation
Cinnaminson, NJ 08077
USA

Abstract:

High density processing via single press / single sinter processing enables powder metallurgy processing of ferrous materials to be both more cost efficient and produce higher performance components. Obtaining high densities via single press / single sintering necessitates a systems approach to preparation of the starting powder premix and subsequent compaction and sintering. This paper will describe a powder and processing method that facilitates single press-single sintered densities approaching 7.5 g/cm^3 . At this sintered density, the mechanical properties of the P/M component are significantly improved over existing compaction techniques and begin to approach the performance of wrought steel.

Introduction:

Increasing sintered part density continues to be a major initiative for the powder metallurgy community. Higher part densities and ensuing higher part performance enables PM to displace many cast and wrought components for both automotive and non-automotive applications. [1] Methods to achieve higher part densities are shown schematically in Figure 1. Traditionally, higher densities are achieved via DP/DS or copper infiltration. Although these processes require additional part handling and additional cost, benefits offered often surpass any cost penalties incurred.

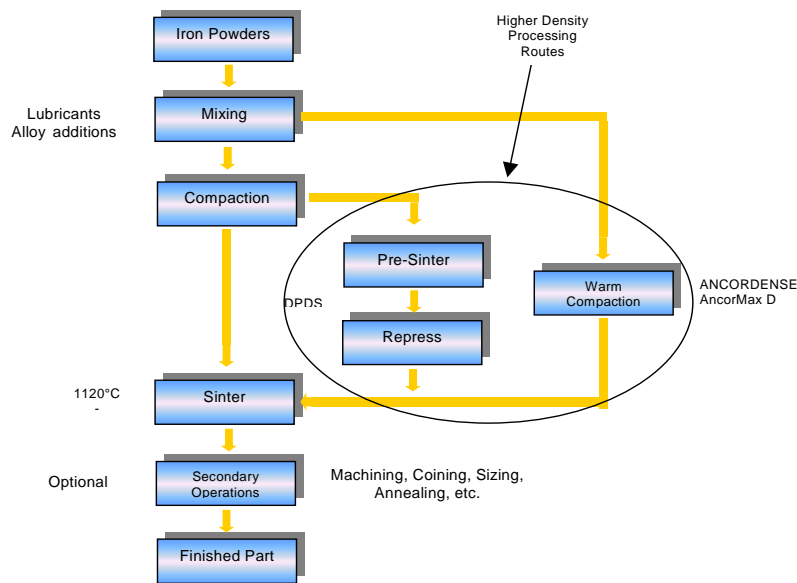


Figure 1: Processing to achieve high density PM

Before discussing methods of achieving high densities via SP/SS processing, it is worthwhile to review the concept of pore-free density (PFD). PFD is defined as the density of any material when all pores within that material are eliminated. In PM materials, the PFD is strongly dependent upon both the amount of lubricant and graphite added to the premix. Figure 1 shows PFD as a function of both lubricant and graphite additions.

Figure 2: Pore free density as a function of lubricant and graphite content

Prior work has shown that achieving 98% of pore free density after ejection from the die is a practical upper limit that can be achieved without initiating micro-laminations within the part. Thus to achieve a single pressed densities of $\sim 7.4 \text{ g/cm}^3$ necessitates that the amount of lubricant be kept to 0.4% or less with a graphite addition of 0.4% or less.

METHODS TO ACHIEVE HIGH DENSITY VIA SINGLE PRESS – SINGLE SINTER

ANCORDENSE (Warm Compaction)

Heated powder / heated die processing commonly referred to as warm compaction or ANCORDENSE™ processing utilizes iron or low alloy powders premixed with a unique binder and lubricant system to facilitate compaction at temperatures ranging from 120 °C to 150 °C. [2] Both the premixed powder and compaction tooling are heated to this temperature range. Higher green densities are obtained via a temperature induced reduction in compressive yield strength coupled with a softening of the lubricant, resulting in a pseudo-isostatic compaction condition within the die as densities approach PFD. [3,4] The amount of lubricant used in warm compaction is typically 0.6%, thus promoting higher PFD relative to conventional compaction. Warm powder pressing has demonstrated greater uniformity of density through out the part and minimizing the neutral zone typically associated with PM. [5,6] Part weights in excess of 1200 grams and part heights up to 60 mm have been made using ANCORDENSE processing.

AncorMax 200™ Processing (Warm-Die Compaction)

A second methodology utilized to achieve higher green densities via SP/SS employs heated dies without any powder preheating, AncorMax 200. This process utilizes a proprietary lubricant system with only 0.4 w/o total lubrication that is most effective at die compaction temperatures of $\sim 93 \text{ °C}$. Depending upon the part geometry no powder heating is required. From Figure 2, at this lubricant level and keeping the graphite content below 0.4 w/o, a green density of 7.4 g/cm^3 is attainable. Depending upon the premix utilized and sintering conditions, sintered densities approaching 7.5 g/cm^3 are attainable. Parts lengths $\geq 30 \text{ mm}$ have been produced with excellent surface finish.

Laboratory evaluation of this lubricant demonstrated advantages including increased compressibility, increased green strength, reduced ejection forces and reduced green expansion. In all laboratory testing, an AncorMax 200 premix, FLN2-4405 with 0.40 w/o graphite, was evaluated. For reference, a similar mix utilizing 0.40% AncorMax 200 lubricant was evaluated. All compaction conditions utilized a die temperature of 93 °C with no powder heating. Figures 3, 4, and 5 present the compressibility, green strength, and green expansion data.

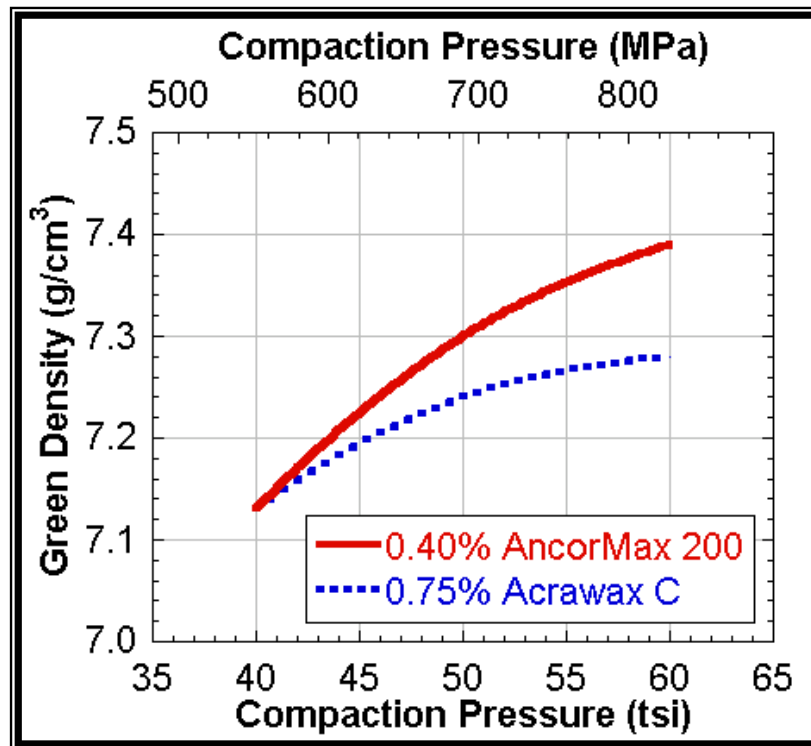


Figure 3: Compressibility of an AncorMax 200 premix and a standard premix containing 0.75% Acrawax.

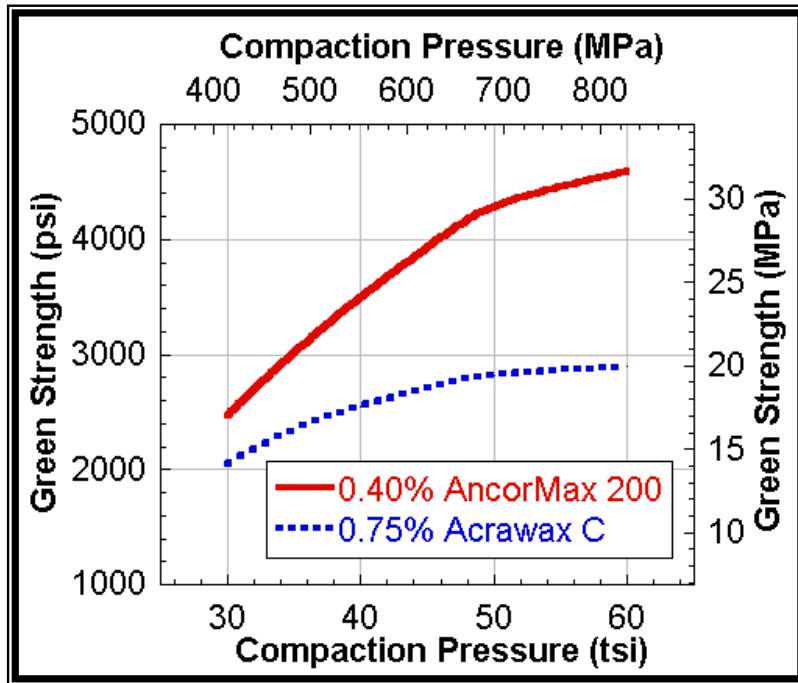


Figure 4: Green strength of the two premixes over a range of compaction pressures.

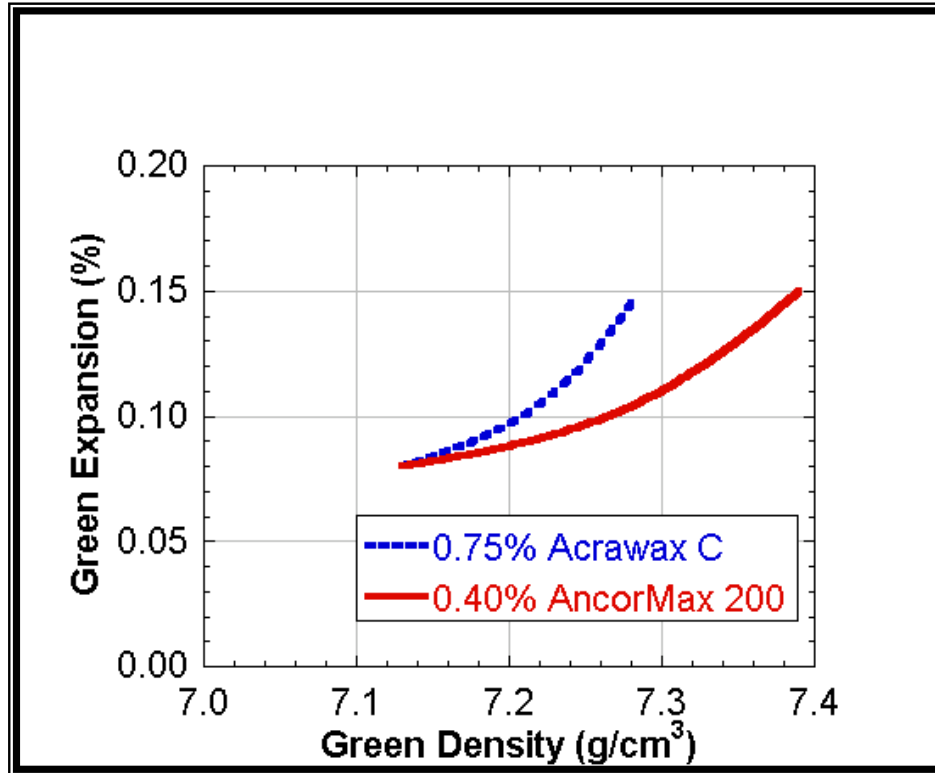


Figure 5: Green expansion over a range of compacted densities.

Significant trends within the data presented in Figures 2 through 4 are as follows:

- AncorMax 200 shows better compressibility at pressures over 550 MPa compared with a standard premix. Maximum green density of this premix approached 7.4 g/cm³ at compaction pressures of 830 MPa.
- Green strength of AncorMax 200 prepared premixes are ~50% greater than the standard premix.
- Green expansion of AncorMax 200 premixes is significantly reduced thus maximizing the green density and minimizing forces to eject parts from the die.
- The reduced green expansion can have a significant impact on micro-cracking within the part. Excessive green expansion stresses the compact and may lead to laminations within the part. Minimizing this green expansion will reduce this tendency.

To verify if AncorMax 200 had improved ejection characteristics, solid cylindrical slugs measuring 25 mm high by 14 mm in diameter were compacted in an instrumented hydraulic compaction press. The test slug and the characteristics measured are shown schematically in Figure 5. Ejection was evaluated by comparing two values: the pressure required to initiate ejection (strip pressure) and the pressure as the compact is exiting the die (slide pressure).

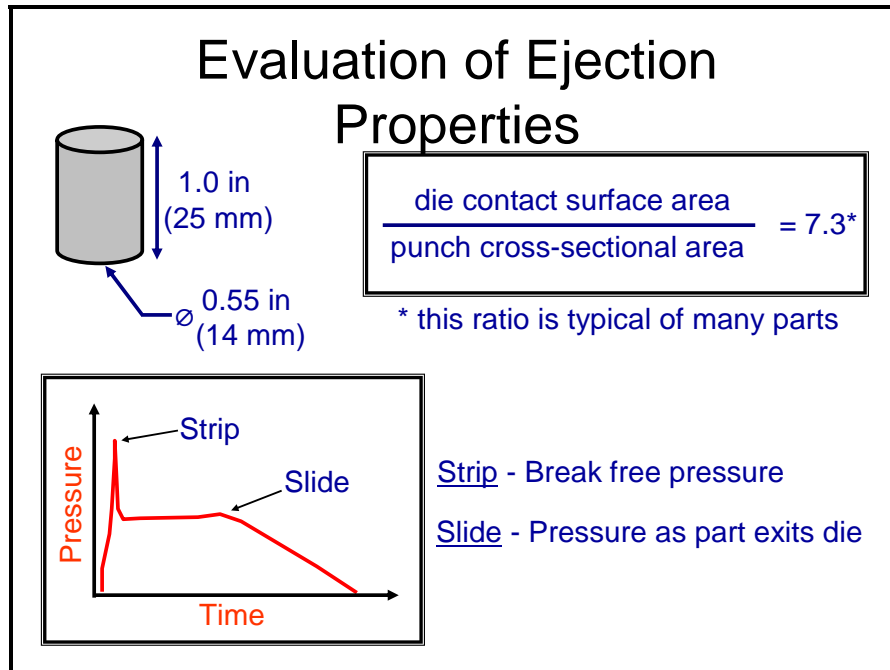


Figure 5: Schematic of ejection measurements. [10].

The ejection characteristics are presented in Figures 6 through 8. The data presented in Figures 6 through 8 were obtained via compaction with a die temperature of 93 °C and no powder pre-heating. As part of this effort an additional premix was prepared; this premix had the same iron powder, nickel and graphite additions but was prepared with 0.40% admixed Acrawax. It was rationalized that higher density could be achieved by simply reducing the amount of conventional lubricant. However, ease of ejection from the die and surface finish appearance after ejection are also key parameters to the successful development of a new lubricant system.

Figures 6 and 7 show the ejection curves for the three mixes using an ejected part surface temperature of 93 °C. No ejection curve for the standard 0.40% Acrawax lubricant is presented at the 830 MPa compaction condition because the test slug showed severe part scoring coupled with very high ejection forces. When reviewing these ejection curves, the peak pressure is the pressure required to initiate ejection and the slide pressure is the pressure required to slide the part out of the die. In the data presented, the AncorMax 200 lubricant system shows consistently lower strip and slide pressures compared to the standard lubricant addition. Figure 9 compare the surface finish appearance of the slugs after compaction. Once again the AncorMax 200 shows improvement over the standard lubricant addition. It is worth noting in Figure 8, the stripping pressure for AncorMax 200 is nearly identical for the four compaction pressures used. There is an increase in sliding forces as compaction pressures increase but both stripping and sliding forces are significantly lower than the reference mixes evaluated.

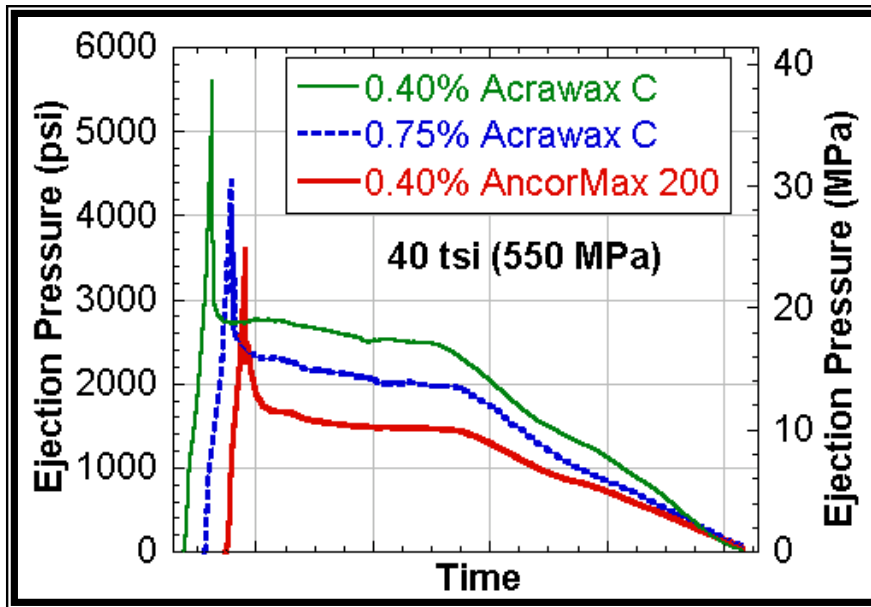


Figure 6: Ejection characteristics at 550 MPa.

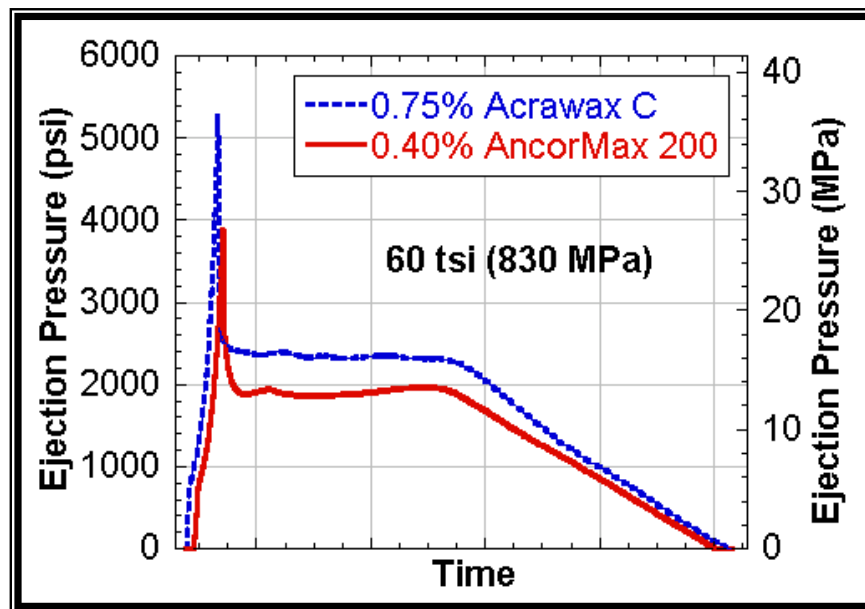


Figure 7: Ejection characteristics at 830 Mpa.

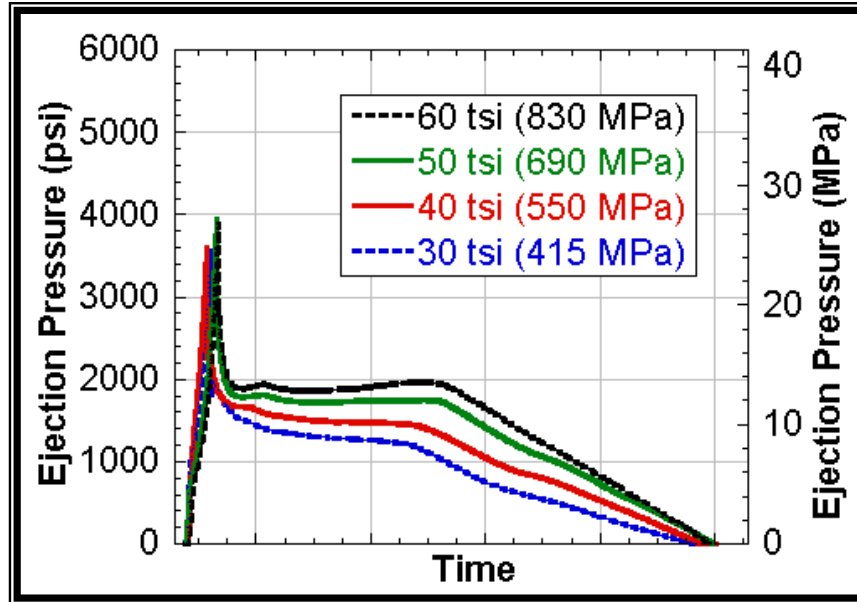


Figure 8: Ejection characteristics of AncorMax 200 at pressures from 550 MPa to 830 MPa.

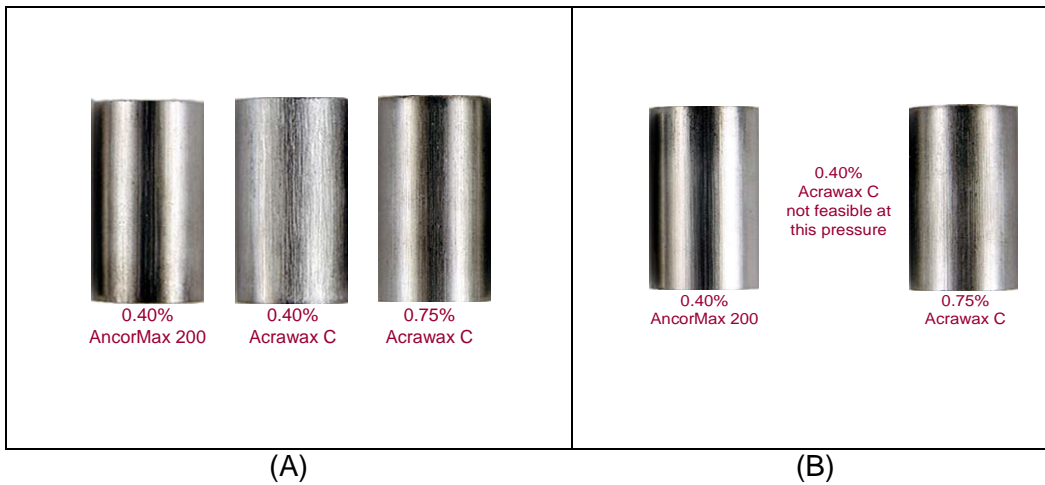


Figure 9: Surface finish of compacted slugs, all slugs compacted to 25 mm length.
 A. At 550 MPa
 B. At 830 MPa

One not so obvious advantage of higher sintered densities is the ability to achieve high strengths without the need for high graphite contents. Typically higher strengths within PM are achieved via higher graphite additions. However, this precludes the possibility to carburize parts and reap the beneficial effects of surface compressive strengths mandated in high performance gears. Traditionally, wrought steel gears have a low carbon core combined with a carburized case thus having high core strength and good ductility combined with a high carbon case for wear resistance and surface residual compressive stresses for fatigue durability. Shown in Table 2 is mechanical property

comparison of FLN2-4400 (with 0.35% added graphite) and AISI 8620 in the quenched and tempered condition. All data shown was generated using machined round specimens. It is interesting to note that nearly equivalent yield and tensile strengths compared with a wrought AISI 8620 can be achieved with a PM steel pressed and sintered to $\sim 7.5 \text{ g/cm}^3$.

Table 2
Mechanical Property Comparison, FLN2-4400 to AISI 8620
in the quenched and tempered condition.

Alloy	Density, g/cm^3	Yield Strength, MPa	Tensile Strength, MPa	Elong, %	Hardness, HRC
FLN2-4400	7.46	1065	1275	1.5	40
AISI 8620	7.85	1100	1340	8.0	45

Preliminary rotating bending fatigue test results of carburized FLN2-4400 show a 90% endurance limit of $\sim 550 \text{ MPa}$.

Summary:

A new lubricant system has been developed (AncorMax 200) that enables the use of low lubricant levels to make high density PM parts. Advantages of this lubricant system are as follows:

- Lubricant levels of 0.4% enabling green densities up to 7.4 g/cm^3
- Heights up to 32 mm for complex parts
- Sintered densities of 7.45 to 7.5 g/cm^3 at $1120 \text{ }^\circ\text{C}$
- Good surface finish on parts
- Reduced part ejection pressures
- Works with pure iron and low alloy systems
- Enhanced green strengths with reduced green expansion
 - Lesser tendency for green cracking

References:

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