

# **Development of New Soft Magnetic Composite Material Possessing Higher Levels of Magnetic and Mechanical Performance.**

**Francis Hanejko  
Hoeganaes Corporation  
Cinnaminson, NJ 08077  
USA**

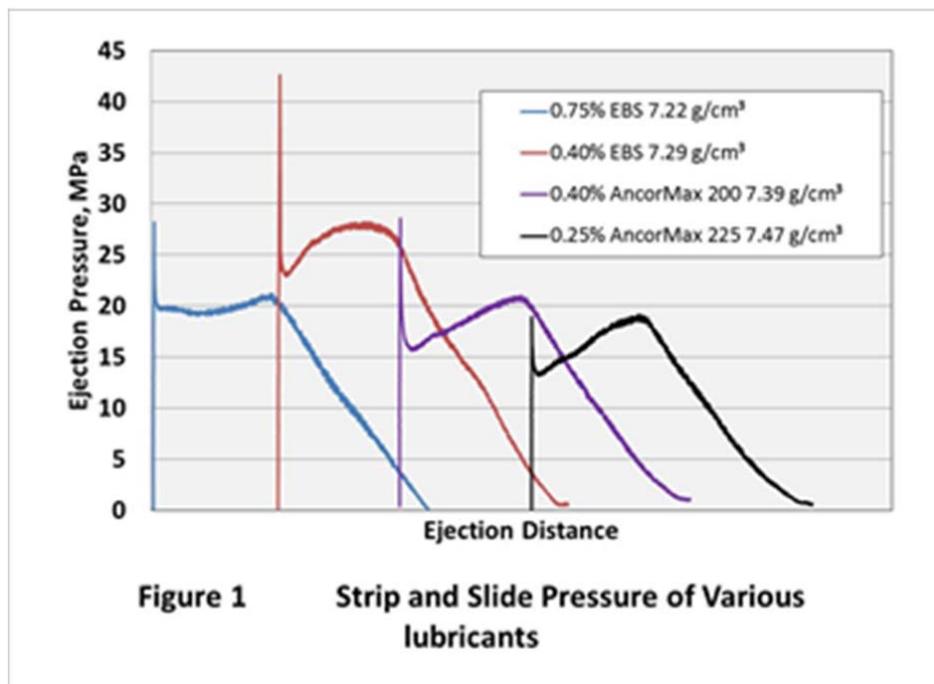
## **Abstract**

Greater usage of soft magnetic composites will depend on attainment of higher magnetic permeability, higher induction and greater mechanical strength. Permeability and induction depend upon the compacted density of the component; higher densities promote improvements in both. Mechanical strength relies on density in addition to the lubricant used during compaction. Described in this paper is a newly developed material capable of achieving  $>7.5 \text{ g/cm}^3$  density while maintaining high resistivity to minimize total core losses under AC operating conditions. Another key aspect of this material is the high cured strength attainable, approaching 130 MPa. Optimal compaction conditions can produce a DC permeability of  $\geq 500$  with a saturation induction at 10,000 amp meter turns of  $>1.6$  Tesla with a resistivity of  $\sim 7,000$  micro-ohm-centimeter; promoting low core losses at operating frequencies up to  $\sim 2$  kHz. Data presented in this paper will be the both the key magnetic and mechanical properties

## **Introduction**

Magnetic performance of soft magnetic composites is analogous to the PM structural press and sinter performance in that high component density is critical to the achievement of high performance. Attaining high density can be accomplished through the use of high purity, high compressibility iron powder coupled with the proper lubricant addition and compaction conditions. Warm die compaction techniques enable as-compacted densities approaching 98% of the pore free density of the iron powder – lubricant theoretical density. [1] Reducing the lubricant content to the lowest possible level while still permitting ejection from the die will produce a soft magnetic composite component giving optimal permeability and saturation induction levels. Additionally, it is crucial to maintain a high resistivity at these high densities because high densities can result in particle to particle contact; leading to increased eddy current losses.

The advanced powder lubrication system utilized in this study was initially developed for conventional press and sinter structural components. This lubricant is a proprietary development enabling the use of 0.25 weight percent (w/o) lubricant offering green densities greater than 7.5 g/cm<sup>3</sup>. Ideal compaction conditions utilize compaction pressures of 830 MPa (60 tsi) and a part ejection temperature of 107 °C (225 °F). [1] Ejection characteristics of this lubricant system were evaluated using an FLN2-4405 material and are shown in Figure 1. The four ejection curves presented in Figure 1 represent two ambient die temperature compaction conditions using either 0.75% or 0.40% EBS lubricant plus a proprietary lubricant designated AncorMax 200 which uses 0.40% total lube with a die temperature of 93 °C and lastly the advanced lubricant system using 0.25% lubricant and a die temperature of 107 °C. The advanced lubricant systems demonstrates nearly identical ejection characteristics as the 0.75% EBS lubricant addition, while providing anywhere from a 0.2 to 0.25 g/cm<sup>3</sup> higher green density. An additional benefit observed for the structural PM premixes was improved green strength. This is critical requirement in soft magnetic components because these materials are non-sintered and attainment of high ‘as-cured’ strength is essential to part performance.



### Experimental Procedure

Table 1 lists the two AncorLam materials evaluated in this study, both premixes utilized a total lubrication addition of 0.25 w/o. Green strength bars (12.5 mm x 12.5 mm x 31.5 mm) and magnetic toroids (36 mm OD x 25 mm ID x 6 mm tall) were compacted via a hydraulic press utilizing dies preheated to 107 °C. Curing was done in a box furnace at 450 °C for 1 hour at temperature using a protective atmosphere of 100% nitrogen. The compacted and cured green strength bars were also used to measure resistivity via the 4 wire method using a Keithley resistance bridge (ASTM Test method A712-75). Room temperature green strength measurements were done in accordance to MPIF Standard 15. [2] After curing, the magnetic toroids were first wrapped with a layer of insulating tape then wrapped with 35 secondary windings of 28 gauge enamel coated copper wire. A second layer of insulating tape was wrapped atop the secondary windings and lastly the primary winding of

200 turns of 22 gauge enamel coated copper wire was wrapped onto the toroid. Testing was done under DC conditions and AC conditions at frequencies up to 10,000 Hz and applied fields up to 12,000 A/m. The magnetic toroids were tested using an automatic hysteresisgraph (Model SMT-700, Magnetic Instrumentation, Inc.).

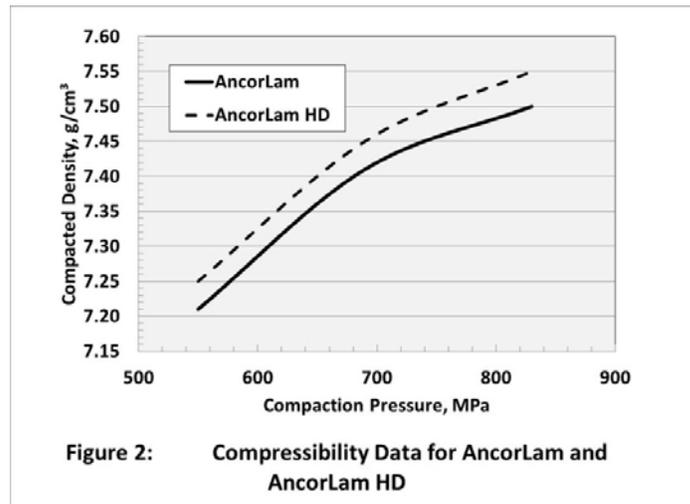
**Table 1**  
**Materials Evaluated**

Material	Key Characteristics
AncorLam HD	High Density, High Perm, highest induction level
AncorLam HR – HD	Moderate density, high resistivity

**Results**

*a. Physical properties*

Presented in Figure 2 is the compressibility comparison for the advanced lubricant in relation to existing AncorLam lubricant system. Reducing the lubricant level from 0.40% to 0.25% results in higher green density over the range of compacting pressures evaluated. At the 830 MPa compaction pressure, the HD material achieves approximately 98% of pore free density. Caution should be used in compacting to higher densities because compaction to densities above 98% of pore free density (PFD) can often result in the formation of micro-laminations within the compacted part. These micro-laminations lower the ‘as-cured’ strength of the soft magnetic composite and will negatively affect the magnetic performance.



**Table 2**  
**Compacted and cured densities of AncorLam and AncorLam HD**

<b>Lube System</b>	<b>Compaction Pressure, MPa</b>	<b>Green density, g/cm<sup>3</sup></b>	<b>Cured density g/cm<sup>3</sup></b>	<b>Cured strength, MPa (psi)</b>	<b>Cured resistivity, uΩcm</b>
<b>Standard AncorLam</b>	550	7.21	7.20	86 (12500)	6,900
	690	7.41	7.39	103 (14950)	6,900
	830	7.51	7.47	107 (15600)	7,000
<b>AncorLam HD</b>	550	7.25	7.24	102 (14850)	8,400
	690	7.43	7.42	119 (17350)	7,400
	830	7.55	7.53	130 (18800)	7,400

Table 2 presents the as compacted and cured densities of both materials utilizing compacting pressures varying from 550 to 830 MPa. Higher ‘cured’ densities are achieved with the lower lubricant of the AncorLam HD material. The decrease in density from compaction to curing results from the lubricant removal during the curing cycle. The AncorLam HD material having reduced lubricant levels show a lesser decrease in ‘cured’ density relative to the standard material. Also, the reduced lubricant level in the AncorLam HD exhibited reduced green expansion after compaction. Also shown in Table 2 is the resistivity and cured strength of the two materials. The AncorLam HD material has higher resistivity despite having higher cured density. ‘Cured’ TRS strength is also increased to ~130 MPa which is approximately 20% higher than the existing material.

**b. Magnetic Properties**

The magnetic data for the AncorLam HD and AncorLam HR – HD is shown in Table 3. All the data shown was measured at 1 Tesla. Note the AncorLam HD maintains constant permeability up to approximately 1000 Hz. Above that frequency the permeability decreases as the eddy current losses increase. The high resistivity AncorLam HR – HD enables constant permeability up to 10 kHz. The AncorLam HR – HD has lower core losses relative to the AncorLam HD at frequencies above ~1 kHz. The post compaction curing was done at 450 °C.

**Table 3**  
**Magnetic Properties of AncorLam HD and AncorLam HR – HD Tested at 1 Tesla**

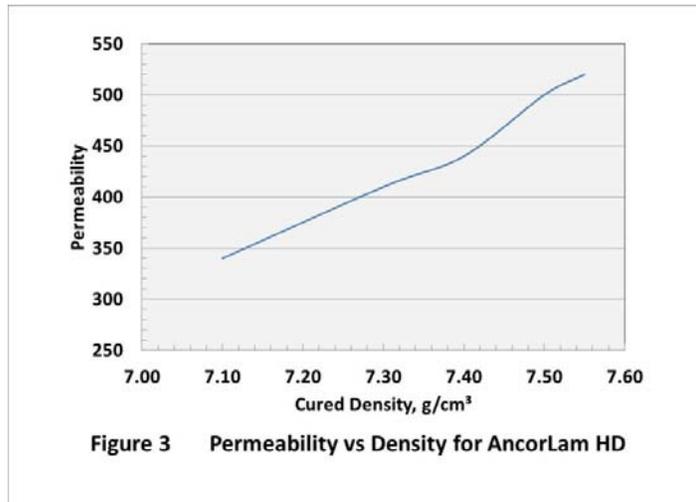
Material & Density	Frequency, Hz	Max Perm, DC	Residual Magnetism, T	Coercive Field Hc (A/m)	Core loss, w/kg
<b>AncorLam HD at 7.53g/cm<sup>3</sup> cured density</b>	DC	515	0.27	264	-
	60	504	0.29	275	7
	400	504	0.32	320	58
	1000	500	0.36	396	178
	5000	450	0.59	870	1955
	10000*	375	0.45	920	2400
<b>AncorLam HR – HD at 7.33 g/cm<sup>3</sup> cured density</b>	DC	240	0.14	323	-
	60	235	0.14	330	8.6
	400	230	0.14	350	61
	1000	230	0.15	375	163
	5000	230	0.20	525	1134
	10000*	230	0.17	510	1250

\* Tested at induction level of 0.6 Tesla

As anticipated, higher cured densities result in higher permeability and higher maximum induction levels. Despite the higher density achieved with the AncorLam HD, the resistivity and core losses are equivalent to existing materials.

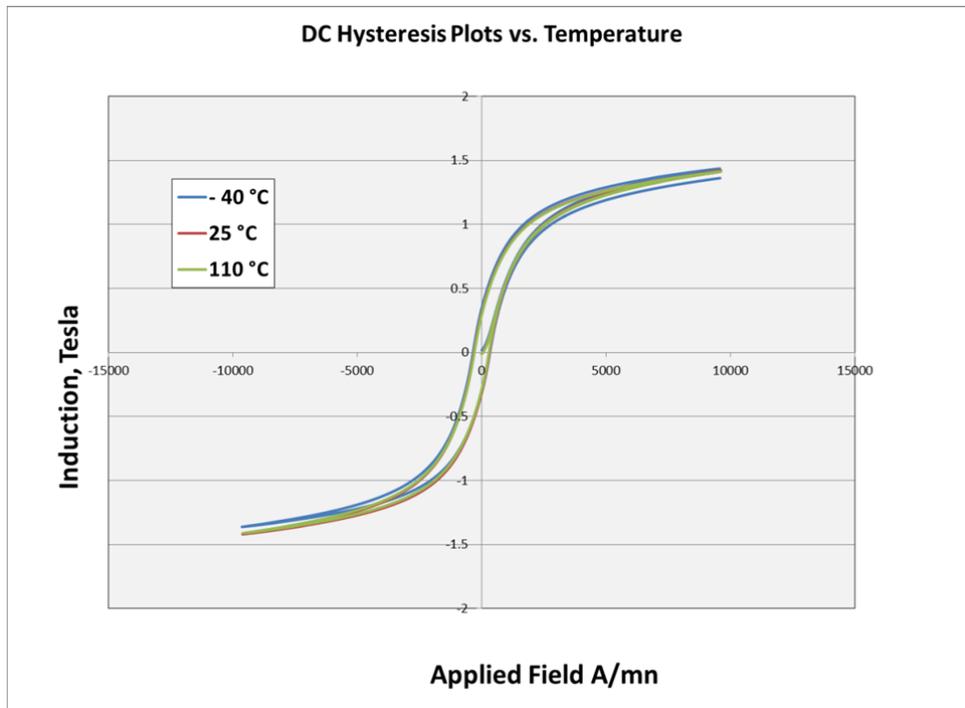
**Discussion**

Density, resistivity and ‘cured’ strength are three fundamental considerations for the use of soft magnetic composites. Implicit in this discussion is the cost of the raw material and ease of producing the final magnetic component. In this study, a standard high purity iron powder was surface treated to provide a magnetically insulating coating. This study evaluated the use of a new lubricant that enabled using only 0.25% total lube. In so



doing, the compacted density was increased to 98% of the PFD or approximately 7.55 g/cm<sup>3</sup>. Increasing the part density increased the magnetic saturation to >1.6T and gave a permeability of >500. Figure 3 shows the effect of density on the magnetic permeability of AncorLam materials. Although higher perms have been reported in the literature, this material offers this level of permeability and magnetic induction using commercially available iron powder. In addition to the high density, the cured strength of this material is >130 MPa.

In addition to testing the AncorLam HD material at room temperature it was also evaluated at test temperatures of -40 °C and ~110 °C. The resulting DC hysteresis graphs are shown in Figure 4. The three DC BH curves are nearly identical implying that this material does not degrade with either low temperatures or temperatures typically associated with automotive under the hood temperature conditions. The losses at the three temperatures were identical. Thus these materials can be used in a variety of applications with operating conditions of -40 °C up to 110 °C.



### Conclusions

From the work performed in this study, the following conclusions are made:

1. AncorLam HD shows improved green density and cured density compared to existing material by about 0.05 g/cm<sup>3</sup>. Post curing at 450 °C, the AncorLam HD has a transverse rupture strength of ~130 MPa. A maximum induction of >1.6 Tesla was achieved with this material.
2. AncorLam HR-HD has higher resistivity and lower density but maintains constant permeability up to ~10 kHz.

3. Cured density has a strong influence on permeability. Higher densities promote higher permeability and higher induction.

## **References**

1. F. Hanejko, "High-Density Compaction Using Lubricant Levels of 0.25 w/o", Oral Presentation, Presented at PowderMet 2013, June 24 – 27, 2013, SIP 3 Technologies for PM Growth.
2. Standard Test Methods for Metal Powders and Powder Metallurgy Products, Metal Powders Industry Federation, 2012 Edition, Princeton NJ 08540, pp. 43-46.