ADVANCES IN BINDER –TREATMENT TECHNOLOGY STATISTICAL DATA ON ANCORBOND PLUS

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Abstract

Binder treatment technology has been well accepted in the marketplace to provide reduced segregation and better powder flowability. However, there is a need to increase the green strength of some parts for better handling of intricate shapes and also a need to improve the bonding of nickel and copper. ANCORBOND Plus is an engineered bonding technology that can produce very high green strength and green density based on conventional compaction processing. The system, which uses a zincless lubricant, is based on the optimization of the bonding mechanism and binder chemistry. This paper will present statistical data collected on parts processed in a production press.

Introduction

The benefits of binder-treated mixes are now well recognized in the P/M industry in terms of substantial improvements in flowability, segregation resistance, green strength and compressibility[1,2,3]. More recently, developments in the technology have led to an even stronger capacity to bond elemental powders such as copper and high contents of alloying additives such as graphite and nickel in excess of 4%. Using a systems approach to optimize the binder chemistry and premixing process, the green strength of bonded mixes has been improved over 50%[4,5]. These developments have positive impacts on the sintered properties as well as the green properties. This paper will review the impact of these developments on parts manufacturing with respect to precision and dimensional tolerance.

The original binder-treated premix, ANCORBOND®, was developed in the late 1980's and the binder acted solely as a binder. It did not exhibit lubricity enhancements measured in terms of the pressure required to strip and slide parts out from a die. Being an elemental glue, the binder actually reduced the internal lubricity required for particle packing and particle deformation during the compaction process. Friction measurements during powder compaction studies showed the importance of a good quality lubricant[5]. The binder did improve die fill or flowability and reduced segregation of the fines.

The second generation of binder-treated premixes utilized a binder that also acted as an internal lubricant. The improvements in compressibility were evident at higher compaction pressures. The binder lubricant treatment reaped the benefits of the original treatment while adding to it increased compressibility, and equivalent or better lubricity.

The third generation of binder-treated premixes incorporated a systems approach to develop ANCORDENSE® or warm compaction technology[6]. The third generation binder is designed for the much higher temperature environment. This method involves investment in peripheral powder heating equipment to warm compact the bonded mix and achieve a substantial improvement in both green and sintered properties. The main impact on parts manufacturing is higher compressibility and higher green strength. With a green strength approaching 4000psi, parts can be machined in the green state.

Recent developments in bonding mechanisms and binder chemistry have yielded properties a level beyond the first and second generation ANCORBOND products[7]. The ANCORBOND Plus™ engineered materials is designed for conventional compaction and do not require the use of peripheral heating equipment as would be needed with ANCORDENSE processing. ANCORBOND Plus induce a much higher green strength in premixes which allows for a reduced green scrap rate and the possibility for green machining. In addition, the green density achievable increases using these material systems and leads to further improvement in the sintered properties. The advanced bonding mechanism allowed better dimensional control in the green state through better distribution of the alloying additives. More importantly, it also allowed better deformation pattern of the particles during the compaction cycles. Statistical measurements on various segments of the green body from several production runs will be analyzed to show the trends and precision level in both composition and dimensional control.

Dimensional Changes and Tolerances

P/M is a net shape process and its value versus other forming process increases as the dimensional tolerances improves. Binder treated premix can improve the ability to maintain very narrow dimensional tolerance on complex shape parts such as gears, cams, and multilevel parts. The problem of maintaining superb dimensional tolerance lies in the fact that the dimensions change at every step of the P/M process. Every step involves momentum, heat and mass transfer between the individual particles and surrounding environment. Some of the factors contribute to dimensional tolerances are summarized below:

a) iron powder properties such as grain sizes, oxygen and residual content
b) variations in the quality and quantities of alloying additives
c) segregation of the powders during handling and die filling
d) internal and external lubricity of the powder premix
e) tool design and tool deflection
f) tool and die wear
g) variation in the compaction load
h) local green density/green expansion variation
i) effect of temperature on green expansion
j) variations in the sintering furnace

Bonding Mechanisms

The segregation of fine powder and efforts to simulate the segregation pattern are well-known[8]. Bonding of fines to coarse particles will reduce segregation. The bonding of powders having different chemistry, particle size and shape is a very delicate and sensitive science. The resultant properties of bonded mixes are heavily dependent on the processing and bonding agents used. Not all binders are created equal. Some have extremely good bonding capability but no lubricating quality. This results in loss of compressibility and increased ejection force. Some have good lubricating quality but poor bonding capability. The ideal binder will have good bonding capability during powder processing and good lubrication quality during compaction and ejection of the green compact. As the alloy additions are mixed into the iron powder, many different bonding mechanisms can be achieved with the ANCORBOND process. As shown in Figure 1, there are different bonding mechanisms and outcomes during the various stages of bonding; some are desirable and others not. Starting with a large iron particle, the ANCORBOND process uses a binder system to bond the fines to the particle surface. The fines can be fine irons, fine lubricant particles, or alloying additives such as nickel, copper, graphite and other ferroalloys.

The different mechanisms are:

a) The binder wets the fines preferentially and forms sizable agglomerates. This could be copper agglomerates or graphite balls. During sintering, these will result in large pores impacting the sintered density negatively. It will also induced localized excessive growth and cause dimensional tolerance problem.
b) The binder wets the iron powder and bonds the fines evenly around the iron particle. This is the preferred state. It evenly distributed the alloying additives and improve dimensional tolerance.
c) The binder bonds the fines in such a way that a rounded shape iron agglomerate is formed. A rounded powder results in better packing within the die cavity. It also improves compressibility and dimensional tolerance.
d) The binder bonds the fines first into a stack agglomerate and then to the iron surface. This bonding is hard to maintain and will eventually break into smaller agglomerates. It will impact flow and dimensional tolerance negatively.
e) The binder forms the core of agglomerate bonding the fines to its surface. This will cause excessive pores and impact the sintered strength negatively.
f) The binder coats the entire iron particle only. There is no bonding achieved.
g) The binder coats the individual particles of the fines only. There is no bonding achieved.
h) The binder remains a binder particle by itself with no bonding of the fines or iron particles.
i) The binder bonds the fines to the iron particles but the bonding fails later resulting in fragmented fines and binder.

Some mechanisms will result in deteriorated green and sintered properties. These problems can stem from an inadequate binder in terms of processability, capacity to bond, preferential attraction towards certain particles, and viscosity or the binder’s ability to distribute and wet surfaces. The second and third mechanism illustrated in the diagram would obviously be the most effective in achieving properties such as segregation resistance, flowability and homogeneity. The coupling of this processing knowledge with the engineered binder systems used in this study contributes to the enhancement in properties relative to conventionally processed premixes.

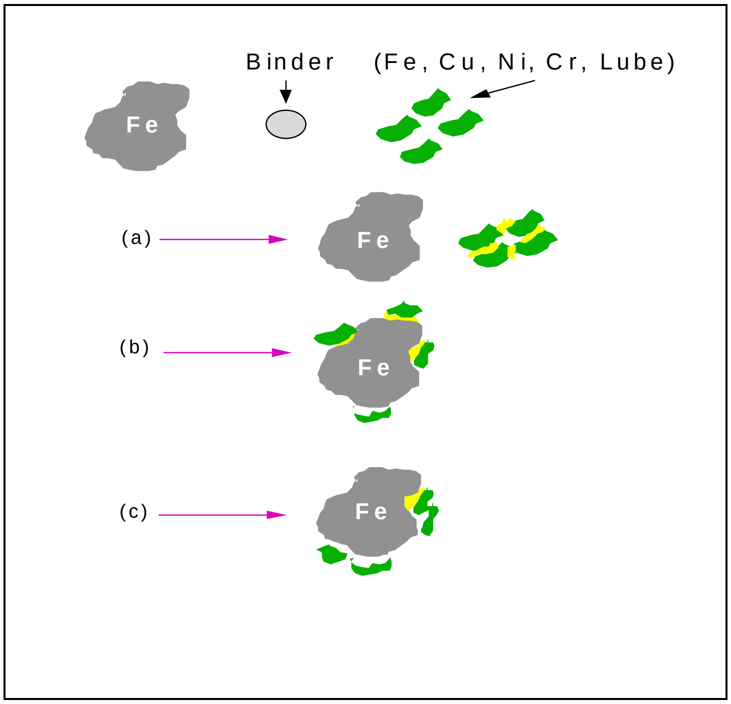

Figure 1 (a-c): Bonding Mechanisms involving alloying additives, lubricants and iron powders in the ANCORBOND process.

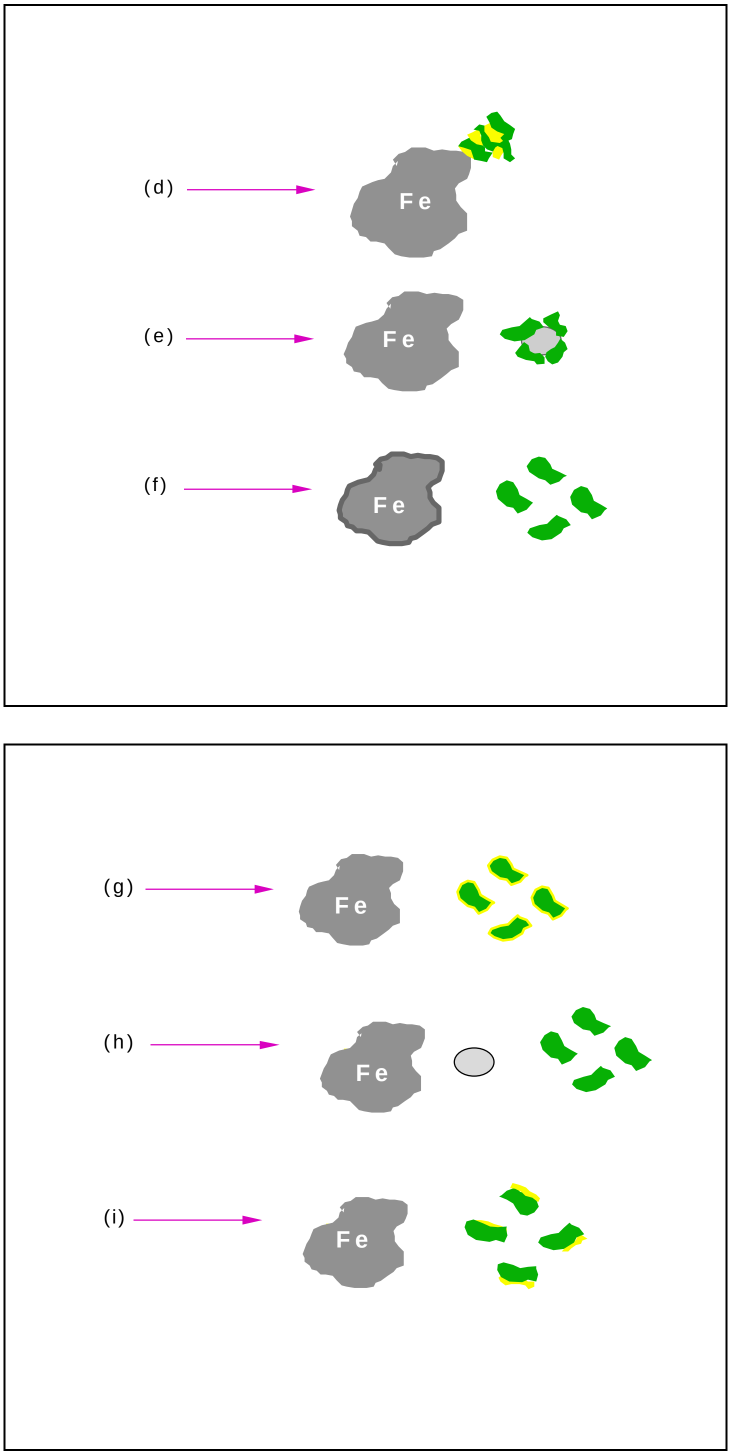

Figure 1 (d-i): Bonding Mechanisms involving alloying additives, lubricants and iron powders in the ANCORBOND process.

Experimental Procedure

Laboratory procedures were performed in accordance with appropriate ASTM standards. The first generation ANCORBOND, improved ANCORBOND, and ANCORBOND Plus products, referenced in this paper as Mix A, Mix B and Mix Plus, respectively. Binders used in the ANCORBOND and ANCORBOND Plus are patented binder systems developed by Hoeganaes Corporation. All other ingredients are commercially available. All the premixes were made from the same lot of iron powder (Ancorsteel 1000B). The nickel 123 was from INCO, 8081 copper was from ACuPowder International, Acrawax-C was from Lonza Inc., and the 3203HS graphite was from Asbury Graphite Mills. In the compaction temperature study, the composition is 303L with 2.25 w/o copper and 1 w/o lubricant.

To evaluate the green and sintered properties, transverse rupture strength (TRS) bars were prepared according to ASTM B 312. The reported values are the average of three bars. The TRS bars in the Ancorsteel 45P studies were pressed at a nominal 145 °F (63°C) die temperature. The TRS bars in the compaction temperature study were pressed at a nominal 75 °F (24 °C), 110 °F (43 °C) 145 °F (63 °C), 180 °F (82 °C) and 215 °F (102 °C) die temperatures. TRS bars were pressed at 30, 40 and 50 tsi (415, 550 and 690 MPa, respectively).

The Ancorsteel 45P, TRS bars were sintered at 2050 °F (1120 °C) for 30 minutes in an atmosphere of synthetic DA. The tabulated data in the Part Fabrication section was produced and compiled using a 220-ton Cincinnati press at the Technical Center of Cincinnati Incorporated. Additional data were generated at the Hoeganaes R&D Laboratory. The data for the study on the large sprocket and the cylinder liners were supplied by a customer (name withheld) and Tecsyn PMP.

Results and Discussion

The demand for higher dimensional tolerance and elimination of green cracks calls for higher green strength and better compressibility in premixes[9,10,11]. Based on different bonding mechanisms and binder chemistries, the improvements in ANCORBOND for conventional compaction provide higher green strength, higher green and sintered densities, and permit the bonding of copper particles. The higher green strength and higher green density achievable in green compacts is becoming more critical in making more robust green compacts. In particular, the higher green strength achieved in the ANCORBOND PLUS system allows the possibilities of green machining of complex parts. The higher compressibility of the new system extends the capabilities of existing compaction press.

The premix compositions chosen for this study were Ancorsteel 45P. The total content of binder plus lubricant, in each mix was kept constant at 0.75 w/o. In each case, an unbonded regular premix with 0.75 w/o Kenolube was used as the reference.

ANCORSTEEL 45P

ANCORBOND Plus is a new engineered binder-treated material system with zero zinc content. It is aimed at increasing the green and sintered density for the conventional compaction process with the additional benefit of a 100% increase in green strength. The advantage of such high green strength is the possibility of green machining without resorting to warm compaction[12,13]. Typically, a green strength of 4000 psi is needed for green machining. High green strength is also required to eliminate green cracks due to handling and excessive ejection stresses.

The 0.45 w/o Phosphorus premix green properties shown in Table I exemplify the capability of enhancing green strength and green density with the improved ANCORBOND (Mix B) and ANCORBOND PLUS (MixPlus). The two reference mix are the original ANCORBOND (mix A) and unbonded premix with 0.75% Kenolube. The green strength of mixes B and Plus are 50-55% and 85-122% higher than the reference premix and mix A. Mixes B and Plus exhibit the better compressibility than the other mixes, up to 0.09 g/cm³ at higher compaction pressures. At low compaction pressures, the ejection characteristics of mix B and Plus are better than the reference premix having the high performing Kenolube. At higher compaction pressures, the data suggests a division in ejection among the mixes. In regard to the higher compaction pressure ejection characteristics, the reference premix is similar to the Plus mix. The Plus mix and reference premix displays better lubricity than mixes A and B.

Table I: Green Properties of 45P Mixes

Mix	Compaction Pressure (tsi)	Green Density (g/cm³)	Green Strength (psi)	Stripping Pressure (psi)	Sliding Pressure (psi)
Mix A	30	6.75	1800	3600	1800
	40	7.05	2500	4200	1900
	50	7.22	3200	4500	2100
Mix B	30	6.75	2700	2700	1500
	40	7.06	3800	3600	1900
	50	7.26	4800	4000	2200
Mix Plus	30	6.81	4000	2300	1200
	40	7.09	5100	3200	1500
	50	7.28	5900	3900	1700
Reference	30	6.79	2200	3100	1500
Premix	40	7.07	2900	3400	1600
	50	7.19	3000	3800	1700

The 0.45 w/o Phosphorus premix sintered properties tabulated in Table II are an indication of what can be achieved with better compressibility and sinterability of the lubricant-binder systems used in mixes B and Plus. If different sintering conditions had been used, i.e., hydrogen atmosphere, 2300°F for 30 minutes, then densification and the resultant sintered properties would be significantly better[2]. Already though, at higher compaction pressures, the density (up to 0.13 g/cm³ increase in sintered density) and correspondingly, the strength of the B and Plus mixes are 7 to 27% higher than the other mixes. The apparent hardness of the Mix B and Plus are similar or slightly higher. By optimizing the bonding mechanism on particle morphology and distribution, it is possible to improve the distribution of the bonded ferrophosphorus. This is shown by the increased shrinkage during sintering. It can also lead to consistent dimensional control.

Table II: Sintered Properties of 45P Mixes

Mix	Compaction Pressure (tsi)	Green Density (g/cm³)	Green Expansion (%)	Sintered Density (g/cm³)	Dimensional Change (%)	Transverse Rupture Strength (10³psi)	Appparent Hardness (HRB)
Mix A	30	6.79	0.08	6.78	-0.11	97	39
	40	7.07	0.10	7.06	-0.09	119	53
	50	7.23	0.14	7.25	-0.07	142	61
Mix B	30	6.80	0.10	6.84	-0.29	112	48
	40	7.09	0.13	7.14	-0.25	140	59
	50	7.27	0.18	7.31	-0.22	154	68
Mix Plus	30	6.84	0.11	6.86	-0.20	109	45
	40	7.12	0.12	7.16	-0.19	147	57
	50	7.32	0.13	7.35	-0.14	165	66
Reference	30	6.82	0.12	6.84	-0.12	102	44
Premix	40	7.07	0.12	7.11	-0.11	120	56
	50	7.19	0.14	7.22	-0.11	130	64

Production Run of a Small Cylinder

The tonnage and part mass variation data presented are from 220 ton Cincinnati production press and are based on 300 part runs. The parts are cylinder of 1.3 inch height, outer diameter of 1.5 inch, inner diameter of 1.0 inch, and wall thickness of 0.25 inch. Each green and sintered part is measured for part weight, part height, wall thickness, inner diameter, and outer diameter.

Each data set is then analyzed by the descriptive statistics package in Microsoft Excel. For each data set, the following statistics is obtained: Mean, Median, Mode, Standard Deviation, Kurtosis, Skewness, Range, Minimum, and Maximum. Mean, Median and Mode will provide location measure of the absolute value in a data set. Median is the number in the middle of a set of data, i.e. half the numbers have values that are greater than the median, and half have values that are less. Mode is the most frequently occurring, or repetitive, numbers in the data set. Standard deviation, kurtosis, and skewness provide a measure of the dispersion and distribution of the data set. For a controlled process, a normal distribution or bell shape curve is preferred. Kurtosis characterized the relative peakedness or flatness of a distribution compared with the normal distribution. Positive kurtosis means a relatively peaked distribution. Negative kurtosis means a relatively flat distribution. A smaller kurtosis value is preferred. Skewness characterizes the degree of asymmetry of a distribution around its mean. Positive skewness means a distribution with an asymmetric tail extending toward more positive values. Negative skewness means a tail extending towards more negative values. Again, a smaller skewness value is preferred.

According to the MPIF Design Book, the dimensional tolerance for outer diameter is +/- 0.002 inch/inch of a green compact. For a sintered compact after coining operatioin, it calls for a dimensional tolerance of +/- 0.001 inch/inch. It is of interest to check the dimensional tolerance of an reference (unbonded) premix vs. an ANCORBOND PLUS 45P premix.
Table III shows the benefits of using bonded products and the improvements achieved by the recent advances in the lubricant-binder technology. For the outer diameter, measurements were taken in the middle of the cylinder at two locations (North-South

and East-West diagonals). This is labeled as OD1 and OD2. The average of these two measurements is labeled as AVE. In both cases, there is no difference between the mean, median, and mode. This showed an evenly distributed data set. In terms of absolute value, the ANCORBOND Plus compacts showed an increased diameter of 0.0003 inch from the reference compact. This is due to the green expansion of the binder. The dimensional tolerance is reviewed in terms of standard deviation, kurtosis, ,skewness, and range. For the ANCORBOND PLUS compact, the standard deviation is less than 0.0001 inch and the data tends toward a normal distribution. For the reference mix, the standard deviations is at least 0.0002 inch and the data tends toward a peaked distribution with a asymmetric tail toward the higher diameter value. The range of the values is also important since it specified the range of the variation in the diameter measured. For the reference mix, the range can be as high as 0.0055 inch for OD2. For the ANCORBOND PLUS, the range can be as high as 0.0009 inch for OD2. In both case, OD1 showed less variation than OD2. For the green compact using the identical compaction press and tooling, the outer diameter dimensional tolerance can be improved significantly by using a binder treated premix. This is due to better die fill and better bonding pattern of the fines.

Table III: Descriptive Statistics on Outer Diameter Measurements of Green Compact in 45P Mixes

	Reference			ANCORBOND PLUS		
Statistics	OD1	OD2	AVE	OD1	OD2	AVE
Mean	1.5031	1.5032	1.5031	1.5033	1.5034	1.5034
Medium	1.5031	1.5031	1.5031	1.5034	1.5034	1.5034
Mode	1.5031	1.5031	1.5031	1.5034	1.5034	1.5034
St. Dev.	0.0002	0.0004	0.0002	0.00008	0.00009	0.00006
Kurtosis	141.5	164.3	141.4	0.50	6.40	0.48
Skewness	8.75	12.30	11.3	-0.17	0.76	-0.20
Range	0.0034	0.0055	0.0031	0.0006	0.0009	0.0004
Minimum	1.5020	1.5029	1.5030	1.5030	1.5031	1.5032
Maximum	1.5054	1.5084	1.5061	1.5036	1.5040	1.5036

For the sintered compact, the results were tabulated in Table IV. There is difference between the mean, median, and mode. This showed a less evenly distributed data set. In terms of absolute value, the ANCORBOND Plus compacts showed a mean diameter same as the reference compact. The dimensional tolerance is reviewed in terms of standard deviation, kurtosis, ,skewness, and range. For the ANCORBOND PLUS compact, the standard deviation is less than 0.0004 inch and the data tends toward a normal distribution. For the reference mix, the standard deviation is at least 0.0007 inch and the data tends to a normal distribution. The range of the values is also important since it specified the range of the variation in the diameter measured. For the reference mix, the range can be as high as 0.0033 inch for OD2. For the ANCORBOND PLUS, the range can be as high as 0.0023 inch for OD2. In both cases, OD1 showed less variation than OD2. For the sintered compact using the identical furnace, the improvement in dimensional tolerance from the green compact is reduced. However, the binder treated premix is still showing a significant improvement in dimensional tolerance vs. that of the reference mix.

Table IV: Descriptive Statistics on Outer Diameter Measurements of Sintered Compact in 45P Mixes

	Reference			ANCORBOND PLUS		
	OD1	OD2	AVE	OD1	OD2	AVE
Mean	1.4966	1.4963	1.4964	1.4963	1.4966	1.4964
Medium	1.4967	1.4963	1.4963	1.4964	1.4966	1.4965
Mode	1.4955	1.4961	1.4973	1.4963	1.4965	1.4967
St. Dev.	0.0009	0.0007	0.0007	0.0004	0.0004	0.0004
Kurtosis	-1.16	0.32	-0.47	-0.42	1.43	-0.41
Skewness	-0.005	0.38	0.14	0.08	0.40	0.30
Range	0.003	0.0033	0.0030	0.0018	0.0023	0.0015
Minimum	1.4952	1.4950	1.4951	1.4956	1.4956	1.4957
Maximum	1.4982	1.4982	1.4981	1.4974	1.4979	1.4972

ANCORBOND Trial of a Large Sprocket

The trial involved the comparison of 10,000lb lots of binder treated FN0205 premix to regular premix at a customer request. The part chosen for the test is a large sprocket. During heat treat process of this sprocket, there exits the common problems of density variation and size stability. By converting to the binder treated premix, the parts producer anticipates less dusting, improved cleanliness, reduced segregation of nickel and carbon in the base powder, improved dimensional stability. The improvements in cleanliness and reduced dusting were documented in a previous report. The parameters used to compare the performance between the mixes are weight control, dimensional stability (-inside diameter between pins, taper), nickel and carbon variability, and Q&T Hardness. The trial is carried out in a hydraulic press set a stroke rate of 6 pieces/min. A total of 500 parts were made for each mix for data analysis. Table V shows the improvements in weight control and dimensional control.

Table V: Weight Control and Sintered Dimensional Responses for a Large Sprocket Production Run

	PREMIX	**ANCORBOND**
Weight Control (g)		
Mean	995.15	999.192
Std. Dev.	2.251	1.144
Range	18.1	9.2
Minimum	986.1	994.6
Maximum	1004.2	1003.8
Press Adjustment	10	2
Dimension Control		
I.D. between Pins		
Mean (inch)	0.96637	0.96762
Std. Dev.	0.00037	0.00017
I.D. Taper		
Mean (inch)	0.00050	0.00053
Std. Dev.	0.00028	0.00028

Sintered chemistry of both nickel and carbon was determined on the as-sintered sprocket samples and is shown in Table VI. A total of 50 samples were collected by choosing the every tenth sprocket out of the total 500 pieces run. Chemical analysis was done on powder collected by drilling to a depth of 0.18 inch from the surface of each sprocket. This depth is important since it represents both the percentage of admixed graphite and effects of sintering atmosphere on the parts surface carbon. The ANCORBOND mix shows significant improved uniformity in both nickel and carbon content.

Table VI: Nickel-Carbon Distribution for a Large Sprocket Production Run

	PREMIX	ANCORBOND
Sintered Carbon (w/o)		
Mean	0.523	0.529
Std. Dev.	0.043	0.010
Range	0.11	0.02
Minimum	0.47	0.52
Maximum	0.58	0.54
Sintered Ni (w/o)		
Mean	1.76	1.84
Std. Dev.	0.233	0.020
Range	0.62	0.05
Minimum	1.50	1.81
Maximum	2.12	1.86

The sprockets were heat treated in a batch type gas carburizing furnace through a carbonitride cycle followed by a direct quench in agitated 115-127 ^{0}C (240-260 ^{0}F) hot oil for distortion control while maintaining quenching capabilities. It then went through a 350 ^{0}F temper for one hour. The dimensional response and apparent hardness were compared and shown in Table VII. Again, the binder treated premix showed a significant improvement in dimensional tolerance.

Table VII: Heat Treated Dimensional Responses for a Large Sprocket Production Run

	Regular Premix	ANCORBOND
Dimensional Control		
I.D. between Pins		
Mean (inch)	0.96820	0.96880
Std. Dev.	0.000167	0.000117
I.D. Taper		
Mean (inch)	0.00043	0.00027
Std. Dev.	0.00034	0.00019
Hardness (HRB)		
Top	118	119
Bottom	119	119

Crown Tonnage Variation of Various Mixes

The significance of lower tonnage variation is that it implies a movement towards more consistent A. D. and Hall Flow within a lot of powder. Due to the increase in compressibility of the improved ANCORBOND and ANCORBOND Plus mixes, a lower compaction tonnage will be needed to reach the desired density. Figure 2 and 3 displays graphically the improvements in lowering tonnage variation. The lines above and below the plot represent the plus and minus 3 sigma values.

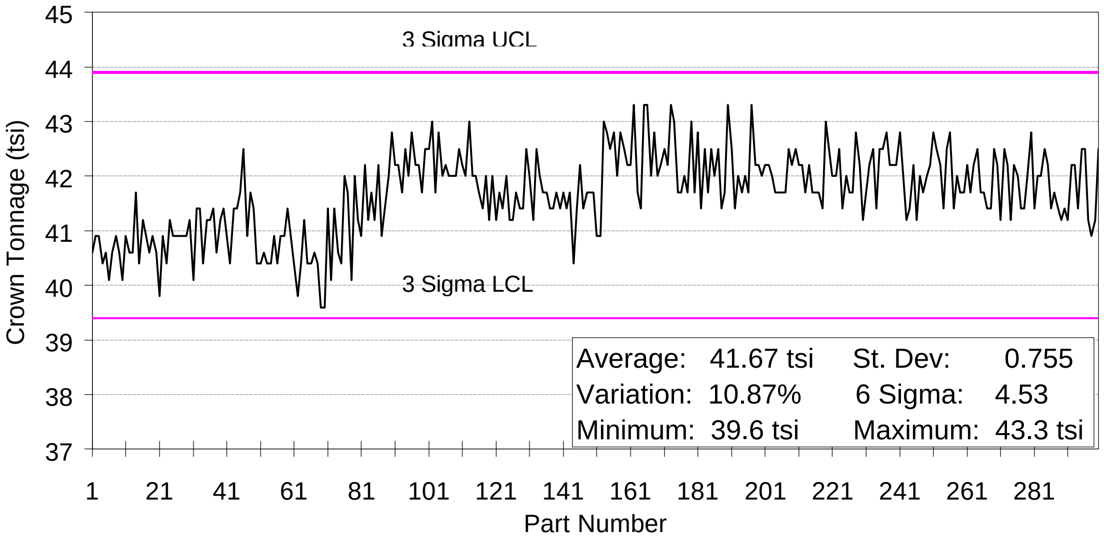

Figure 2: Crown Tonnage Variation of an first generation ANCORBOND I FN-0208 Composition

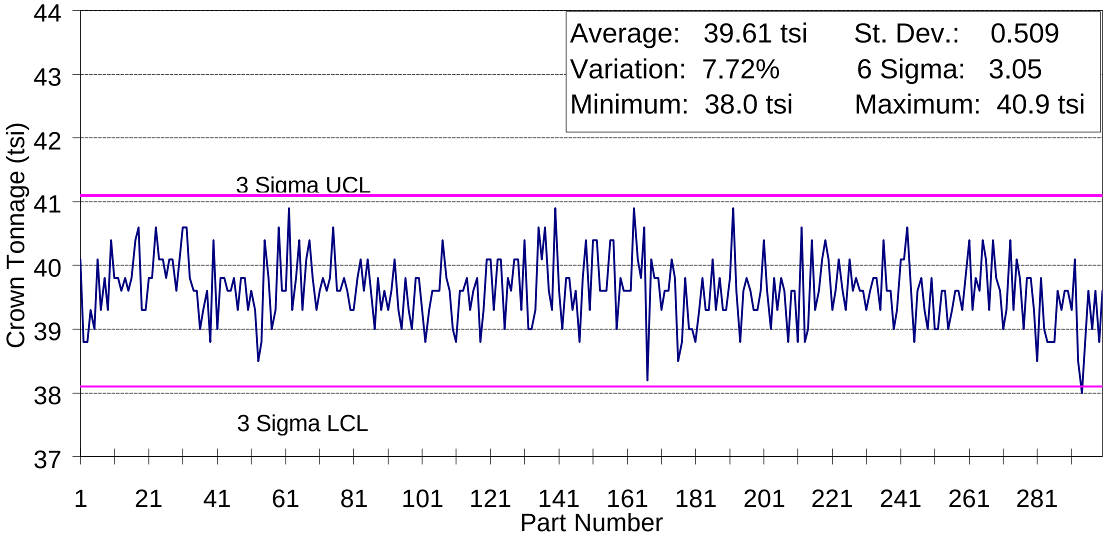

Figure 3: Crown Tonnage Variation of an ANCORBOND V FN-0208 Composition

The more consistent ANCORBOND V powder fill and flow leads to more consistent parts. Table VIII shows the consistent part to part mass of ANCORBOND V relative to ANCORBOND I for FC-0208 and FN-0208 compositions. The data is based on the measurement of every tenth part. The variation of the ANCORBOND V mixes are 24 to 48% lower than that of ANCORBOND I mixes. Relative to unbonded premixes[4], ANCORBOND processed premixes used in industry usually exhibit a reducuction in dimensional variability by 25-60%; weight and density variability by 30-50%, press speed improvements of 10-50%, reduced scrap rate of 97% as well as reduction in dusting and press adjustments. As for part weight control, Mix B is far superior to Mix A as shown in Table IX.

Table IX: Part Mass Variation of Various Mixes

Mix Composition	Average Part Weight (grams)	Minimum Weight (grams)	Maximum Weight (grams)	Standard Deviation	6 Sigma Value	Variation (%)
Mix A FC-0208	113.969	113.353	114.767	0.36	2.16	1.90
Mix B FC-0208	104.771	104.280	105.278	0.25	1.52	1.45
Mix A FN-0208	116.364	115.070	116.831	0.40	2.37	2.04
Mix B FN-0208	106.595	106.238	107.152	0.19	1.13	1.06

Compositional Tolerance

A specific binder is required for the making of an engine cylinder liner made of PM steel. This is to ensure consistent dispersion 1.15% graphite in a Ancorsteel 45P composition with machining additive. A long term tracking of carbon content in the powder and in sintered cylinder liner was initiated at Tecsyn PMP. A total of 64 bulk packs of TS56S powder were analyzed. This amounts to a total of 320,000 pounds of powder collected over a period of six months. Five random samples were taken from each 5000lb bulk pack. The results were shown in Figure 4. The descriptive statistic analysis on % carbon in the powder showed a mean of 1.1494, median of 1.1526, mode of 1.1406, standard deviation of 0.0238, range of 0.0800, minimum of 1.1155, maximum of 1.1955, kurtosis of –1.25, skewness of 0.215. This binder treated premix is able to hold a carbon content within +/-0.04% for a 1.0 % graphite addition.

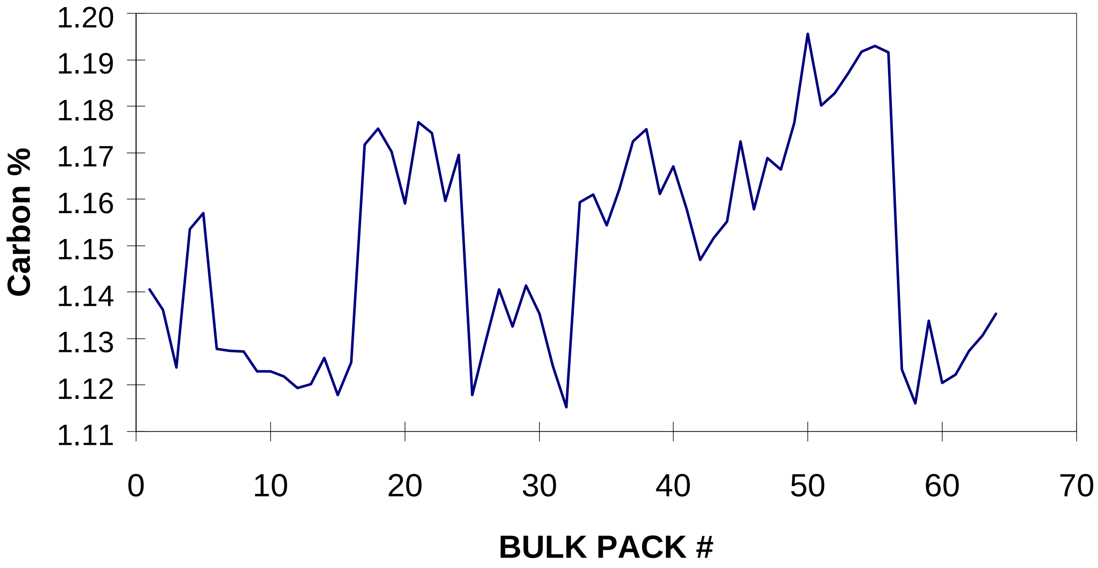

Figure 4. Carbon Analysis on powder samples from 64 bulk packs.

Figure 5 showed the sintered carbon results for four lots of powder. The sintered carbon data were taken from cylinder liners. The liners were tracked to each production lot. Five drilled samples were taken from each liner. The descriptive statistic analysis on % sintered carbon in the liners showed a mean of 09855, median of 0.9854, mode of 0.9700, standard deviation of 0.0222, range of 0.0860, minimum of 0.9461, maximum of 1.0321, kurtosis of –0.92, skewness of 0.225. This binder treated premix is able to hold a carbon content within +/-0.043% for a 1.0 % graphite addition. This work is continued at TecSyn PMP. Additional data on mechanical properties will be available in the future.

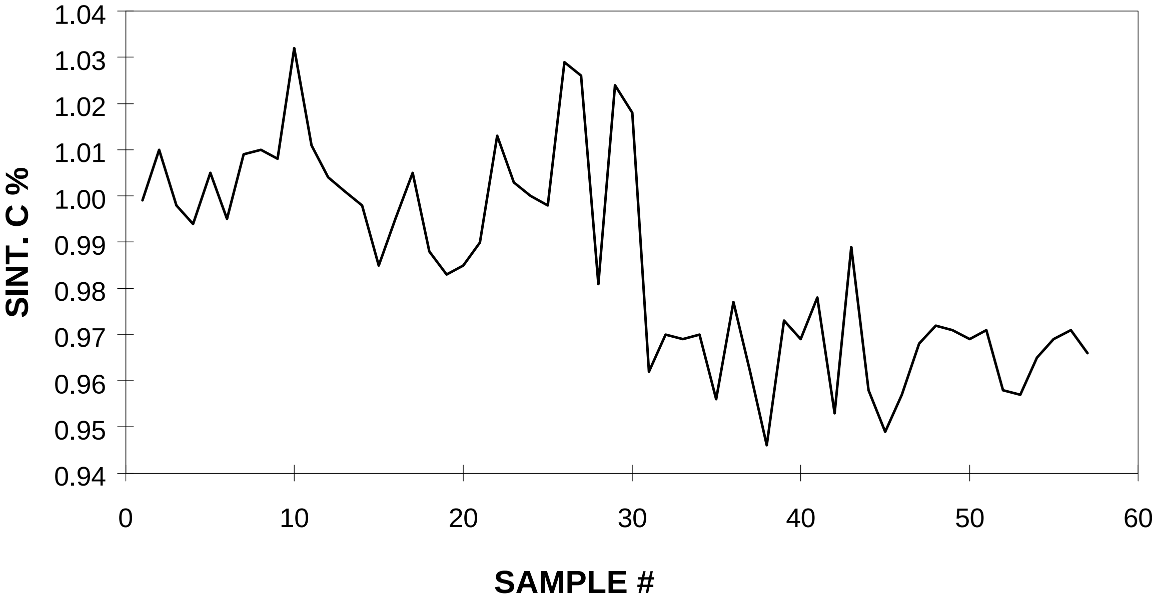

Figure 5. Sintered Carbon Analysis on powder samples from 32 bulk packs.

Effect of Temperature on Green Expansion

In the compaction temperature study, the composition is 303L with 2.25w/o copper and 1w/o lubricant. Three lubricant systems are studied and label as IA, IB, and IC. The labels IA, IB, and IC refer to the lubricants GS6000, 50:50 mix of Lithium Stearate and GS6000, and Lithium Stearate respectively. The effect of temperature on green expansion with respect to compacting pressure is shown in Figure 5. For a given compaction pressure, as temperature increases, the green expansion decreases. There is a significant decrease in green expansion at 180°F (82°C) and above for the three different lubricant mixes. The fact that binder softened at 180F° has little impact on the value of green expansion in this dimension. This is due to the corresponding residual stress relief within the die cavity. The residual stress is released first through the top and bottom direction as the top punch retracts from the compact. At this point the green compact will spring back (expand) in the pressing direction. The majority of the remaining residual stress is radial stress, corresponding to the energy stored in the metal to metal particle contact points. The stress stored in the lubricant is minimal.

Temperature has the most influence on the relief of radial stress. For a compaction pressure of 30 tsi, the green expansion can decrease from 0.1 to 0.01% as temperature increases from 75°F to 215°F. This indicates that temperature can be used as a means to reduce green expansion and related internal stress concentrations within the compact. In general, green expansion is inversely proportional to temperature. A better understanding of the green expansion characteristics of the green expansion characteristics would provide designers with information about the relationship between green cracks and excessive expansion of the compact. This is also important to the dimensional control aspect for any green machining operation.

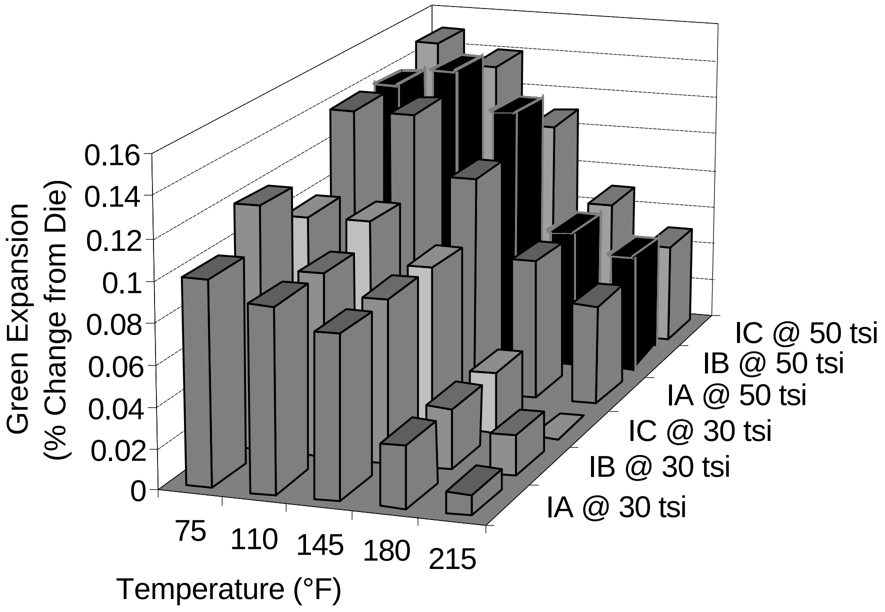

Figure 5: Effect of Temperature on Green Expansion in Direction Normal to the Die Wall at Compaction Pressures Indicated

Conclusions

Various generations of binder-treated products were engineered to satisfy specific market niches.

ANCORBOND PLUS, provides higher green strength for green machining possibilities and higher compressibility to extend press capabilities.

Significant improvement in dimensional tolerance is achieved by binder-treated premix in production runs of a large sprocket and a small cylinder.

Improvements in compositional tolerance is achieved by binder-treated premix in the production of cylinder liners over long term tracking of green and sintered parts.

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