HIGHER GREEN STRENGTH ENHANCEMENTS TO INCREASE PROCESS ROBUSTNESS

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Abstract

The use of binder-treated premixes has grown dramatically since the introduction of the technology in the late 1980's. Decreased levels of respirable dust coupled with reduced segregation and significantly improved powder flow have helped to stimulate this growth. More recently, binder-treated premixes that significantly enhance the green strength of P/M parts have been developed. The higher green strength results in more robust handling of green parts prior to the sintering operation and reduced levels of green scrap. In addition, the significantly higher green strength provides an opportunity for "green" machining of the P/M parts prior to sintering. This paper will discuss recent advances in binder-treatment technology and will review production experience with binder-treated premixes.

Introduction

Powder metallurgy enables producers to create mixtures of powders with properties targeted for specific applications and net shape capability. To fuel the further growth of P/M, the current challenge is higher performance and lower cost of production. Higher performance means higher density, higher dimensional accuracy, higher fatigue properties, and higher quality in terms of delivery and customer support services. Lower cost of production means better material choice, better design, and improved processing capability.

The following are the most obvious means of reducing the cost of P/M part production:

a) Press speed - need to run at the highest possible speed.
b) Size and weight control - good control means more press time for making parts and less time taken adjusting the tooling.
c) Green strength - becoming much more important as P/M parts become more complex and more prone to ejection or compaction cracks.
d) Tool wear - must be minimized to reduce tooling cost.
e) Clean sintering - no soot, stains or deposits on the part's surface.
f) Dimensional control - better dimensional tolerance in the green state can also eliminate the need for secondary operations, or at least reduce them.
g) Finished part properties.
h) Environmental issues– reduced dusting and emission means less environmental compliance cost.

These factors are linked together in many ways that can influence each other and can be directly influenced by the properties of the lubricants and binder systems.
The following are the restrictions of P/M part production to a part designer:

a) Sharp corners on tooling can lead to tool failure.
b) Components with re-entrant angles cannot be ejected from the die during the pressing cycle and will therefore require machining after processing.
c) Thin components with large surface areas are difficult to produce due to large density variations.
d) Thin or very fine part features are fragile and tend to crack during production.
e) Lack of concentricity.

To address these issues of higher performance and lower cost, continuous improvements have been made in ANCORBOND® (binder-treated) premix technology. The benefits of using binder-lubricant treated and binder-treated mixes are 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 ferrophosphorus and copper. The ANCORBOND Plus™ engineered materials are designed for conventional compaction and do not require the use of peripheral heating equipment as would be needed with ANCORDENSE® processing. Using a systems approach to optimize the binder and premixing process, the green strength of bonded mixes has been improved over 50%[4]. ANCORBOND Plus produces 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. This increase in density leads to further improvement in the sintered properties. These developments have positive impacts on the dimensional tolerance and productivity. This paper will review these recent developments and the case study of producing a thin wall sleeve.

Binder-treated Premixes and Bonding Mechanisms

The segregation of fine powder and efforts to simulate the segregation pattern are well known[7]. 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 resulting properties of bonded mixes are heavily dependent on the processing and bonding agents used. All binders are not created equal. Some have extremely good bonding capability but no lubricating quality. This results in loss of compressibility and increased ejection force. The original binder-treated premixes developed in the eighties required lubricants to be admixed to the premix. In this first generation, 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. Friction measurements during powder compaction studies showed the importance of a good quality lubricant[5]. The binder did improve die fill or flowability and segregation resistance resulting in more consistent compacts relative to non-bonded mixes.

The ideal binder will have good bonding capability during powder processing and good lubrication quality during compaction and ejection of the green compact. The new generation of binder-treated premixes utilized a binder that also acted as a 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. 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 are not. Starting with a large iron particle, the ANCORBOND process uses a binder system to bond the fines to the particle's 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 would result in large pores impacting the sintered properties negatively.

b) The binder wets the iron powder and bonds the fines evenly around the iron particle. This is the preferred state.

c) The binder bonds the fines in such a way that rounder iron agglomerates are formed. This results in better packing in the die cavity and improves compressibility.

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 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.

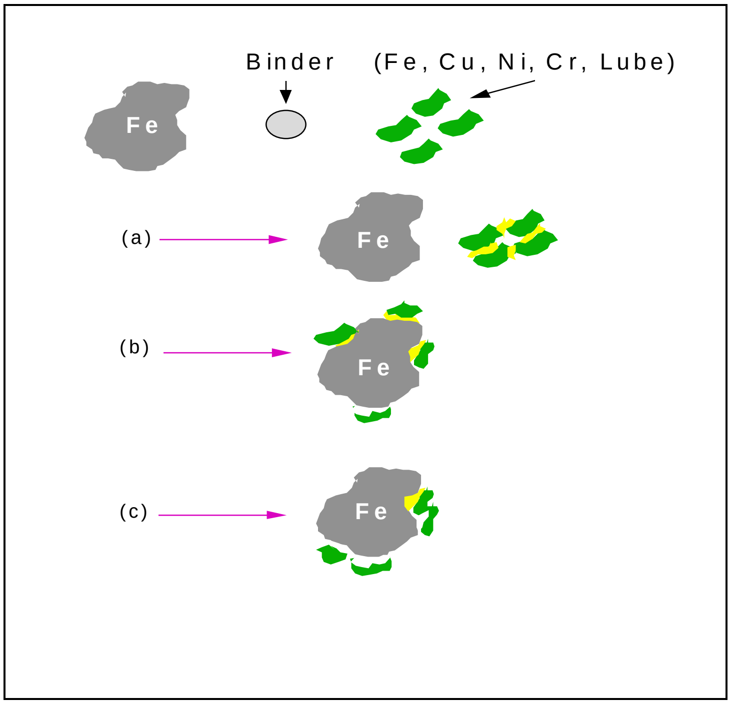

Figure 1 (a-c): Bonding Mechanisms involving alloying additives, lubricants and iron powders in the ANCORBOND process.

Examples of ANCORBOND

To verify the bonding mechanisms, scanning electron microscope (SEM) pictures of several ANCORBOND examples are shown in Figures 2 and 3. The first example shows that the proper bonding mechanism can be used to bond fine particles such as fine irons and ferrophosphorus to larger iron particles in a binder-treated Ancorsteel 45P premix. The ANCORBOND process prevents the segregation of the particles due to size and density difference. This bonding mechanism firmly bonds fines onto the larger iron particles. The ferrophosphorus particles have an average size of 5 – 10 microns. The bonding strength is strong, so no bonded fine particles are broken away during to further mixing or handling. There is almost no dusting of the fines in this case. This is illustrated in Figure 2.

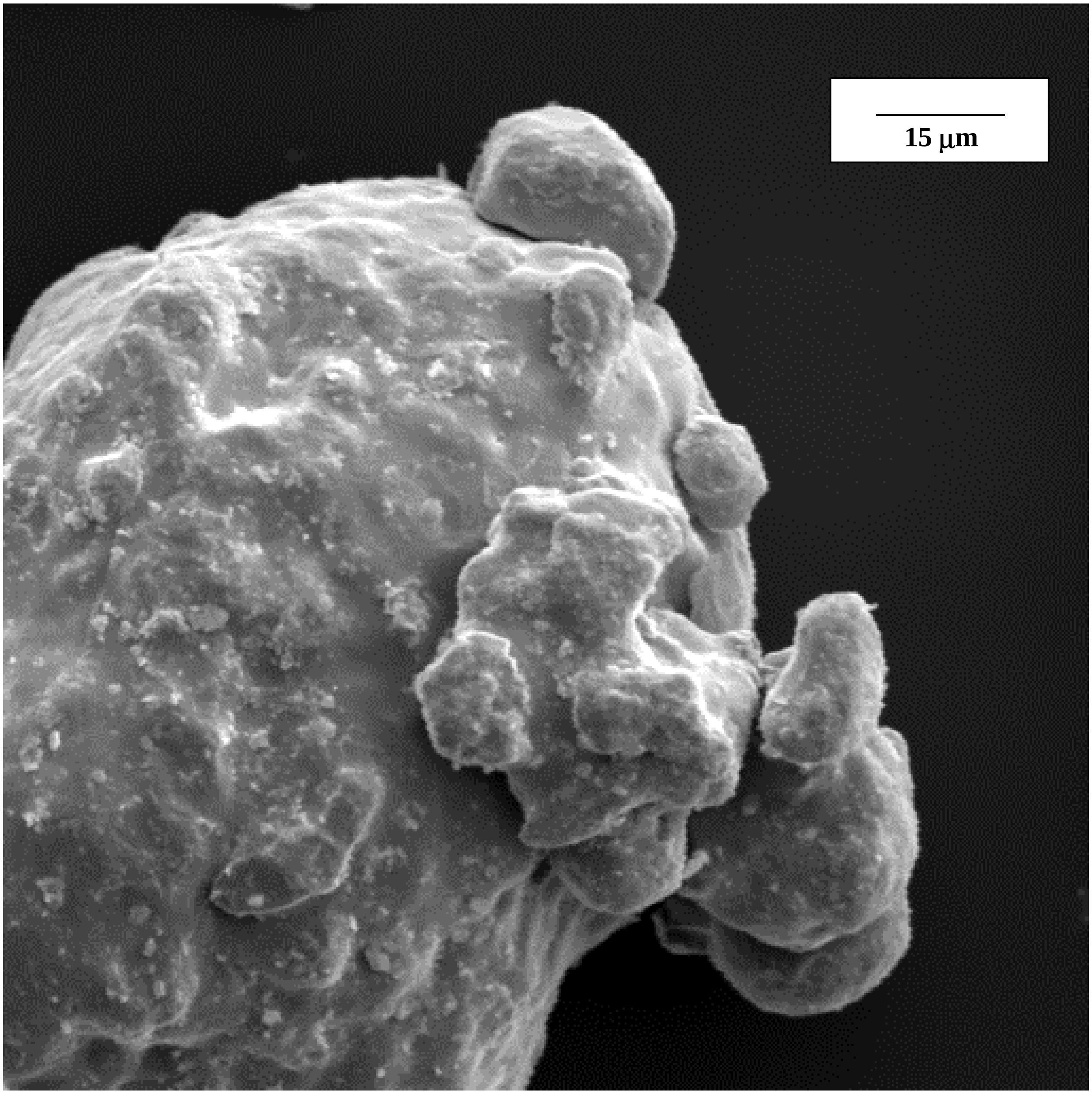

Figure 2: Bonding of the fines in an Ancorsteel 45P premix.

The last example is a FN-0208 premix where the nickel particles are evenly bonded over the entire surface of the iron particles, as shown in Figure 3.

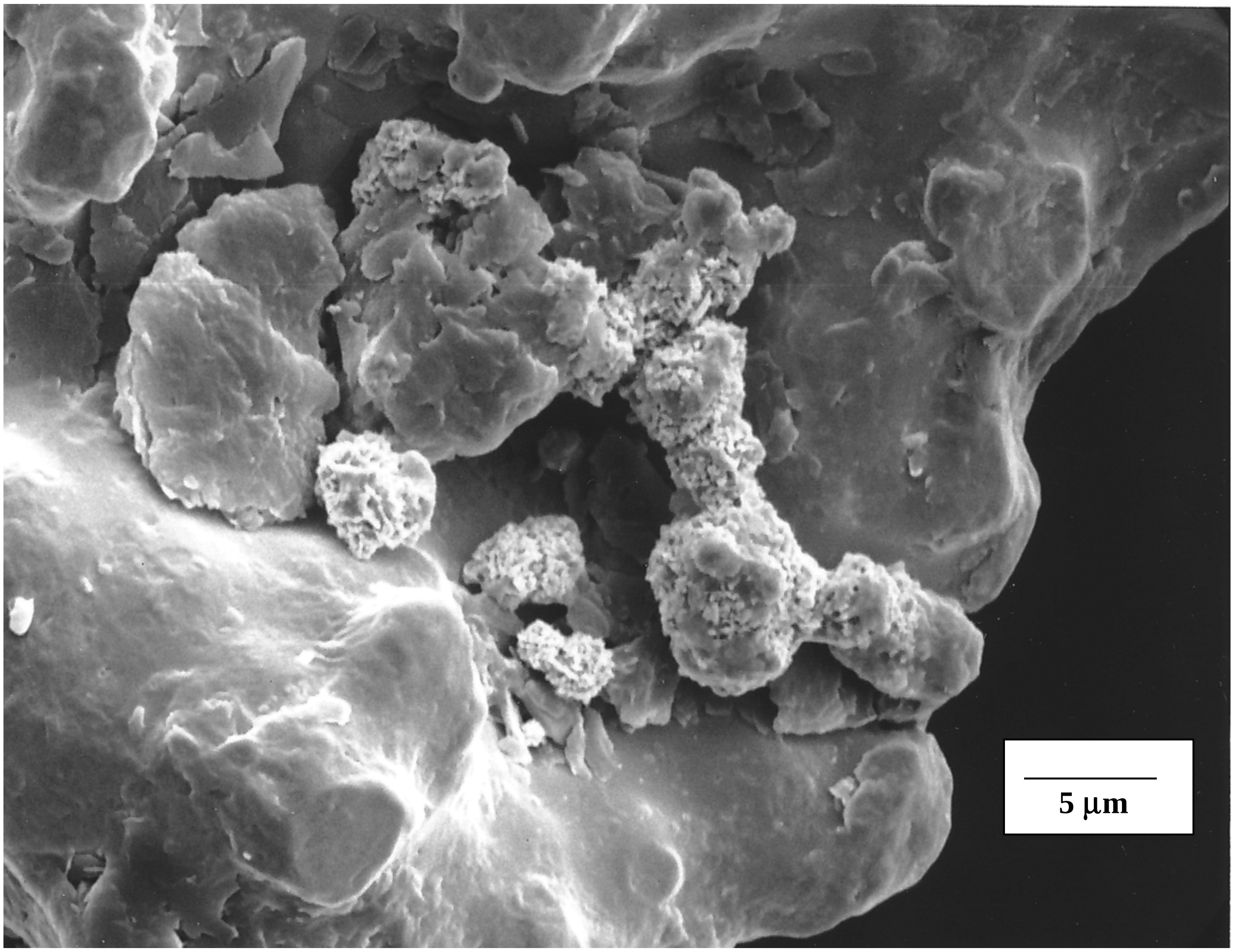

Figure 3: Bonding of the nickel in an FN-0208 mix.

Experimental Procedure

Laboratory procedures were conducted in accordance with appropriate ASTM standards. The improved ANCORBOND and ANCORBOND Plus products are referenced in this paper as Mix B and Mix Plus, respectively. ANCORBOND and ANCORBOND Plus are patented premix treatment 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). 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 in the Ancorsteel 45P studies and were pressed at a nominal 145° F (63° C) die temperature to a compaction pressure of 30, 40 and 50 tsi (415, 550 and 690 MPa, respectively). 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 were 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.

Results and Discussion

The demand for higher dimensional tolerance and elimination of green cracks calls for higher green strength and better compressibility in premixes[8,9,10]. 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. The premix composition chosen for this study was Ancorsteel 45P. The total content of binder plus lubricant, in each mix was kept constant at 0.75 w/o. In each case, a non-bonded regular premix with 0.75 w/o Kenolube was used as the reference.

Metallographic Analysis

Figure 4 shows the distribution of ferrophosphorus in the cross section of the thin walled sleeve green part collected from the case study at Atlas Pressed Metals, Inc. This green part is pressed to a nominal density of 6.9 g/cm^3. The ferrophosphorus particles are distributed around each iron particle. There are no ferrophosphorus agglomerates. The microstructure of the sintered part is shown in Figures 5 and 6 using the conditions mentioned above. A comparison of the microstructures shows that the binder-treated and non-bonded premix samples possess similar features, a good degree of sinter, non-uniform grain size and microstructures which consist of ferrite with grain boundary carbides and a trace amount of pearlite. This implies that their response to the sintering conditions is similar and that because of the improvement in compressibility the sintered properties will improve because of the higher density. Figure 7 shows the microstructure of an Ancorsteel 45P premix and the X-ray mapping of the ferrophosphorus particles in the matrix. Figure 8 shows the corresponding picture of a binder-treated premix.

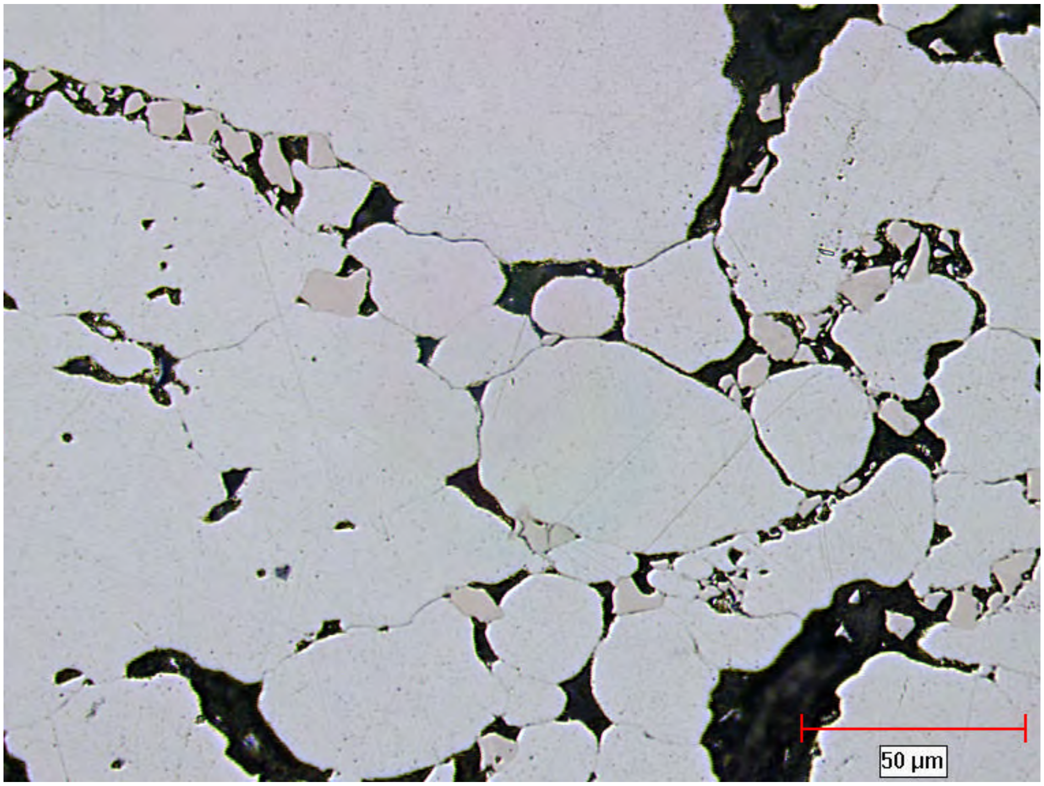

Figure 4: Distribution of the ferrophosphorus particles in an Ancorsteel 45P premix as shown in the cross section of a green part.

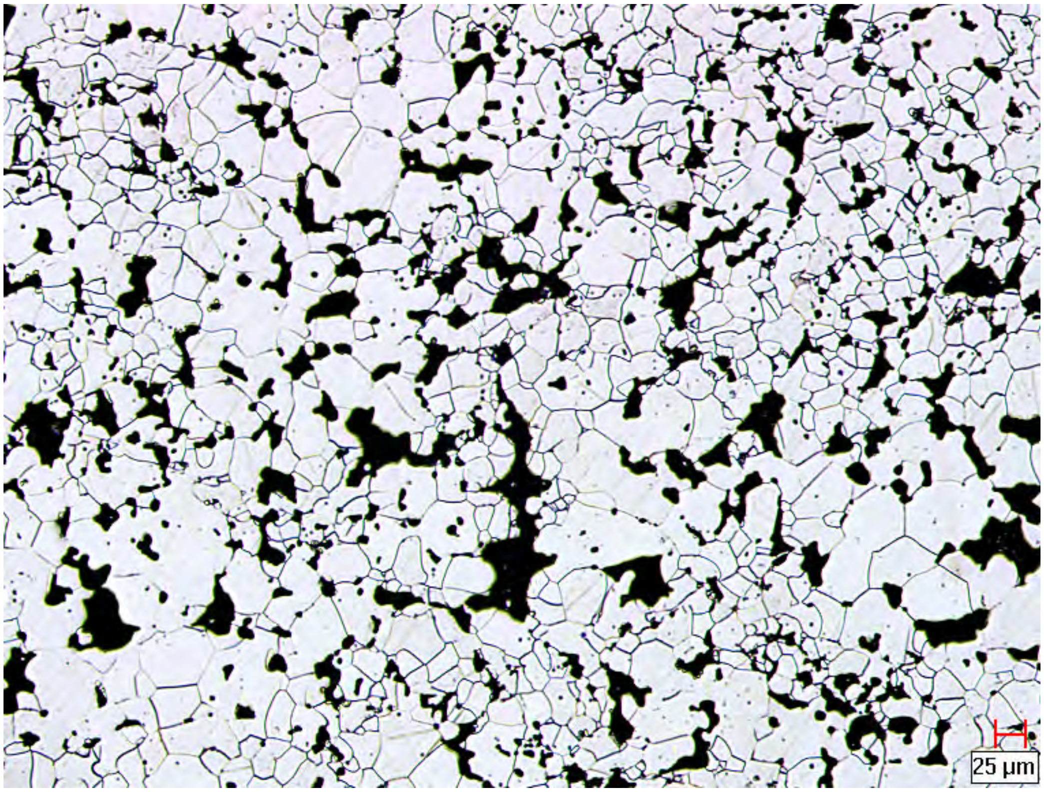

Figure 5: Microstructure of a sintered part using non-bonded Ancorsteel 45P.

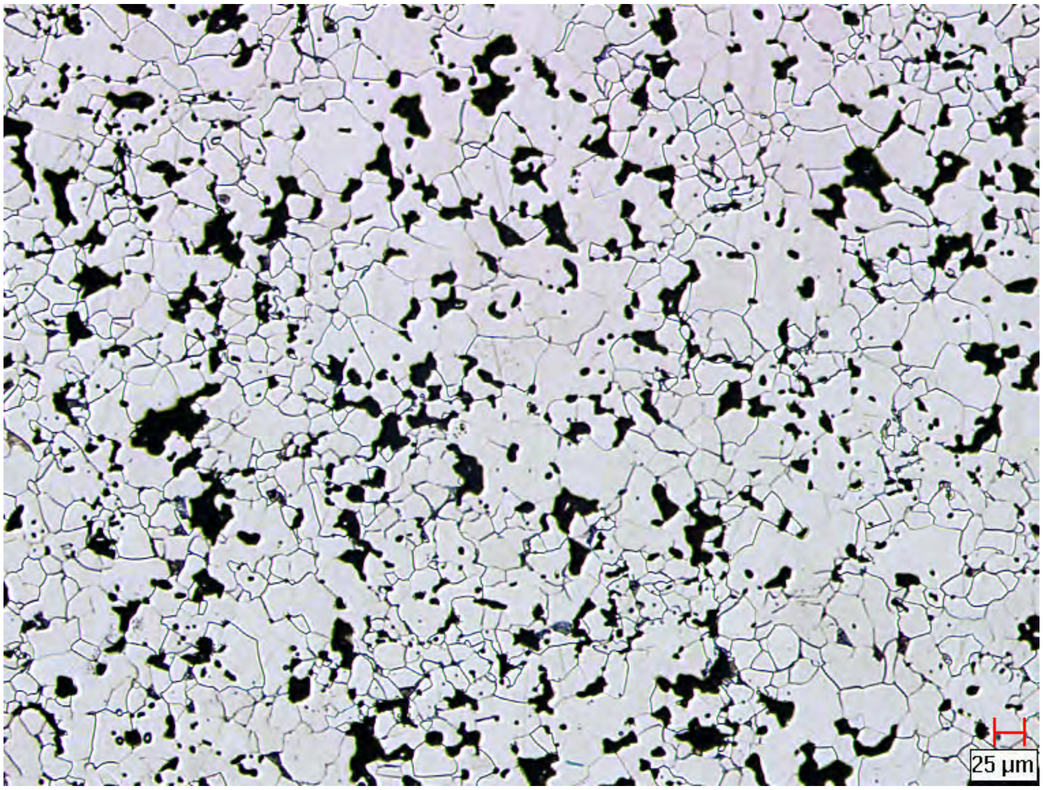

Figure 6: Microstructure of a sintered part using binder-treated Ancorsteel 45P.

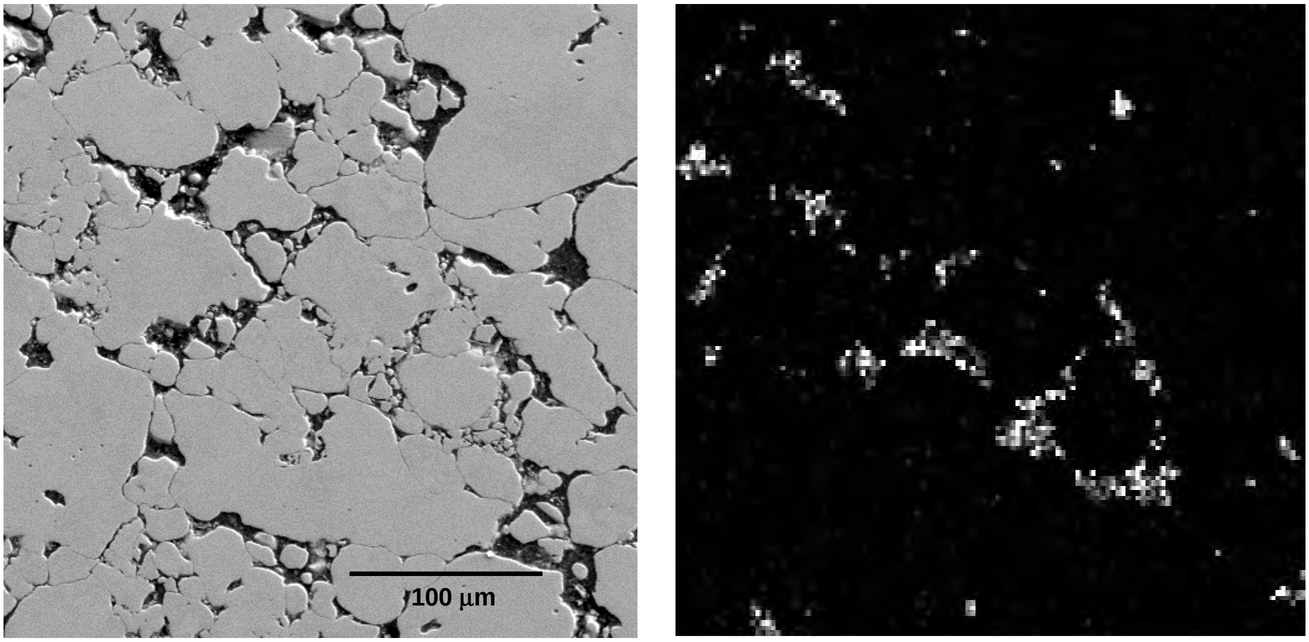

Figure 7: Microstructure of Ancorsteel 45P premix and X-ray mapping of the phosphorous particles in the matrix.

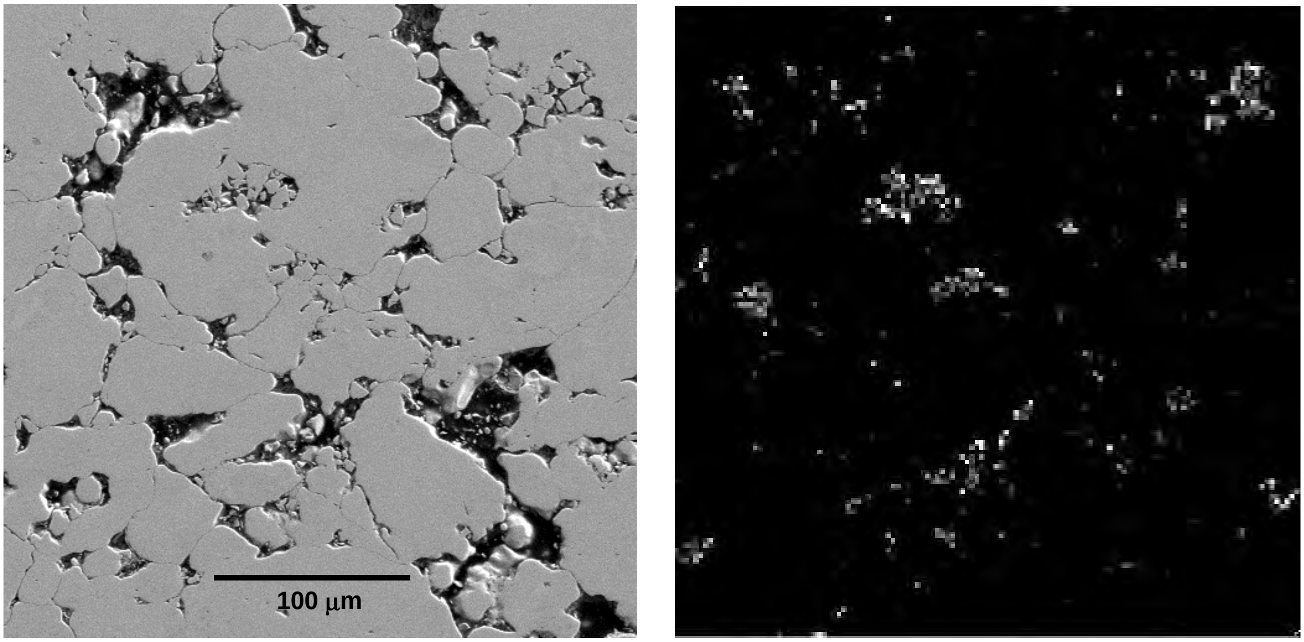

Figure 8: Microstructure of Ancorsteel 45P ANCORBOND Plus premix and X-ray mapping of the phosphorous particles in the matrix.

ANCORBOND PLUS

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[11,12]. 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.

Hall Flow and Apparent Density

Hall flow and apparent density measurements for the various compositions are shown in Table XI. The Hall flow for the ANCORBOND premixes is less than 30 sec/50g. With a better understanding of the bonding mechanism and binder chemistry, the total surface area of the powder mix can be manipulated to match the apparent density of the existing non-bonded premix. On the other hand, to improve die fill capability, the apparent density can be increased and the flow characteristics improved. The ejection characteristics of such premixes are also enhanced. With the capability of manipulating the apparent density, a more consistent part-to-part weight control may be anticipated in the production environment compared with processing regular premixes. With the improved lubricity, the tooling will also have a longer projected life for a given tonnage compared with conventional premixes of equivalent alloy content.

Table XI: Apparent Density and Hall Flow Properties of the Premixes Studied

Composition	Mix	AD (g/cm³)	Flow (s/50g)
FC-0208	A	3.13	26
	B	3.04	25
	Plus	3.10	25
	Reference	3.08	34
FN-0208	A	3.17	26
	B	3.07	24
	Plus	3.10	25
	Reference	3.08	36
Ancorsteel 45P	A	3.05	28
	B	3.00	24
	Plus	3.02	26
	Reference	2.98	29

ANCORSTEEL 45P

The 0.45 w/o phosphorus premix green properties shown in Table VII exemplify the capability of enhancing green strength and green density with the improved ANCORBOND (Mix B) and ANCORBOND Plus (Mix Plus). The two reference mixes are the original ANCORBOND (Mix A) and the non-bonded premix with 0.75 w/o 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 better compressibility than the other premixes, up to 0.09 g/cm³, at higher compaction pressures. At low compaction pressures, the ejection characteristics of Mixes 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 force among the premixes. With regard to the higher compaction pressure ejection characteristics, the reference premix is similar to the Plus mix. The Plus mix and reference premix display better lubricity than Mixes A and B.

The 0.45 w/o phosphorus premix sintered properties tabulated in Table VIII are an indication of what can be achieved with the 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 (1260°C) 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 values of 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 VII: Green Properties of Ancorsteel 45P Premixes

Mix	Comp. Press. (tsi)	Green Density (g/cm³)	Green Strength (psi)	Stripping Presssure (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
Ref.	30	6.79	2200	3100	1500
Premix	40	7.07	2900	3400	1600
	50	7.19	3000	3800	1700

Table VIII: Sintered Properties of Ancorsteel 45P Premixes

Mix	Compaction Pressure (tsi)	Green Density (g/cm³)	Green Expansion (%)	Sintered Density (g/cm³)	Dimensional Change (%)	Transverse Rupture Strength (10^3psi)	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

Part Fabrication

The tonnage and part weight variation data presented are from the 220-ton Cincinnati production press run. They are based on runs of 300 parts. No adjustments were made to the press during the runs. The parts were 1-inch tall, outer diameter of 1-inch and wall thickness of 0.25 inch.

Table IX shows the benefits of using bonded products and the improvements achieved by the recent advances in the lubricant-binder technology. The significance of the lower tonnage variation is that it implies a movement towards more consistent apparent density 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 was needed to reach the desired density. Figures 9 and 10 display graphically the improvements in lowering tonnage variation. The lines above and below the plot represent the plus and minus 3 sigma values.

Table IX: Crown Tonnage Variation of Various Mixes

Mix Composition	Average Crown Tonnage (tsi)	Minimum Tonnage (tsi)	Maximum Tonnage (tsi)	Standard Deviation	6 Sigma Value	Variation (%)
Mix A FC-0208	41.30	39.0	43.3	0.815	4.95	11.83
Mix B FC-0208	41.02	39.3	43.0	0.758	4.55	11.09
Mix A FN-0208	41.67	39.6	43.3	0.755	4.53	10.87
Mix B FN-0208	39.61	38.0	40.9	0.509	3.05	7.72

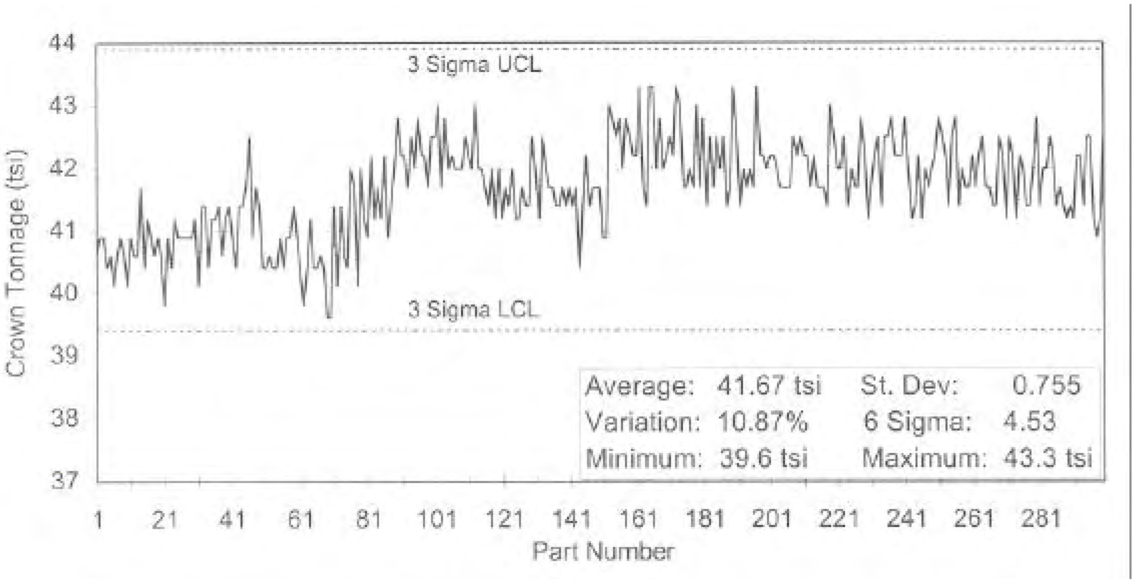

Figure 9: Crown Tonnage Variation of the Original ANCORBOND (Mix A) FN-0208 Composition.

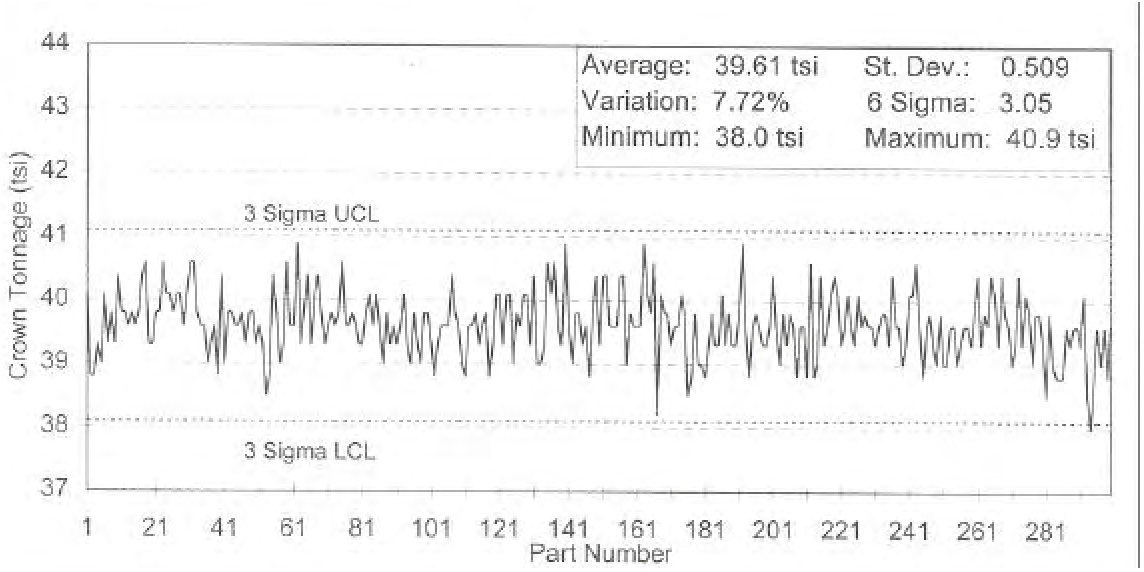

Figure 10: Crown Tonnage Variation of the Improved ANCORBOND (Mix B) FN-0208 Composition

The more consistent ANCORBOND process improves die fill and leads to more consistent parts. Table X shows the consistent part-to-part weight of improved ANCORBOND relative to the original ANCORBOND for FC-0208 and FN-0208 compositions. The data are based on the measurement of every tenth part and show an improvement of 24 to 48%. Relative to non-bonded premixes[3], ANCORBOND processed premixes used in industry usually exhibit a reduction 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 a reduction in dusting and the need for press adjustments. As for part weight control, Mix B is far superior to Mix A as shown in Table X.

Table X: Part Weight Variation of Various Premixes

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

Case Study of a Thin Walled Sleeve

Problem Statement

A part which generated the interest in ANCORBOND Plus is a thin walled sleeve with a slot extending into the part from one end, as shown in Figure 11. The sleeve is 0.750" long, the slot is 0.350" deep and the wall thickness is 0.081", with an O.D. of 1.312". The part weighs 25.20g with a weight tolerance of ±0.20g. The density is 6.85 - 6.95 g/cm^3.

At the time of this trial a production run of the part had just been completed. The production material “1300” used was virgin lot of Ancorsteel 1000C based 45P non-bonded premix. The tools were in a 200-ton Gasbarre press, as the 60-ton press preferred could not eject this part consistently. Whichever press the part is put into requires that a die-setter "baby-sit" the part throughout the run, making constant adjustments in an attempt to maintain the weight and size within the specified limits. Many parts are routinely scrapped in the course of a production run. Without this constant adjustment the limits would be far exceeded. The press speed is set at 8 strokes/minute (spm), or 480 pieces/hour.

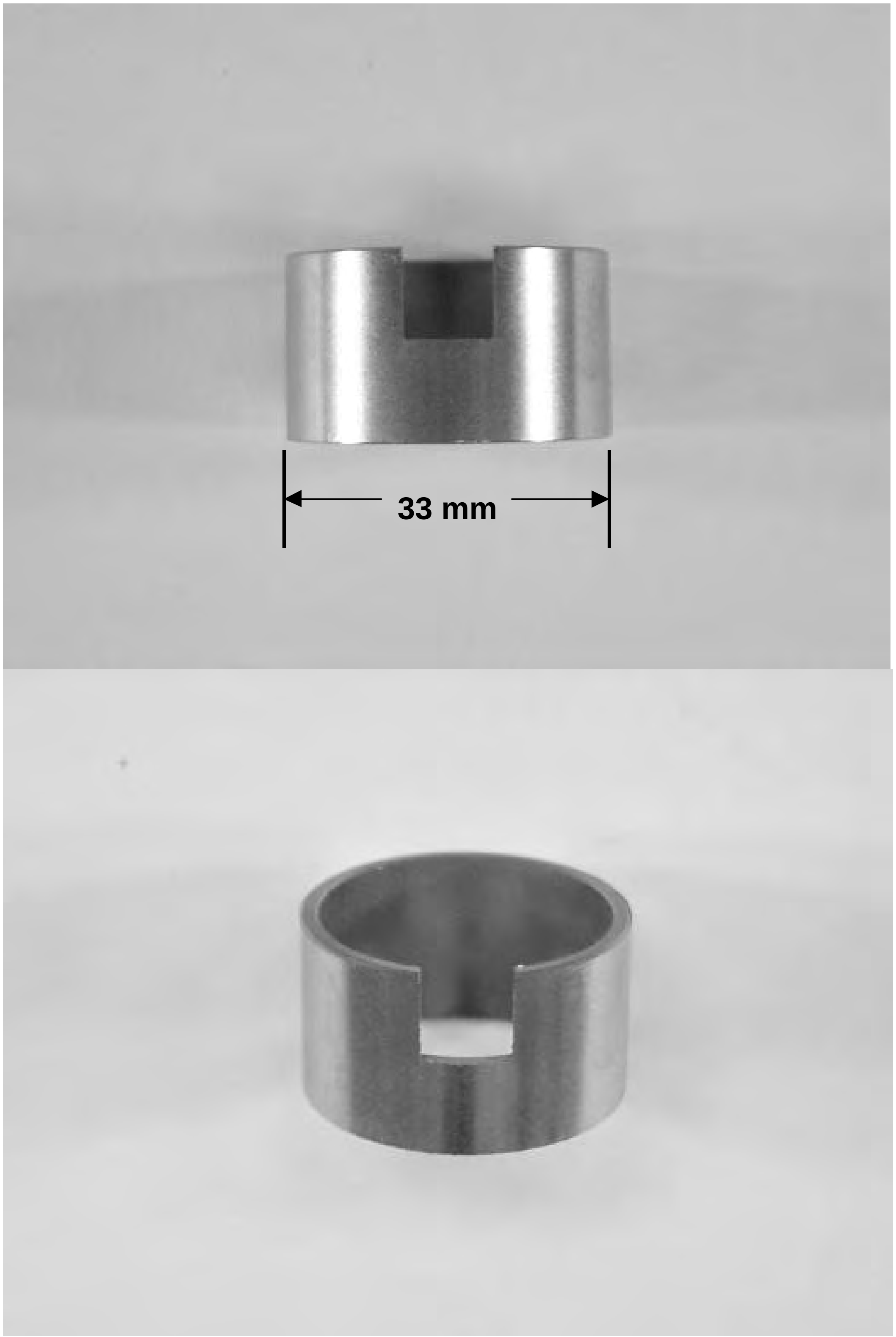

Figure 11: Thin Walled Sleeve produced for the case study using binder-treated Ancorsteel 45P premix.

Test Runs with Binder-treated Premixes

The first sample run was the first generation ANCORBOND version. This was initially chosen because it provides superior bonding and flow properties. Since the part is a thin walled sleeve with a wall thickness of 2 mm (0.081 inch), it was believed that improved flow and die fill capability would allow a higher press speed. The press chosen, for the reason stated earlier, was a 200-ton Gasbarre. The press settings were adjusted to give size and weight, the density was checked and was in limits, and the run commenced at the same 8 stroke/min press speed normally used. Initial run of 100 pieces was produced but the ejected parts were very hot (over 250F). It was seen that the part surfaces were scored badly. This was due to pick-up on the carbide die wall. This trial was immediately aborted and the die was removed from the press. It was then cleaned and polished. The conclusion is that there is a need for improved lubricity to reduce ejection scoring, in addition to better die fill capability.

The second trial was run with the ANCORBOND Plus version of binder-treated premix. The press was then set up again to run the ANCORBOND Plus sample. Again it was adjusted to give the correct size, weight and density and was run at the 8 stroke/min setting previously in use. The part then ran, holding size and holding weight within 0.10g, until approx. 300 - 400 pieces had been run. At this point the operator was satisfied that weight and size control were possible with this material. It was then suggested that the press speed should be increased until the weight control was seen to deteriorate. The speed was increased to 10 stroke/min, then to 12, 14, 16 and finally 20 stroke/min. Approx. 100 - 200 pieces were run at each setting. In every case there was a small drop in weight when the press speed was increased, due to the progressively decreased fill time at each higher speed. A small weight adjustment was made each time to compensate for this, and after it was made the weight control was again maintained at less than 0.10gm total variation, even at 20 stroke/min (1200 pcs/hr).

Another interesting observation was of the temperature of the parts being made. At 8 stroke/min the parts very quickly heated up to a steady operating temperature, at which time they could only just be handled. As the press speed was increased, the resulting part temperature did increase, but only very little, even at 20 stroke/min. The increase in green strength over the regular premix normally used, was dramatic, while the part finish, after running around 1,000 pieces, was still as good as the first part out of the die after it was cleaned and polished. Parts from each stage of the testing were sintered and were all found to be in compliance with the part print, except that the I.D. was slightly below print tolerance. This, however, was not unexpected, as there is a very tight tolerance on this, and it is normal to have to adjust the core rod size and/or the furnace conditions to get this dimension into specification for any particular run. It was later realized that the much improved part roundness was the reason for the I.D. appearing to be slightly oversize.

The material was then run on a 60 ton Gasbarre Press with a different feed shoe design. As shown in Figure 12, the weight control for the ANCORBOND Plus material showed a bell shaped distribution around a mean value of 25.3/25.4 gm. The non-bonded premix showed a broad distribution range, from 25.2 to 25.6 gm. This indicated the possibility of using a binder treated premix to overcome the deficiency of improper feeding due to the limitation of existing feeding system and tooling. A total of 26 samples were selected randomly from the 200 piece run for analysis of weight distribution, concentricity, and roundness.

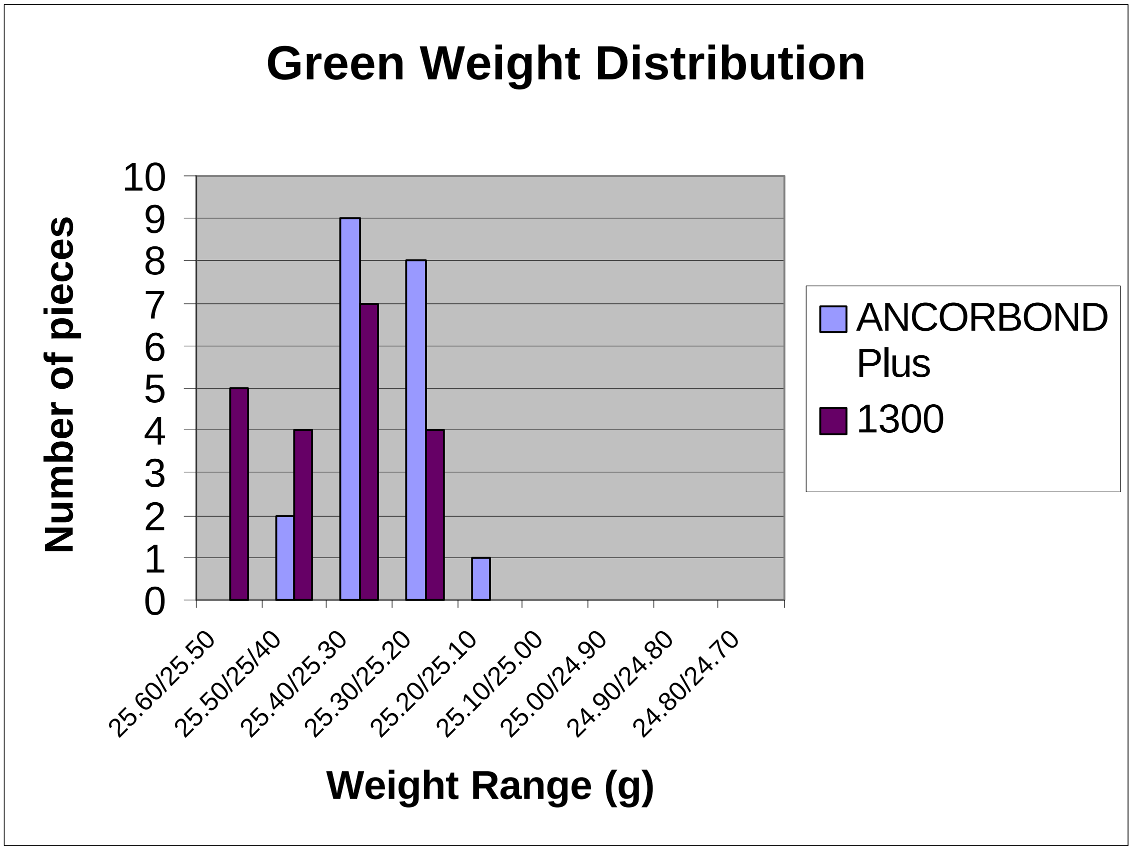

Figure 12: Comparison of Weight Control of Green Parts using ANCORBOND PLUS vs. non-bonded premix 1300.

Concentricity and Roundness

Comparison of the concentricity tolerances and roundness achieved in the thin walled sleeve in this case study is shown in Figure 13 -15. The ANCORBOND Plus mix and the non-bonded premix are denoted by the symbols “A+” and “1300”, respectively. The ideal concentricity tolerances obtainable are directly dependent upon the number of tool items such as punches and core rods in the assembly. Typical tolerance for the thin walled sleeve involves a lower punch and the core-rod each with a clearance of 0.0005-0.0010 inch. When compaction pressure is applied, it must be assumed that all clearance may be taken up in one direction. The punch and core rod, each with 0.00010 inch clearance, will yield an eccentricity between die and core rod of 0.0020 inch total indicator reading at the beginning of a new set of tools. This will increase as the tool wears. This does not take into account of other factors such as green expansion and sintering distortion. The lack of concentricity of a P/M part is more a function of how the die fills, and thus how the part expands after ejection, than it is a function of the tooling clearances. Typically the lack of concentricity far exceeds the sum of the clearances built into the tooling. Its major cause is uneven fill of the die cavity, resulting in density variation around the part, which tries to equalize via the mechanism of variable expansion during ejection. As the ANCORBOND Plus premix provides better die fill, the concentricity tolerance for the production run varies from 0.0015 to 0.0030 inch. This is a significant improvement over that of the non-bonded premix, which varies from 0.0030 to 0.0045 inch.

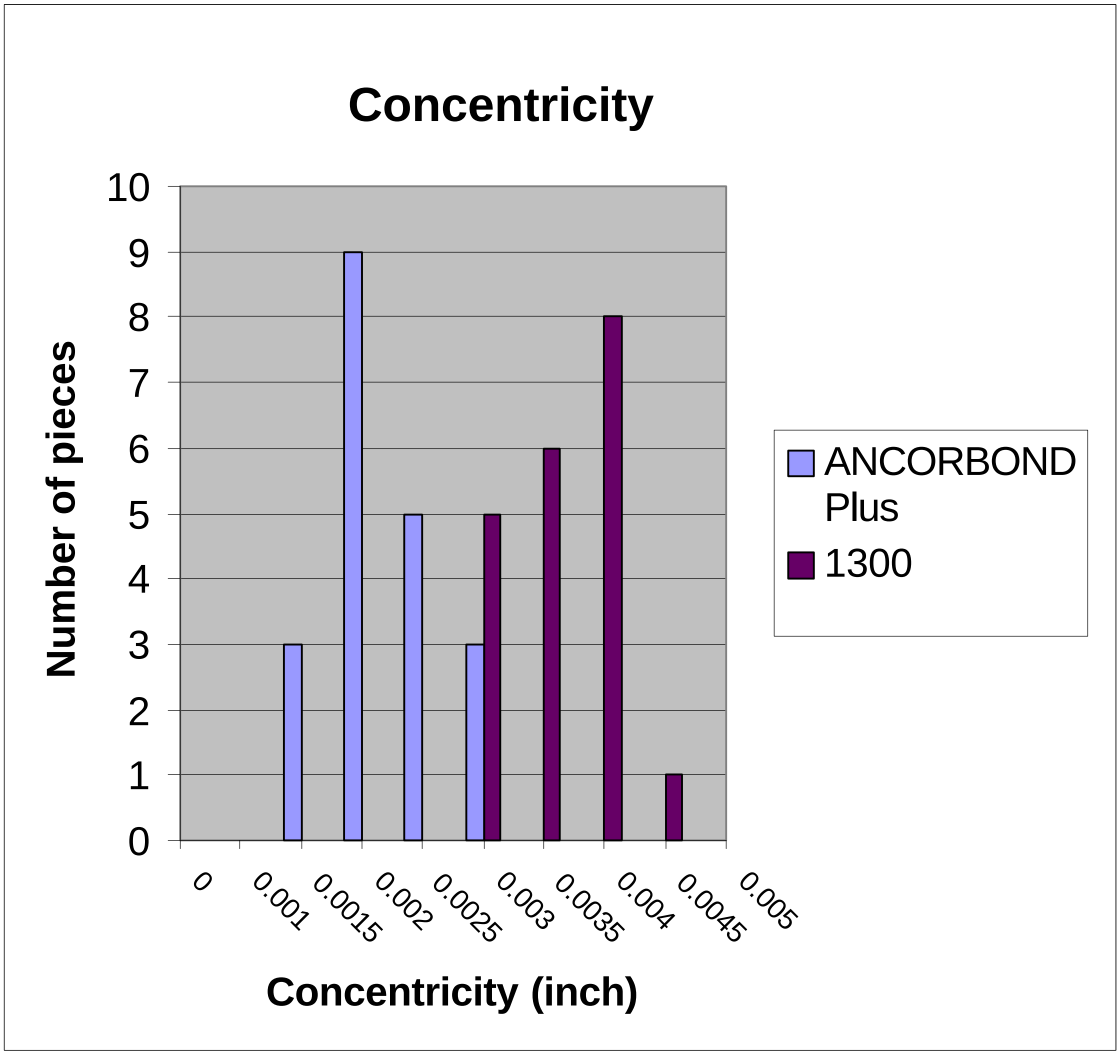

Figure 13: Comparison of Concentricity of Green Parts using ANCORBOND PLUS vs. non-bonded premix 1300.

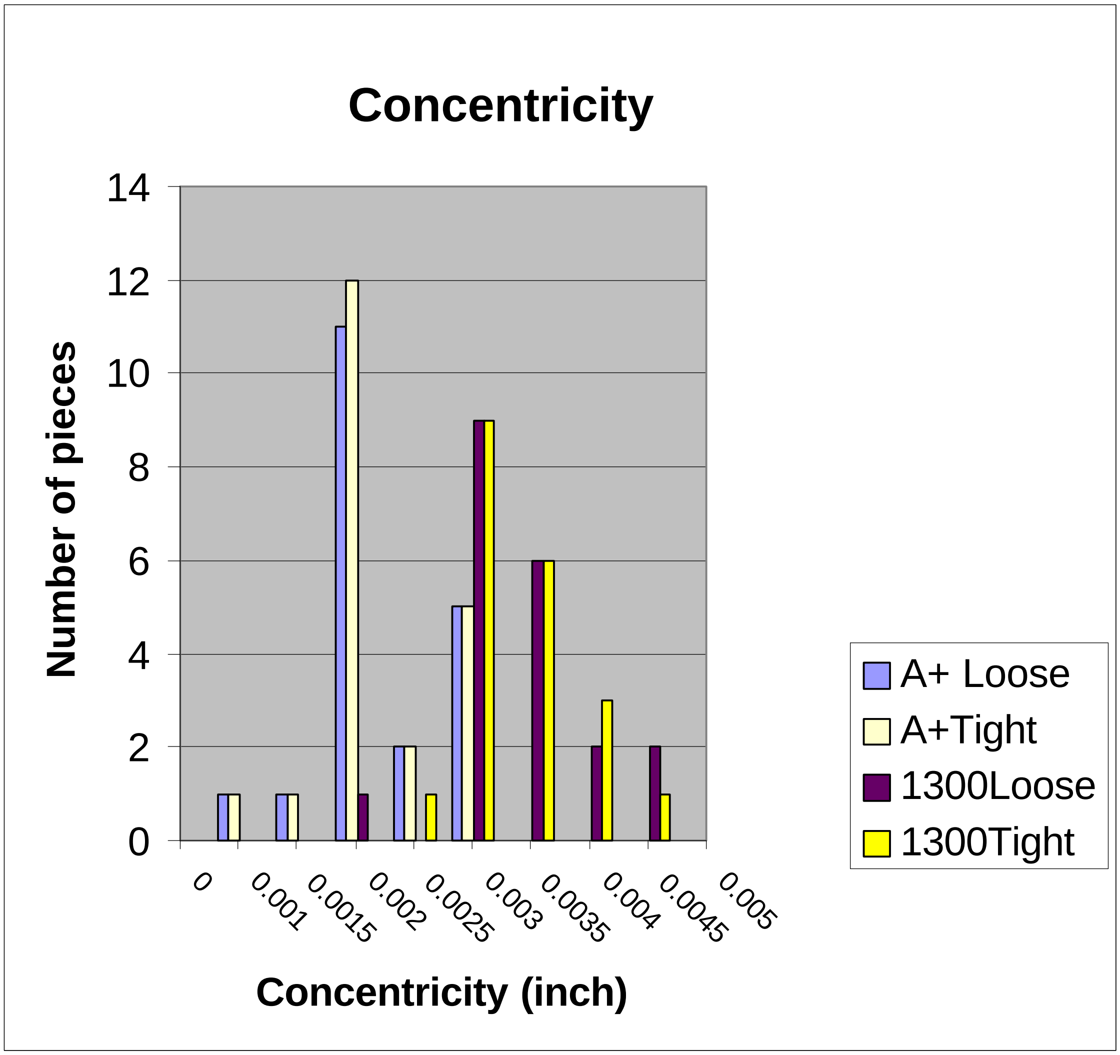

Figure 14: Comparison of Concentricity of Sintered Parts using ANCORBOND PLUS vs. non-bonded premix 1300.

The green parts from the sample run were sintered at 2050°F (1120° C) for 30 minutes in an atmosphere of synthetic DA. The parts were placed on the belt in two different formats of either in tight formation or loose formation. This is done to check the influence of heat distribution between the parts on concentricity and roundness. The results were shown in Figure 14 – 15. The symbol "A + loose" denotes ANCORBOND Plus mix and the samples were placed on the furnace belt "loose" i.e. not touching each other. "A + tight" denotes ANCORBOND Plus mix and the sleeves are placed on the furnace belt "tight" i.e. touching each other. Similarly, the non-bonded premixes were denoted by "1300 loose" and "1300 tight". The results indicated that significant improvements in both concentricity and roundness are achieved when the binder-treated ANCORBOND PLUS material is used. This improvement in dimensional tolerance can be carried over to the sintered parts.

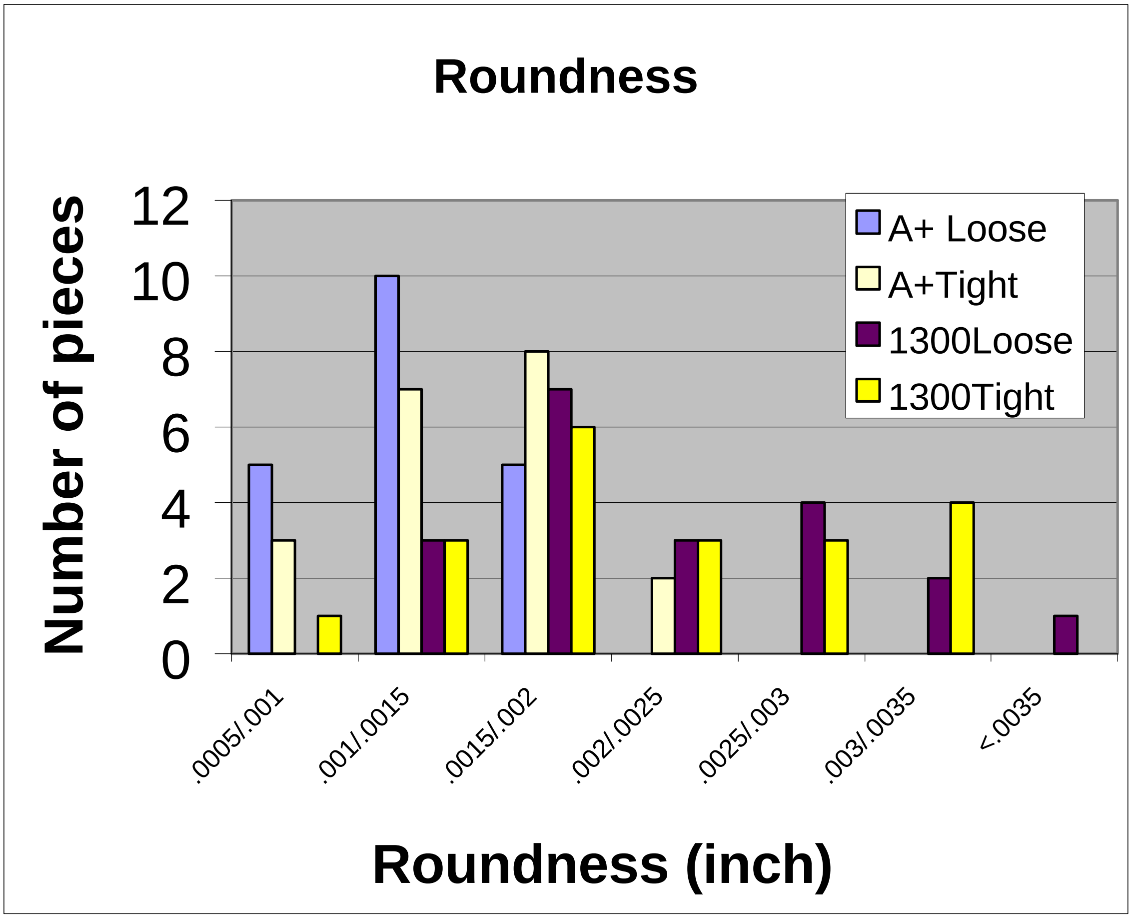

Figure 15: Comparison of Roundness of Sintered Parts using ANCORBOND PLUS vs. non-bonded premix 1300.

The significance of such improvement in concentricity is important to the P/M process. Figure 16 showed another example of a thin wall part where binder-treated material with very high green strength is required to reduce the segregation of copper in the FC0208 composition in addition to the dimensional tolerance improvements. Figure 16 showed a possible application of producing a gear that required the higher green strength to reduce handling cracks and improved dimensional tolerance. In the case of P/M gears, it is generally accepted that a pressed and sintered gear will typically meet the requirements of AGMA Class 6. This is a measure of the tooth-to tooth error, the eccentricity of the gear, and the sum of these, the total composite error. Of the two components the eccentricity reading is by far the greater. Thus, if the gear is given a secondary boring operation, held off the O.D., or off the P.D. of the teeth, then most of the eccentricity can be eliminated. This typically results in an improvement to AGMA Class 7.

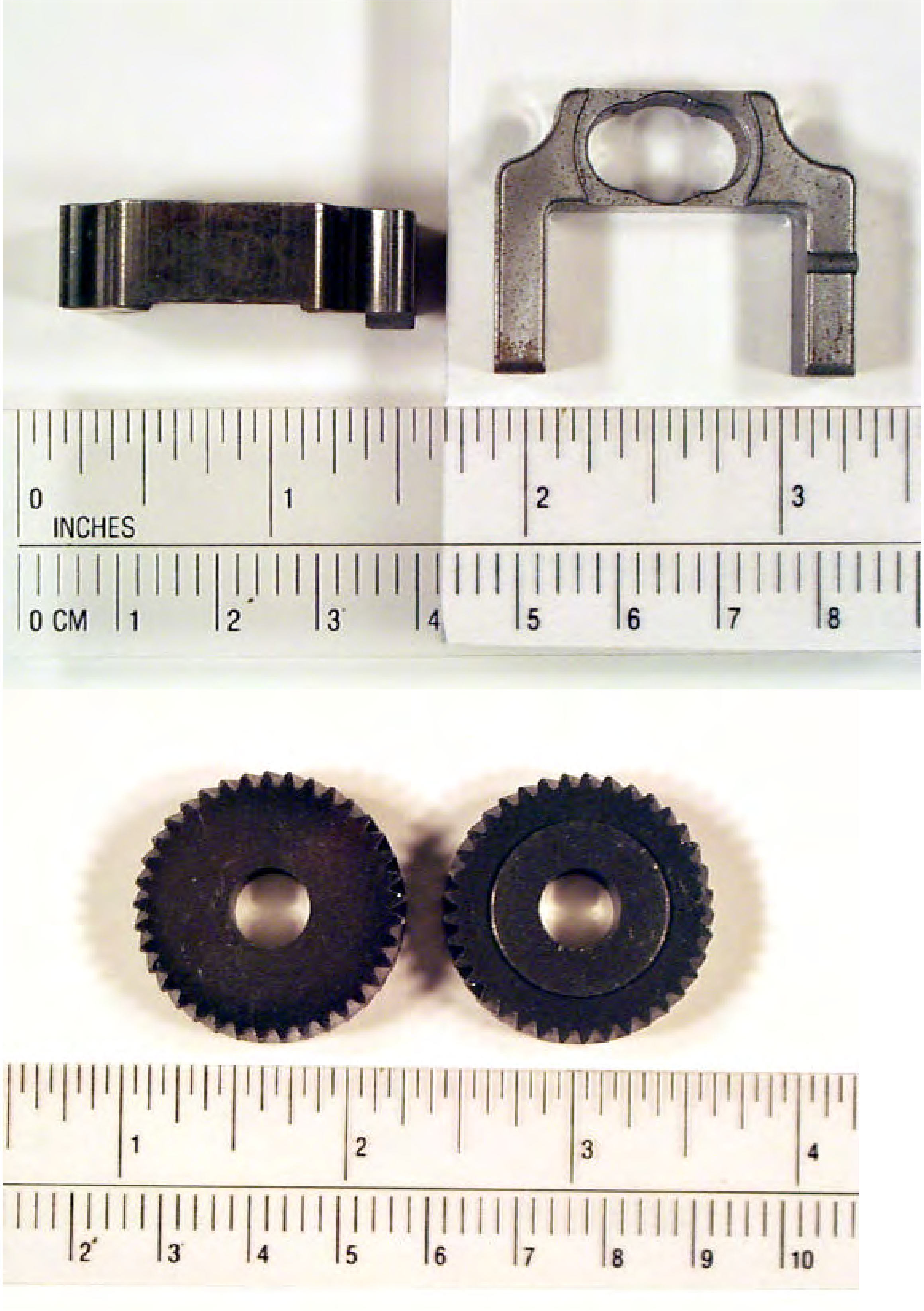

Figure 16. Examples of P/M parts that can be made with the ANCORBOND PLUS FC0208 powder.

In the case of bearings, bushings and other routable parts, lack of concentricity results in uneven running and wear of the components[13]. In many cases a secondary machining operation is not an option, since this would tend to close off, by smearing metal, the desirable open pores often required for self-lubricating purposes. The sizing operation cannot be expected to correct eccentricity. In the case of thin walled sleeve components pressed with a certain eccentricity, this means too much metal in one half and too little in the other. For any part that has an excessive degree of out-of-roundness, it is impossible to move the excess metal radials through 180 degrees. It also runs the risk of over-densifying half of the component while running the risk of producing distortion and tool breakdown. Another important factor is the consistency of tolerance achievable from with ANCORBOND Plus premix. The final tolerance on a P/M part is dependent upon green compact dimensional tolerances, sintering conditions, sizing and re-pressing. Any method that improves the consistency of the die-fill, both part-to-part and around the die cavity, will improve the concentricity and roundness of the parts being pressed.

Conclusions

With better understanding of the bonding mechanism binder-treated premix can be designed to enhance and optimize the P/M parts making capabilities.

New binder systems in ANCORBOND PLUS provides better bonding capability, higher green strength and compressibility in an Ancorsteel 45P, FC0208, and FN0208 premix.

In the case study of a thin walled sleeve where press speed is limited to 8 strokes/min, productivity is improved by increasing the press speed to as high as 20 strokes/min. This is due to improved process robustness through the new binder-treated Ancorsteel 45P premix.

Concentricity and roundness of the thin wall sleeve using the binder-treated premix is improved over 50% for both green and sintered part.

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