HIGHER GREEN STRENGTH AND IMPROVED DENSITY BY CONVENTIONAL COMPACTION

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Abstract

A new material system that can produce very high green strength and green density has been developed for conventional compaction processing. The system, which uses a zincless lubricant, is based on the optimization of the bonding mechanism and binder chemistry. This approach permits the bonding of copper particles in a FC-0208 mix. Examples of the binder-treatment of FN-0208, Ancorstee145P, and Ancorstee150 HP are also included.

Introduction

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 copper. Using a systems approach to optimize the binder and premixing process, the green strength of bonded mixes has been improved over 50%[4]. These developments have positive impacts on the sintered properties as well as the green properties. This paper will review these recent developments.

The original binder-treated premixes 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 unbonded mixes.

The second 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.

The third generation of binder-treated premixes incorporated a systems approach to develop ANCORDENSE® or warm compaction technology[6]. This method involves investment in peripheral powder heating equipment to warm compact the bonded mix and achieve a substantial improvement in properties.

Recent developments in bonding mechanisms and binder chemistry have yielded properties a level beyond the first and second-generation ANCORBOND products. Two systems will be discussed in this paper; the improved ANCORBOND and the ANCORBOND Plus™ engineered materials. Both systems are designed for conventional compaction and do not require the use of peripheral heating equipment as would be needed with ANCORDENSE processing. ANCORBOND and 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. This increase in density leads to further improvement in the sintered properties.

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 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 an 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:

1. 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.
2. The binder wets the iron powder and bonds the fines evenly around the iron particle. This is the preferred state.
3. The binder bonds the fines in such a way that more rounded shape iron agglomerate is formed. More rounded powder results in better packing in the die cavity and improves compressibility.
4. 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.
5. The binder forms the core of an agglomerate bonding the fines to itself.
6. The binder coats the entire iron particle only.
7. The binder coats the individual particles of the fines only.
8. The binder remains a binder particle by itself with no bonding of the fines or iron particles.
9. 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 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.

Examples of ANCORBOND

To verify the bonding mechanisms, scanning electron microscope (SEM) pictures of several ANCORBOND examples are shown in Figures 2 through 10. The first example shows that the wrong bonding mechanism for copper can create copper agglomerates. On the other hand, the proper bonding mechanism can be used to bond copper and prevent the segregation of the sizable copper particles. The second example shows the progressive steps in making an 8 w/o graphite bonded mix. This bonding mechanism allows layers of graphite to firmly bond onto the iron particle. There is almost no dusting of the graphite in this case. The third example shows the distribution of copper in the improved ANCORBOND processed FC-0208 premix. The copper is evenly distributed on each iron particle. There are no copper agglomerates. The bonding strength is good so no bonded copper particles are broken away due to further mixing or handling. The last example is a FN-0208 premix where the nickel particles are evenly bonded over the entire surface of the iron particles.

Experimental Procedure

Laboratory procedures were performed in accordance with appropriate ASTM standards.
All the premixes were made from the same lot of iron powder (Ancorstee11000B). 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.

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 FC-0208 and the Ancorstee145P studies were pressed at a nominal 145°F (63°C) die temperature. The TRS bars in the FN-0208 study were pressed at a nominal 100°F (38°C), 120°F (49°C) and 1450F (63°C) die temperatures. The TRS bars in the 0.5 w/o molybdenum (0.5 Mo) mixes were pressed at 75°F (24°C) die temperature. TRS bars were pressed at 30, 40 and 50 tsi (415, 550 and 690 MPa, respectively), also 15 tsi (207 MPa) for the FN-0208 study.

The FN-0208, FC-0208, Ancorstee145P, and Ancorstee150 HP with 2 w/o nickel, 0.6 w/o graphite TRS bars were sintered at 2050°F (1120°C) for 30 minutes in an atmosphere of synthetic DA. The Ancorsteel 50 HP with 1 w/o nickel, 1 w/o manganese, 0.6 w/o graphite was sintered at 2300°F (1260°C) for 30 minutes in a hydrogen atmosphere.

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.

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 compositions chosen for this study were Ancorsteel 45P, FC-0208, FN-0208, and one based on Ancorsteel 50 HP. 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 50 HP

The application of the recent developments in ANCORBOND technology to prealloyed grades can yield the same benefits as with conventional water atomized base iron powder. Two compositions were studied using Ancorsteel 50 HP, 0.5 w/o Mo prealloyed steel base. The first premix contained 2 w/o nickel and 0.6 w/o graphite. The second premix contained 1 w/o nickel, 1 w/o manganese, 0.6 w/o graphite. For the first premix, apparent density and Hall flow were 2.88 and 26 s/50g. For the second premix, apparent density and Hall flow times were 2.90 and 26 s/50g, respectively. Green and sintered properties for the two premixes are shown in Tables I and II.

FC-0208 Properties

The green properties of the FC-0208 composition shown in Table III accentuate the improvement in green strength and compressibility attainable in the improved ANCORBOND system (Mix B). Mix A represents the original ANCORBOND process where the copper particles are not well bonded. The green strength of Mix B increases up to 70% compared with Mix A for a given compaction pressure. A similar trend is observed when compared with the unbonded reference mix. The green density of Mix B increases up to 0.05 g/cm^3 compared with the other mixes. The improvements are more noticeable at higher compaction pressures due to the inherent properties of the new organic materials in Mix B. The improved ANCORBOND process optimizes the bonding mechanism so that a better packing of the powder bed is achieved during compaction. More importantly, most of the copper particles are bonded to the iron surface. The copper particles uniformly distributed on the iron surface reduce the friction factor between particles and die surface. As a result, the stripping pressure of Mix B is 6-17% lower than the unbonded premix. The corresponding sliding pressure is 40% lower than the unbonded premix. Note that the premix used 0.75 w/o Kenolube which is a much better lubricant than zinc stearate. This indicates that optimizing the bonding mechanisms to utilize the copper as an added lubricant reduces friction at the die wall. It translates into a reduction of wear on the tools and dies in part fabrication resulting in extended tool life.

The sintered properties of the FC-0208 compositions tabulated in Table IV show that Mix B exhibits better or equivalent density, strength and apparent hardness compared with the regular premix. The transverse rupture strength at 50 tsi compaction pressure is especially noteworthy. Mix B is about 11% stronger than the regular premix at 50 tsi, indicative of better organic burn-off. In general, the ANCORBOND series have considerably better or nearly equivalent properties than the regular premix. Mix B also demonstrated less growth than the regular premix. This is due to the reduced segregation of the copper particles in the improved ANCORBOND processed material.

Metallographic Analysis

Figures 11 and 12 display microstructures of the FC-0208 composition sintered using the conditions mentioned above. A comparison of the microstructures shows that the ANCORBOND and premix samples possess similar features, a good degree of sinter, large copper diffusion-type porosity and microstructures, which consist of lamellar pearlite, ferrite, and diffused copper. 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.

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.

FN-0208 Premixes

Table V tabulates the green and sintered properties of FN-0208 mixes as a function of die temperature during compaction. Mix Plus is the ANCORBOND Plus with 0.75 w/o total binder content and no lubricant. The corresponding reference mix is an unbonded premix with 0.75 w/o Kenolube. The data show that the properties are stable within the range of temperatures tested (100"F to 145°F/37.8 to 62.8°C). The green strength of Mix Plus is consistently 100-200% over that of the reference Premix. At higher compaction pressures, the green density of Mix Plus is on the average 0.13 g/cm^3 greater than that of the reference premix. The increase in green density translates into improved sintered properties. The sintered density experiences the same improvements as the green density; correspondingly, the sintered strength increases up to 10% over the reference premix. The dimensional change from the die after sintering of Mix Plus remains equivalent to the reference premix.

ANCORSTEEL 45P

The 0.45 w/o phosphorus premix green properties shown in Table VI 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 unbonded 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/cm^3 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. In 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 VII 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, 23000F (1260°O) 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/cm^3 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.

Part Fabrication

The tonnage and part weight variation data presented are from the 200-ton Cincinnati production press run. They are based on runs of 300 parts. There were no adjustments 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 VIII 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 will be needed to reach the desired density. Figures 13 and 14 display graphically the improvements in lowering tonnage variation. The lines above and below the plot represent the plus and minus 3 sigma values.

The more consistent ANCORBOND process improves die fill and leads to more consistent parts. Table IX 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 unbonded 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.

Hall Flow and Apparent Density

Hall flow and apparent density measurements for the various compositions are shown in Table XI. The Hall flows for the ANCORBOND premixes are less than 30 s/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 unbonded 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 to manipulate the apparent density, a more consistent part to part weight control in the production environment may be anticipated compared with processing regular premixes. With improved lubricity, the tooling will also have a longer projected life for a given tonnage compared with conventional premixes of equivalent alloy content.

Conclusions

Bonding mechanisms and SEM pictures showed that ANCORBOND processed premixes are a family of material systems designed to enhance and optimize the P/M parts making capabilities.

The improvements in ANCORBOND processed premixes lead to higher green strength and green density and produce more robust P/M parts.

Bonding of copper powder is now possible.

ANCORBOND Plus processing provides a zincless organic system that optimizes the conventional compaction process to achieve much higher green and sintered properties than regular premixes. The higher green strength makes green machining a possibility for conventionally compacted pads. The higher green density will extend the pressing capability of conventional presses.

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Table II: Sintered Properties of 0.5 w/o Mo Prealloyed Base Premixes

Pressure (tsi)	Green Density (g/cm³)	Green Expansion (%)	Sintered Density (g/cm³)	Dimensional Change (%)	Transverse Rupture Strength (10^3psi)	Appparent Hardness
ANCORBOND: 0.5 w/o Mo base + 2 w/o Ni + 0.6 w/o graphite						
30	6.76	0.14	6.75	-0.06	134	70.2 (HRB)
40	7.02	0.17	7.02	-0.03	167	80.2 (HRB)
50	7.15	0.24	7.16	0.00	183	85.3 (HRB)
ANCORBOND: 0.5 w/o Mo base + 1 w/o Ni + 1 w/o Mn + 0.6 w/o graphite						
30	6.72	0.18	6.66	+0.09	131	27.4 (HRC)
40	6.97	0.21	6.90	+0.22	162	31.5 (HRC)
50	7.11	0.24	7.04	+0.27	143	29.6 (HRC)

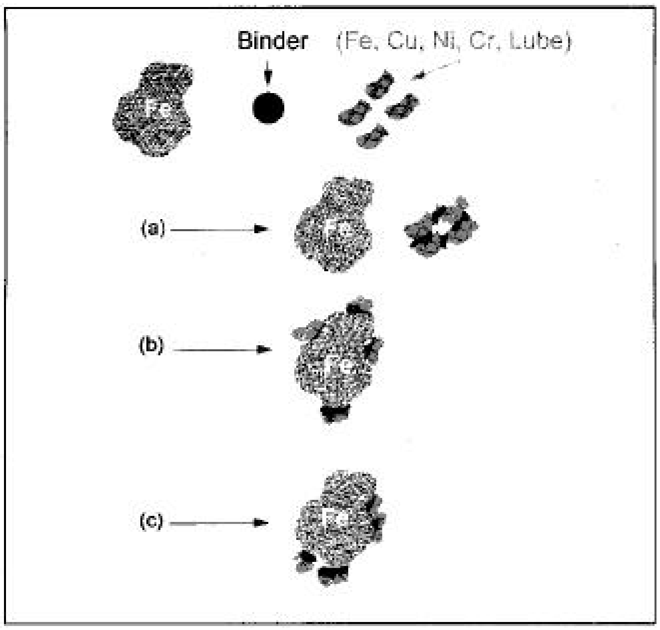

Figure 1 (a-c): Bonding Mechanisms involving alloying additives, lubricants and iron powders in the ANCORBOND process.

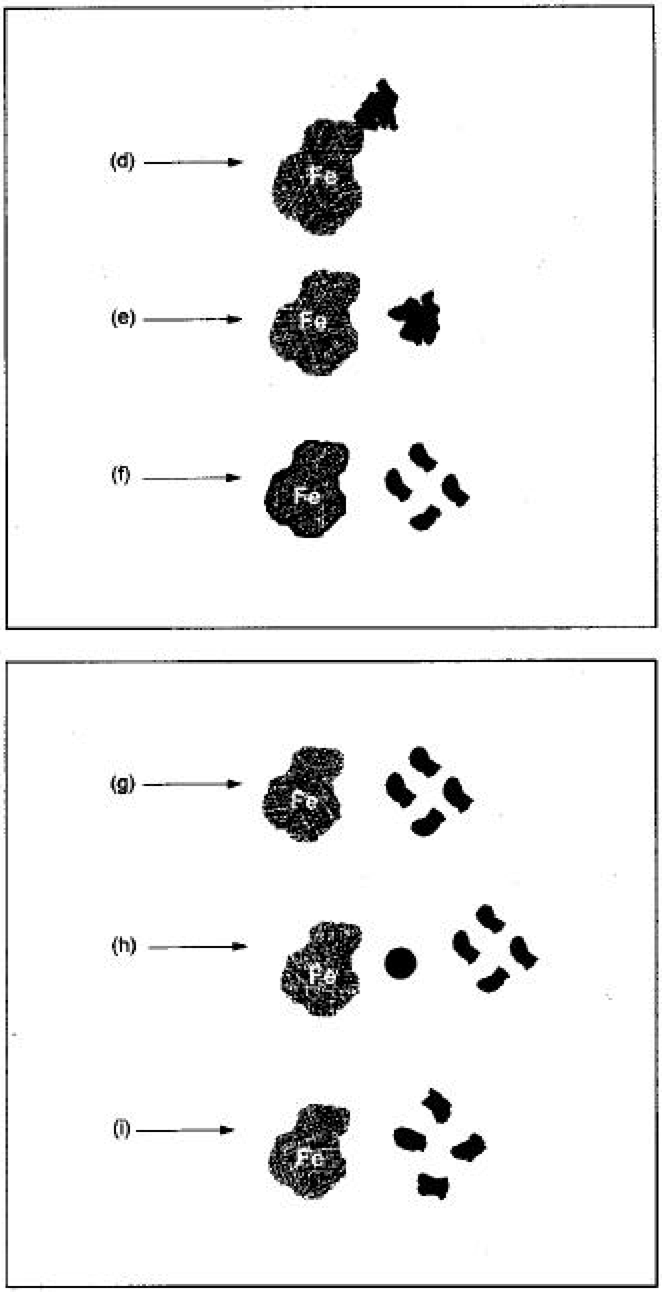

Figure 1 (d-i): Bonding Mechanisms involving alloying additives, lubricants and iron powders in the ANCORBOND process.

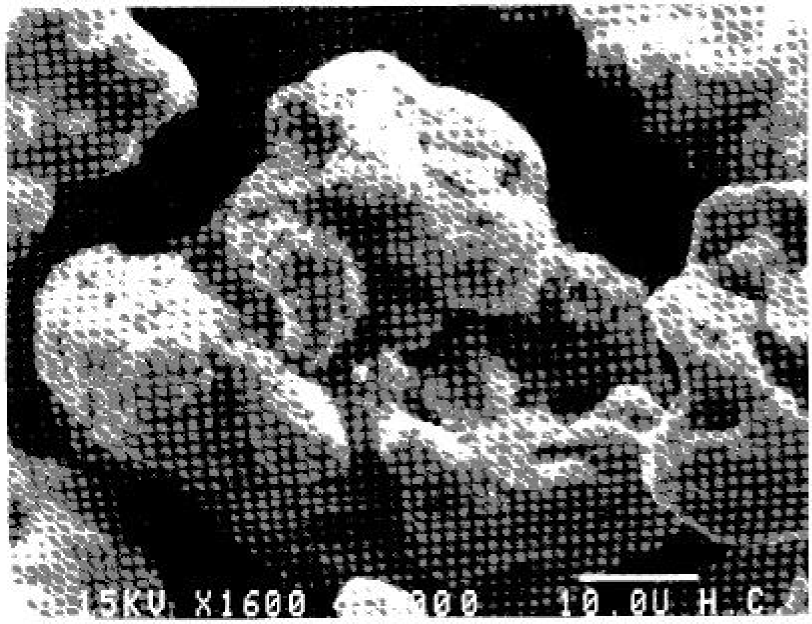

Figure 2: Bonding of four copper particles to form a copper agglomerate.

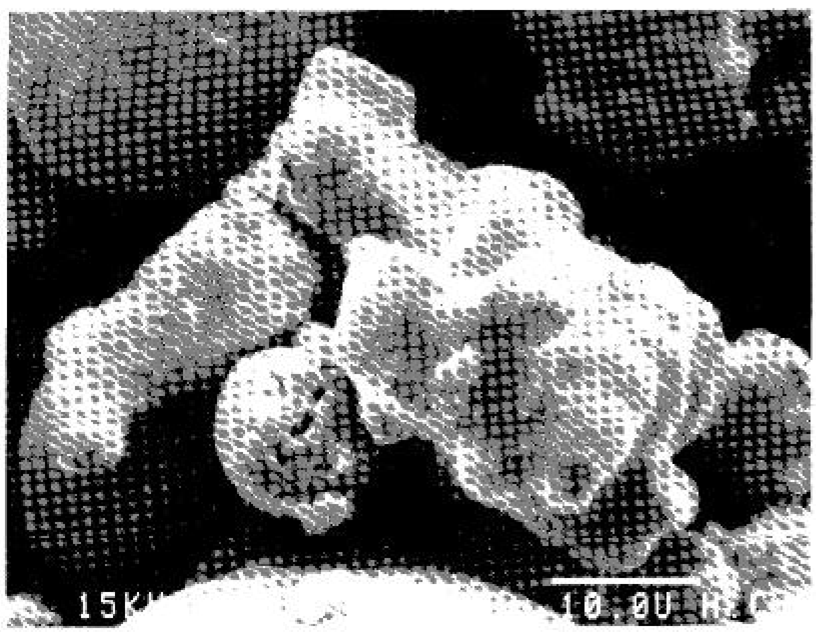

Figure 3: Bonding of a copper particle between two iron particles.

Figure 4: Bare iron particle surface prepared for bonding of 8 w/o graphite.

Figure 5: Bonding of the first layer of graphite particles to the iron particle surface.

Figure 6: Bonding of multiple layers of graphite particles on the surface of an iron particle resulting in a 8 w/o graphite-bonded particle.

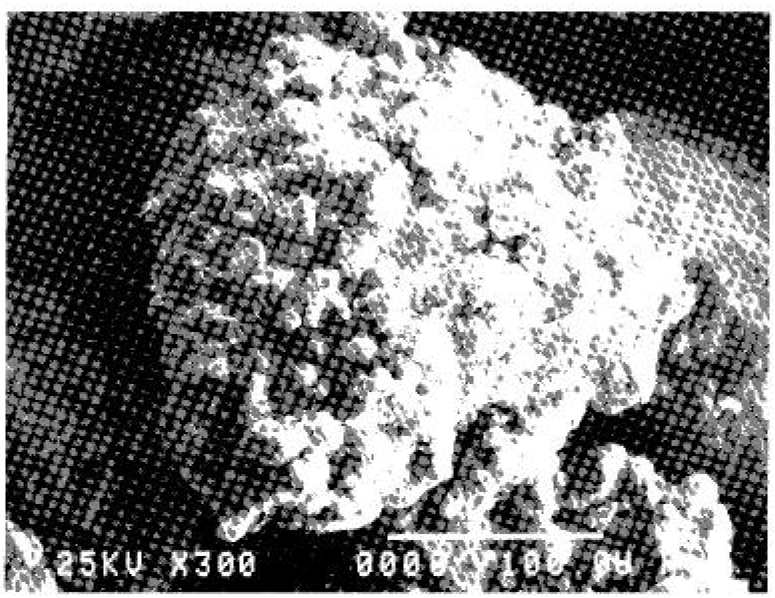

Figure 7: Bonding of copper in an FC-0208 premix.

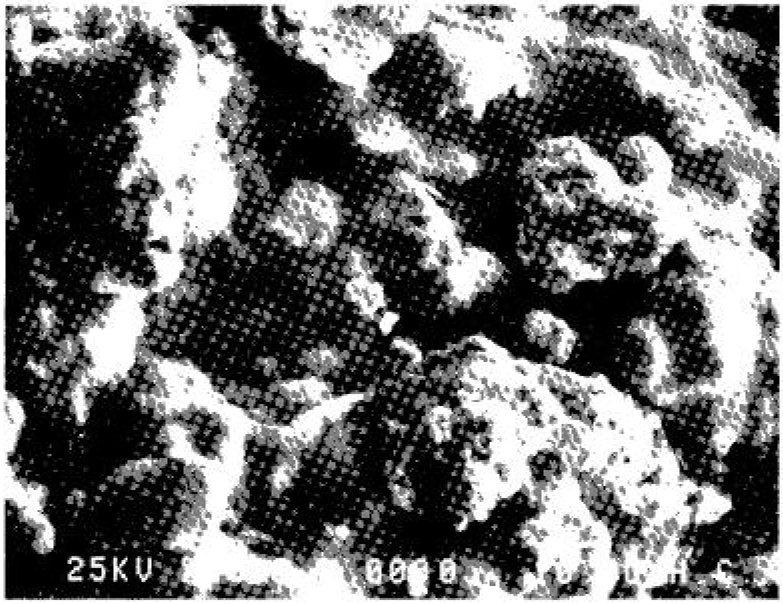

Figure 8: Close-up view of the copper bonding. The location of the copper particles may be identified by reference to the X-ray map shown in Figure 9.

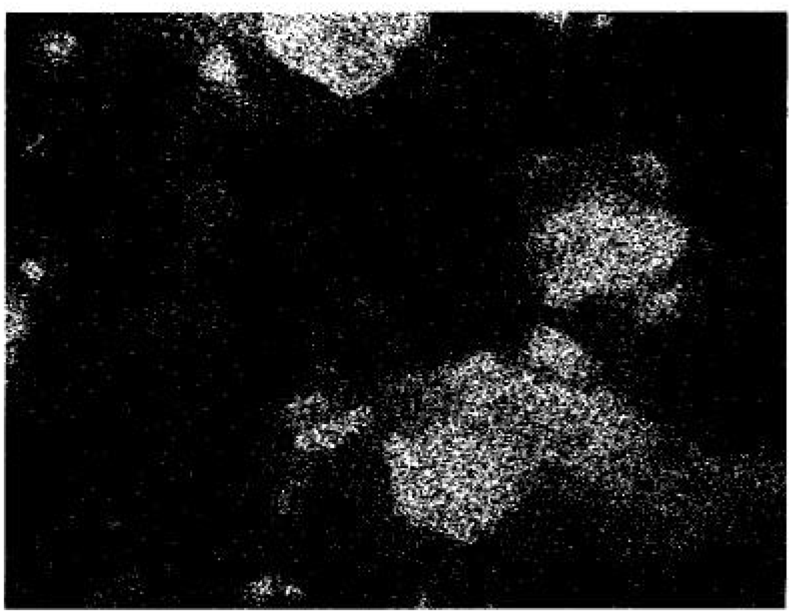

Figure 9: X-ray mapping of the copper particles in the matrix.

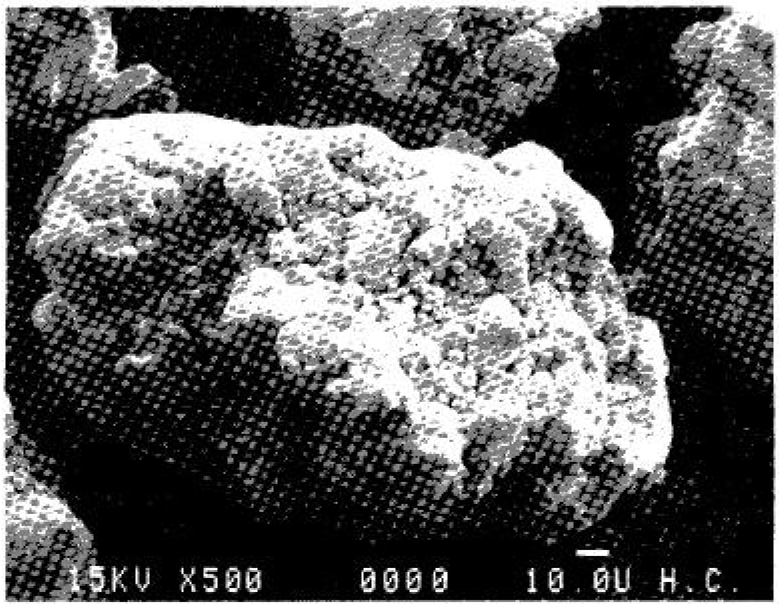

Figure 10: Bonding of the nickel in an FN-0208 premix.

Table I : Green Properties of 0.5 w/o Mo Prealloyed Base Premixes

Compaction Pressure (tsi)	Green Density (g/cm^3)	Green Strength (psi)	Stripping Pressure (psi)	Sliding Pressure (psi)
ANCORBOND: 0.5 w/o Mo base + 2 w/o Ni + 0.6 w/o graphite				
30	6.76	1650	2170	1360
40	7.01	2110	2640	1500
50	7.14	2410	3050	1630
ANCORBOND: 0.5 w/o Mo base + 1 w/o Ni + 1 w/o Mn + 0.6 w/o graphite				
30	6.70	1630	2200	1380
40	6.96	2240	2690	1560
50	7.12	2650	3110	2700

Table III: Green Properties of FC-0208 Premixes

Mix	Compaction Pressure (tsi)	Green Density (g/cm^3)	Green Strength (psi)	Stripping Pressure (psi)	Sliding Pressure (psi)
Mix A	30	6.85	1700	3100	1300
	40	7.08	2000	3400	1700
	50	7.19	2100	3900	2100
Mix B	30	6.85	2800	3100	1000
	40	7.12	3300	3200	1150
	50	7.23	3400	3500	1200
Reference	30	6.86	1700	3300	1600
Premix	40	7.09	1900	3700	1800
	50	7.18	2000	4200	2000

Table IV: Sintered Properties of the FC-0208 Composition

Mix	Pressure (tsi)	Green Density (g/cm^3)	Green Expansion (%)	Sintered Density (g/cm^3)	Dimensional Change (%)	Transverse Rupture Strength (10^3psi)	Appparent Hardness (HRB)
Mix A	30	6.86	0.05	6.75	+0.30	136	74
	40	7.08	0.09	6.96	+0.33	160	81
	50	7.19	0.11	7.09	+0.34	175	84
Mix B	30	6.89	0.03	6.80	+0.20	144	77
	40	7.12	0.11	7.02	+0.27	170	86
	50	7.20	0.23	7.12	+0.30	205	92
Reference	30	6.88	0.04	6.77	+0.26	143	78
Premix	40	7.09	0.09	6.98	+0.30	163	84
	50	7.15	0.14	7.08	+0.33	184	89

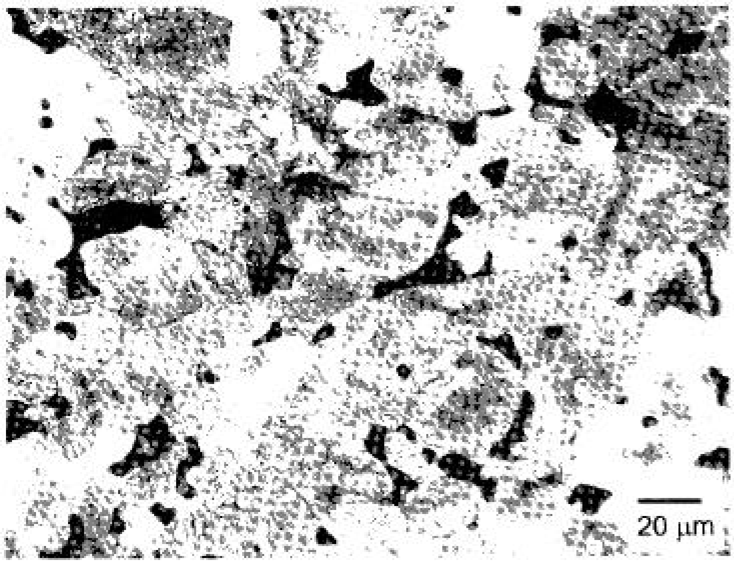

Figure 11: Microstructure of Improved ANCORBOND FC-0208 at 500x magnification

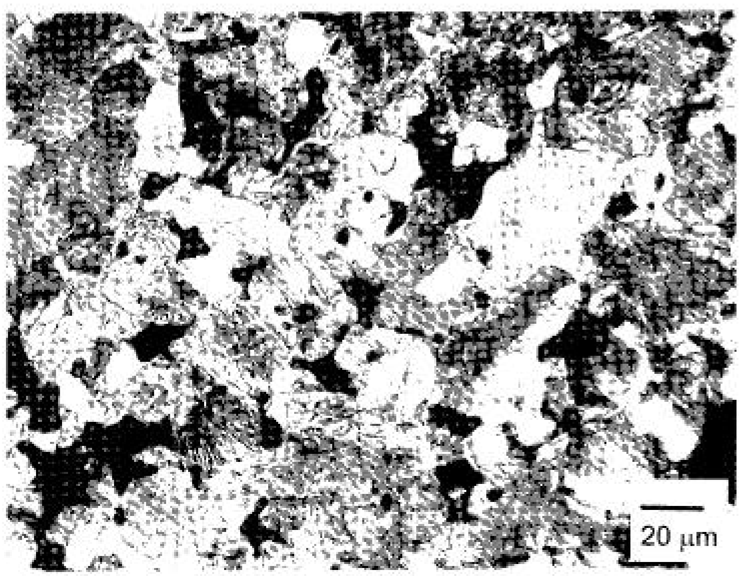

Figure 12: Microstructure of regular premix FC-0208 at 500x magnification

Table V: Properties of FN-0208 Premixes as a Function of Die Temperature During Compaction

Die Temperature (°F)	Compaction Pressure (tsi)	Green Density (g/cm^3)	Green Strength (psi)	Sintered Density (g/cm^3)	Transverse Rupture Strength ($x10^3$ psi)	Apparent Hardness (HRB)	Dimensional Change (%)
Mix Plus							
100	15	6.32	2000	6.21	65	56	+0.02
	30	7.02	5100	6.94	130	81	+0.08
	40	7.19	5700	7.16	147	86	+0.22
	50	7.25	6000	7.24	161	89	+0.26
120	15	6.29	2200	6.24	69	58	0.00
	30	7.01	5600	6.95	127	80	+0.10
	40	7.20	6200	7.15	146	86	+0.22
	50	7.26	6200	7.26	159	90	+0.27
145	15	6.25	2500	6.20	68	59	+0.02
	30	7.00	5300	6.96	128	85	+0.14
	40	7.21	6100	7.21	157	89	+0.24
	50	7.27	6200	7.28	163	90	+0.29
Reference Premix							
100	15	6.37	1100	6.17	65	59	+0.08
	30	6.92	2100	6.85	114	80	+0.18
	40	7.06	2300	7.04	137	85	+0.24
	50	7.12	2400	7.13	154	89	+0.25
120	15	6.24	800	6.22	67	58	+0.06
	30	6.92	1900	6.88	115	78	+0.17
	40	7.07	2100	7.06	136	86	+0.21
	50	7.12	2100	7.13	141	88	+0.25
145	15	6.28	1100	6.24	67	59	+0.04
	30	6.94	2400	6.90	122	81	+0.15
	40	7.07	2500	7.06	137	85	+0.20
	50	7.13	2500	7.14	147	88	+0.23

Table VI: Green Properties of Ancorsteel 45P Premixes

Mix	Compaction Pressure (tsi)	Green Density (g/cm^3)	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

Table VII: Sintered Properties of Ancorsteel 45P Premixes

Mix	Compaction Pressure (tsi)	Green Density (g/cm^3)	Green Expansion (%)	Sintered Density (g/cm^3)	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

Table VIII: 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

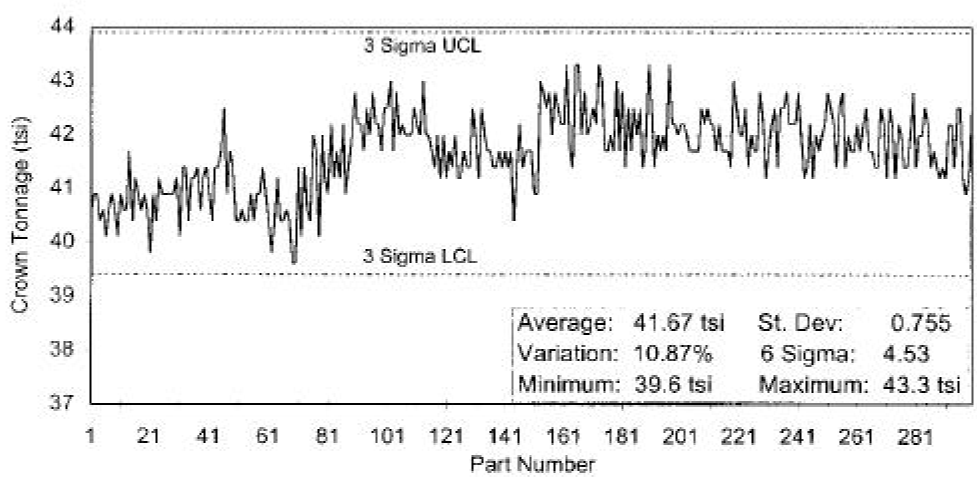

Figure 13: Crown Tonnage Variation of the Original ANCORBOND (Mix A) FN-0208 Composition

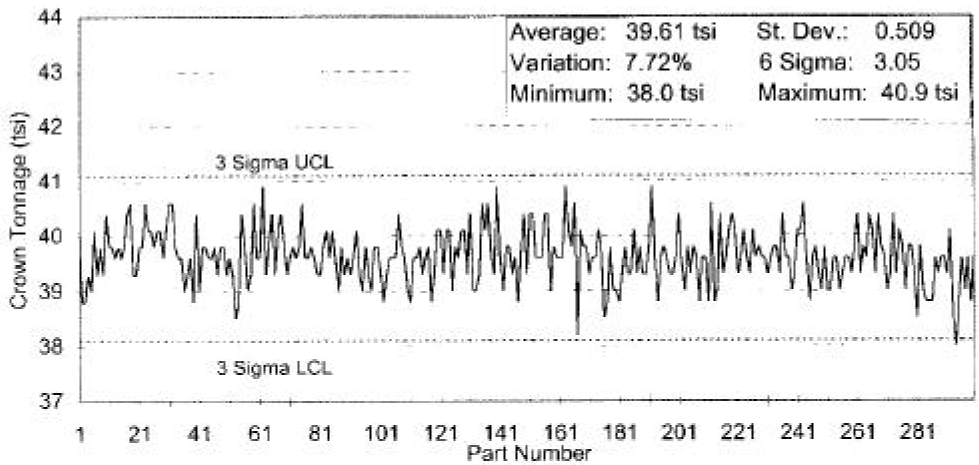

Figure 14: Crown Tonnage Variation of the Improved ANCORBOND (Mix B) FN-0208 Composition

Table IX: 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

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

Composition	Mix	AD (g/cm^3)	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 45	A	3.05	28
	B	3.00	24
	Plus	3.02	26
	Reference	2.98	29

Table XI: Reduction in Surface Area and Apparent Density of ANCORBOND Premixes

FC-0208	Reduction in Surface Area* (m^2/g)	Apparent Density (g/cm^3)	Hall Flow (s/50 g)	Green Density (psi)	Strip Pressure (psi)	Slide Pressure (psi)
Reference	0.0302	3.08	34	7.18	4200	1800
ANCORBOND A	0.0302	2.86	27	7.21	3700	1200
ANCORBOND B	0.0292	2.94	27	7.23	3400	1000
ANCORBOND C	0.0287	2.98	26	7.22	3300	900
ANCORBOND D	0.0282	3.04	25	7.21	3200	800
ANCORBOND E	0.0272	3.14	26	7.16	3600	1300
* as measured by BET						
Note: Data is compiled from a compaction pressure of 50 tsi, and 145°F die temperature.						