

DUST AND SEGREGATION-FREE POWDERS FOR FLEXIBLE P/M PROCESSING

Sydney H. Luk and Jack A. Hamill, Jr.
Hoeganaes Corporation, Riverton, NJ 08077

ABSTRACT

During the past few years, there has been increasing demand placed on P/M parts producers to improve density uniformity, weight variation, alloy homogeneity and dimensional control. Enhanced flow and die fill characteristics are also required to improve productivity and reduce the percentage of green scrap. The ANCORBOND® process developed by Hoeganaes has satisfied many of these requirements by bonding the alloy additives and fines to the base iron particles. Increased concerns regarding the inability to retrofit higher apparent density premixes to existing tool sets, a slight loss of compressibility and the desire to reduce the total organic content for improved burnout response led to further improvements in the bonding process. Several factors that contribute to the performance and greater flexibility of binder-treated mixes compared with regular mixes will be discussed in this paper.

INTRODUCTION

ANCORBOND is a bonding process based on a proprietary mixing process and patented binders. It is the starting point of a systems approach to produce high performance P/M parts which provides greater flexibility with respect to achieving specific application characteristics. The flexibility is derived from the manipulation of the bonding mechanism with respect to the admixed composition, type of lubricant and binder selection.

BONDING

During the process, small particles are bonded to larger particles while the original matrix particles maintain their identity as discrete particles. Numerous benefits result from this technology as shown in Table I.

Table I: ANCORBOND Benefits

- Flow: Faster, consistent flow is obtained.

- **Die Fill:** Better die fill results from improvements in flow characteristics.
- **Weight Control** Consistent weight distributions result from uniform die fill.
- **Green Strength** Increased green strength for a full range of compaction pressures.
- **Dusting** Fine particles of alloy materials, normally lost as dust in powder mixes, are reduced dramatically, resulting in improved alloy efficiency and plant cleanliness.
- **Compressibility** Better compressibility resulting from improved internal lubricity.

The different mechanisms which take place during bonding are chiefly dependent upon the physical and chemical characteristics of the selected binder system. "Materials bridging" is the formation of a solid interface which forms between particles by the crystallization of a dissolved substance during drying of an oil or the hardening of a bonding agent such as a glue or resin formulation. Before the solid bridges can be formed, the particles go through a mobile liquid bonding stage depending upon the volume and concentration of the binder solution (Figures 1 and 2).

Binder strength can be characterized by the theoretical calculation of the bonding strength of agglomerates as shown in Figure 3. Applying this relationship, a proprietary mixing process was developed to optimize the bond strength thereby allowing control or manipulation of various premix characteristics to enhance flexibility and material performance.

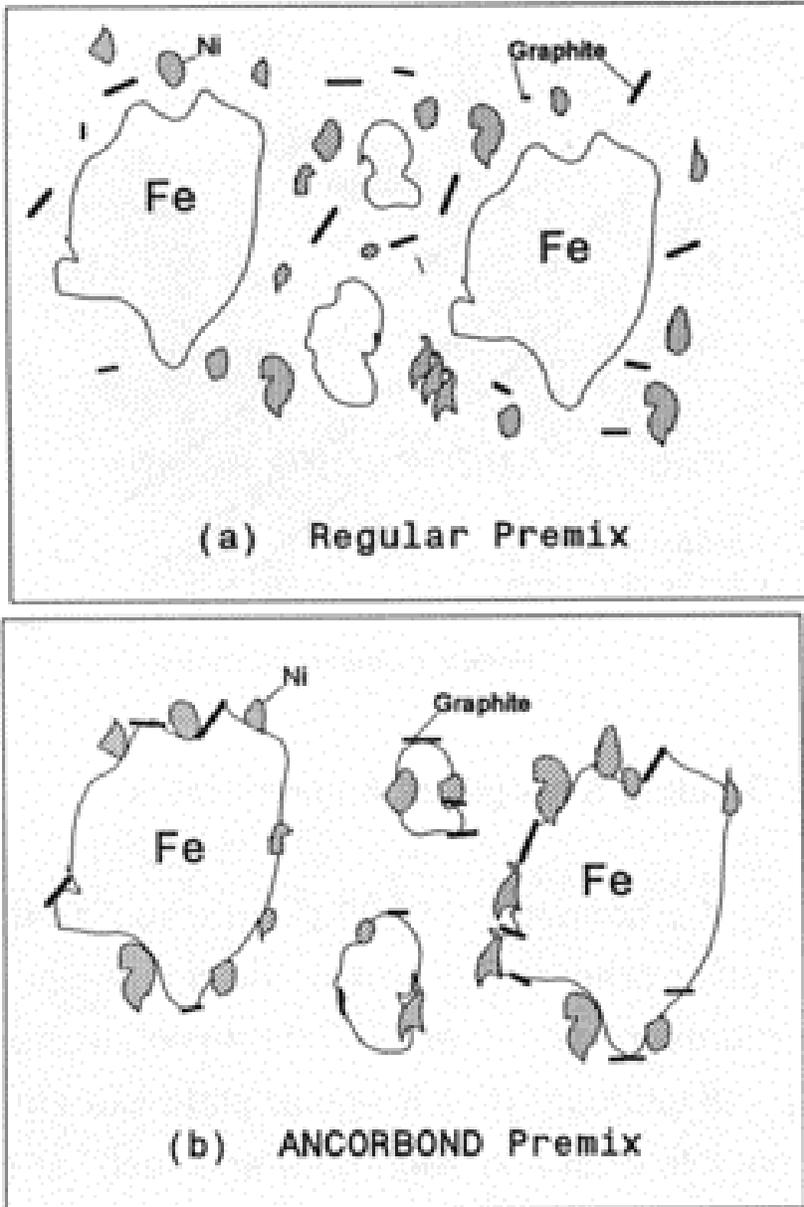


Figure 1: Schematic of Alloy Distribution in the Various Types of Premixes

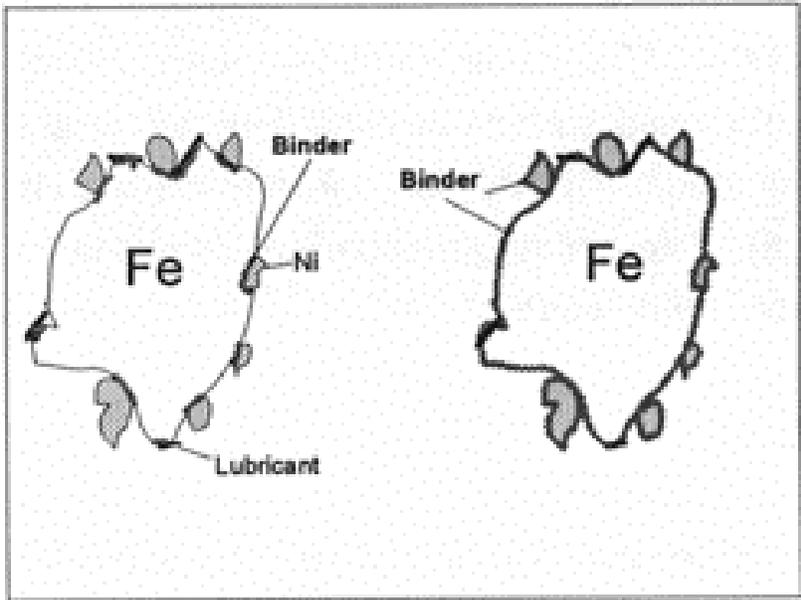


Figure 2: Binder Location with Respect to Lubricant and Admixed Fines

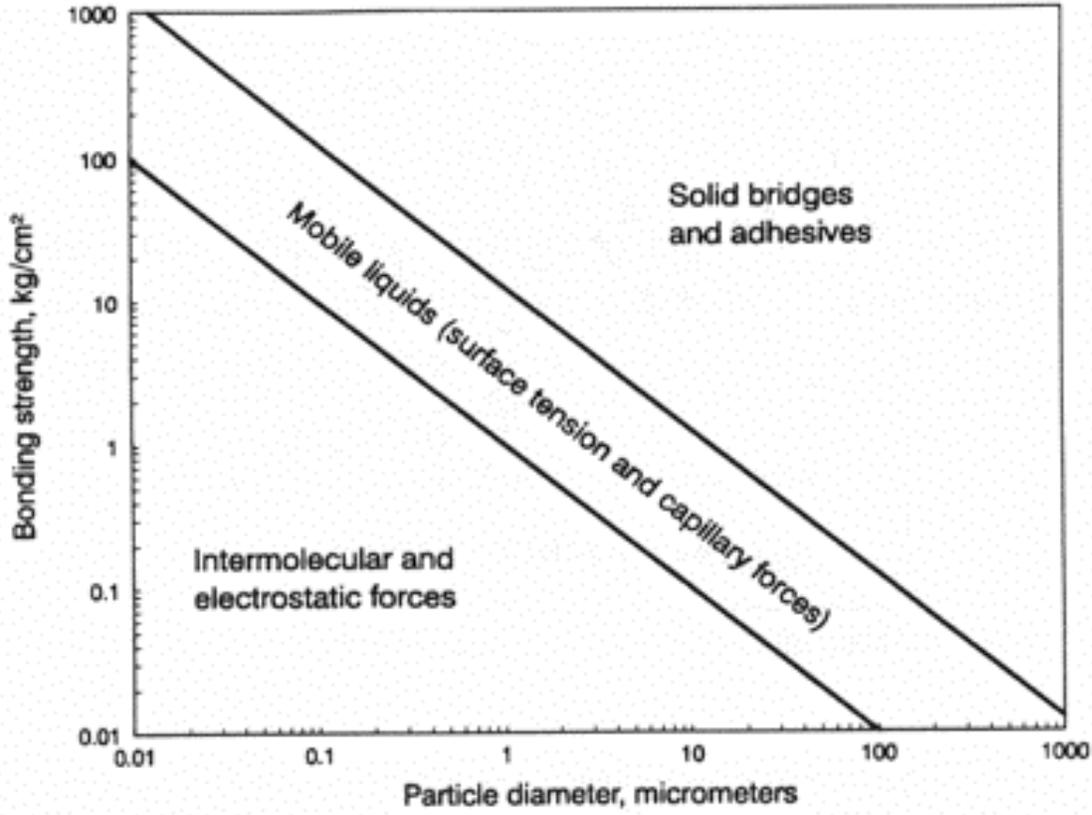
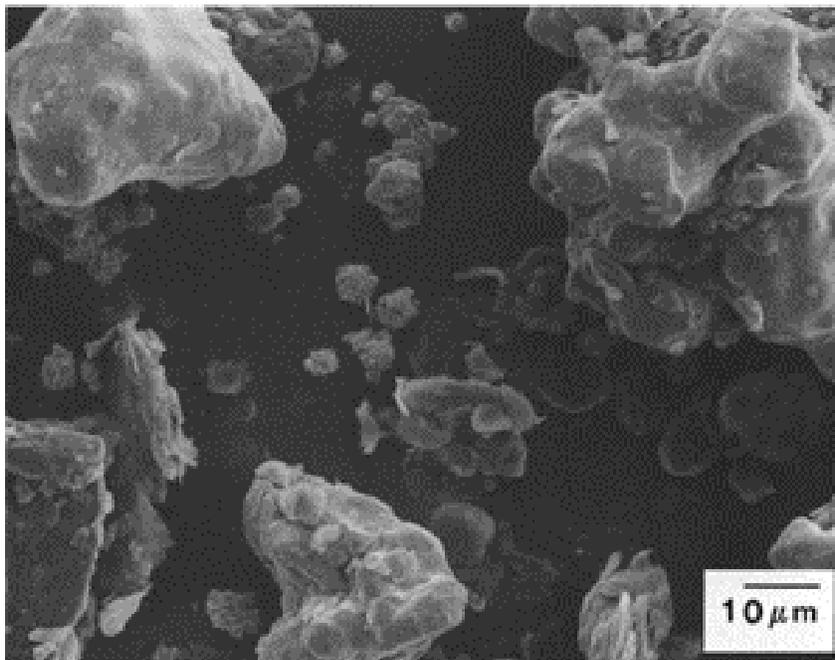


Figure 3: Theoretical Bonding Strength of Agglomerates

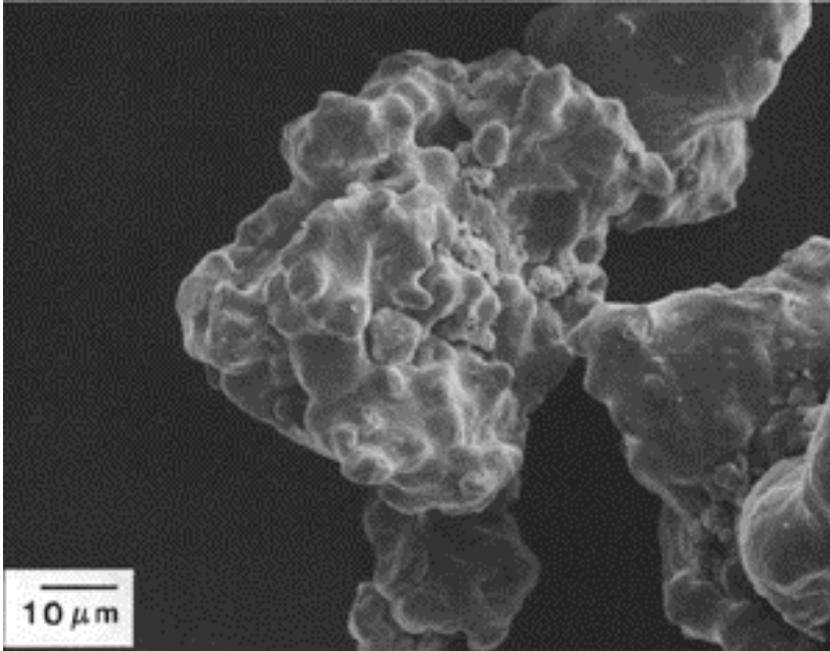
SEM photomicrographs of a bonded FN-0208 premix and a regular premix are shown in Figure 4. For the regular premix (Figure 4a), there is a high background level of fine powders. These represent iron, graphite (plate-like structure), nickel (rounded sponge-like structure) and lubricant (fine irregular plate-like structure). These loose fines will have a tendency to dust and segregate and result in higher ejection forces. In contrast, for the binder-treated powder, the background level of fine particles is extremely low (Figure 4b). All the iron, nickel, graphite and lubricant fines are bonded to the primary iron powder particles. In particular, they fill the surface cavities of the primary iron powder particles. The binder-treatment mechanism allows preferential bonding of the fines into these surface cavities (Figures 4c and 4d). Segregation of fines is therefore eliminated. The fine iron particles are also bonded to the coarser iron particles (Figure 5). The bonding mechanism allows even distribution of the fines rather than a cluster of fine powders.

FLOW AND DIE FILL

Previous research indicates that "rat-hole" formation in the feed hopper must be eliminated to achieve uniform die filling performance. The rat-hole phenomena is related to powder flow which becomes inhibited by the cohesive forces between particles.



Regular Premix (a)

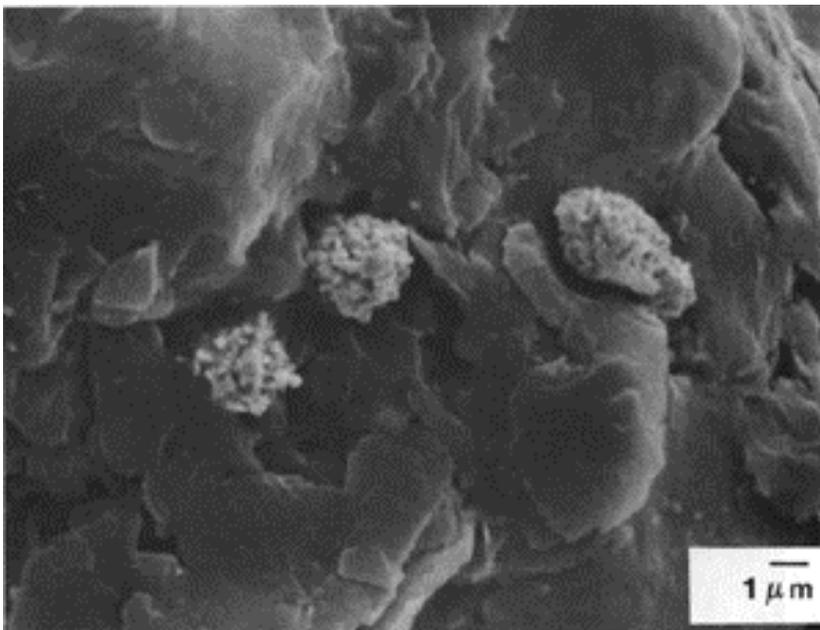


Binder-Treated Premix (b)

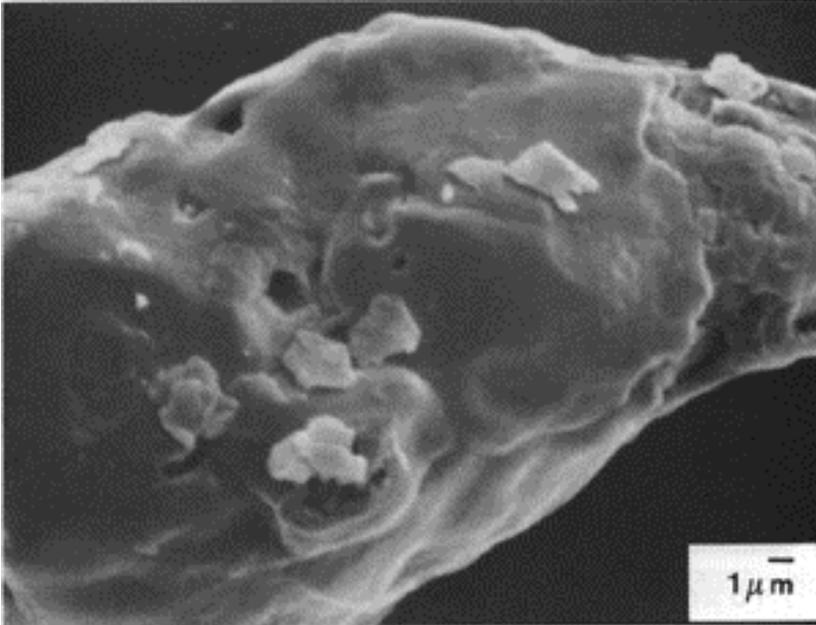
Figure 4: SEM photomicrographs of regular and binder-treated premixes

(a) Regular Premix

(b) Binder-Treated Premix



Nickel Premix (c)

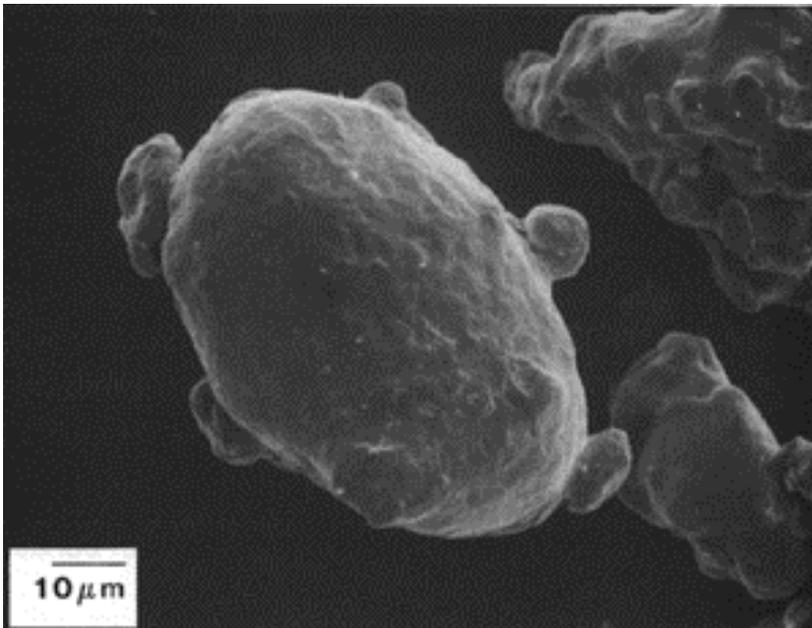


Graphite Premix (d)

Figure 4: SEM photomicrographs of regular and binder-treated premixes

(c) Higher magnification of nickel particles in binder-treated premix

(d) Higher magnification of graphite particles in binder-treated premix



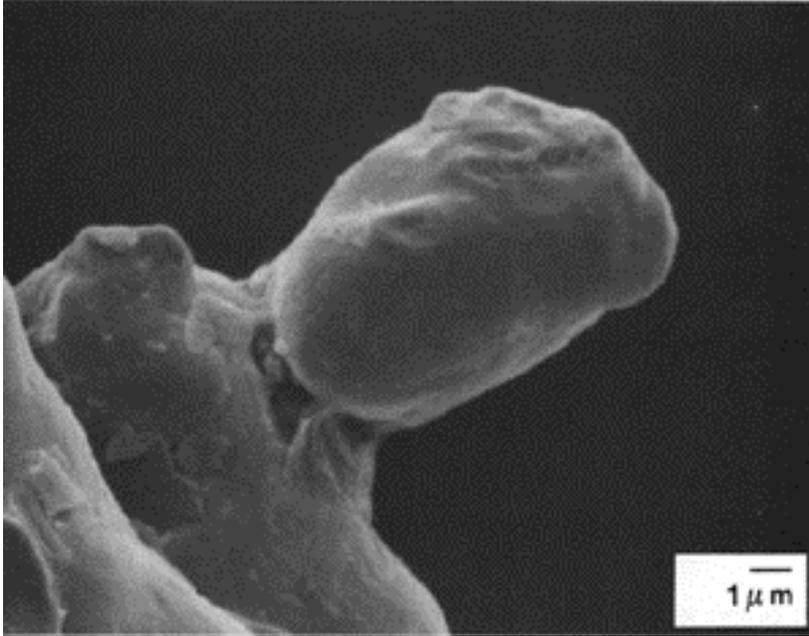


Figure 5: SEM photomicrographs of binder-treated premix showing fine iron particles bonded to coarser iron particles.

The complexity of the flow behavior is due to the lack of control of interparticle cohesive forces. With the binder film, it is now possible to manipulate the surface forces through additives in the binder film. These short-range forces counterbalance the mass of the particles. They are dependent on the molecular arrangements at the surface of the solids. The binder treatment process optimizes and balances the interfacial forces between the various patented binders, lubricants and metal powders. It also rearranges the particle size distribution and particle shapes to promote planar sliding of one internal surface of particles over another to eliminate rat-hole formation. In addition, it is now possible to obtain different apparent density and flow characteristics with the same powder composition. For example, when retrofitting current tool sets or fixed-shelf dies, the apparent density can be duplicated to approximately the same values as a regular premix. For new tool sets, the apparent density requirement for optimum die fill characteristics and density uniformity is commonly achieved using the highest values attainable. The greater capability achieved with bonded premixes is shown in Table II.

Table II
Apparent Density Flexibility in a Binder-Treated F-0008 Premix

	After 24 Hours	After One Week
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Mix Condition	A.D. g/cm³	Flow s/50g	A.D. g/cm³	Flow s/50g
Regular Premix	3.13	37	3.15	38
<u>Binder Treated Premixes</u>				
A	3.30	23	3.34	23
B	3.40	24	3.42	23
C	3.17	28	3.18	28

As indicated, the apparent density of the mix can be increased from 3.17 to 3.40 g/cm³ by varying the bonding mechanism. This is accomplished by adjusting the relative proportions of binder and lubricant in the premix. An important characteristic of the selected lubricant-binder combinations is their stability with respect to time. This is demonstrated by the results for tests conducted one week after the initial evaluation of the premixes.

WEIGHT CONTROL

Statistical techniques provide an accurate assessment of specific performance characteristics. This is particularly useful for trial situations which compare each material's capability to meet or exceed established product.

To illustrate the improvement in weight control, two control charts were generated during a manufacturing trial which compared green part weight for a binder-treated premix and a regular premix of F-0008 chemistry (Figures 6 and 7).

The greater amplitude of variation evidenced for the regular mix is associated with the inherent demixing and segregation common with admixed materials. A 500-part sample resulted in a mean value of 166.47 grams and standard deviation of 0.54 for compact weight.

In contrast, the ANCORBOND material under the same trial conditions shows a marked improvement in weight control. The mean value was calculated as 166.56 grams with a 0.32 standard deviation. This indicates a significantly greater statistical capability for the ANCORBOND material which is supported by a 41% reduction in standard deviation. Consistent weight distributions result from more uniform die fill characteristics and faster, more uniform powder flow.

GREEN STRENGTH

An additional benefit of the bonding process which enhances part manufacturing capabilities, particularly for more difficult geometries, is improved green strength. The fine alloy particles which become attached to the surface of the iron powder effectively increase surface area and the related degree of interlocking between particles. The physical nature of the binder along with the ability to "glue" particles together also improves green strength performance.

A comparison made between a regular and a binder-treated premix using a MPIF FC-0208 composition indicates binder treatment can increase green strength at compaction pressures ranging from 20 to 50 tsi as shown in Table III. The most significant improvements were realized at the lower compaction pressures.

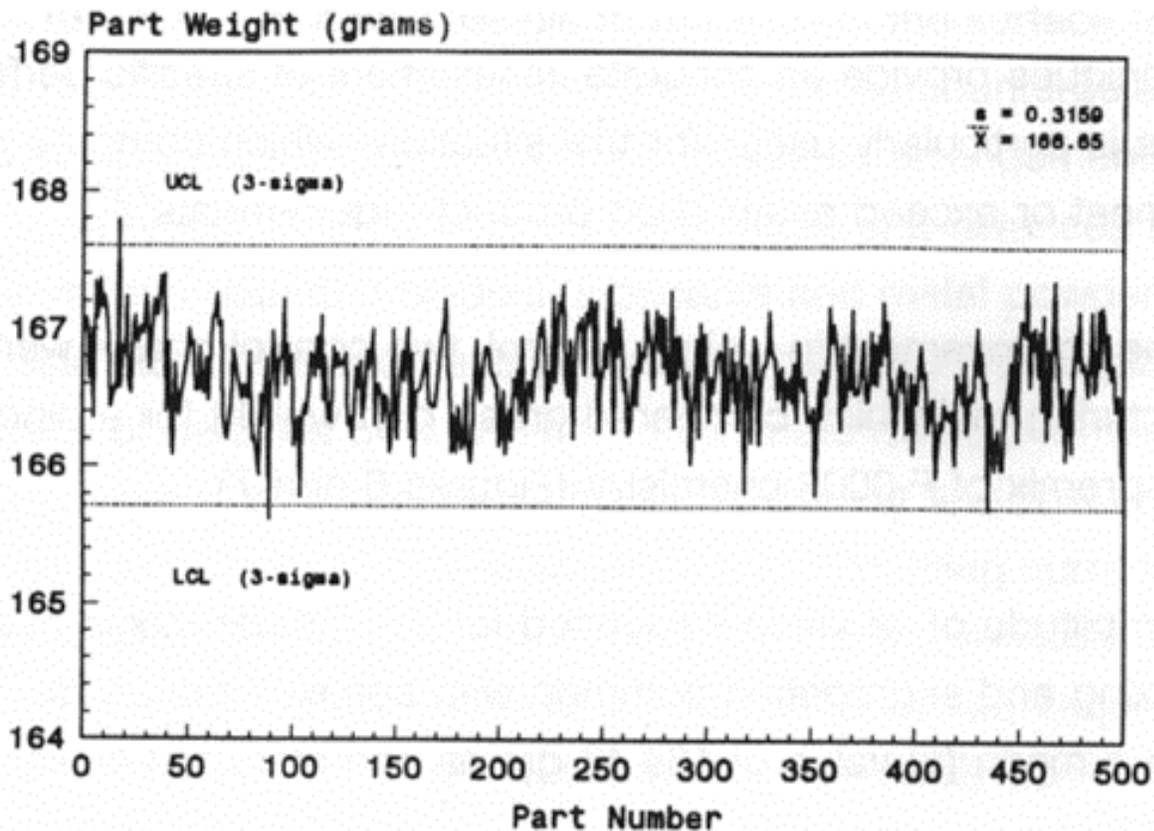


Figure 6: Binder-Treated Premix

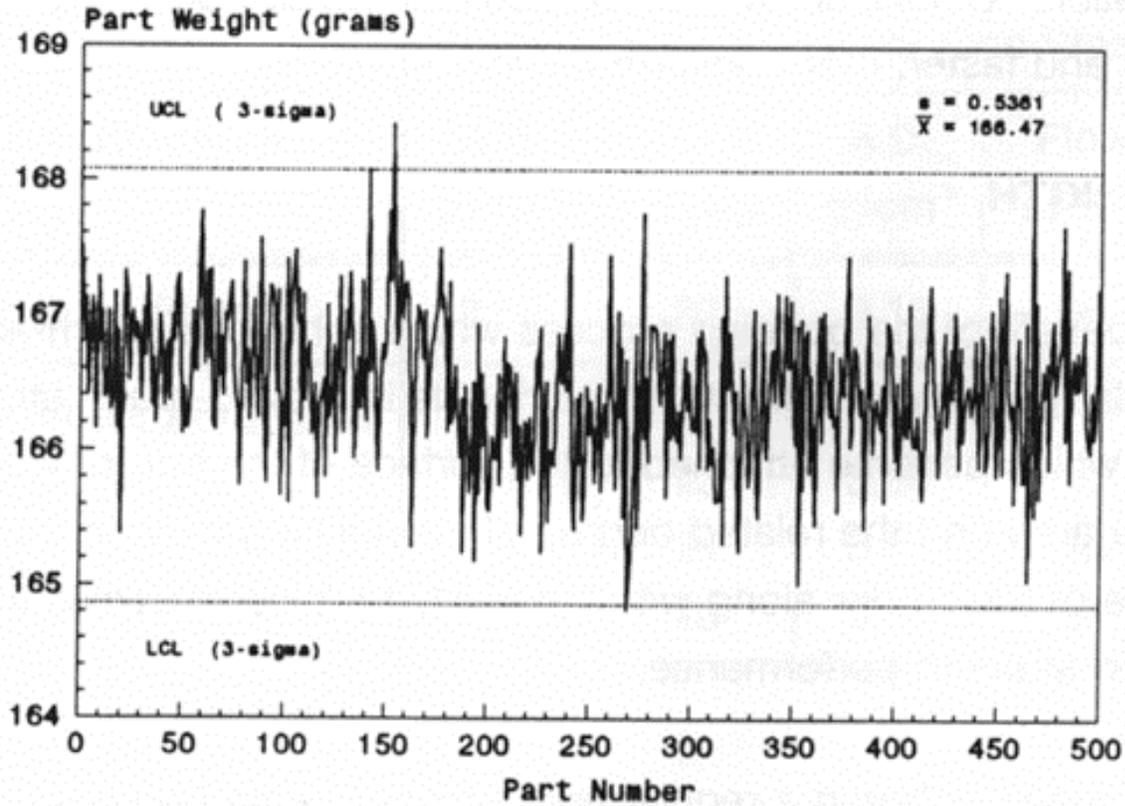


Figure 7: Regular Unbonded Premix

Table III
Increased Green Strength for Binder-Treated Premixes

Compaction Pressure (tsi)	Green Strength (psi)		Increase (%)
	Regular	Bonded	
20	1200	1500	25
30	2000	2300	15
40	2400	2700	13
50	2500	2700	8

IMPROVED COMPRESSIBILITY

The extended flexibility of the binder treatment process has been directed toward improving both the internal (particle to particle) and external (die wall-tooling) lubricity of the bonded materials.

New binders have been developed which have inherent lubricating characteristics. These can be used to replace a portion of the conventional solid lubricant which in turn reduces the overall percentage of organic material added to the mix. This results in a two-fold advantage. It increases the compressibility of the premix and improves the burnout characteristics as a result of lower total organic content. The example shown in Table IV represents a FC-0208 composition with 0.75% zinc stearate as lubricant.

The bonded mix is able to achieve a green density of 7.22 g/cm³ at a compaction pressure of 50 tsi. This is an increase of 0.07 g/cm³ over the regular premix. The corresponding ejection force measured by the stripping and sliding pressure is also lower for the binder-treated premix. The stripping pressure measures the static friction at the die wall, i.e. the force required to set the green compact into motion. This force needs to be as low as possible to avoid possible initiation of green cracks during ejection. The sliding pressure measures the kinetic friction at the die wall, i.e. the force

Table IV
Improved Compressibility for a FC-0208 Premix

	Regular Premix	ANCORBOND Premix
A.D. (g/cm ³)	3.10	3.24
Flow (s/50g)	32	26
Green Density (g/cm ³)	7.15	7.22
Stripping Pressure (psi)	3400	3200
Sliding Pressure (psi)	2400	1300

required to continue ejection of the green compact. This force is maximized when the green compact reaches the upper opening of the die cavity and should be as low as possible to minimize die wear.

ENVIRONMENTAL DUST TESTING

Much greater emphasis has been placed recently on environmental conditions in the workplace. Regulatory agencies have proposed legislation requiring closed looped systems along with strict monitoring practices to control exposure to powders in the

atmosphere. Assorted system designs which incorporate a dust hood connected to an exhaust fan have been suggested, while more elaborate systems include collectors and bag filter devices. The various equipment and facility modifications to accommodate the new regulations would require considerable capital expenditure to meet proposed air quality standards or exposure limits.

Anticipating the new environmental legislation for the workplace and bolstered by laboratory dust test results, a comparative evaluation of airborne particulate emissions was performed between a regular premix and an ANCORBOND premix of the same composition. Experience indicates the binder technology can substantially offset the need for sophisticated and costly equipment to improve air quality standards in the workplace.

The air quality dust test conditions represent actual parts manufacturing in a P/M fabricator's facility. An environmental engineering firm was retained to sample and analyze for respirable nuisance dust and elemental airborne particulates using National Institute for Occupational Safety and Health (NIOSH) Methods 0600 and 7300. Samples were collected from three locations with each representing specific target parameters. Background sampling was used to establish baseline information to ensure consistent conditions had been maintained between trials. Air quality monitors were placed in the operator's work area to simulate the individual's airspace. The third sampling station monitored dusting immediately adjacent to the compacting tools and provides the relative degree of alloy efficiency between materials.

Specimens were collected on a 37mm polyvinyl chloride filter using a 10mm Dorr-Oliver Cyclone to isolate the respirable fraction of airborne particulate matter. The respirable fraction is defined as those particles which would pass through a filter size of 3.5 micrometers. Airborne particles of this size are capable of penetrating the air exchange regions of the lung. Sample flow rates were approximately 1.7 liters per minute. Sample results are reported in milligram per cubic meter of air (mg/m³) (Figure 8). Every effort was made to limit trial variables, i.e. the same press and tool set were utilized by the same operator while maintaining similar plant conditions.

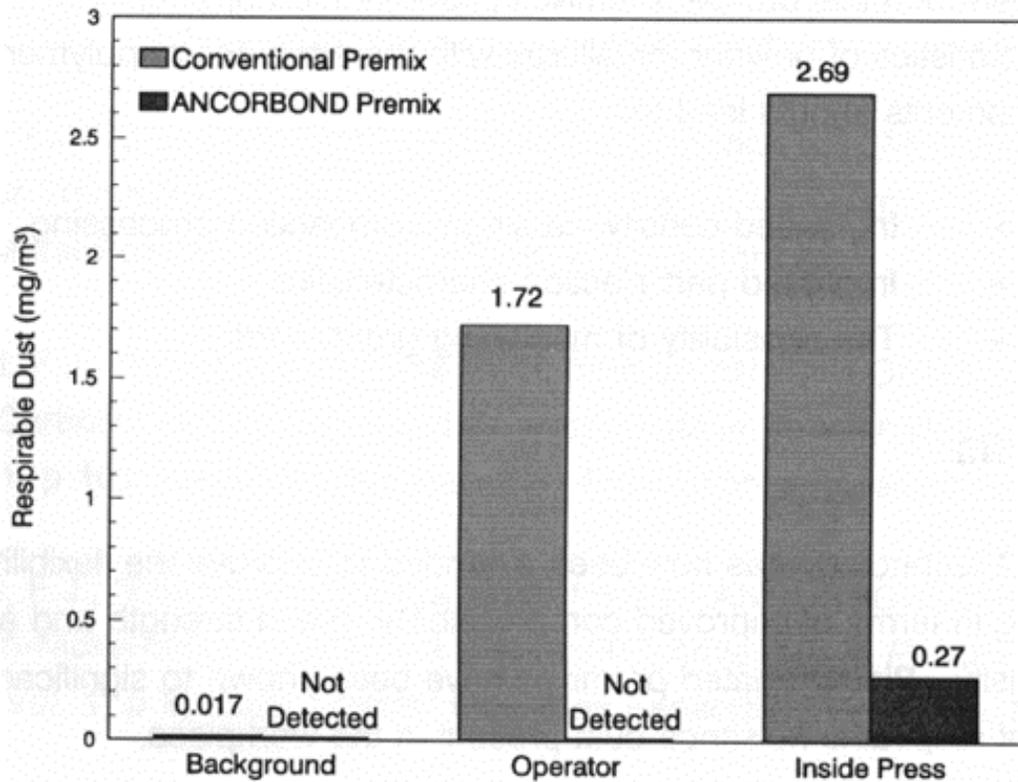


Figure 8: Respirable Dust in Work Area for a Conventional Premix and an ANCORBOND Premix

The samples collected during the ANCORBOND trial indicate a significant reduction in the airborne concentrations of respirable nuisance dust. This translates into a better working environment, improved plant cleanliness with less related maintenance requirements and could potentially eliminate significant capital expenditure to meet the proposed air quality standards in the workplace.

FUTURE DEVELOPMENTS

ANCORBOND processing is important not only for the potential it offers for improving productivity and reducing variability in the manufacture of P/M parts but also for the opportunities it offers for new alloy development and the range of fine particle additives that can be used. It has great promise as part of a systems approach to achieving increased P/M part densities without the need to resort to double press/double sinter techniques. ANCORBOND processing offers the potential for combining the best features of prealloyed, partially alloyed and admixed materials to optimize the raw materials phase of the parts making process.

The way the powder is constituted will significantly influence the nature of the porosity and the microstructure of the finished part. Correct selection of the alloy constituents and the added lubricant is vital to the compaction process.

Binder treatment of metal powder premixes provides the opportunity to combine the unique characteristics of powder metallurgy with the attributes of polymer technology. Future developments should lead to:

- Increased density via single compaction processing
- Improved part ejection characteristics
- The possibility of machining green parts

CONCLUSIONS

ANCORBOND technology has now been extended to improve the flexibility of P/M manufacturing in terms of improved compressibility, green strength and adjustment of apparent density. Binder-treated premixes have been shown to significantly reduce the amount of respirable nuisance dust present in the workplace

ACKNOWLEDGMENT

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