HIGH PERFORMING PREMIXES FOR DEMANDING PM APPLICATIONS

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ABSTRACT

The number of complex and high performance parts required by PM customers is continuously growing. The production of such parts requires increasingly higher performance powder premixes. Binder-treated premixes fall into that category. The binder treatment blending technique consists in bonding fine particles of graphite, metallic additives and lubricants to the coarser iron particles using a solid organic binder. The main advantages of binder-treated mixes compared to conventional mixes are better flow, improved productivity and part consistency and reduced dusting and segregation. It also allows the use of very fine alloying additives that may improve the mechanical properties. In addition, the binder technology opens the doors for new and more efficient lubricating systems. In particular, these lubricating systems are needed for high density applications. These attributes make binder-treated mixes well suited for high performance P/M applications as well as other types of applications requiring mixes with excellent die filling characteristics.

I. INTRODUCTION

The PM market can expand either by improving the part manufacturing capability and productivity or by developing new higher performance applications. In both cases, it is clear that the behaviour of powdered materials during compaction, which remains one of the most important steps of the manufacturing processing route, is crucial. In this regard, a new mixing technology called FLOMET was introduced in the 1990's in order to improve the flow behaviour of mixes for demanding applications or difficult die cavity filling conditions. The FLOMET technology is a binder-treatment blending technique in which the additives are bonded to the iron particles using a patented polymeric solid binder [***1***,***2***]. This bonding technology is also an excellent platform for high density applications. Indeed, specifically designed lubricant-binder systems can be used to achieve high density by conventional or warm compaction and can be assisted by the die wall lubrication technique. This paper reviews the characteristics and performances of bonded materials produced with the FLOMET binder-treatment technology.

II. PARTICLE BONDING AND DUSTING RESISTANCE

Figure 1 shows SEM micrographs of the powder particles of a FN0208 binder-treated mix. It can be seen that most of the graphite, lubricant and nickel particles are effectively attached to the iron particles. It should be noted that in regular mixes, a certain level of graphite, lubricant and even nickel are attached to the iron particles. However, this dry-bonding is mainly associated with the van der Waals forces that take place between particles. Nevertheless, the strength of these bonds is very small.

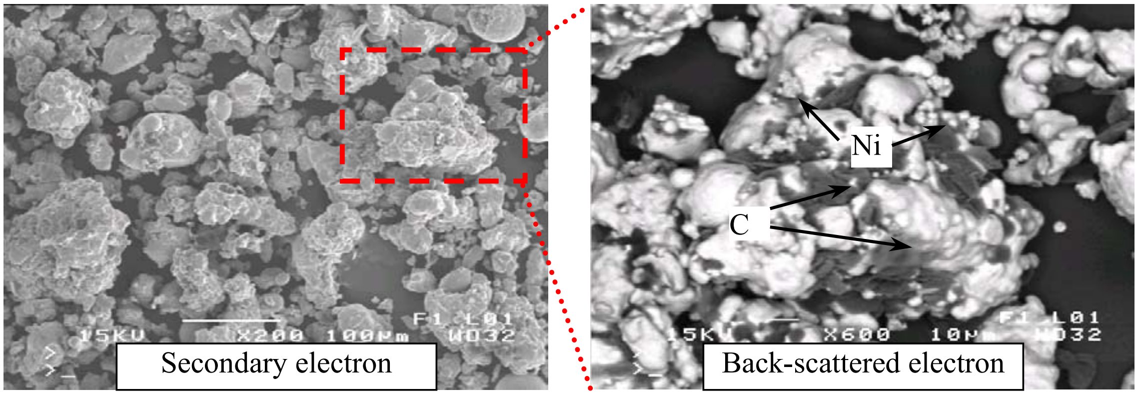

Figure 1. SEM micrographs of particles from a binder-treated mix made of ATOMET 1001, 2% Ni, 0.85% graphite and 0.75% wax+binder. C represents either graphite or lubricant.

The influence of binder-treatment on the bonding efficiency of fine particles is very well demonstrated in Figure 2, which shows the size distribution of regular and binder-treated FN0208 mixes as evaluated with a laser diffractometer. As expected, addition of fine nickel, graphite and lubricant significantly increases the proportion of fines in the regular mix. In the case of the binder-treated mix, size distribution is almost equivalent to that of the base powder, clearly showing that the solid polymeric film formed during the binder-treatment is very efficient in bonding particles below 60 µm to the larger ones or to form larger size agglomerates.

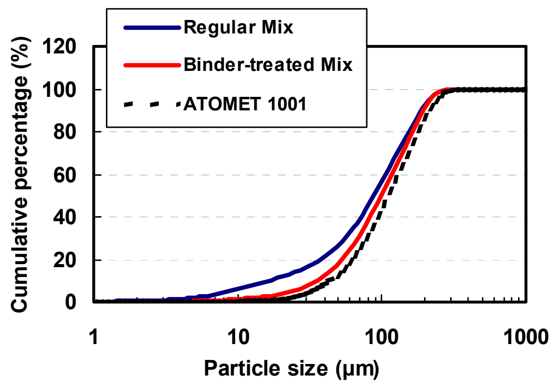

Figure 2. Particle size distribution of regular and binder-treated FLOMET mixes (laser diffractometer).

The efficiency of the coating film formed during the binder-treatment on the dusting resistance of F008 mixes was quantitatively measured with the experimental assembly shown in Figure 3a (see ref ***3*** for more details). It can be seen in Figure 3b that the concentration of dust (particles below 10 µm) in the air as a function of time is strongly reduced with the binder-treated material, the peak concentration being around 4 times lower. The percent retention of some additives, when mixes are subjected to more turbulent flow of air is another method to evaluate the bonding efficiency. The dusting resistance of various additives is

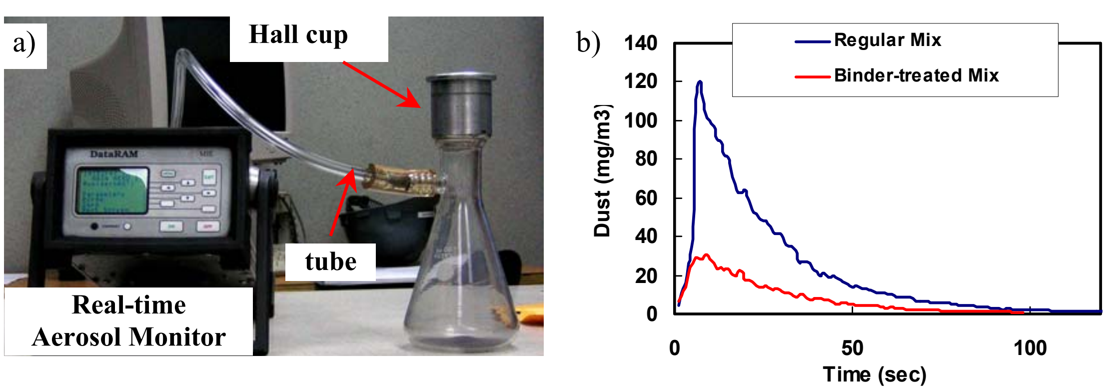

Figure 3. Quantity of dust (particles < 10 µm) created by a regular and a binder-treated F0008 mixes when powders flow in a recipient. a) Experimental assembly b) Results.

given in Table 1. Typically, the level of retention is increased by a factor of 2 after binder-treatment. This confirms that the thin coating film formed during the binder-treatment is strong enough to withstand high turbulence flow. The dusting resistance of binder-treated materials is also influenced by the size of additives (ref 3 and 4). For example, the Ni dust resistance was increased from 60 to 97% by reducing the mean diameter D_{50} from 8 to 3 µm.

Table 1. Typical dust resistance of carbon, copper and nickel in mixes.

Type of mix	Carbon, % [1]	Copper, % [2]	Nickel, % [3]
Regular (ATOMET)	50-65	20	25
Binder-Treated (FLOMET)	85-95	50	60

1. Lubricant and graphite, 2. -325 mesh grade, 3. Carbonyl grade, $D_{50} \approx$ 8-10 µm

III. FLOWABILITY AND DIE FILL CAPABILITY

As mentioned earlier, bonding fine particles to the coarser ones helps to improve the flow. In general, improvement in flow obtained by binder-treatment is typically in the order of 4 to 10 s/50g, depending on the mix formulation. Normally, the slower the flow rate for the regular mix, the larger the gain in flow rate after binder-treatment.

Nevertheless, the Hall flow rate does not necessarily indicate the performance of the mix in a production press. Indeed, it is well known that the filling conditions (gravity or suction fill, shoe configuration, number and amplitude of shakes, size and type of tube, etc…) have a large impact on the part weight and chemical consistency. Several studies were conducted on mechanical production presses to validate the die filling performance of regular and binder-treated mixes under different filling conditions.

A first test was carried out under relatively easy filling conditions. Rings with an outside diameter (OD) of ~6.1 cm, an inside diameter (ID) of ~3.6 cm , and a height of 1.27 cm were pressed using the suction fill mode. Figure 4 gives the part weight variation obtained at 14 and 20 strokes per minutes (SPM). The filling time at 14 and 20 SPM was respectively 1.8 and 1.4 sec. All mixes gave very similar part weight variation, which increases only slightly at 20 SPM. These results indicate that for relatively easy filling conditions, and when the suction fill mode is used, there is no real advantage to use a binder-treated material in term of weight consistency.

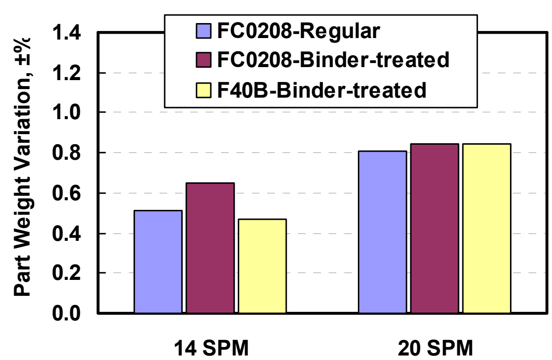

Figure 4. Part weight variation for test #1 carried out under easy filling conditions and suction fill (fill height/wall thickness = 2).

A similar test was then conducted with another ring-die. Rings having an OD of 5.3 cm, an ID of 4.4 cm and a height of 1.9 cm were pressed in the suction and gravity fill modes. The die cavity filling conditions were significantly more challenging than for the previous test, with a height to wall thickness ratio more than 4 times higher. Figure 5a shows the part weight variation as obtained in the suction fill mode at a compaction rate of ~22 SPM. The fill time was adjusted to 1 and 0.8 sec. Contrary to the results obtained in the previous test, the part weight variation obtained with the binder-treated mix was 66% to 105% lower than that obtained with the regular mix. Figure 5b shows the part weight variation as a function of the filling time in the gravity mode. Compaction was done at 10 SPM and the filling time was varied from 1.2 to 1.8 sec. The weight variation was significantly lower with the binder-treated materials, up to 600% at 1.8 sec and between 20 and 60% at 1.2 and 1.4 sec. These results confirmed the superior filling properties of the binder-treated materials when more difficult filling conditions are used, both in the suction and gravity fill modes.

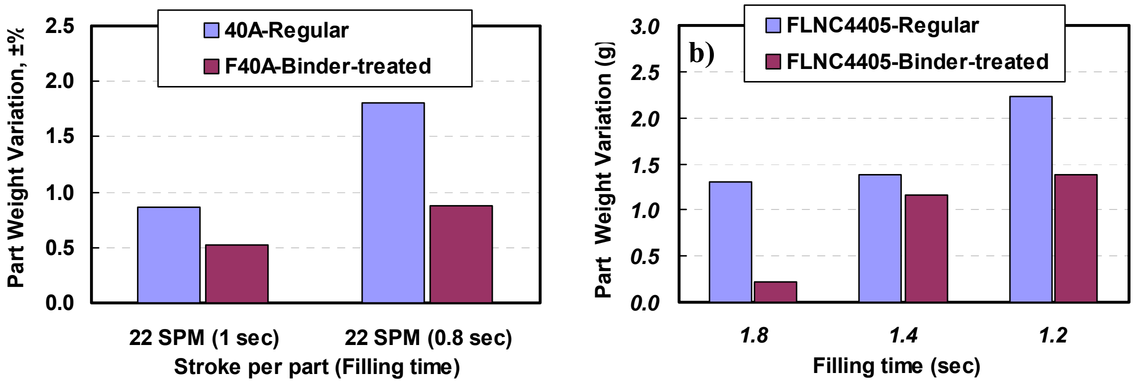

Figure 5. Part weight variation for tests carried out under more difficult filling conditions (fill height/wall thickness = 8.2). a) Suction fill b) Gravity fill

Finally, a trial was carried out on a small drive nut under actual industrial compaction conditions. A regular and two versions of binder-treated FC0208 mixes were evaluated. ATOMET 29M, a free-machining iron powder was used as the base powder. The second version of FLOMET was optimized for flowability by adding a flow agent to the binder formulation. Series of ~ 1500 parts were produced at 21 and 27 SPM. 21 SPM corresponds to the maximum rate that can be used with the non-bonded mix while 27 SPM corresponds to the upper limit of the press. It should be noted that it was not possible to run the regular mix at 27 SPM due to excessive variation in weight. The filling mode was mainly gravity. Figure 6 gives the part weight variation obtained during the runs. At 21 SPM, the two binder-treated materials gave lower part weight variation, the improvement versus the regular mix being between 15 and 22%. Increasing the compaction rate to 27 SPM did not affect the part weight stability of the binder-treated mixes. In fact, the part weight variation even dropped by 25 % for the second version. This represents an improvement of 36% as compared to the regular mix pressed at 21 SPM. Both binder-treated mixes allowed increasing the production rate by 28%, while reducing the weight variability versus the non-bonded material.

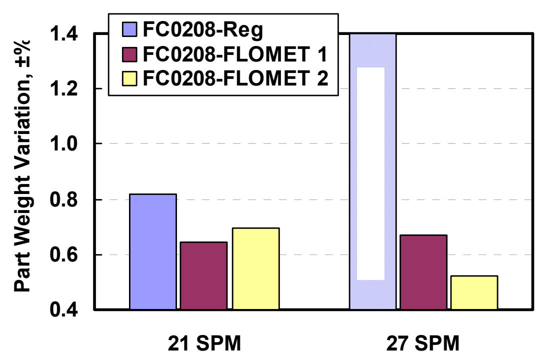

Figure 6. Part weight variation obtained during production of drive nuts at two compaction rates. * Regular mix was not run at 27 SPM.

PART CONSISTENCY AND HOMOGENEITY

As demonstrated in the previous section, binder-treatment is an effective method to ensure that fine additives attached to the larger iron particles during the transfer of the powder to the die cavity. As a result, part-to-part chemical consistency and in turn, dimensional stability are improved. The benefit of using both fine additives and the binder-treatment on the dimensional stability of thin rings made with a pre-alloyed Mo steel powders admixed with Ni, Cu and graphite is given in Figure 7. Rings were 5.25 cm OD, 4.31 cm ID and 1.27 cm thick. The dimensional variation reported here is the difference in dimensional change between the top and the bottom of the ring. It can be seen that using very fine copper and graphite grades resulted in a significant drop in dimensional variation. The variation from one part to another was also reduced with the extra fine copper and graphite grades.

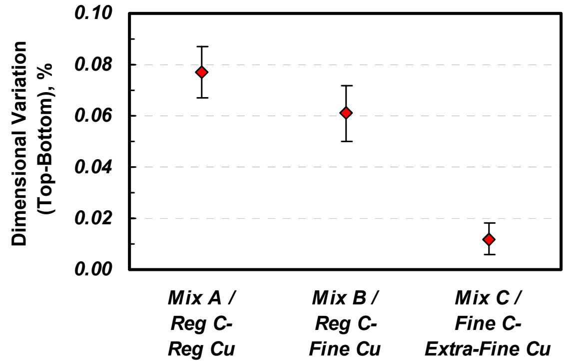

Figure 7. Dimensional variation between the top and the bottom of rings made of FLN4-4405 mixes with 4%Ni, 2.6%Cu and 0.5%C.

COMPACTION AND GREEN PROPERTIES

The primary objective of using binder-treatment is to improve flow and reduce dusting and segregation. Nevertheless, the compaction characteristics and green strength of a mix are always major concerns for PM part producers, especially for complex, high aspect ratio and high-density parts. Therefore, in order to maintain excellent compressibility and ejection properties, it is crucial to use binders with very good lubricity characteristics and that do not compromise lubrication. Figure 8 shows the compacting pressure and green strength obtained at 7.0 g/cm³ for ATOMET4401 based mixes, a pre-alloyed Mo steel powder. An addition of 0.65% EBS wax was used in all cases. Compaction was done at 60°C, which is more representative of production conditions. It can be seen that the compacting pressure was slightly lower for the binder-treated mix, despite the fact that the total amount of organics is higher in this mix. Green strength is also higher for the binder-treated mix. The gain in green strength was about 20% at 7.0 g/cm³.

Figure 9 shows the ejection curves for the same mixes. Ejection was determined with an instrumented laboratory press called Powder Testing Center, model PTC-03DT. Cylindrical specimens 9.525 mm in diameter and 10 mm in height were pressed at 60°C and 620 MPa. It is seen that the ejection performance was improved with the binder-treated material. Indeed, even if the stripping pressure remained almost unchanged, the ejection energy, which corresponds to the area under the curves, was reduced by 10% with the binder-treated materials. It should be noted that the green density achieved with the binder-treated materials was 0.04 g/cm³ higher, confirming the results shown in Figure 8.

As mentioned earlier, binder-treatment is a very effective platform for development of high performance materials. Figure 10 shows the compaction and ejection performance of FN0205

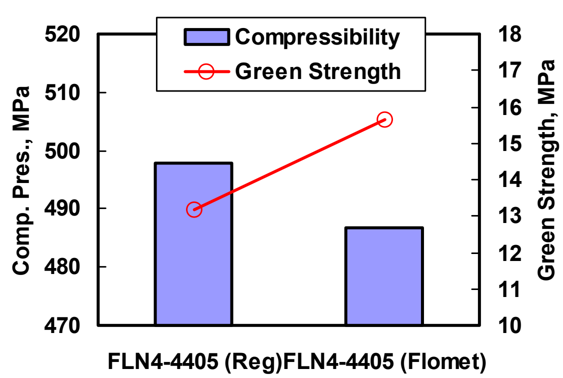

Figure 8. Compacting pressure and green strength at 7.0 g/cm³ for FLN4-4405-1.5% Cu mixes with 0.65% EBS wax. Specimens pressed at 60°C.

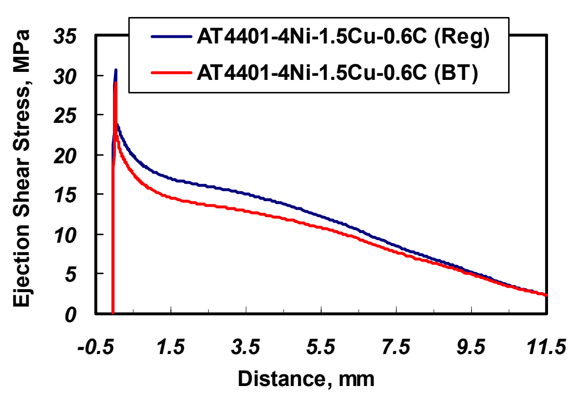

Figure 9. Ejection curves for FLN4-4405-1.5% Cu mixes with 0.65% EBS wax. AT4401 refers to ATOMET 4401 (0.85%Mo steel powder).

mixes containing a lubricant-binder system currently under development for high density applications. Compaction was done in the PTC at 60°C and 840 MPa. It can be seen that green density and ejection energy achieved with this new organic system are respectively 0.10 to 0.14 g/cm³ higher and 18 to 30% lower than those of a mix with 0.75% EBS wax. Such an organic system can give densities of 7.40 g/cm³ or higher, when its content is reduced and the die wall lubrication technique is used.

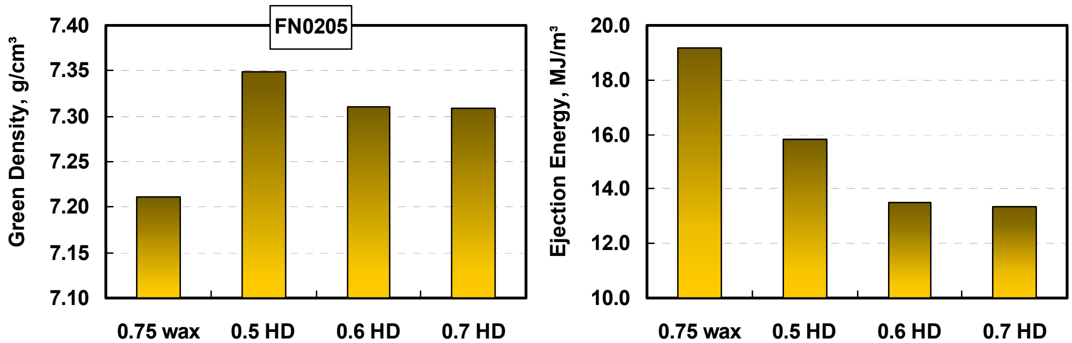

Figure 10. Performance of a new lubricant-binder system under development for high density applications. a) Green density b) Ejection energy (FN0205 mixes pressed at 60°C and 840 Mpa)

CONCLUSIONS

- Binder-treatment is a very effective method to bond fine additives to the larger iron particles.
- The thin binder film is sufficiently strong to significantly reduce the dusting produced during powder handling or powder transfer to the die cavity. For example, the amount of dust produced during powder transfer is ~ 4 times lower with a binder-treated mix.
- Improvement in flow obtained with the binder-treatment technology is typically in the order of 4 to 8 sec/50g.
- Binder-treated materials significantly improve the part weight stability and/or productivity on a production press under difficult filling conditions involving long fill depth and/or gravity fill.
- For example, the part weight variation was reduced by at least 20% and productivity was increased by 28% with binder-treated materials, when producing small parts in actual production conditions.
- New lubricant-binder systems currently under development achieve a density of 7.30 g/cm³ or higher with much superior ejection characteristics compared to EBS waxes.

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