

CONTINUING IMPROVEMENTS IN BINDER TREATMENT TECHNOLOGY

F. J. Semel and S. H. Luk
Hoeganaes Corporation
Riverton, New Jersey 08077

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ABSTRACT

The binder-lubricant concept in which the binder acts to lubricate as well as to bond is introduced. The binder treatment effects on premix properties of an ordinary binder versus one with lubricating properties are compared. It is shown that the lubricating binder is superior in terms of its effects on compressibility and die ejection forces. Otherwise, it is shown to be similar to the ordinary binder in suppressing dusting and segregation, and improving powder flow.

INTRODUCTION

Binder-treated mixes became commercially available on a large scale in the United States under the tradename, ANCORBOND™, in 1989 [1,2]. Since then, there have been two major advances on the original technology. One, hereafter referred to as the binder-lubricant technology, was quietly introduced in 1992. The other, the ANCORDERSE™ or warm compaction technology, was introduced in 1994 [3]. The subject of the present paper is the earlier of these two advances, the binder-lubricant technology.

The research that led to the original bonding technology was initiated in 1984 and was developed around the premix requirements of that time. However, by the time of its commercialization and even earlier, it was evident that premix requirements were changing and that changes to the technology would be necessary if it was to remain viable.

The particular difficulty that was foreseen was in the compressibility property. The original technology was designed specifically to accommodate green densities of up to 6.9 g/cm³ without significant loss of compressibility compared with the unbonded condition. However, even as early as 1987, there were two industry trends that suggested that this circumstance would not be adequate for future needs. One was the willingness of P/M fabricators to quote on parts of yet higher and higher sintered density. The other was a slow but steady drift towards the use of mixes of higher admixed alloy content. The latter was potentially problematical because it indicated the necessity for increased

binder contents. The difficulty, of course, being that increased organic contents of any kind generally lead to lower compressibilities.

Research to deal with what were seen as the potential shortfalls of the original technology was initiated in 1988. The specific aim was to modify the technology to accommodate density requirements of up to 7.1 g/cm^3 as well as mixes of higher admixed alloy contents. At the same time, it was considered essential to retain the principal benefits of the original technology in terms of reduced dusting and segregation, and improved powder flowrate characteristics [4].

The Binder-Lubricant Concept

The research that was subsequently conducted with the indicated objectives started from a simple idea. This was to reduce the lubricant content by the amount of the binder addition. Pore-free density calculations had suggested that, depending on the amount of the binder addition, this could result in density increases of as much as 0.10 g/cm^3 versus the usual method of simply adding the binder in addition to the lubricant. In due course, preliminary studies showed that such increases were indeed attainable. However, the studies also showed that there were serious drawbacks as well. These included attendant increases in the die ejection forces and eventual, if not immediate, crazing of the part surfaces. In the worse cases, the increase in the ejection forces was roughly in proportion to the decrease in the lubricant addition. In other words, if the decrease in the lubricant was 20%, the resultant increase in the ejection forces correspondingly was about 20%.

It was evident from these findings that the action of the binder in these cases was essentially limited to bonding. It was evident also that what was needed was a binder that acted to lubricate as well as to bond. Since most binders and lubricants are polymeric in nature and exhibit many of the same structural characteristics, it seemed reasonable to expect that such a material existed.

The experimental approach that was subsequently pursued was mainly empirical but not entirely so. During the development of the original technology, there was one material, in particular, that had displayed both bonding and lubricating effects. For reasons that need not be elaborated here, this material was eventually eliminated from the earlier development. However, it now seemed like a good starting point for the present study.

As it turned out, this was a good choice. The first binder-lubricant to be discovered was a member of the same polymeric

family. Subsequently, several other binder-lubricants were found by using this material as a molecular model.

Significantly, many of these materials contributed a lubricating effect that was beyond the effect of the ordinary lubricant that they replaced. There were two notable effects in this regard. One was that the density increases that were observed were greater than what were explainable on the basis of the attendant decreases in the total organic contents. The other was that the die ejection forces were lowered compared with what they would be with an ordinary lubricant.

The purpose of the present paper is to report selected findings that exemplify these effects. The results of a relatively simple study of one of the most interesting of the several binder-lubricants that were discovered will be presented. Basically, the study indicates the property improvements that are obtainable with this material as compared with the original bonding technology and the unbonded condition. The premix employed in the study was a copper-nickel-graphite composition of relatively high alloy content.

EXPERIMENTAL PROCEDURE

The entire study is based on comparisons between four mixes. The general procedure employed was to prepare the mixes and to determine their powder, green and sintered properties under similar conditions. The major differences from mix to mix were essentially compositional in nature and had to do with the binder and the regular lubricant additions. These details are best left to the presentation of the findings. In all other respects, the procedure was as follows.

All of the mixes were made from the same lot of iron powder (Ancorsteel 1000) and were lubricated with additions from the same lot of Lonza Acrawax C. The graphite used in the mixes was from Asbury Graphite Mills and had a mean particle size in the range of 4 to 6 micrometers. The copper used was Alcan 301 with a mean particle size in the range of 20 to 25 micrometers. The nickel used was Inco 123 with a mean particle size in the range of 10 to 14 micrometers. The average mix weight was 2 kilograms and mixing was by dry mixing for 30 minutes using standard bottle mixing equipment. The mixes that were designated for binder treatment were bonded after dry mixing according to procedures that have been described elsewhere [5].

The finished mixes were tested initially for apparent density, Hall flow and dusting resistance. The dusting tests included determinations for each alloying ingredient present

Green density and green strength determinations were conducted next using standard transverse rupture bars. Three different compaction procedures were used in preparing the specimens. The aim was to obtain data that would be applicable to presenting as complete a characterization of the compaction behavior of the mixes as was reasonably possible.

In one procedure, the mixes were compacted to a common density of 6.9 g/cm^3 . In this case, the aim was to determine the effects of the various mix differences on the compaction pressure required to attain this density. These specimens also were later used to determine the sintered properties of the mixes. Sintering was at 2050°C for 30 minutes at temperature in synthetic DA. Besides the sintered properties, these determinations included chemical analyses for each admixed alloy present and for the sintered oxygen content.

In the second compaction procedure used, the mixes were each compacted at a common pressure of 550 MPa (40 tsi). In this case, the aim was to determine the effects of the mix differences on the die ejection forces as well as on the green density and green strength properties. Two values related to the ejection forces were measured. One, called the stripping pressure, is a measure of the static friction that must be overcome to initiate the ejection process. It is calculated as the quotient of the load needed to start ejection over the total cross-sectional area of the part in contact with the die. The other, called the sliding pressure, is a measure of the dynamic friction that must be overcome to continue the ejection process once it is started. It is calculated as the quotient of the average load observed as the part traverses the distance from the point of compaction to the top of the die over the area of the part in contact with the die.

In the third compaction procedure used, each of the mixes was compacted at a series of pressures using tools that were pre-heated to a temperature of $\sim 70^\circ\text{C}$. The pressures used included 415, 550, and 690 MPa (30, 40, and 50 tsi). The aim, in this case, was to determine the effects of the mix differences under conditions that were more like those met in actual practice. The use of 70°C , in particular, was based on studies that indicated it to be typical of the temperatures that arise from frictional heating under normal production conditions. For example, the steady state values that were observed in the studies were ordinarily upwards of 60°C but, given reasonable operating conditions, seldom exceeded 80°C .

RESULTS AND DISCUSSION

The nominal admix alloy contents of the four mixes that composed the study were 1 w/o graphite, 2 w/o copper and 2 w/o nickel.

Otherwise, the mixes were each made with various lubricant and binder contents and different binder types as indicated in the following table.

Table I: Lubricant and Binder Contents and Binder Types by Mix

Mix Number	Acrawax C w/o	Binder	
		w/o	Type
1	1.00	--	--
2	1.00	0.25	Simple
3	0.75	0.25	Simple
4	0.75	0.25	Lubricating

Mix 1 in the table represents the unbonded condition. Mixes 2, 3, and 4 are all bonded. Mixes 2 and 3 represent the original bonding technology. The difference between the two is that the lubricant in Mix 3 has been reduced by the amount of the binder addition. Notice that the binder type in both of these mixes is listed as 'simple'. This designation is given to underscore the fact that this particular binder does little more than bond. Finally, Mix 4 represents the binder-lubricant technology. Here again, the lubricant has been reduced by the amount of the binder addition.

The powder, green and sintered properties of the mixes are presented in Table II. A brief review of these data will serve to indicate both the problem facing the original bonding technology and the solution represented by the use of binder-lubricants.

Table II: Properties of Copper-Nickel-Graphite Mixes

Property	Mix Number			
	1	2	3	4
Powder Properties				
Dust Resistance (%)				
Graphite	16	98	97	96
Copper	29	98	96	93
Nickel	20	96	89	96
Apparent Density (g/cm ³)	3.03	31.0	3.14	3.15
Hall Flow (sec/S0g)	No Flow	25.8	24.7	25.3
Green Properties @ 6.9 g/cm³				
Compacting Pressure (MPa)	515	633	574	516
Dimensional Change vs Die (%)	0.24	0.27	0.26	0.22
Sintered Properties @ 6.9 g/cm³				
Dimensional Change vs Die (%)	0.18	0.19	.019	0.16
Sintered Density (g/cm ³)	6.82	6.82	6.81	6.81
Transverse Rupture Strength (M Pa)	1195	1144	1180	1185

Apparent Hardness (HRB)	88	86	85	87
Sintered Chemistries				
Carbon (w/o)	0.94	0.92	0.93	0.95
Copper (w/o)	20.3	2.05	2.02	2.06
Nickel (w/o)	1.99	2.00	1.97	1.99
Oxygen (w/o)	0.05	0.05	0.05	0.05

Compaction to 6.9 g/cm³

The data in the Green Properties section of the table showing the pressures required to achieve the 6.9 g/cm³ density level provide a capsule view of the situation. Accordingly, the pressure indicated for Mix 2, representing bonding with a simple binder, is substantially higher than that of Mix 1, the unbonded condition. As indicated by the pressure shown for Mix 3, reducing the regular lubricant content in this case by the amount of the binder was helpful but not entirely satisfactory. Only in the case of Mix 4, the binder lubricant mix, is there reasonable parity between the pressures required for the bonded and unbonded conditions.

The balance of the data in Table II is of interest to indicate that the binder-lubricant technology is basically equivalent to the original technology in other respects. The data in the Powder Properties section show that the particular binder-lubricant used in this study effected essentially the same improvements in dusting resistance and powder flowrate as are indicated for the simple binder. Similarly, the data in the Sintered Properties section show that there was little, if any, effect of the new binder on the sintered properties and chemistries.

Compaction to 550 MPa

The properties resulting from compaction of the mixes to a common pressure of 550 MPa, (40 tsi), are shown in Table III. In addition to density and green strength, these determinations also included measurements of the attendant ejection forces. As a point of reference, the tools in this study were at ambient temperature, ~20°C (i.e. laboratory temperature).

Table III: Compaction at Ambient Temperature

Properties	Mix Number			
	1	2	3	4
Pressure @ 550 MPa & Tools @ ~20°C				
Green Density (g/cm ³)	6.93	6.82	6.88	6.93
Green Strength (MPa)	8.3	7.8	8.0	10.3
Stripping Pressure (MPa)	16.8	16.4	18.4	14.0
Sliding Pressure (MPa)	12.4	12.6	13.0	8.7

The density data in Table III show essentially the same trend as the pressure data in Table II. Compared with the unbonded condition, the compressibility was decreased by the use of the simple binder and returned to parity by the binder-lubricant. Interestingly, the green strength data show somewhat the same trend. However, in this case, the decreases associated with the simple binder are relatively smaller and the increase with the binder-lubricant, unexpectedly much larger. Accordingly, the green strength shown for the binder-lubricant mix in the table is about 20% greater than that of the unbonded mix.

The ejection force data in the table show yet another trend. In the case of the simple binder, Mix 2 exhibited about the same ejection forces as the unbonded mix. Recall that each of these mixes had the same lubricant content. In comparison, Mix 3, with a reduced lubricant content, showed somewhat higher forces. The increases in this case were less proportionately than the decrease in the lubricant content but nevertheless were significant. In contrast, the binder-lubricant mix exhibited the lowest ejection forces. Compared with the unbonded mix, the stripping pressure was ~15% lower and the sliding pressure, ~30% lower. Recall also that this mix had a reduced lubricant content. Thus, not only did the binder in this case act to lubricate but apparently it was much better in this respect than the regular lubricant that it replaced.

Compaction at an Elevated Temperature

The properties resulting from compaction of the mixes at various pressures using preheated tools at about 70°C are shown in Table IV. The pressures used included 415, 550 and 690 MPa, (30, 40, and 50 tsi). The properties determined were the same as in the previous study.

Table IV: Compaction at Elevated Temperatures

Properties	Mix Number			
	1	2	3	4
Pressure @ 415 MPa & Tools @ ~70°C				
Green Density (g/cm ³)	6.77	6.73	6.75	6.78
Green Strength (MPa)	7.9	14.6	15.3	11.3
Stripping Pressure (MPa)	16.5	16.0	18.3	15.9
Sliding Pressure (MPa)	11.4	11.5	11.9	11.7
Pressure @ 550 MPa & Tools @ ~70°C				
Green Density (g/cm ³)	6.97	6.89	6.94	7.01
Green Strength (MPa)	10.4	14.9	16.9	13.7
Stripping Pressure (MPa)	17.6	16.9	18.8	17.0
Sliding Pressure (MPa)	12.4	11.9	14.5	10.6

Pressure @ 690 MPa & Tools @ ~70°C					
Green Density	(g/cm ³)	7.06	6.99	7.05	7.11
Green Strength	(MPa)	10.6	15.6	17.4	12.6
Stripping Pressure	(MPa)	18.4	17.7	19.5	16.5
Sliding Pressure	(MPa)	13.5	11.6	16.9	8.5

Effects of the Temperature Increase

The data in Table IV corresponding to compaction at 550 MPa initially were compared to those in Table III to indicate the effects of temperature on properties. As a review of the data will show, the main effect of the temperature increase was to increase each of the four properties listed.

The density increases with temperature were of primary interest. Significantly, the greatest relative improvement in this regard was in the binder-lubricant mix. The upshot was that the density of the binder-lubricant mix now exceeded that of the unbonded mix. Moreover, as a cursory review of the balance of the data in Table IV will show, this also was true at each of the other pressures listed.

The increases in green strength with temperature also were significant. Unexpectedly, the greatest relative increases in this case were in the simple binder mixes. As inspection of the appropriate data in the two tables will show, the values resulting from compaction at the elevated temperature were roughly twice those indicated for compaction at ambient temperature.

The green strength increases of the binder-lubricant mix also were substantial. Although not as great as for the simple binder mixes, they were, in any case, greater than those of the unbonded mix. Thus, the binder-lubricant mix continued to exhibit the greater green strength of the two.

Finally, of all of the effects of compaction temperature, the increases in the ejection forces were, perhaps, the most curious. With the exception of the binder-lubricant mix, they were all rather smaller than expected; averaging less than about 5%. In comparison, the increases in the binder-lubricant mix were slightly upwards of 20%. Yet, the binder-lubricant mix still indicated the lowest overall values. For example, compared with the unbonded mix, its stripping value was a little less than 5% lower while the corresponding sliding value was well over 10% lower.

Effects of the Increases in Pressure

The responses of the mixes to the pressure increases generally were the expected ones. Each of the listed properties increased with increasing pressure. However, there was one exception. This was in the binder-lubricant mix. Amazingly, the ejection forces in this case decreased with increasing pressure. Thus, as reference to the data will show, at the highest pressure, the binder-lubricant mix exhibited just about the lowest ejection force values listed in the entire table. As a matter of general interest, not all binder-lubricants exhibit this particular behavior.

In other respects, the trends in the mix to mix variations in the data were similar at each pressure level. The binder-lubricant mix exhibited higher densities, green strengths and lower ejection forces than the unbonded mix. Except for green strength, it was superior to both of the simple binder mixes as well. The simple binder mixes, on the other hand, exhibited the highest green strengths overall. Otherwise, generally they were less compressible than the unbonded mix. Interestingly, the compressibility of Mix 3 with the reduced lubricant content approached that of the unbonded mix at the highest pressure. However, both at this pressure and otherwise, Mix 3 exhibited the highest ejection forces overall. For example, compared with Mixes 1 and 2, the average stripping pressure of the mix was ~10% higher and the average sliding pressure, almost 25% higher. Thus, as indicated at the outset, the percentage increase in the ejection forces in this case approached the percentage decrease in the lubricant content.

Application Of The Findings - The Binder-Lubricant Technology

As is evident from the findings, binder-lubricants clearly offered the possibility to extend the range of applicability of the original bonding technology. In addition, they offered the opportunity to improve upon it. Consequently, the technology that eventually was commercialized incorporated both of these enhancements.

The current technology is applicable to premixes of higher alloy content and to densities up to 7.1 g/cm^3 . The resulting mixes continue to display the benefits of the original technology in terms of reduced dusting and segregation, and improved powder flow characteristics. In addition, compared with the unbonded condition, they exhibit significantly higher green strengths and, given normal pressing conditions, equivalent to higher compressibilities. As a practical matter, knowledge of the prospective part geometry and green density is essential to provide the optimum that the technology has to offer. This is especially true in the case of compressibility.

SUMMARY AND CONCLUSIONS

Compared with the unbonded condition, the original bonding technology mainly offered improvements in dusting resistance and powder flow. Otherwise, it was limited by compressibility constraints to densities under 6.9 g/cm^3 and to premixes of low to moderate alloy content. Industry trends suggested the need to extend the technology to higher densities, specifically to the 7.1 g/cm^3 level, and to premixes of higher alloy content. Thus, research with this objective was undertaken.

The principal indication of the findings of this research was that the use of binders that act to lubricate as well as to bond offered the possibility to improve the original technology as well as to extend it. Subsequent application of these findings culminated in the binder-lubricant technology just described.

The research that produced these results was conducted prior to 1992. In fact, many of the findings indicated here were already available as early as 1989. Apart from their applicability to solve the problems that were foreseen for the original bonding technology, they also had implications that went well beyond this particular objective. It was as a consequence of this that it was considered prudent to withhold them until now. There were two such findings in particular. Each is discussed briefly below.

One of the indicated findings was the effect of increased compaction temperatures to increase density. H. G. Rutz had independently observed this effect in regular mixes. Subsequently, Rutz and S. H. Luk collaborated to investigate the effect in binder treated mixes [6]. The upshot, of course, was the warm compaction technology.

The other finding of interest was the significant increases in green strength that were observed. These and similar increases with other binders that were under study were strongly indicative of potential new benefits. Upon completion of the subject research, one of the present authors, S. H. Luk, went on to investigate these possibilities. A number of new applications now appear to be on the horizon. One such use is the topic of another of the current presentations [7].

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