PROPERTIES OF PARTS MADE FROM AN ANCORBOND® PROCESSED CARBON-NICKEL-STEEL POWDER MIX (FN-02O8)

F. J. Semel

Hoeganaes Corporation
River Road & Taylors Lane
Riverton, NJ 08077

Presented at the Annual Powder Metallurgy Conference,
San Diego, California, June 11-14, 1989

ABSTRACT

Studies were conducted to determine the effects on property variability of parts made from a bonded Ancorsteel 1000 mix containing 0.95% graphite, 2.0% nickel, 0.6% Acrawax and 0.3% zinc stearate. The part geometry studied was that of a cylindrical bushing. The treatment effects on powder properties and on several parts properties were determined. The powder properties included the traditional green and sintered properties and the graphite and nickel dusting resistance's. The parts properties surveyed included both green and sintered properties and sintered carbon and nickel contents. Similar studies of a companion regular mix of nominally the same composition were conducted for purposes of comparison.

Compared with the regular mix, the bonded mix exhibited marked improvements in graphite and nickel dusting resistance and in powder flow properties. In the parts-making study, the bonded mix showed significant differences in mean dimensional change characteristics but was otherwise reasonably similar to the regular mix in terms of mean property values. In the case of variability, the bonded mix was statistically equivalent in green and sintered dimensional change characteristics and sintered nickel content but otherwise significantly improved relative to the regular mix in all of the other properties of interest. The latter included green weight and density and sintered density, hardness, crush strength and carbon content.

The variability improvements in the parts from the bonded mix were attributed both to the effects of the binder treatment in improving powder flow properties and reducing carbon segregation. The difference in mean dimensional change characteristics between the parts from the bonded mix and those from the regular mix were also attributed to the effect of the binder treatment in improving alloy admix uniformity.

The fact that the parts variability improvements of the bonded mix did not extend to the dimensional change characteristics was suspected to be due largely to a purely statistical effect arising from the dissimilarity in the mean dimensional change values relative to those of the regular mix. A limited laboratory-scale study was subsequently conducted to examine this possibility. In general, the findings supported the idea. In addition, they also presented a strong indication that it may be possible by virtue of the ANCORBOND process to effect significant reductions in the nickel contents of graphite-nickel mixes without sacrificing either mechanical

properties or dimensional change characteristics.

INTRODUCTION

The ANCORBOND process is a proprietary method of making premixes. It differs from regular premixing to the extent that it includes a special binder treatment step. The aim of the step is to preserve premix uniformity against the natural tendency to demix during handling in subsequent processing. Full-scale production of premixes made according to the process is presently being implemented at a newly constructed facility located in Milton, PA. Truckload size quantities according to the conventional method of premixing are also available from this facility.

The properties of premixes made by the ANCORBOND process differ from those of conventional premixes in two important respects: (1) bonded mixes typically exhibit substantially increased resistance to compositional variations arising either by alloy particle migration within the mix or by dusting from the mix; and, (2) they also exhibit a much more uniform or lamellar flow behavior which is very frequently accompanied by substantially increased rates of flow. The first effect is thought to be primarily attributable to the fine agglomeration, which attends the binder treatment step of the process. Agglomeration also contributes to the second effect but other factors are known to be involved as well, including especially the composition of the mix and the physical properties of the particular admix ingredients, which are selected to make it.

Ultimately, the objective of the ANCORBOND development was to enhance premix performance in the parts-making process. Thus, pursuant to the development of the process, a very extensive program of study was undertaken to examine these effects. The studies were carefully planned with several aims in mind. The priority aim, of course, was to verify the anticipated benefits in parts making. However, beyond this, the intent was also to (1) develop an understanding of the underlying mechanisms involved, (2) create a data base of information applicable to commercialization of the process, and (3) indicate areas requiring additional research of the technology and/or directions offering potential for yet further improvement.

The indicated program of study included both laboratory-scale trials as well as much larger pre-production trials. Both types of study have provided useful knowledge but the laboratory trials have been the most useful from the standpoint of achieving the foregoing aims. This part of the program was composed of individual but similar parts-making studies of the four most commonly ordered premix compositions. These included iron/graphite as F-O008, iron/graphite/copper as FC-0208, iron/graphite/nickel as FN-0208 and iron/ ferrophosphorus as Ancorsteel 45P. With the exception of the FN-0208 study, which forms the basis of the present report, the results of the other studies have all been reported in the open literature (1, 2, and 3).

As a general matter, these studies have shown that bonded mixes are effective in reducing the variability of the process-sensitive properties in parts making. Typically, in the studies so far reported, the reductions have occurred over several properties and while the findings from study to study have not been the same, there has nevertheless been a clear cut pattern of similitude among them. For example, all of the studies have shown variability improvements in sintered strength and dimensional change and in two cases out of three, variability improvements in sintered

density, hardness and alloy content. In addition, these improvements have been accompanied in all cases by only minor changes in the corresponding mean values of the affected properties. Thus, the general thrust of the studies has been to suggest that the ANCORBOND process is broadly applicable to improve variability without the necessity to modify the premix and thus to be immediately useful on a large scale.

The pre-production trials mentioned also showed variability improvements with ANCORBOND but only in those studies, which were conducted under the auspices of an appropriate statistical design. More generally, the pre-production trials have shown the existence of other benefits which are also important and which, from a practical standpoint, are probably of even wider applicability. These particular benefits were especially manifest in the pressing operation and depending on the application included one or more of the following: (1) increased pressing rates; (2) greater reliability of satisfactory pressing characteristics on a batch to batch basis; and, (3) greater operator acceptance and less housekeeping due to reduced dusting.

The indications of the studies as to the mechanisms underlying the observed variability reductions of bonded mixes were that they were due in part to their greater resistance to segregation and dusting during parts making {1,2) and in part to the improved uniformity of powder flow characteristics {3). The favorable response in terms of press performance, which was noted, was generally attributable to the latter improvements, of course, but also in many cases, especially to the very substantial increases in flow rate which typically accompany bonding.

The results of the FN-0208 study of present interest were largely in agreement with the foregoing but yet broke the indicated pattern of similitude of the earlier studies in two ways. First, in spite of substantial variability improvements in several properties, the dimensional change characteristics of the parts of the bonded mix failed to show such improvements and, second, the corresponding mean values of these properties differed significantly from those of the parts of the companion regular mix. Of course, each of these findings was important but, as a practical matter, the second was, perhaps, the more important of the two. In particular, it strongly indicated the need for additional research of bonding effects on dimensional change in the FN-0208 composition.

As a general matter, it has often been noted in studies of processes involving dimensional change that the amount of size variation present at a particular point of the process is apt to be proportional to the mean size at that point (4, 5). Thus, it seemed reasonable that the foregoing findings could be interrelated and more importantly, that success in eliminating the adverse size effects that were observed might also result in a simultaneous restoration of the missing variability improvements. In addition, as is well known, size change in nickel mixes is sensitive to nickel content.(6) Consequently, a study to explore the relation of size change to size change variation via changes in nickel content seemed a good point to initiate the additional research.

The purpose of the present report is to present the results of this study and of those of the original parts-making study which led to it.

EXPERIMENTAL PROCEDURE

Parts-Making Studies

The experimental procedure employed in the parts-making studies was essentially the same as that used in the earlier reported studies. Other than certain differences in pressing, the details were the same as those reported in connection with the Ancorsteel 45P-study (3). The basics of the procedure along with the indicated pressing differences are briefly outlined below.

The general scheme employed was to process a bonded mix and a regular mix of the same composition under nominally the same condition and compare the variability in properties of the resulting parts. The part geometry was that of a cylindrical bushing with inside and outside diameters of 1.0 and 1.5 inches, respectively. The effects on four green properties and seven sintered properties were determined. The green properties included green weight and density and the I.D. and O.D. dimensional changes. The sintered properties also included density and the I.D. and O.D. size changes along with hardness, crush strength and the final carbon and nickel contents. The nominal composition of the mixes was 0.95% graphite, 2.0% nickel, 0.6% Acrawax, 0.3% zinc stearate and the balance Ancorsteel 1000. The average premix size employed in the study was 500 pounds. The regular mix was made in the traditional manner by blending the ingredients in a double cone blender. The bonded mix was made by the ANCHORBOND process.

The mixes were each tested in advance of any actual parts making as a quality control measure. The tests included determinations of the traditional powder, green and sintered properties as well as of the graphite and nickel dusting resistance properties. The particulars of the dusting resistance test and the apparatus used to conduct it have been reported elsewhere (3).

In the parts-making portion of the study, the processing was carried out using regular P/M production equipment. In the pressing step, the work was done on a Dorst TPA-180 press. The mixes were automatically charged to the press hopper in a single operation using a screw feeder equipped with a hydraulic drum dumper. The aim density and height were 6.8 g/cm^3 and 1.6 inches, respectively. The total number of parts compacted was upwards of 800 for each of the two mixes composing the study. This number was important in that it affected the choice of the parts eventually selected to represent the mixes in the balance of the processing.

As previously mentioned, a somewhat different set of pressing conditions had been used in the Ancorsteel 45P study which was referenced as otherwise being indicative of the procedural details of the present work (3). Briefly, these conditions were as follows. First, the compaction was done on a Dorst TPA-50 press. Second, the mixes were manually charged to the press hopper in 100-pound increments using a special charging funnel, which had the objective to produce reasonably the same charging conditions from increment to increment. Third, although the aim density was the same as in the present study, the aim height was 2.0 inches rather than 1.5. And finally, the choice of the parts eventually selected to represent the mixes subsequent to pressing was arbitrarily restricted to the product of one of the aforementioned 100-pound increments. Thus, the number of parts of the two mixes ultimately composing

the study was only about 200 in each case.

The sintering step of the present study as in all of the earlier studies was carried out in a 10" P/M belt-type furnace. The hot zone conditions were nominally 2050'F for 30 minutes at temperature. The atmosphere was dissociated ammonia treated with sufficient methane to maintain a carbon potential consistent with carbon equilibrium, (i.e. neither carburizing nor decar-burizing. In the present case, this was in the neighborhood of 0.85% carbon.

A total of 48 parts each was selected to represent the product of the two mixes in the sintering step. Since the parts had been packed out in sequence subsequent to pressing, the selection was made in accordance with the order of pressing. For each mix, it was composed of six groups of eight consecutive parts each. The groups were evenly spaced over the entire product of the two mixes and the spacing was identical in both cases.

Highly specialized arrangements of the parts were employed in the sintering step both to maintain similarity of treatment of the two mixes as well as to implement an Analysis of Variance of the findings, cf.-(3). The objective of the ANOVA was to enable an assessment of the relative contributions of testing, processing and segregation. The particular experimental design employed was of the hierarchical or so-called nested type of ANOVA (7). Other than testing, up to five variance sources were defined depending upon the particular property of interest.

For the purposes of the present report, it will be sufficient to limit the discussion of the ANOVA findings to those indicating alloy effects and, in this case, to only two of the several components that were actually examined. These are the microsegregation and macrosegregation components. Within the context of the analysis, microsegregation was defined in terms of alloy variations within the parts and macrosegregation in terms of alloy variations among the various part groups selected to represent the mix. The alloy content of a group in this scheme was taken as the average of the alloy contents of the eight parts comprising the group.

Nickel Effects on Dimensional Change and Dimensional Change Variability

The study to investigate the effects of Nickel content on size change versus size change variability was limited to laboratory processing and equipment. Five bench-size mixes were prepared according to the ANCORBOND process. The mixes differed in nickel content but were otherwise the same in admix composition each containing 0.9% graphite, 0.6% Acrawax and 0.3% zinc stearate. The base powder was Ancorsteel 1000. The nickel contents are listed in Table I below. As will be evident from a cursory examination of the table, four of the five-nickel contents shown fall within the FN-0208 specification range.

The procedure to determine the size change of the mixes consisted of comparing the sintered properties of 40 standard transverse rupture bars in each case. The bars were initially pressed to a green density of $6.80 \pm 0.01 g/cm^3$ and subsequently sintered at 2050'F in dissociated ammonia for nominally 30 minutes at temperature. The sintering was carried out continuously in a 3" P/M-type belt furnace. The bars

were charged to the furnace in 40 boats, each boat containing one bar of each of the five mixes. In order to avoid position effects within the boats, the bars of the various mixes were systemically rotated with respect to position from boat to boat.

TABLE 1: Nickel Contents of the Mixes in the Size Change Study

Mix Identity	% Ni
A	0.5
B	1.0
C	1.5
D	2.0
E	2.5

In addition to size change, the bars were tested for hardness and transverse rupture strength and spot checked for carbon content. The resulting data were submitted to standard methods of statistical analysis and correlation techniques (8).

RESULTS AND DISCUSSION

Preliminary QC Results

The results of the preliminary QC tests on the two mixes of the parts-making study are shown in Table II. A review of these findings will show that the two mixes differed mainly in green properties. Based on experience to date, the findings in this respect are typical of the general effects of bonding versus conventional mixing. Ordinarily with green properties, the largest changes on a percentage basis normally occur in flow rate and dusting resistance and without exception always favor the bonded mix. Thus, in the present case, the flow rate improvement shown by the data for the bonded mix is upwards of 22% and the graphite and nickel dusting resistance improvements are both well in excess of 150%. As will become apparent in what follows the effects of these improvements on parts making were clearly evident in the results.

In contrast with the green properties, the sintered properties of the two mixes as indicated in the table appeared to be virtually identical. However, a closer inspection of the data will show that there were in fact significant differences between the two in dimensional change values. These differences are not immediately apparent because in accordance with common practice, the values are stated "versus the die" which in this particular case is misleading. For example, had the values been stated "versus the green size" instead, they would have indicated a 20 to 25% greater shrinkage in favor of the bonded mix. As will be seen, it turned out that this difference was a rather significant one.

Results of the Parts-Making Study

The Grand Statistical Results of the study are presented in Table III. The first four columns of the table list the means and standard deviation values of two green properties and seven sintered properties of the parts made from each mix. The standard deviation values are presented instead of the corresponding variance values because they have the same units of measurement as the associated mean values and

are thus more readily understandable. The fifth column of the table lists the answer to the question: Is the variability estimate of the mix which exhibited the numerically larger value of the two, i.e. S2~, statistically significantly larger than that of the companion mix, i.e. S2s? A YES answer indicates that the data were conclusive in this regard at the 95% confidence level. A NO answer, on the other hand, simply means that the data were inconclusive. The sixth column of the table indicates the percent improvement of the less variable mix over the companion mix in terms of the corresponding standard deviation values for those cases where the variance differences between the two were found to be statistically significant.

A cursory review of the data in Table III will show that the parts made from the two mixes exhibited significant differences, both in variability and mean property values. For purposes of discussion, it will simplify matters to treat the two separately and, in particular, to discuss the variability differences first, and to return to the mean property differences later.

The Variability Results

The data in Table III show that the bonded mix exhibited statistically significant improvements in variability in six of the nine properties listed. These included green weight and density and sintered density, crush strength, hardness and sintered carbon content. In the three remaining properties, the data showed little or no difference in variability between the two mixes. These three included the sintered dimensional change properties and the sintered nickel content.

In terms of the standard deviation values, the greatest improvement in the bonded mix was in the sintered carbon content and the least improvement was in the Rockwell hardness. The corresponding values were 52.8% and 34.8%, respectively. The overall improvement in the parts of the bonded mix, as averaged over each of the six properties affected, was 43.2%.

As to the causes of the variability improvements, it will be evident that of the present findings both the green property and sintered carbon results correlate directly with the flow rate and graphite dusting resistance improvements which were originally observed in the powder properties of the mixes. Iteratively, since sintered density and hardness are well known to vary in accordance with one or the other or all three of green weight, green density and sintered carbon, it will be evident that the variability improvements in these properties also correlate, albeit indirectly, with the indicated improvements in flow rate and dusting resistance. And finally, as will be shown in a later section, actual correlation showed a similar connection of crush strength to sintered density and carbon content and, thus indicated a similar explanation of the variability improvements in this property as well.

The ANOVA Results

As a general matter, the ANOVA results of the study were consistent with the foregoing and as already mentioned will not be presented in detail. The alloy ANOVA results, however, are of interest to show the contributions of segregation to alloy

variability.

The results of these studies are presented in Table IV. To facilitate interpretation of the data, the variance components of both mixes are indicated in common terms, i.e. as fractions of the corresponding overall regular mix variance in each case. Only those values, which were statistically significant at the 95% confidence level or higher, are reported.

A review of the data in Table IV will show that the analysis recognized two statistically significant contributions to the sintered carbon variations of the regular mix. One was due to the carbon differences found within the individual parts and the other to the differences found between the averages of the various groups. When expressed as 99% statistical tolerance limits, these figures indicate carbon content variations of as much as 0.035% from point to point within the parts and up to 0.05% from group to group.

The data in Table IV also showed that the analysis recognized a small but statistically significant contribution from within part differences in sintered carbon to the parts of the bonded mix. When converted to tolerance limits as in the foregoing this value was found to indicate variations of less than half those indicated for the parts of the regular mix.

In addition, the ANOVA results were also interesting in that they showed effects in nickel variability which were not indicated by the Grand Statistical Results of the study. As is evident in the data in Table IV, the analysis · recognized statistically significant contributions from within part
Differences in nickel to the variability's of both mixes. Here again, the results favored the bonded mix but in this case only modestly so. For example, when converted to 99% statistical tolerance limits the values in the table equate to within part differences in the regular mix of up to 0.16% versus 0.13% for the parts of the bonded mix.

The fact that the improvement in the bonded mix in this regard was not better than indicated was unexpected and thus far remains unexplained. It is suspected, however, that while the true benefit of bonding is to reduce microsegregation, what is being measured and called microsegregation in the present case is in reality a sort of short-range macrosegregation. It is further suspected that this type of segregation does not have a very pronounced effect on properties, which is perhaps fortuitous because bonding is evidently not very effective to suppress it.

The Mean Property Results

Returning to the Grand Statistical Results in Table III, it will be seen that the two mixes differed in mean property values in just about every property listed. In most cases, however, these differences were numerically small and in general would not be considered to be physically significant. Nevertheless, there were four cases in which the differences were exceptional. These included in order of increasing importance from a practical standpoint, sintered carbon, crush strength, and depending on application, either or both of the two dimensional change differences. Each is discussed separately below.

The indicated sintered carbon difference is perhaps the easiest to explain. Even

though the difference is small and possibly attributable to a blending error, experience to date suggests that it is instead a consequence of the improved graphite dusting resistance of the bonded mix. For example, the various pre-production trials mentioned in the introductory remarks have shown similar such differences between bonded and regular mixes time and again. In addition, what is perhaps especially interesting in this case is that the analysis presently to be presented will show this particular difference to be the main cause of the observed crush strength differences.

The existence of crush strength differences similar to the present one have been explained with the aid of statistical correlation techniques in two of the earlier reported studies of this type as being due to corresponding differences in average sintered density (1,3). In the present study, the average sintered densities of the two mixes were almost identical thus eliminating density differences as a possible explanation. However, preliminary correlation's very quickly showed a relation of crush strength to sintered carbon content. Subsequently, in attempting to refine this result, it was found that the best correlation from the standpoint of statistical significance arose when the effects on crush strength of both sintered density and carbon content were simultaneously considered using multiple regression techniques. The correlation, which resulted from this analysis, was as follows:

Eq (1) CS: **$26.4\delta + 129.9\%C - 189.8$;**

Where CS, δ and %C represent crush strength in ksi, sintered density in g/cm^3 and sintered carbon content, respectively. The associated correlation coefficient was 0.905 and the equation was significant at the 99% confidence level.

When crush strength according to this equation is evaluated as a function of the average sintered density and carbon content values listed in Table III, the resulting values for both the bonded and regular mixes are each within 0.5 ksi of the values as actually observed. For example, the calculated values for the two mixes are 99.2 and 95.7 as compared with the observed values of 99.6 and 95.3, respectively. Thus, the crush strength differences between the two mixes were considered to be adequately explained.

In addition, it will be appreciated that the correlation result in Equation (1) also provides direct support for the view as previously stated that the variability improvement in the crush strength of the bonded mix was a direct consequence of the corresponding variability improvements in sintered density and carbon content and indirectly via these properties to the observed flow rate and dusting resistance improvements of the mix.

Finally, of the various mean property differences which were cited as being significant, the dimensional change differences between the mixes were decidedly the most significant from a practical standpoint. For example, as will be evident from the data in Table III, the values for both mixes indicated that the parts had undergone net shrinkage "versus the die" but that the values of the bonded mix were about twice those of the regular mix.

As will be seen, these particular differences were similar to each of the preceding mean property differences in that they were explainable in terms of certain of the other findings of the study. However, prior to discussing these findings, it will be useful to introduce the dimensional change values, which characterized the parts of the mixes prior to sintering. These data are shown in Table V below.

TABLE V: Green Dimensional Change Data

Property	*Mean*	*Std. Dev*	*Mean*	*Std. Dev*
I.D. Dim. Change versus Die (%)	**+0.100**	**0.0046**	**+0.113**	**0.0055**
O.D. Dim. Change versus Die (%)	**+0.186**	**0.0062**	**+0.185**	**0.0058**

As will be evident from a comparison of the values in this table, the parts of the mixes had been reasonably similar in dimensions prior to sintering. Therefore, it will be appreciated that there was no possibility that the differences after sintering were in any way the result of either a difference in the responses of the mixes to the pressing operation or to an inadvertent difference in pressing conditions.

The data in Table V are also useful to assess the sintered differences in terms of the changes "versus the green size". Thus, when combined with the data in Table III, the resulting values for both mixes again indicated that the parts had undergone net shrinkage but in this case the values of the bonded mix were now only about 30% larger than those of the regular mix. As may be recalled, the preliminary Q.C. tests of the mixes had also indicated a similar although slightly smaller dimensional change difference between the two.

In any case, it was thought that the differences were primarily attributable to the greater compositional uniformity of the bonded mix compared with the regular mix and to the effects of the associated microstructural differences between the two on sintering behavior. There were two findings in support of this view. First, in one of the earlier reported studies, it had been shown that dimensional change decreased with increasing compositional uniformity on a particle to particle basis. (1) Second, the present differences correlated directly with the indications of the alloy ANOVA to the effect that there was less microsegregation of both carbon and nickel in the parts of the bonded mix. Thus, the implication was that the bonded mix had been more uniform on a particle to particle basis initially and had responded accordingly.

There was, however, one potential difficulty with the alloy ANOVA findings in these regards. This was that they tended to suggest that the carbon had played a more important role than the nickel in effecting the differences and this may not be true. In fact, there are at least three reasons for doubting it. First, as already indicated, the alloy ANOVA results are not thought to be truly indicative of the microsegregation actually present. Second, bonding of graphite per se has never previously been associated with such large dimensional change differences. And third, in contrast with this, studies of the effects on sintering of parts made from nickel-plated iron powders versus conventional admixtures of iron and nickel showed substantially greater shrinkage in the case of the plated powders (g). Thus, while there seems little doubt that the differences in the present case are due to differences in compositional uniformity, it is also thought that the nickel contribution to the differences may have been considerably greater than suggested by the findings.

Nickel Content versus Size Change versus Size Change Variability

The findings of the size change versus size change variability study are shown in Table VI. The table indicates both the mean and standard deviation values of all the properties listed other than sintered carbon. Only the mean values are listed in this case because the corresponding tests were limited to random spot checks of only 20% of the specimens which otherwise composed the study.

Examination of these data will show that the mean carbon contents of the five mixes were all reasonably the same. Therefore, the property effects shown may be assumed to be predominantly the result of the differences in nickel content. Further review of the data will additionally show that there were differing trends in the means and standard deviation values of the properties. Thus, it will simplify matters somewhat to discuss each separately.

The Mean Value Results

The general trend in the data in this respect was that each of the four sintered properties was affected by the changes in nickel content but the green properties were not. The greatest changes on a percentage basis were in the dimensional change characteristics which more than doubled over the range of nickel contents involved and otherwise decreased with increasing nickel. In comparison, each of the other properties increased with increasing nickel but the changes were in all cases relatively modest. For example, the next largest change was in hardness, which increased by

only 10% over the same range of nickel content. Thus, the general indication of the findings was that while dimensional change was sensitive to nickel, the other properties were not. Therefore, with regard to the question of modifying the mix to effect dimensional change parity, the important implication was that even if large changes in nickel content proved necessary, they almost certainly would not be accompanied by prohibitive changes in other respects.

In order to quantify this result, an estimate was made of the nickel content that would have been necessary to achieve dimensional change parity in the present case. The procedure which was employed to do this made use of the data in Table VI as well as of the dimensional change data from the parts-making study. The indications were that a nickel content of about 1.2-% would have effected the desired size change behavior. In addition, since this would place the composition of the resulting mix just about midway between those of mixes B and C of the present study, the indications were as anticipated above that such a change would not have had a marked effect on the other properties involved (cf-the data in Table VI).

The Standard Deviation Results

A careful review of the data in Table VI will also show that there were only two cases in which the standard deviation values were systemically affected by the changes in the mixes. These were dimensional change and transverse rupture strength. The existence of effects in dimensional change data was expected. However, the effects on the transverse rupture data were not and since subsequent analysis showed them to have no significant bearing on the important issues of the study, they will not be further discussed.

In any case, the finding was significant because it provided a reasonable explanation of the dimensional change variability performance of the bonded mix in this case versus the experience of the earlier reported studies. As will be recalled, the major distinguishing features of the present study versus the earlier ones was the failure of the bonded mix to exhibit either dimensional change parity or variability improvement relative to the regular mix. Evidently, according to the present findings, these two features were interrelated with the larger dimensional change values of the bonded mix being partially or entirely responsible for the missing variability improvements.

In the case of the dimensional change property, correlation of the standard deviation values versus the corresponding mean values showed the existence of a strong statistical association. For example, the correlation coefficient was 0.995 and the resulting equation was statistically significant at the 99% Confidence Level. These findings are indicated in both Figure 1 and the following equation.

Eq {2} **Std. Dev. of %DC = 0.0152 - 0.0353%DC**

It will be appreciated that the existence of this relation makes a fairly strong case for the idea that dimensional change variability is significantly influenced by the magnitude of the corresponding dimensional change value. Unfortunately, however, the relation is not applicable for estimation purposes beyond the precincts of the particular mixes that contributed to its establishment. Consequently, while the

relation has general value to explain certain of the present findings as well as to speculate on future ones, it cannot be used to quantify the explanations and/or predictions.

The foregoing idea also led to the speculation as mentioned in the introductory remarks that success in eliminating the adverse size effects, which were observed, might also result in a simultaneous restoration of the missing variability improvements. Thus, in conclusion, it is of interest to mention that there is presently in progress a parts-making study which was designed specifically to test both this possibility and the earlier speculation regarding the applicability of reduced nickel contents in bonded mixes. Hopefully, it will be possible to present the findings of this study in the near future.

ACKNOWLEDGEMENTS

Special thanks are due to Mr. Eber Reese of Reese Metal Products Corporation, who freely extended both the facilities and personnel at his disposal to assist in the press work for the present studies. The contributions of Messrs. Baron {Bud) Schwalm and Norman Myers of Reese Metal Products Corporation were especially valuable in these regards and are duly appreciated.

REFERENCES

1. "Properties of Parts Made From An ANCORBOND Processed Carbon Steel Powder Mix (F-O008)", F. J. Semel, Modern Developments in Powder Metallurgy, Vol. 21, 1988, pp 101.

2. "Statistical Process Control in Iron Powder Production and New Product Development", F. J. Semel, D. J. Kasputis and P. Ulf Gummeson, SAE Technical Paper No. 880114, International Congress and Exposition, Detroit, MI, 1988.

3. "Properties of Parts Made From A Binder Treated 0.45% Phosphorus Containing Iron powder Blend", F. J. Semel, Progress in Powder Metallurgy, 1987, Vol. 43, Metal Powder Industries Federation, 1987, pp 723.

4. "The Statistical Analysis of Variance - Heterogeneity and The Logarithmic Transformation", Journal of the Royal Statistical Society, Supplement Vol. VIII, No. 1, pp 128-138, 1946.

5. "The Influence of Process Parameters on The Precision of P/M Parts", G. F. Bocchini, Powder Metallurgy, 1985, Vol. 28, No. 3, pp 155.

6. "The Affect of Additions of Copper, Nickel and Graphite on The Sintered Properties of Iron-Base Sintered P/M Parts", C. Durdaller, Progress in Powder Metallurgy 1969, Vol. 25, Metal Powder Industries Federation, pp 71.

7. "Statistics for Experimenters", Box, Hunter & Hunter, John Wiley & Sons, New York, pp 571.

8. "Experimental Statistics", M. G. Natrella, National Bureau of Standards Handbook

91. U.S. Government Printing Office, Washington, D.C., 1966

9. "Sintering Behavior of Fe-Ni Compacts Prepared With Plated Powder", Shiro Kohara and Kiyohiko Tatsuzawa, Journal of Japan Society of Powder Metallurgy, Vol. 31, No. 6, pp 1, 1984.

Table II: Preliminary Test Results of the FN-0208 Mixes Used in the Parts-Making Studies

Property/Component	Bonded Mix	Regular Mix
GREEN PROPERTIES		
Apparent Density (g/cm^3)	3.11	3.04
Hall Flow (sec/50g)	31.0	38.0
Green Density @ 30 TSI (g/cm^3)	6.67	6.70
Green Expansion vs Die @ 30 TSI (%)	0.14	0.13
Green Strength @ 30 TSI (psi)	1450	1560
Dust Resistance		
Graphite (%)	96.0	35.0
Nickel (%)	85.0	31.0
SINTERED PROPERTIES		
Green Density (g/cm^3)	6.80	6.80
Green Expansion vs Die @ 6.8g/cm^3 (%)	0.165	0.140
Sintered Density (g/cm^3)	6.77	6.78
Dimensional Change vs. Die (%)	-0.008	-0.001
TRS (ksi)	121,100	124,200
Hardness (Rb)	73	74
Carbon (%)	0.80	0.81
Nickel (%)	2.15	2.18
Oxygen (%)	0.07	0.05

TABLE III: Grand Statistical Results

Property/Component	Bonded Mix Mean	Bonded Mix Std. Dev.	Regular Mix Mean	Regular Mix Std. Dev.	Is $S^2_\ell > S^2_s$?	$\frac{(S_\ell - S_s)_\%}{S_\ell}$
GREEN PROPERTIES						
Green Wgt (g)	166.06	0.142	165.39	0.286	YES	50.3
Green Dens. (g/cm³)	6.816	0.0061	6.806	0.0094	YES	35.1
SINTERED PROPERTIES						
Sint.Dens. (g/cm³)	6.793	0.0052	6.795	0.0091	YES	42.9
I.D.Dim.Chg.vs Die (%)	-0.214	0.0105	-0.087	0.0102	NO	--
O.D.Dim.Chg.vs Die (%)	-0.064	0.0073	-0.035	0.0068	NO	--
Hardness (R_b)	65.6	0.920	66.9	1.410	YES	34.8
Crush Str. (ksi)	99.6	1.082	95.3	1.552	YES	43.4
Sint.Carbon (%)	0.844	0.0058	0.817	0.0123	YES	52.8
Sint.Nickel (%)	2.05	0.0291	2.06	0.0288	NO	--

TABLE IV: Analysis of Alloy Variance Results In Percent of Total Regular Mix Variance

Property	Variance Component	Bonded Mix	Regular Mix
Sintered % Carbon	Microsegregation as Within Part Variations	4.9	19.1
	Macrosegregation as Group to Group Variations	--	42.9
Sintered % Nickel	Microsegregation as Within Part Variations	62.6	76.6
	Macrosegregation As Group to Group Variations	--	--

TABLE VI: Findings of the Size Change vs Size Change Variability Study

Mix Identity		GREEN PROPERTIES Dens. g/cm³	% Dim.Chg. vs. Die	TRS ksi	Hard. R_b	SINTERED PROPERTIES Dens. g/cm³	% Dim.Chg. vs.Grn.	C %
A	$\bar{x}$	6.801	0.211	118.0	66.7	6.777	-0.186	0.79
	s	0.0038	0.0046	3.48	3.96	0.0062	0.0215	--
B	$\bar{x}$	6.803	0.216	123.5	68.6	6.788	-0.237	0.80
	s	0.0043	0.0071	4.27	3.61	0.0060	0.0238	--
C	$\bar{x}$	6.805	0.206	127.7	67.6	6.793	-0.277	0.81
	s	0.0049	0.0034	4.61	3.51	0.0180	0.0253	--
D	$\bar{x}$	6.801	0.211	126.6	72.3	6.805	-0.333	0.81
	s	0.0042	0.0063	6.28	3.83	0.0073	0.0269	--
E	$\bar{x}$	6.797	0.212	127.1	73.9	6.810	-0.382	0.80
	s	0.0048	0.0051	6.64	3.46	0.0068	0.0286	--

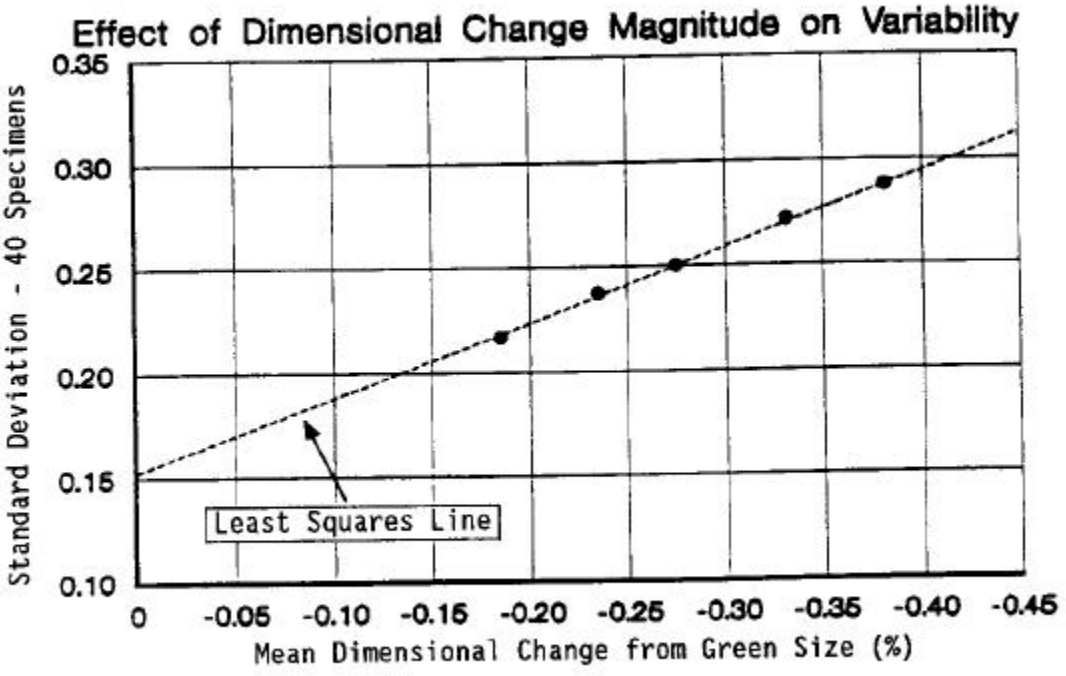

Figure 1