

STATISTICAL PROCESS CONTROL IN IRON PINDER PRODUCTION AND NEW PRODUCT DEVELOPMENT

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ABSTRACT

SPC is discussed with a view to indicating its implications not only to manufacturing and quality but to research and PC is product development as well.

In the manufacturing/quality area, the efforts and methods attending full-scale implementation of SPC are briefly reviewed with special reference to the differences inherent in powder making versus manufacturing of parts. SPC charting techniques suitable for powder making are described and discussed.

In the product development area, it is shown how SPC influenced a major research program. The objective of the program was to improve premixed products with a view to reducing variability in parts manufacturing.

ANOVA studies of production mixes generally showed that the main sources of premix variability were mix to mix differences and within mix differences arising from demixing subsequent to premix manufacture. It was recognized that SPC is especially applicable to dealing with the first of these and subsequent efforts to implement it to premixes are described. In the case of demixing, the developments of a new premixing process is reported in which the alloy admix ingredients are bonded to the iron.

The general findings of extensive studies, which show the benefits of the new process in terms of reduced variability in parts manufacturing, are reviewed and the results of a study of a FC-0208 premix are presented as an example. SPC theory and concepts are used to indicate the significance of the results and their potential applicability to the production of parts.

INTRODUCTION

Statistical process control is having a profound effect on manufacturing and quality control in the P/M industry. Its effects, however, are not limited to these functions.

It is also influencing research and product development. The purpose of this paper is to report experiences with SPC in each of these two areas. Since different issues are addressed in each case, the paper has been divided into two parts.

In a previous paper, the challenges and problems inherent in adapting SPC techniques to a process industry, notably steel powder manufacturing were discussed. (1) The statistical charting techniques best suited to this process are not always the same as those best suited to structural parts manufacturing. Therefore, there is a need for a dialogue to reach a mutual understanding of these differences. Part I of this paper will briefly review experiences in the early implementation of SPC and expand the discussion to include the specific charting techniques which were found most

suitable for powder manufacturing.

Part II of the paper will discuss research and development aspects with special reference to premixed products. This experience is especially interesting because it provides an example of a major R&D program, which both benefited from SPC and resulted in a new product, which has special application to SPC.

PART I

STATISTICAL PROCESS CONTROL

A competitive position in the market is defined by at least three components related to manufacturing:

- Quality
- Productivity
- Cost

Any process or product should address improvements in all three components. Particularly important is the acceptance that quality; productivity and costs are essentially inseparable issues. Emphasis on one to the exclusion of the others may accomplish short-term goals, but often necessitates a costly "catching up" approach in the longer term. The quest for sustained competitive strength is greatly enhanced by focusing on the process rather than the product. The distinction between Process Control and Product Control can best be depicted through the diagrams shown below. (2) Product Control orients the classical control cycle in a feed-forward mode as shown in Figure 1. Process Control is a feedback system as seen in Figure 2. A characterization of the two control systems is summarized in Table I.

Picture page3

INITIAL IMPLEMENTATION

A substantial percentage of powder shipments are in the form of press-ready mixes in bulk containers, produced and shipped to individual customer specifications. These provide some very specific challenges in terms of SPC, but it was obvious that bringing premixes under Statistical Process Control would have to start with full control of the major ingredient, iron powder.

Initially, the application of SPC to the powder manufacturing process was performed on pilot applications within a single product line to gain experience and build momentum. The atomizing process was selected as the starting point since the time from melting to final packaging in the atomizing process is significantly less than for the equivalent steps in the sponge iron process.

It was also felt that successful implementation of SPC in the steel atomizing process would more quickly bring direct benefits to our customers.

A course of action was agreed upon and a coordinated program to introduce SPC was formulated. A consultant was brought in to assist and advise the management team. Following the earlier educational and introductory events, a broader training program was initiated. Middle management, front-line management, operators, quality control engineers and laboratory technicians received up to 32 hours of off-premises training in the theory and use of control charts and statistical process control techniques. Additional training on the premises was then provided for a complete cross section of the organization, i.e. quality control, additional operations personnel, plant engineering, maintenance, sales and marketing, purchasing and R&D, all received the same 32 hours of formal training.

Five to ten properties were charted at each process location: melting, atomizing, annealing and packaging. Initially, properties were plotted without the use of control limits until 30 data points were obtained and trial limits were established. Data collection continued until 75 points were recorded for each property. A review was then conducted to determine process stability and to calculate control limits. It was at this stage that the validity of the powder properties selected for charting could be appraised. It became clear that some property charts could be eliminated. These were the

properties that were dependent on other properties and not "dominant" in and of themselves.

CONTROL CHARTING TECHNIQUES

There are some differences in the types of preferred control charts between a 4-process industry, (metal powder manufacturing) and a component industry, (P/M parts fabrication). In powder production, the product flows in a defined pattern from raw materials to finished products through elevators, belt conveyors, tubes and pipes. The direct reduction process (sponge iron) in particular, is continuous from powdered iron ore to powdered steel, like the product in an oil refinery, while the atomized powders begin as "batches" in the electric arc furnace.

There are notable and distinct differences between a finished lot of parts and of powder. The parts producer and the parts buyer can more easily agree on the attributes of a part or a lot of parts than is the case with a powder lot. The difference is manifested in sampling techniques. On the one hand, sampling a lot of parts is rather straightforward in terms of selecting randomly chosen components out of a population. The size and nature of a sample can be clearly defined. In a powder batch which is always prone to segregation, sampling becomes critical, more difficult, and at times a controversial task. Unless sampling is very good, the quality of the powder cannot be assessed.

In atomizing, dynamic SPC involves statistical methods to monitor the process with control charts and to establish the quality level of the batch. Each batch or melt must conform to the statistical limits established for that particular process area. After these statistical limits have been achieved, further reduction of variability is accomplished through the use of equalization which takes these statistically controlled individual melts and blends them into a single uniform 200 ton lot of iron powder.

The primary control in the case of component manufacturing are X and R charts. Specialized control charts such as Individual Moving Range, Moving Average, and Cumulative Summary Charts (CUSUM) are, however, often more appropriate in powder production.

Individual Moving Range Charts

In some processes, and powder production provides several examples, it would not be practical to take a number of sequential samples at the same time, ending up with essentially a number of values differing only in the variability of the method of analysis. An example is a liquid batch, such as a heat of steel. In such cases, individual values, spaced apart in time, are preferred over an average value of a number of samples. The term "Individual Moving Range Chart" refers to the method of calculating control limits for both the X value and the Range. Absolute values, are plotted on the X chart and successive differences between individual sequential X values, (i.e. $R = \Delta X$), are plotted on the range chart. The sigma value is calculated from the formula:

$$\sigma = R / d_2$$

Where d_2 is a factor derived from statistical mathematics.

A case in point is the process with one measurement per day or one measure per batch. In such circumstances, it is desirable to plot individual X values to determine batch to batch variations. (3)

Moving Averages

The moving average is particularly appropriate in continuous process manufacturing, when applied to quality characteristics of raw materials and products in process. The smoothing effect of the moving average often affects the values, in a manner similar to the effect on the product of the blending and mixing that takes place in the remainder of the production process. The major item to consider is the subgroup size or the number of points, which will be averaged. We have found it particularly appropriate in powder manufacturing to consider the use of moving averages to plot time-spaced sampling of certain constituents in raw materials, products in process, and finished products. (3)

Cumulative Summary Charts (CUSUM)

These charts are preferentially used in continuous process operations, although they can be used in batch type processes. The actual value X is compared with a target value, and the difference from the target, whether positive or

negative, is plotted on a cumulative basis. The appropriate difference is added or subtracted from the previous cumulative value.

For statistical process control purposes, the CUSUM chart is used with a "V mask" as illustrated in Figure 3. The mask is defined by its angle, O , and the locations of its vertex in relationship to the previous point d . Actual values for O and d can be mathematically derived on statistical principles, but are commonly based on careful analysis of common cause variability and an expression of the degree of sensitivity desired for determining out-of-control conditions.

One benefit of CUSUM charts is the quick and simple detection of important process trends for operator judgment. Changes in the slope of the plot are indications of shifts in the mean away from the target, and the process is judged to have shifted unacceptably if the plot falls outside the mask. (4,5,6)

Picture page6

PREMIXED PRODUCTS

Hoeganaes had been aware well in advance of the advent of SPC in the P/M industry that parts variability was a matter of growing concern to the final user. There was little doubt that variability in powders was a contributing factor, but neither the magnitude of the contribution nor the specific causes in terms of powder properties were sufficiently well known to even define a problem, let alone initiate work towards a solution. The difficulty was that virtually all parts are made from premixes and the premixing process obscures the relationship between the properties of the primary base powder and those of the resultant parts. Given this situation and the fact that a substantial amount of iron powder is shipped in the premixed form, it appeared as if work on the premixed powders as opposed to the primary powders would be a more reasonable approach to a solution.

Hoeganaes, therefore, started a major research project with the objectives to quantify the sources of premix variability and to effect improvements, which could be used to improve the variability of the final parts. The research was necessarily statistical in nature and considerable use was made of the Analysis of Variance technique. Early ANOVA studies indicated that variations between mixes were more important than those occurring within a mix. However, this was only true for the premix as initially made. Other experience showed that demixing during handling subsequent to premix manufacture was also a factor, which could not be ignored.

Just about the time that these findings were coming to light, SPC was making its debut in the PM industry. A review of its concepts showed that, except for demixing, SPC involved precisely the kind of strategy which was needed as a practical matter, not only to cope with premixed products, but, to address the more fundamental issue of variability in primary products. Consequently, its concepts were applied almost immediately.

Simultaneously, research on the demixing problem continued. The findings indicated the need for a mixing process to bond the admix ingredients to the iron powder. Such a process has been developed and is planned for commercialization later this year under the tradename AncorBond.

In the balance of the paper, we will present the main findings of the indicated research and discuss their applicability in terms of SPC. The presentation will include premixes in general and the bonding process in particular. In the latter case, the findings of early studies of the applicability of bonded premixes to parts manufacturing are reviewed with special reference to a FC-0208 type premix.

VARIATIONS DUE TO MIX TO MIX DIFFERENCES

The idea that there was a direct connection between premix variability and mix to mix differences was an outcome of a review of quality testing records representing years of experience. However, as a general matter, there were three other possible sources of the observed variations including testing, sampling, and within mix differences. Compared with these three, the mix to mix source was definitely the most reasonable. Nevertheless, the contributions of the other three sources mentioned also had to be considered. Premixes by their very nature offer greater opportunities for error in testing and sampling, and the possibility of within mix differences due to inadequate mixing or to demixing during mixer

discharge could not be ignored. Consequently, the Analysis of Variance method was used as one of the early steps in our study of premix variability to assess the relative contribution of the mix to mix source versus these other three sources.

Several different premix compositions were included in the study in hopes of obtaining a general indication of the contributions of the indicated sources. The experimental procedure was designed to implement a hierarchical or nested ANOVA as opposed to the linear regression type. (7) Nominally, the properties of ten production mixes made sequentially as ordered were surveyed to represent the behavior of each premix. The findings in regard to the indicated variability of each property were analyzed so as to separate the contribution of the mix to mix differences as a pure value, and of testing, sampling, and within mix differences as a combined value.

The general result of the study was, as anticipated at the outset, that mix to mix differences were the predominant source of variability. Overall variability varied from premix to premix and thus in absolute terms the magnitudes of the mix to mix contributions were rather disparate. However, in relative terms, it was possible to detect two general trends. As averaged over all of the premixes studied, the mix to mix contribution to overall variability was upwards of 75% for green properties and 60% for sintered properties. Efforts to correlate these findings to alloy content differences on a mix to mix basis were generally not successful. However, the analysis did show a correlation with processing and feedstock variations. Thus, the overall implication of the study was that mix to mix differences and hence premix variability in general was predominantly attributable to processing and feedstock variations.

THE APPLICABILITY OF SPC AND FUTURE PLANS

It will be evident that SPC was applicable to improved premix uniformity. In fact, given the finding that premix variability was due primarily to mix to mix differences arising from processing and feedstock variability, SPC was perhaps the optimum strategy. However, as mentioned earlier, at the time of the foregoing findings, SPC had just made its appearance in the industry and Hoeganaes had little experience with it. Subsequently, when Hoeganaes decided to implement the SPC strategy, premixes were quite logically placed downstream of high volume primary products and had to await their turn in the implementation process.

We have since implemented SPC on all of the major primary products and the strategy is well established. Current plans are to apply it to premixes and implementation is in progress.

In the not too distant future, a premix facility, which is currently under construction in Milton, Pennsylvania, is expected to play a very significant role in these regards. Automation, via computer control, is a component of this facility. When complete, the entire system will be electronically interlocked so that all process details, including feedstock identities and weights will be accessible for process control and analysis. Thus, it should be possible to achieve the optimum benefits attainable through SPC.

PREMIX VARIABILITY DUE TO DEMIXING PHENOMENA

Compositional variations in premixes by virtue of demixing phenomena including, in particular, particle segregation and dusting phenomena, are well known in the P/M industry. Such effects are especially apparent in high alloy compositions but are present to an extent in all admixtures regardless of alloy content. In the case of dusting, visual indications are a common daily occurrence. In the case of segregation by particle migration, visual indications are less frequent but no less well known. Almost anyone reasonably experienced in the art can cite at least one instance of such phenomena.

Compositional variations associated with demixing phenomena are, of course, manifest in variations in the physical and mechanical properties of both the blends and the parts which are made from them. Consequently, they exact both technical and economic penalties.

Basically, there are three ways to avoid or minimize the adverse effects of demixing. These include prealloying by atomization, diffusion bonding to produce Distalloys, and binder treatment of premixes. (8,9,10) Over the years, considerable effort has been devoted to the first two and, as a consequence, they are both well developed and of considerable industrial importance. In contrast, the binder treatment method has received little attention.

Starting in late 1982, and encouraged by the favorable outcome of binder research in Sweden, Hoeganaes set out to remedy this particular situation. (11) The ensuing efforts led eventually to the development of the AncorBond process. Rather extensive trials both in the laboratory and under actual production conditions have indicated that bonded premixes have a very significant potential to reduce variability in the parts manufacturing process.

The research, which led to the AncorBond process, was carried out in two stages: 1) development of an effective binder treatment process, and 2) verification of the parts manufacturing advantages of the resulting product. Interest here is mainly in the findings of the second stage. However, a brief discussion of the first is also in order, both to indicate the scope of the underlying efforts and to provide certain useful background information.

DEVELOPMENT OF THE AncorBond PROCESS

The details of the AncorBond process and the binders employed in connection with it are proprietary. However, there are certain aspects of the development, which are of general interest and which can be discussed.

The process itself was several years in development and is relatively complex compared with premix manufacture by traditional methods. The binders employed in the process are non-toxic and decompose during sintering leaving no residue.

The binder addition, of course, is a critical aspect of the process. It must be capable of adequately suppressing demixing phenomena without significant adverse effect on the other properties of the mix. However, there are very few, if any, materials which can be added to a premix which will not have some effect on its properties. Thus, minor effects were anticipated. Quite unexpectedly, however, the research led to the identification of a binder, which was capable of producing rather extraordinary improvements in flow behavior. Thus, relative to a regular mix, a binder treated mix of nominally the same composition will exhibit a somewhat higher apparent density and a substantially improved rate of flow. When sintered under similar conditions essentially the same values of hardness and sintered strength and a slightly decreased dimensional change characteristic are observed,

DUSTING RESISTANCE

In addition, it was also necessary in the course of the development to devise a means of assessing the potential effectiveness of the binder treatment process to suppress demixing phenomena. The method eventually developed to do this involved measuring the so-called dusting resistance properties of the mix. The particulars of this method and the apparatus used to conduct the associated test have been described elsewhere. (12) For the purposes of the present discussion, it suffices to say that the test consists very simply of elutriating a sample of the subject mix under controlled conditions of flowrate and time with the objective to cause demixing of susceptible admix ingredients by segregation and eventual dusting. The parameter which is of interest to assess the demixing tendency of a particular ingredient of the mixture is the ratio, as determined by chemical analysis, of the ingredient's content after the test to that before. This value is typically expressed in percent and is referred to as the ingredient's 'dusting resistance'.

Given that an increase in dusting resistance is synonymous with a decrease in demixing tendency, a primary aim of adding a binder to a premix would be to increase its dusting resistance properties, particularly as they relate to the various alloying ingredients. The typical effects of the AncorBond process in these regards are shown in Table I.

As a cursory review of the data in this table will confirm, the process is capable of effecting very significant dusting resistance improvements for each of the four alloying ingredients which are most commonly admixed with iron powders.

Table I: Typical Dusting Resistance Values of the Common Alloy Admix Ingredients in Bonded and Regular Mixes

Admix Ingredients	% Dusting Resistance	
	Bonded Mixes	Regular Mixes
Graphite	95	25
Nickel	85	20
Ferrophosphorus	95	30
Copper	95	85

The properties shown for the bonded mixes in the foregoing table were also typical of those attainable by the process as developed at the conclusion of the first stage of the program. They indicated that the process was effective as a binder treatment but it still remained to demonstrate that they were truly meaningful in terms of parts production.

PARTS MANUFACTURING

A number of parts manufacturing studies aimed at quantifying the effects of the AncorBond process are currently in progress or have just been completed. Various premix compositions containing one or more of the common admix ingredients including graphite; copper, nickel and ferrophosphorus are included in the studies. The following results are drawn mainly from early laboratory studies, which were an attempt to simulate actual production processing, but under controlled conditions compatible with conducting research. The general scheme employed was to process a binder treated mix and a regular mix of the same composition under nominally the same conditions and compare the properties of the resulting parts as to statistical variability.

The part studied was a cylindrical bushing and the effects on six properties were determined: sintered density, the O.D. and I.D. dimensional changes, hardness, crush strength and alloy content. Since property variability may arise in several ways, the Analysis of Variance method was employed in an effort to assess the relative contributions of testing, processing, and segregation to the results.

GENERAL FINDINGS OF THE PARTS MANUFACTURING STUDIES

The AncorBond processing reduced variability or resulted in equivalent performance. Although there were some negative indications in the findings, there was nothing that looked as if it wouldn't eventually yield to additional research and development. Naturally, some premix compositions responded better than others and certain properties were more affected than others. Yet where there was improvement, it was rather substantial. For example, it was not at all unusual to see two-fold reductions in variability and in some cases, improvement by factors as high as fifteen were actually observed. Significantly, the largest improvements were consistently observed in dimensional change and crush strength. In contrast, hardness and sintered density were either less affected or, more often than not, remained essentially unaffected.

Interestingly, the results of the studies with respect to variations in composition were mixed. In some cases, there was clear cut evidence of reduced segregation associated with the AncorBond process, whereas in others there was not. Where the results exhibited reduced segregation they consistently showed corresponding improvements in the variabilities of the other properties studied. In some cases, however, there were instances of very significant variability improvements in the mechanical and physical properties of the AncorBond premix without corresponding reduction in segregation.

Reference to the Analysis of Variance results provided additional insight into the underlying causes of the findings in the studies where segregation phenomena were observed. The general indications were that microsegregation, (i.e. within part variations), was more prevalent than macrosegregation, (i.e. part to part variations), and that the parts variability improvement accompanying reduced segregation was in a large measure associated with what appeared to be a reduced sensitivity of the parts to the process variations which normally occur in sintering.

In contrast, the Analysis of Variance results were not very helpful to explain the findings where significant segregation effects were not observed. An expanded database and a more comprehensive method of analysis is now thought to be needed in these cases. For example, in the study of one premix, the results yielded to the addition of green property data and the use of correlation techniques. The indications of the expanded analysis in this case led to the idea that reduced variations in pressing, presumably attributable to the enhanced flow behavior of the bonded premix, had contributed significantly to the final parts improvements.

Thus far, the existence of similar effects still remains to be confirmed in other studies, which have been conducted. However in consideration of this finding, the current view as to the general origins of the observed improvements with the AncorBond process is that they are related to one or both of the following: (a) improved uniformity in compaction due to the improved powder flow characteristics resulting from the process; and, (b) improved uniformity in sintering due to a significantly decreased tendency to demix during handling in advance of pressing.

THE RESULTS OF A STUDY OF AN FC-0208 COMPOSITION

The highlights of the foregoing are perhaps best illustrated by the findings of an actual study. One such study has already been reported in the literature. (12) This was concerned with the application of the AncorBond process to what was essentially an Ancorsteel 45P composition. Another study planned for the coming International P/M Conference will report the effects in a straight 1% graphite mix. (13) The following section presents some results to date from our studies of graphite/copper mixes. The particular mixes selected for this purpose were made with Ancorsteel 1000 and otherwise contained 0.95% graphite, 2% copper and 1% zinc stearate.

General Procedure and Preliminary Test Results

The experimental procedure employed was essentially the same as that used in connection with the Ancorsteel 45P composition. (12) In general, the procedure involved typical parts fabrication steps but was rather more complicated because of the Analysis of Variance study, which it included. The basics of the procedure are briefly outlined below.

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 binder treated mix was made by the AncorBond process. The various parts manufacturing steps were carried out on regular P/M production equipment. Sintering was nominally at 2050°F for 30 minutes at temperature in a dissociated ammonia atmosphere.

The mixes were each tested in advance of any actual parts making as a quality control measure. The tests included determinations of dusting resistance as well as more traditional powder, green, and sintered properties. The results are shown in Table II. A brief review of this table will show that the findings are in general agreement with what was previously stated about the effects of the binder treatment process in these regards. The most significant changes shown are the improvements indicated for the bonded mix in flow behavior and graphite dusting resistance.

Picture page12

Picture page13

PRINCIPAL PARTS MANUFACTURING RESULTS

The grand statistical results of the parts made in the study are presented in Table III. The first four columns of the table list the means and standard deviation values of seven different parts properties for 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 I the variability estimate of the mix which exhibited the numerically larger value of the two, i.e. S_1^2 , statistically significantly larger than that of the companion mix, i.e. S_2^2 ? 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 variances between the two were found to be statistically significant.

A review of the data in Table III will show that the bonded mix exhibited statistically significant improvements in variability in five of the seven properties listed. These included sintered density, the I.D. and O.D. dimensional changes, crush strength and sintered carbon content. The two properties for which the results did not show an improvement were hardness and sintered copper content. There was apparently no effect of the treatment on hardness variability and an adverse effect on copper variability.

In terms of the standard deviation values, the greatest improvement in the bonded mix was in the crush strength and the least improvement was in the sintered density. The corresponding values were 74.3% and 28.0%, respectively. The improvement in the variability of the sintered carbon content of the bonded mix is also noteworthy insofar as it was ostensibly responsible for the other improvements observed. As reference to the data will show, the improvement in this instance was 58.8%.

In contrast, the indicated effect of the processing on copper variability was a truly negative finding, but it was the only such finding in this case and one of the very few such findings in the parts-making studies in general. Subsequent research has shown that the effect is preventable.

Further review of the data in Table III will also show that there were differences in the mean values of the properties of the two mixes. These differences were numerically small but they were, in most instances, statistically significant. From the physical standpoint, the dimensional change differences between the two mixes are perhaps the most significant.

Indications of the Analysis of Variance Results

The general indication of the Analysis of Variance results was that the variability improvements in the bonded mix were due to the accompanying reductions in carbon segregation and to the beneficial effects of these reductions on sintering behavior. There was no hint, in the data, that the improvements were in any way connected to reduced variations in pressing. However, it must also be said, that the findings were not necessarily conclusive in these regards.

The reductions in carbon segregation were, according to the findings, composed of decreases in microsegregation and macrosegregation. Of the two, the decreases in microsegregation were predominant. For example, they represented about three fourths of the overall decreases in carbon variability which are indicated in Table III.

In comparison, the analysis showed that the decreases in the variabilities of physical and mechanical properties were composed of decreases associated with the variation with the sintering and to the effects of macrosegregation of carbon. Of the two, the decrease associated with sintering constituted the predominant factor as regards the improvements seen in dimensional change characteristics and crush strength. In the case of sintered density, the contribution associated with the effects of the reduction in carbon macrosegregation was predominant. For example, the contribution of the sintering component to the improvements in dimensional change characteristics and crush strength amounted to 80% of the improvements shown in Table III, whereas reduced macrosegregation of carbon was responsible for about two-thirds of the improvement shown in sintered density.

The contribution of microsegregation to the improvements is thought to arise in connection with the sintering component. This component measures the effects of variations within the parts as well as of variations in the external conditions attending the process. Microsegregation is a prime example of a within part variation and as far as presently known was the only one present in this study.

APPLICABILITY OF AncorBond IN TERMS OF SPC

A rather thorough discussion of the applicability of the AncorBond process in SPC terms has already been presented in the literature. (12) Thus, a brief review is perhaps all that is appropriate.

The improvements associated with AncorBond premixes offer potential opportunities for economic advantage to the parts maker. The opportunities are inherent in the associated effects of the improvements to increase quality and/or provide an advantage in processing.

The improvements in flow behavior offer an advantage in processing including increased productivity at the press and greater reliability of adequate pressing performance on a mix to mix basis. In addition, to the extent that the onset of poor flow with increasing alloy content limits premix design, the advent of the AncorBond process should provide considerable latitude for many new compositions.

Improvements in variability associated with the AncorBond process are thought to be even more significance than the flow improvements in that they offer not only more but differing opportunities for advantage. These opportunities are perhaps most apparent when the improvements are considered in terms of SPC.

Picture page15.

The control chart concept of SPC is especially useful in these regards. A schematic of such a chart is shown in Figure 4. The chart compares the behavior of a regular mix to that of a bonded mix. It is based on experience with the regular mix. The engineering or customer part specification/ requirements are shown as slightly bracketing the control lines, which are taken as the 3 σ limits of the mix about the associated mean. The corresponding properties of a typical bonded mix are also shown. The placement of these data in the figure is such as to suggest replacement of the regular mix by the bonded mix.

The changes occasioned by the transition to the bonded mix are as indicated in the figure, a tightening of the 3 σ limits of the process and a slight displacement of the mean value of the charted property. This displacement of the mean, of course, is undesirable because it diminishes somewhat the impact of the associated improvements in the 3 σ limits. It may be possible to adjust it by minor changes in processing or in the composition of the mix. However, this will depend on the particular application. For example, in spite of the foregoing view to the contrary, the change may in certain instances be regarded as a desirable one.

In any case, whether the displacement of the mean is desirable or not, the indicated narrowing of the 3 σ limits very definitely is. In SPC terms it represents a quality improvement. It permits the part to be offered at tighter specifications than otherwise possible. Or, if the part continues to be made to the same specifications, then it should be possible to derive advantage in accordance with SPC theory including decreased rejections and optimization of facilities planning and utilization due to greater reliability in processing.

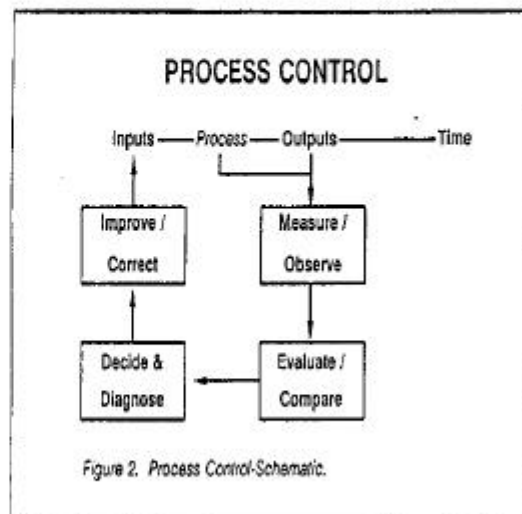
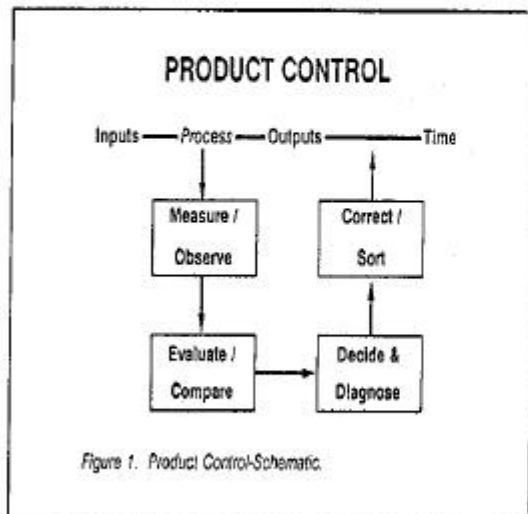
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The benefits of Process Control over those of Product Control are substantial and are now recognized throughout the P/M industry. A Statistical Process Control culture is rapidly developing, with generally accepted principles of sampling, charting and analysis.

<u>Product Control</u>		<u>Process Control</u>
Product	<i>Focus</i>	Process
Specification Limits	<i>Goal</i>	On TARGET with Smallest Variation
Acceptance Sampling	<i>Typical Tools</i>	Control Charts
Outgoing Quality Only	<i>Improvement Nature</i>	Quality AND Productivity
Detection Containment	<i>Philosophy</i>	Prevention of Problems

Table 1. Product Control/Process Control: a Contrast

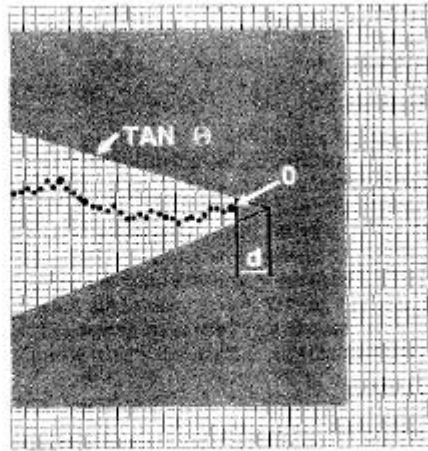


Figure 3 Example of a CUSUM Chart

PART II

Table II: Preliminary Test Results of Two of the FC-0208 Mixes Used in the Parts-Making Studies of the AncorBond Process

Property/Component	Bonded Mix	Regular Mix
GREEN PROPERTIES		
Apparent Density (g/cm ³)	3.34	3.21
Hall Flow (sec/50g)	23.5	36.9
Green Density @ 30 TSI (g/cm ³)	6.67	6.70
Green Expansion @ 30 TSI (%)	0.14	0.14
Green Strength @ 30 TSI (psi)	1360	1420
Dust Resistance		
Graphite (%)	90.0	8.0
Copper (%)	93.0	90.0
SINTERED PROPERTIES		
Green Density (g/cm ³)	6.80	6.81
Green Expansion (%)	0.17	0.16
Sintered Density (g/cm ³)	6.71	6.72
Dimensional Change vs Die (%)	0.22	0.26
TRS (ksi)	153.0	152.0
Hardness (Rb)	83.0	84.0
Carbon (%)	0.80	0.81
Copper (%)	2.21	2.20
Oxygen (%)	0.10	0.07

Table III: Grand Statistical Results For The FC-0208 Premixes

Property	<u>Bonded Mix</u>		<u>Regular Mix</u>		Is $S_l^2 > S_s^2$	$\frac{(S_l - S_s)}{S_s} \%$
	Mean	Standard Deviation	Mean	Standard Deviation		
Sintered Density (g/cm ³)	6.725	0.0059	6.721	0.0082	YES	28.0
I.D. Dimensional Chg. (%)	0.0974	0.0257	0.1064	0.0368	YES	30.2
O.D. Dimensional Chg. (%)	0.2086	0.0130	0.2340	0.0203	YES	36.0
Hardness (Rb)	75.2	1.08	73.8	1.06	NO	--
Crush Strength (ksi)	123.7	1.91	121.3	7.45	YES	74.3
Carbon (%)	0.810	0.013	0.851	0.033	YES	58.8
Copper (%)	2.12	0.085	2.13	0.032	YES	62.3

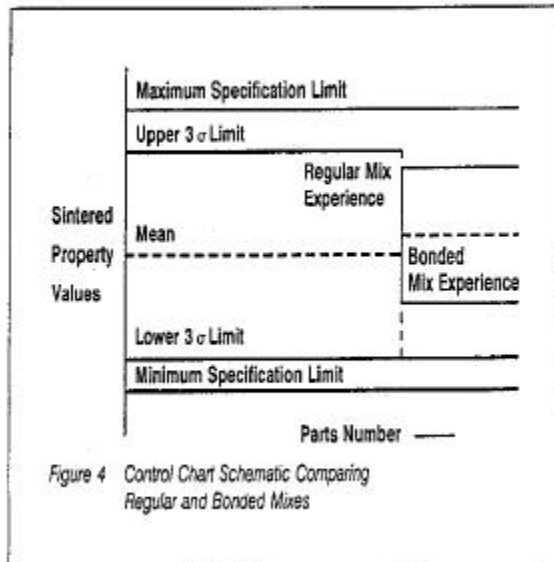


Figure 4 Control Chart Schematic Comparing Regular and Bonded Mixes