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INCREASING PRODUCTION CAPACITY
FOR COMPONENTS OF
INDUSTRIAL CERAMIC SUBSTRATES

by

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ABSTRACT

An increase in the efficiency and quality of the production of ceramic substrates was achieved through development of a raw material accountability system, new and improved batch formulations, development of a ball mill scheduling method, and improved tape casting operations.

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CHAPTER 1. INTRODUCTION TO THE PRODUCTION PROCESS

Many companies have had the experience of being able to sell more of their product than they are able to produce. When this happens the company must make a decision--turn the additional business away or find a way to produce more. A local ceramics company had this problem. One of the largest customers continued to increase its annual orders a little each year. Every time this occurred the ceramics firm had to struggle to increase production of a line that was already producing at "top capacity." Since buying additional equipment was not considered to be economically sound and would not provide short run solutions, a quicker way had to be found.

The product is a ceramic substrate made from an alumina based tape casting process. Tape casting is an old art used in ceramics as well as in the paper, plastics, paint, and other industries. Its use in ceramics began during World War II as a substitute for mica in high-quality capacitors.

The process begins when 3000 pounds of high purity aluminum oxide, organic liquids, and solvents are manually loaded into a large cylindrical ball mill filled with one inch ceramic grinding balls. A liquid slip results after the mill rotates 40 hours, grinding and mixing the raw materials. This particular "batch type" is a virgin batch. There are two other batch types that are made of recycled slip or of recycled tape scrap from the casting and punch operations. All three batch types, or formulations, produce the same end product, liquid slip, which is similar to a warm, thick, purple milkshake. Each formulation is milled a different length of time. Tape scrap batches are made of a recycled, smooth, flexible, purple, plastic sheet-like tape. Twenty-nine hundred pounds of tape scrap are packed into the mill by physically stepping on it until it fits. Liquid solvents make up the other 700 pounds of weight, and are a catalyst to the 20 hours of grinding action of the rotating mill media in breaking the chunks of tape down into the liquid slip. The third formulation is made of 3500 pounds of leftover slip from casting previous batches, and is milled 10 hours to assure even mixing.

When the milling is complete the slip viscosity (thickness) and density are tested against specifications, and adjusted with additional grinding, with or without more material being added. Once the slip meets these specifications it is unloaded, or dumped, into 3 or 4 large pressure pots. These five foot tall, cylindrical vessels weigh 500 pounds empty, and hold 950 pounds of slip. Each "pot" contains an agitation device that is used to keep the slip uniformly mixed while it waits to be cast. Four hours prior to casting each pot is connected to a vacuum-agitation motor to remove all the air from the slip so it will cast properly. The pot is then hooked up to the front of an 80 foot long casting machine by means of a 10-foot long, 1/2-inch diameter plastic hose.

The slip is forced from the pot, under pressure, through the plastic hose into a 17-inch long rectangular, metal "doctor box." An eighteen inch wide, 5 mil thick (.005 inches) plastic sheet moves under the doctor box at 95 feet an hour pulling the slip under the "doctor blade," or scraping blade, onto the plastic sheet. The doctor blade is adjusted to allow the slip to form a 17 inch wide, 30 mil thick coating on the plastic. As the plastic and slip travel through the casting machine, a series of heater beds ranging in temperature from 80 to 200°F slowly dry the slip into the flexible purple tape. Once dried, the tape can then be cut in various shapes in the punching process. It takes 24 to 48 hours to cast an entire batch of slip, depending on batch size (virgin, tape scrap, or liquid scrap), casting machine condition, slip characteristics (viscosity and density), and casting operator ability. After the green (unfired) parts are punched out of the tape they are fired in a 100-foot long tunnel kiln into a hard, white, brittle, ceramic substrate. From beginning to end it takes six to ten weeks, including any necessary rework of the slip, for a batch to be processed completely through the system.

To begin the task of increasing the production capacity it was necessary to thoroughly understand the production process. This was accomplished by working every job in the production line until each job was mastered. This required a total investment of 2 1/2 months of physical labor and thick, rubber-soled shoes. The process starts in the Ceramic Material Preparation (CMP) department with the milling process. Many insights gained during those ten weeks became the basis for testing the methods of increasing capacity discussed in this paper.

The focus of all efforts to increase production capacity was limited to CMP and casting because the biggest returns could be realized in these areas. If either the slip or the tape was processed incorrectly it could not be salvaged in subsequent departments. Also, the number of substrates obtained from each batch, and most of the substrate quality, was determined in CMP and casting.

Wide variation in the number of substrates produced from individual batches had been observed and could not be totally explained by punch and firing scrap rates. The first effort was directed toward developing a material accountability system to see how much of the material loaded into a mill was actually dumped from the mill, and how much was then cast. The intention was to make the initial batch sizes more consistent, and then to predict the final batch yield in terms of the number of substrates shipped to the customer. This material accountability system will be described in Chapter 2.

Another idea dealt with improving the method of scheduling the CMP operations of loading and dumping the mills, and milling time. The milling time is a fixed quantity for each formulation type, but the mill loading and unloading (dumping) varied. There is also the slip adjustment variable that is stochastic-like because of the difficulty of accurately predicting when an adjustment will be required and how long it will take. Time and motion study data revealed that mill loading time was formulation dependent, with virgin and liquid scrap batches requiring 1 hour, and tape scrap batches 2 hours. The existing mill scheduling method was modified as described in Chapter Two. A production quota of milling 17 batches per week was imposed by management in April 1979 and was the measurement of the success of the scheduling method. Unfortunately, adequate testing of the method was not done due to a continuous barrage of production-related problems. The brief testing that did occur indicated the method would work provided solutions were implemented for infringing problems.

Increasing capacity and efficiency in the CMP area had promising potential. Testing to determine if a mill could adequately mix larger amounts of materials than previously loaded was initiated. The liquid scrap batch charge was increased by 17 percent to 3500 pounds. This did not affect the slip characteristics in any way, but did favorably affect the batch size, and thus, the number of parts made per batch. Increased loadings for virgin and tape scrap formulations were not tested, but appear promising.

A new formulation was developed by milling a charge consisting of 50 percent virgin raw materials and 50 percent tape scrap. Twenty-seven of these 50/50 batches were processed. The results, discussed in Chapter Two, strongly indicated that these batches produced superior substrates.

A second new formulation, the details of which are proprietary, was developed to improve the chemical properties of the slip so it could be cast with less difficulty.

The main problems addressed by this formulation were casting defects due to machine airflow and the stresses caused by shrinkage due to the drying of the slip. Two batches of this formulation were tested with good results. Further testing is required before this batch type can be instituted into regular production.

Other aspects related to production capacity and efficiency surfaced during the course of this study. These other aspects and their implications are discussed in the remainder of this paper.

CHAPTER 2. METHODS AND RESULTS

In April 1979 the CMP and the Casting departments were combined into one department. This set the stage for implementing methods to increase finished product output. Two basic methods exist for increasing output--increasing efficiency and increasing capacity. Capacity can be increased by adding more equipment. The method of increasing existing process efficiency was the object of this study.

Two separate operations in the newly formed department are responsible for scrap production. If the raw materials are not prepared correctly, very little can be done to turn "bad slip" into good substrates. If the slip is good the other way of producing scrap involves improper casting. The defects introduced in casting cannot be corrected in subsequent departments.

The raw materials milling process was the logical starting point for the study. Prior to the consolidaton of the tape CMP and casting operations, the CMP operators rotated on a weekly basis between four different CMP duties. Each operator performed each duty, one of which was tape milling, one week every month. The operators themselves thought this was difficult since every Monday they had to orient themselves to a different job. Some of the workers took longer than others to get reoriented each week, especially if they didn't like the job they were assigned to do. When the tape mill component of CMP, which is the hardest job, and the casting component were made one department, the rotational schedule was eliminated. After new operators were hired and trained, each operator was able to develop his skills without the interruptions of a rotational schedule.

Since the same operators worked with the mills every day, communication also improved between process engineering personnel and tape CMP personnel. Improved communications resulted in more uniform slip characteristics and valuable feedback on test results. The customer, casting, got a better product from the supplier, CMP. During the first four weeks of this new arrangement milling quality improved by a reduction in slip adjustments of 22 percent, and a decrease in the number of unusable batches from two to zero during the first month. Since May 1979, only two batches have been unusable. Slip adjustments changed from merely salvaging the material to fine-tuning adjustments to maintain better control of the slip. This reduction of the variability of the slip characteristics also made the casting process easier to control.

Material Accountability System

It was desired by management to be able to predict the quantity of substrates that would result from each batch of materials milled, and to reduce the variation in size from batch to batch. In order to obtain this predictability, information about yields was needed from each component of the production process in CMP and casting. A material accountability system was developed for this purpose in these two areas that accounted for every pound of material milled.

Since the amount of material loaded into the mill was known for each batch type, the amount, in pounds, to be dumped from the mill should equal the amount loaded. A scale was purchased for weighing the slip dumped from each mill. The tare weight of each pressure pot was determined, and the weight of the slip in each pot was figured by subtracting the pot tare weight from the weight of a full pot. The quantity of slip for an entire batch was the sum of the slip weights from the 3 or 4 pots required for dumping the mill. This data was recorded by batch in a log book at the time of mill unloading.

Until this system was installed, only the CMP operator knew the batch sizes, and they knew the size only by the number of pressure pots a batch would fill. Therefore, it was impossible to quantifiably evaluate production performance in CMP and casting (see Table I) as well as control the size of the basic unit of production, the batch. With the institution of this slip weighing system, it quickly became apparent that production yield information should be collected on individual batches rather than on the daily basis used by the company. Information gathered using this system revealed that the batch size varied depending on the type of formulation milled, and that the yield rates of subsequent department were relatively constant. Thus, use of the weighing system demonstrated that the number of final parts produced from a batch varied with the initial size of the batch. Also, knowing how much slip should be expected from each batch led to the possibility of making each batch type more consistent with respect to size. Dumping batches from the mills to a specific weight was not instituted and, therefore, did not result in a consistent number of parts per batch type.

A basis for comparing productivity from month to month did result from the use of this weighing system. The weighing procedure was extended to the casting operation where the total amount, in pounds, of good tape cast was weighed and recorded for each batch. Thus, total accountability for every pound of material used in milling was achieved up through casting. This was the useful extent of the material accountability system by weight since counts are in terms of number

Table I

Impact of Material Accountability System
on Production Performance

Before

weigh materials,
record weights

↓

load mill

↓

milling time

↓

dump mill

↓

cast slip

↓

punch

↓

record punch yield

↓

no quantified performance
evaluation possible
for production in CMP
and casting

After

weigh material,
record weights

↓

load mill

↓

milling time

↓

dump mill, weigh slip,
record weight per batch

↓

predict casting yield in
lbs of good tape cast

↓

cast slip

↓

weigh pounds of good
tape cast

↓

predict punch yield

↓

punch

↓

record punch yield

↓

compare casting & punch
yields with predicted yields

↓

quantified performance
evaluation possible for
production in CMP & casting

of parts per batch in all departments after casting. Once accountability had been established, predicting future yields was possible. A monthly report resulted that summarized the performance of CMP and casting, and compared the performance of CMP and casting from month to month, and compared the performance to predicted values. Briefly stated, this monthly report gives the number of batches produced, the number of slip adjustments required to maintain batch quality, and compares the pounds of slip dumped and pounds of good tape cast per batch type (virgin, tape scrap, etc.) to the predicted values of these two items. These reports provide useful information on past performance, and, more importantly, can be used to set realistic goals for future performance. Figures A(1), A(2), and B show typical results for a four month period. Figure A(1) is a graph of the number of batches produced per month; Figure A(2) shows the necessary slip adjustments as a percentage of the total number of batches milled for a given month. Figure B shows the relationship between per batch averages of actual pounds of good tape cast and the predicted pounds of good tape cast.

The slip adjustments in Figure A(2) are separated as to the reason for the adjustment. The 0-0 line indicates those adjustments required to salvage the slip. This is necessary when the weighing, loading, or milling procedures have not been followed properly. This will normally result in slip characteristics that are far below or far above the specification limits. For example, the slip viscosity will be 5 to 10 points or more above the upper limit when the amount of solvents in the batch is less than required. The viscosity is the same amount below the lower limit when too much solvent or too little alumina has been loaded in the mill. The X - X line shows the trend of "fine tuning" adjustments that are required to bring the slip characteristics to the midpoint of the specification limits. These types of adjustments are required to compensate for minor differences in material amounts loaded due to weight variations in prepackaged raw materials, fluctuations of readings in weighing equipment, and weather changes that affect mill temperature. The slip in these cases could be case, but the fine tuning adjustments reduce the likelihood of casting problems due to normal inherent differences between batches that naturally result because of the batch milling process. It is possible to have less than 5 percent adjustments on a monthly basis if all CMP procedures for weighing, loading, and milling are properly followed. Although the fine tuning adjustments aid casting they take time to perform, thus reducing the time available to mill new batches. The greater the number of adjustments that occur each month, the fewer the number of batches processed in CMP. Therefore, adjustments reduce milling capacity, and should be minimized.

FIGURE A(1)
Number of Batches Produced

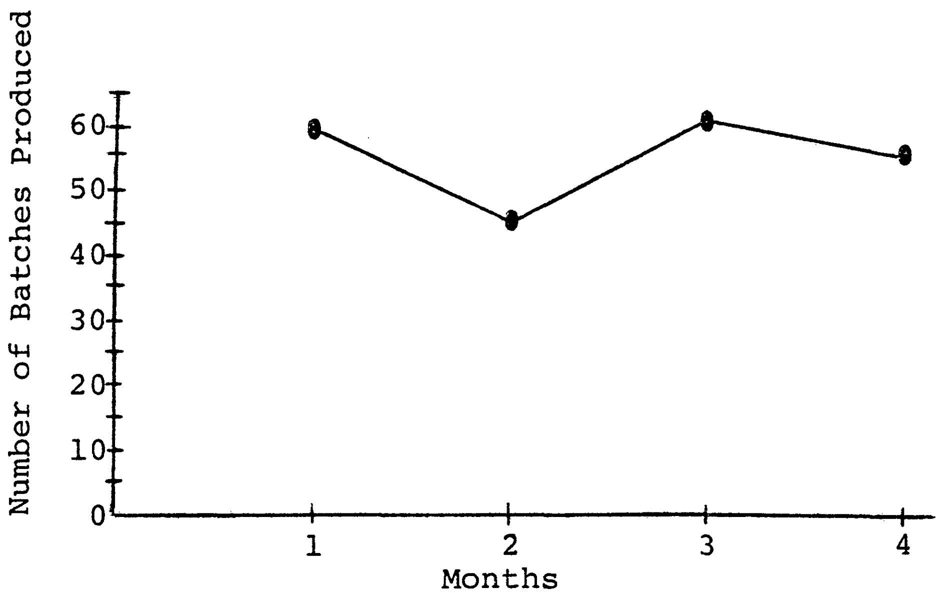
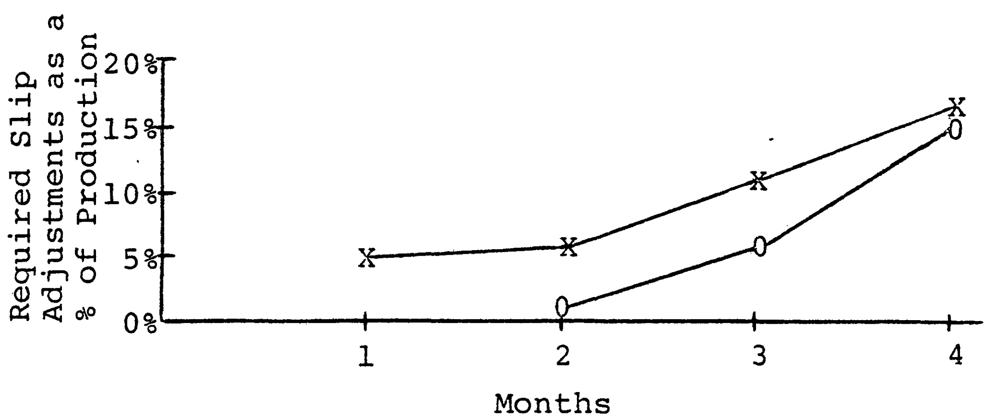
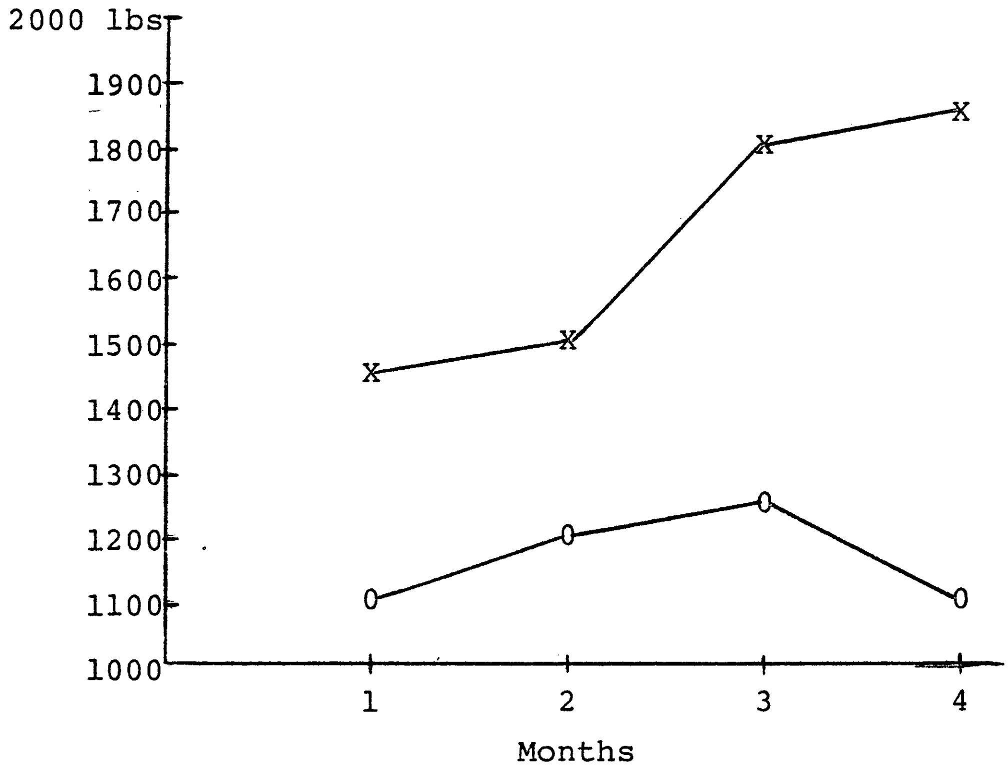


FIGURE A(2)
Percentage of Slip Adjustments Required



X—X Fine-tuning slip adjustments
0—0 Salvaging slip adjustments

FIGURE B
Predicted vs Actual Pounds
of Good Tape Cast per Batch



0—0 Actual pounds of good tape cast per batch
X—X Predicted pounds of good tape cast - based on actual pounds of slip milled and actual current monthly average casting yield

After using the material accountability system in CMP and casting for four months several things became apparent. If predictability was desired, it was necessary to dump each batch to a specific weight to provide a consistent starting point for determining the number of pounds of good tape to be expected from casting. With this information about predicted pounds of tape cast and the number of batches cast each day, fluctuations in batch yields will be immediately visable and, thus, any problems that exist can be corrected in a more timely fashion.

Secondly, production information on the progress through casting of each batch was a much more useful indicator of production success and problems than recording total daily production yield information. This is so for the simple reason that most problems are localized to one specific batch when they occur. Having records separated by batch reduces the tendency to view a production problem as being wide-spread when, in fact, it is specific to only one or two batches. This helps provide accurate information as to the nature and extent of production problems and when immediate attention from management is required, as well as facilitating determination of where improvement efforts will have the largest positive impact on profits.

Lastly, quantitative data, previously unavailable, can be collected from the use of the accountability system that will reduce the time required to determine the results of changes in the production process.

Liquid Scrap Batches

Liquid scrap batches are merely collections of uncastable and residual slip from previous batches that require remixing in the mill. They mill for ten hours to assure uniform mixing. Since tape scrap batches mill 3600 pounds of material and the liquid scrap batches milled only 3000 pounds of material, an increase in the size of liquid scrap batches seemed possible.

The charge of liquid scrap batches was increased to 3500 pounds in April 1979. This charge amount increased mill utilization by increasing the batch size without reducing the number of possible liquid scrap batches per week significantly. Using a 3500 pound charge still allows production of two liquid scrap batches per week. This is an important consideration for milling 17 batches per week. The slip characteristics were not changed at all by this increased charge. All liquid scrap batches milled since April have had a 3500 pound charge.

50/50 Batches

A certain nameless director of the production process speculated on the usefulness of mixing both new and recycled raw materials to form a batch of slip. The obvious advantages would be higher quality slip due to the more uniform distribution of the particle sizes in the resulting slip. Resulting research produced a new formation type that led to a mill scheduling method that was superior to the established scheduling method.

Time constraints precluded extensive test batch runs of all combinations of 30 percent virgin material--70 percent recycled tape scrap, 40%-60%, 50%-50%, 60%-40%, and 70%-30%. Pilot research indicated 50 percent virgin-50 percent tape scrap batches produced good tape at substantial savings. Twenty-seven 50/50 test batches were successfully produced during a three-month period after the details of the formulation had been worked out. These 27 test batches produced, on the average, 450 more good feet (or about 85 pounds) of tape per batch than virgin batches did during the same period of time. Milling 50/50 batches can reduce the daily requirement for tape scrap up to 50 percent compared to milling only tape scrap batches. In addition, the 50/50 batches are loaded with 3300 pounds of material and require only 25 hours milling time. An added advantage of using 50/50 batches is that it then becomes feasible to consistently schedule slip production to meet the 17 batch per week requirement. This was accomplished through the development of the VedaKat Scheduling Method discussed below. Table II is a comparison of virgin, 50/50, and tape scrap batches.

Table II

Comparison of Virgin, 50/50, and Tape Scrap Batches

	Virgin	50/50	Tape Scrap
Loading time	1 hr	1 hr	2 hr
Milling time	40 hrs	25 hrs	20 hrs
Amount loaded	3000 lbs	3300 lbs	3600 lbs
Required amount of tape scrap	--	1460 lbs	2864 lbs
Average amount of good tape cost	4950 ft	5400 ft	5600 ft

Initial observations indicated that the amount of tape scrap that was recycled per batch varied from 30 percent to 50 percent of the amount dumped from the mill. Using an established total milling time per batch type, the following values were computed. A virgin batch takes a total of 43 hours to process. A tape scrap batch requires 24 hours, and a 50/50 batch takes 28 hours (see Table III). Since the scrap rate of individual batches ranged from 30 percent to 50 percent, milling time savings using 50/50 batches were developed. Figures C and F represent the lower and upper limits, respectively, of the percentage of tape scrap recycled per batch. Figure D and E depict the normal, or anticipated, range. The actual average percentage of tape scrap recycled per batch for a 4-month period was 38 percent, and results in a savings approximated by Figure E.

Table III

Formulation and Mill Information

Batch Type:	Virgin	Tape Scrap	Liquid Scrap	50%V-50%Scp
Loading Time:	1 hr	2 hrs	1 hr	2 hrs
Milling Time:	40 hrs	20 hrs	10 hrs	10 hrs
Unloading Time:	2 hrs	2 hrs	2 hrs	2 hrs
Total Time	43 hrs	24 hrs	13 hrs	28 hrs

These four figures show that 50/50 batches, in addition to producing better tape, are more economical than the combination of straight virgin and straight tape scrap batches. In addition, since virgin batches produce 3000 pounds of slip and each 50/50 batch produces 3300 pounds of slip, each 50/50 batch produces 14 percent more slip, while requiring only 62.5 percent as long a milling time. The 37.5 percent (28 hrs vs. 43 hrs) increase in milling time efficiency and the 115 percent output is a total net improvement of 43.4 percent of 50/50 batches over virgin batches.

Figure C

10% Scrap Return Per Batch

1 virgin batch results in 0.1 scrap batch

1V ⟶ 0.1 Scp

therefore,

10V ⟶ 1.0 Scp ⟶ 0.1 Scp
100 V ⟶ 10 SCP ⟶ 1.0 Scp

or

100V ⟶ 11 Scp

100 V @ 43 hrs each plus 11 Scp @ 24 hrs each equals a total of 4,564 hrs milling time.

This is an average of 41.1 hrs/batch

17 batches @ 41.1 hrs each equals 698.7 total hrs.

1V ⟶ .1 Scp ⟶ .2 50/50
5V ⟶ .5 Scp ⟶ 1 50/50 ⟶ .1 Scp

therefore,

25V ⟶ 5 50/50 ⟶ 1 50/50 for a total of six 50/50 batches

25 V @ 43 hrs each plus 6 50/50 @ 28 hrs each equals a total of 1,243 hrs milling time.

This is an average of 40.09 hrs/batch

Savings for 17 batches:

298.7 hrs - 691.53 hrs = 17.17 hrs or enough time for one liquid scrap batch.

ABBREVIATIONS:

V equals virgin batch
Scp equals scrap batch
50/50 equals 50%V-50%Scp batch

Figure D

30% Scrap Return Per Batch

1V ⟶ .33 Scp
3V ⟶ 1 Scp ⟶ .33 Scp

therefore,

3V ⟶ 1 Scp

3V @ 43 hrs plus 1 Scp at 24 hrs equals 153 hrs or an average of 38.25 hrs/batch

17 batches @ 38.25 hrs equals 650.25 hrs.

1V ⟶ .33 Scp
2V ⟶ .67 Scp ⟶ 1 50/50 plus .15 SCP plus .33 Scp

therefore,

2V ⟶ 2 50/50

2V @ 43 hrs plus 2 50/50 @ 28 hrs equals 142 hrs or an average of 35.5 hrs/batch

17 batches @ 35.5 hrs equals 603.5 hrs.

Savings for 17 batches:

650.25 hrs - 603.5 hrs = 46.75 hrs.

Figure E

40% Scrap Return Per Batch

```
1V ──→  .4 Scp
2V ──→  .8 Scp
3V ──→ 1.2 Scp ──→ 1 Scp plus .2 Scp
4V ──→ 1.6 Scp ──→ 1 Scp plus .6 Scp
                   plus .4 Scp
```

therefore,

```
4V ──→ 2 Scp
```

4V @ 43 hrs plus 2 Scp @ 24 hrs equals 220 hrs, or an average of 36.67 hrs/batch

17 batches @ 36.67 hrs equals 623 hrs

```
1V ──→ .4 Scp
2V ──→ .8 Scp ──→ 1 50/50 plus .3 Scp
                    plus .4 Scp
              ──→ 2 50/50 plus .2 Scp
                    plus .4 Scp
              ──→ 3 50/50 plus .1 Scp
                    plus .4 Scp
              ──→ 4 50/50 plus .4 Scp
```

therefore,

```
2V ──→ 4 50/50
```

2V @ 43 hrs plus 4 50/50 @ 28 hrs equals 198 hrs or an average of 33 hrs/batch

17 batches @ 33 hrs equals 561 hrs.

Savings for 17 batches:

623 hrs - 561 hrs equals 62 hrs.

Figure F

50% Scrap Return Per Batch

1V $\longrightarrow$ .5 Scp
2V $\longrightarrow$ 1.0 Scp $\longrightarrow$ .5 Scp
3V $\longrightarrow$ 1.5 Scp $\longrightarrow$ 2 Scp

therefore,

3V $\longrightarrow$ 2 Scp

3V @ 43 hrs plus 2 Scp @ 24 hrs equals 177 hrs, or an average of 35.4 hrs/batch

17 batches @ 35.4 hrs equals 601.8 hrs.

1V $\longrightarrow$ .5 Scp $\longrightarrow$ 1 50/50 plus .5 Scp
$\longrightarrow$ 2 50/50 plus .5 Scp
$\longrightarrow$ 3 50/50 plus .5 Scp up to
N 50/50 batches

If N equals 16, then

1V @ 43 hrs plus 16 50/50 @ 28 hrs equals 491 hrs, or an average of 28.88 hrs/batch

17 batches @ 28.88 hrs equals 491 hrs.

Savings for 17 batches:

601.8 hrs - 491 hrs equals 110.8 hrs.

VedaKat Scheduling Method

Prior to April 1979 the mill scheduling was done by a CMP operator. This operator determined how much of each material (tape scrap, liquid scrap, and new raw materials) was available at the beginning of each day. Scheduling for Monday through Friday was done daily, while weekends were scheduled on Friday morning. There was no production quota as such. The only requirement was that there be enough slip to keep the casting machines operating. When the schedule was made each morning the time of day was not a factor; the only consideration was what to load once a mill was emptied.

In April a quota of milling 17 batches per week was established by management. This quota necessitated an increase in efficiency. It was possible to keep records and identify, fairly accurately, the amounts of time lost and the reasons for this milling time loss. The major reasons for time loss involved poor operator performance due to poor time management, or "lack of hustle." Another source was time lost at the beginning of each day while waiting for the mill schedule to be developed. A third reason for time loss was due to slip adjustments. Slip adjustments were dealt with effectively by better formulations as discussed earlier.

Scheduling for more than one day at a time was known to be possible since this was already being done for weekends. Such scheduling was deemed desirable to reduce mill idle time at the start of each shift or day. The rub came in when something happened, equipment or personnel related, to cause delays in operations. By scheduling sufficient time to allow for minor delays, based upon data for each phase of the milling process, it should be possible to monitor operator performance more closely and establish standards for performance as well as prevent idle mill time while awaiting determination of mill contents.

The VedaKat Scheduling Method, named after the CMP operator who inspired the development of the method and the author, is a fairly straight-forward one, requiring knowledge of the milling process more than anything else. It involves consideration of both time scheduling and personnel scheduling. When the time requirements for loading, milling, and unloading the mills are known, a simple scheme can be developed.

In order to do this, information about the batch types and weighing and loading procedures was needed. This information was obtained while the author worked as a CMP operator for two weeks. Since the materials were weighed while the mills were grinding, the time it took to do this for a batch was not pertinent to reducing mill idle time, but the time needed to load and dump a mill was important. Loading time is dependent on the batch type. Mill dumping took approximately the same amount of time regardless of batch size or type, and can be assumed constant. The actual milling times are known. Using the information in Table III, a combination of batch types was derived to meet the following criteria. The batch type mix for any given week must not require more of any material than is available. Loading and dumping operations can be scheduled for only one mill at a time. The schedule must result in 17 batches per week while also allowing sufficient "slack" time for any unscheduled slip adjustments that may be necessary. This slack time can also be used for preventive mill maintenance where needed. Table IV represents a sample schedule for one mill for one week.

Two separate schedules were developed on the basis of material availability. The quantities of tape scrap and liquid scrap are the only constraints on material availability, since there is a comparative unlimited supply of virgin material. Data for the first seven months of 1979 indicated the average weekly output of 14.5 batches contained six tape scrap and two liquid scrap batches. Figure G shows the first schedule, based on six tape scrap and 2 liquid scrap batches per week. Since each 50/50 batch represents 1/2 of a tape scrap batch, this allows production

Table IV

A Sample Schedule for One Mill for One Week

Day of Week	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Time Off			1 am	1 am	4 pm	8 pm	11 am
Unloading Time		-	2 hrs	2 hrs	2 hrs	2 hrs	2 hrs
Reloaded with Bath	V		TS	LS	HH	LS	--
Loading Time			2 hrs	1 hr	1 HR	1 hr	
Milling Starts	7 a.m.		5 am	4 am	7 pm	11 pm	
Milling Time	40 hrs		20 hrs	10 hrs	25 hrs	10 hrs	

Abbreviations: V - Virgin batch

TS - Tape scrap batch

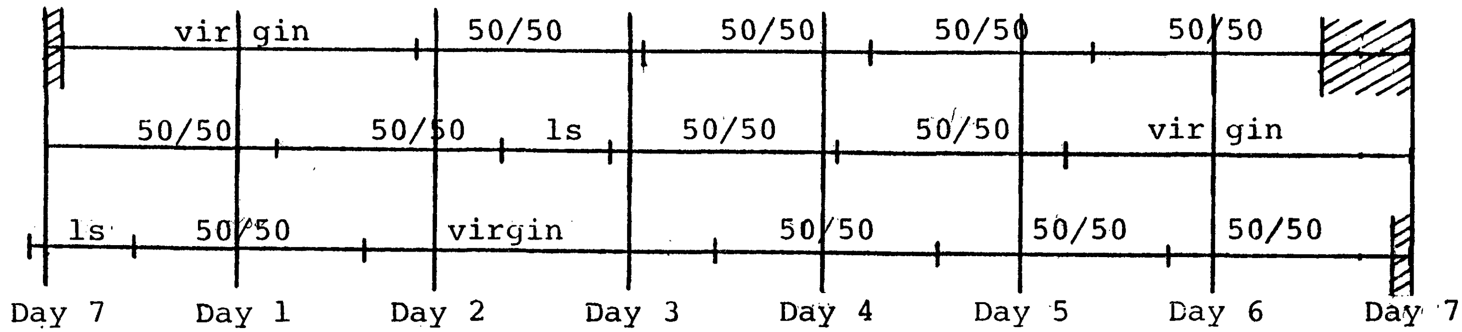
LS - Liquid scrap batch

HH - 50% virgin/50% tape scrap batch

of twelve 50/50 batches per week. Figure H is a schedule requiring the equivalent of 7 1/2 tape scrap batches. Each individual mill schedule must be rotated so that each mill will have scheduled slack time once every three weeks to allow for preventive mill maintenance and slip adjustments.

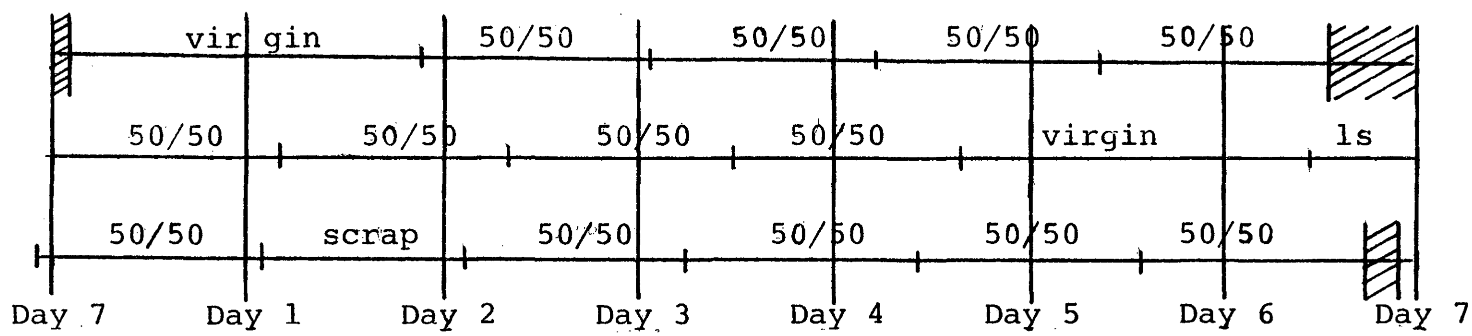
These two schedules can be used separately, or in combination, with any excess material accumulation being used by substitution of different batch types when needed. For example, the accumulation of tape and liquid scrap might be such that using the Figure G schedule for three weeks, then the Figure H schedule for one week, will prevent the accumulation of too much of either material during any given week. It must be pointed out that both schedules require CMP operator coverage 24 hours per day, 7 days per week. It must also be stressed that the scheduled slack time must be observed for a number of reasons. Though an experienced and motivated CMP operator can perform the loading and dumping operations in much less time than the scheduled time, any attempt to tighten the schedule would not permit minor associated problems. For example, sometimes delays occur when the operator must wait his "turn" to use the forklift to move pallets of materials to the mills for loading. Also, observing the scheduled slack time makes each schedule repetitive on a three-week cycle. This enables each operator

FIGURE G
MILL SCHEDULE 1



3 virgin batches(virgin)
2 liquid scrap (1s) batches
12 50/50 batches(50/50)

FIGURE H
MILL SCHEDULE 2



2 virgin batches(virgin)
1 scrap batch (scrap)
1 liquid scrap batch (1s)
13 50/50 batches (50/50)

Idle Mill Time

to know his work load in advance. The same information is useful for evaluating individual operator performance. Sloppy, or haphazard loading, which subsequently necessitates adjustments, or consistently failing to meet scheduled times would indicate to the alert supervisor the possible need for more training or other forms of attention.

The advantages of using the VedaKat Scheduling Method allow a substantial increase in CMP milling capacity. The most obvious is an increase in the number of batches produced weekly. This increase would not be feasible over a long period of time without the use of the 50/50 batches because of the constraints in the availability of tape and liquid scrap. The 50/50 batches produce high quality slip and, more importantly, improve the utilization of tape scrap by 50 percent. Another advantage of this scheduling method is its repetitious nature that allows CNP problems to be easily and quickly spotted. If the number of adjustments increases so that there is no slack mill time available, a problem with loading and unloading or with mill equipment is indicated. Using this scheduling scheme as a guide management will have accurate information, previously unavailable, in the overall performance of the CMP area and will be able to provide support in a more timely fashion.

Casting

Tape casting did not receive as much attention as CMP since it did not have capacity restrictions to the same degree. There are four casting machines, and each machine can handle the production of one mill fairly well. Normally three machines are run continuously, with the fourth used to handle the excess output from the mills. In order to run the casting operation continuously at full capacity the CMP production would need to be at about 19 batches per week. The effort in casting was more in the direction of improving casting yields. Two of the important variables here are operator ability and machine performance.

Operator ability is very important because it can compensate for poor machine performance to a significant degree. The operator is in the best position to determine the cause of machine trouble and correct it in a timely manner. Thus, the operator's ability to spot changes in the tape quality and the cause of the changes plays the biggest role in the resulting batch yield at casting. It is, therefore, important to train casting operators carefully. The variability of performance in the present group of operators definitely influences the amount of acceptable tape produced per batch. Machine performance is also a function of preventive maintenance. This requires an adequate schedule of machine checkups to attend to items before they cause machine failure.

The attention given to the casting area was directed toward improving the output of the casting machines without regard to machine failure due to mechanical breakdowns. A casting machine output of 95 feet of tape an hour was the standard. No basis of rationale for this standard was found; it appeared to be an arbitrary decision. There was apparently a relationship between the machine speed and the drying of the slip. One machine was used to test the effects of different machine speeds and tape drying temperatures. It must be noted that each machine operates somewhat differently because of its age and design characteristics. The testing was undertaken with the understanding that the other machines would have to be "reprofiled" on an individual basis. Only one day was required to determine that a 26 percent increase in machine speed would not have ill affects on tape quality cast on the test machine. The other machines were immediately reprofiled, resulting in increases from 15 to 26 percent in speed per machine. The increases in casting machine speed made it possible to cast more batches--an average of 26 hours per batch resulted, which was a 10-hour improvement over the previous average of 36 hours. This put increased pressure on CMP to produce enough material to keep the casting machines running because of the yield loss that results from complete start-up (or shut-down) of a casting machine when there is no slip to cast. The average loss due to machine start-up (or shut-down) is one to two hours or about 200 linear feet of tape (about 500 substrates).

Improvement was made in the slip formulation that improved the ability to cast tape. A new ingredient, the specifics of which are proprietary, was added at milling that reduced the effects of airflow and shrinkage during drying the casting machines. As the slip comes out under the doctor blade, it is still a viscous liquid, so any excessive air currents will cause rippling and crackling of the tape, which is undesirable. As the slip dries from the top and from the bottom toward the middle, it shrinks, creating uneven stress across the bed of tape. This causes the edges of the plastic sheet under the tape to curl upwards, disturbing the uniformity of thickness of the partially dry tape. Since the tape thickness must be uniform to produce the final product, controlling it during casting is important. The ingredient added to the formulation retards the evaporation of solvents and thereby reduces edge curling. It also reduces the static electricity between the finished tape and the plastic sheet. The result is a dried tape that is easier to take up into rolls from the plastic sheet.

Mention must be made of the impact of the VedaKat Scheduling Method on casting. The main result is increased pressure on the efficiency of the casting operation. In order to effectively use the scheduling method, no delays that are caused by casting can be allowed. Specifically, the casting of batches must be scheduled to ensure that enough pressure pots are available to dump the mills at all times. Having a milling delay because there is nowhere to unload a mill is costly and, with rare exception, never warranted. Casting equipment utilization is low compared to milling equipment utilization because there is an extra casting machine available to handle excess material from CMP. Since there is more capacity in casting than in CMP, casting maintenance can be scheduled so it does not interrupt CMP operations and more than adequately maintain casting equipment in good working order.

Since efficient scheduling of CMP operations is possible, it follows that effective scheduling of casting operations is required to maintain smooth flow of production. With the current amounts of equipment in the two areas, casting can never be the bottleneck unless major casting equipment failure is present.

Summary

In summary, the greatest potential for any increase in production capacity is in CMP and casting because this is where the greatest restrictions on capacity exist. The efforts to make the batch sizes more consistent and to improve mill scheduling met with moderate success. There is still room for improvement provided adequate testing is undertaken. This is also true for the batch formulation with the chemical additive that improved the ability to cast the slip into tape. The new 50/50 formulation was thoroughly tested and the realization of its benefits will only come when the formulation is integrated into regular production so that the VedaKat Scheduling Method can be implemented.

CHAPTER 3. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The procedures undertaken during this study were designed to improve production efficiency and capacity in the production of ceramic substrates. Initial analysis indicated the major limitations to higher output were in the CMP and casting areas. In CMP the limitations were under utilization of milling capacity, inadequate CMP operator coverage, need for an improved method of mill scheduling, and an unnecessarily large proportion of batch adjustments. Casting limitations consisted of inappropriate scheduling of equipment so that casting-caused milling delays were avoided, and a need to improve casting quality through adequate personnel training and improved casting methods.

The material accountability system discussed on page 10 made it possible to account for every pound of material milled by weighing all materials dumped from the mills and all good tape cast. It led to an enhanced understanding and more precise identification of problematic areas, such as the reasons for variation in batch sizes. It also provided a basis for comparison between predicted yields and actual results of production output in CMP and casting, which was not available prior to the implementation of this system in April 1979.

The increase to 3500 pounds of the amount loaded into a mill for the liquid scrap batches increased the mill utilization by 17 percent and did not decrease the number of these batches that can be produced weekly.

The development of a new batch formulation combining virgin and recycled materials discussed on page 19 resulted in an increase in milling efficiency of 43.4 percent over that possible with the use of only virgin and tape scrap batches. This new 50/50 batch type also permitted the development of the VedaKat Scheduling Method that increases the net milling capacity 14 percent by increasing the number of batches produced from 14.5 to 17 batches per week. The VedaKat Scheduling Method also allows scheduling of mill maintenance in advance as well as allowing enough slack time for slip adjustments that may be necessary.

The casting machine efficiency was increased 15 to 26 percent for the four casting machines by increasing the machine speeds. Casting quality was improved with the use of the ingredient added to batches, discussed on page 35.

This research effort has demonstrated that a number of technical and procedureal improvements can significantly increase production performance in CMP and casting. Technical refinements themselves, however, do not increase production; they have to be implemented. A glaring and consistent observation during the course of this study is that there is a lack of support and communication from upper level management to develop a consistent and accountable improvement program. Daily and weekly changes in direction, and conflicting directives and goals produce confusion and frustration at lower levels. Rather than a teamwork approach to improving production, the politics of blaming, scapegoating, and power-plays divert attention from the stated goal of increasing production efficiency. Until a clearly defined production improvement plan is delineated and agreed to by all levels, is pursued consistently without daily variations, is of a duration sufficient to permit development of a sound data base, and allows decisions to be made on objective evaluation, the fire-fighting approach to problem solving will continue. It would seem that the development of a plan and consistency of adherence to that plan would be essential for meaningful and production-related performance evaluation not only for hourly personnel, but also for supervision and management. Such a plan and its consistent and systematic pursuit would indicate to lower echelons that mere lip service to enhanced production has been replaced by a real commitment to improved production.

Recommendations for Future Research

Future efforts need to be directed toward solving the problems, especially mill idle time, that prevented thorough testing of the mill scheduling method and the use of the material accountability system to reduce variations in batch sizes. Specifically, a minimum of one month of scheduling the mills using the VedaKat Method would be necessary before the method could be fine-tuned and adjustments made, especially with respect to performance standards for mill loading and adjustments. Furthermore, the possiblity of producing consistent batch sizes (via enforcement of dump weight limits) would also seem to warrant a one-month test period. This weight limit enforcement can be done in conjunction with, or separately from, the testing of the mill scheduling method. If the two are tested simultaneously, the interactive effects would be present, and, therefore, would also add valuable information concerning the usefulness of the two methods.

Further study directed toward various combinations of virgin-tape scrap mixtures (i.e., 40%V-60%Scp and 60%V-40%Scp) would seem profitable, especially in conjunction with milling times and weights.

Research directed toward increasing the loaded weights of virgin and tape scrap batches could result in additional capacity improvements. This is especially true of virgin batches. Since the 50 percent virgin-50 percent tape scrap batches are smaller than the current tape scrap batches, it seems reasonable that they could also be increased in size without jeopardizing the slip quality. If an increase in size proves unsatisfactory, a reduction in milling time may be feasible, and could give the same results. The ability to produce acceptable products from the 50/50 batches indicates that 100 percent virgin batches need not necessarily be milled 40 hours. This idea will remain a definite possibility until it is disproved through systematic testing. Reducing the milling time for tape scrap batches will be possible when a good method is found to reduce the size of the scrap prior to milling. A "tape chopping" machine, similar to a pecan chopper, would probably reduce the size of the tape scrap enough to allow loading the mill without packing the scrap in so tightly. With the scrap in smaller pieces at the outset, less milling time would be required to break the scrap down to a sufficiently small size for the actual blending action to occur, and reduced loading time might also result.

Additional testing of the chemical additive for improving the ability to cast slip is needed. The results of the two test batches already run indicate that casting yields can be improved substantially. This testing would probably take three to six months (to allow the test batches to be processed completely through the production process). Experimentation with the amount of the chemical added to all formulations is recommended so the effect on final product quality can be determined.

Finally, attention to other areas, punching, handling, and kiln loading could reduce damage and reject rates of the substrates. A standardization of final inspection and calibration with the consumer's specification would insure maximum output by minimizing statistical Beta error.