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STATISTICAL ANALYSIS OF THE RESULTS
OF A SERIES OF EXPERIMENTS ON THE
CARBON-FOAM PRODUCTION PROCESS

W. E. Lever (ORNL)
J. M. Gerwels
C. W. Holland

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE Y-12 PLANT

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OAK RIDGE Y-12 PLANT
P. O. Box Y
OAK RIDGE, TENNESSEE 37830

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ABSTRACT

A statistical analysis was performed on the results of four experiments conducted on the carbon-foam production process. The factors which appeared to be most important in the production of carbon-foam castings have been identified.

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SUMMARY

A series of four experiments involving the production of carbon-foam green castings was conducted and analyzed. Each of the experiments was designed in a manner so that valid statistical significance statements could be made regarding the experimental results.

The purpose of these experiments was to determine a setting for the controllable variables of the production procedures, so that a high degree of quality for the castings would result.

The results of the experiments are summarized in the sections that follow.

Experiment 1 - The first experiment was a screening experiment, using sixteen green castings. The purpose of this experiment was to investigate eleven controllable variables (factors) which were thought to be important in the production of acceptable green castings. On the basis of the evaluation of the sixteen green castings made under experimental conditions, five factors were selected for future investigation; the remaining six factors would be held fixed.

Experiment 2 - The next experiment was designed to investigate each of the indicated five factors along with their interactions. This experiment used a total of 64 green castings.

The results of this experiment indicated that the combination of a turntable speed of 10 rpm and a blade immersion depth of 1/2 inch from the bottom of the mixing container produced near-perfect castings with regard to black streaks, cracks, and fractures. However, the experimental results also indicated that the factor of mixing time needed further investigation, especially in regard to unacceptable voids.

Experiment 3 - While the blade immersion depth and turntable speed were held fixed at 1/2 inch and 10 rpm, respectively, the effects of four levels of mixing time (30, 40, 50, and 60 seconds) were studied. Also in this experiment, the decision was made to investigate two other mixing blade speeds (300 and 400 rpm). This experiment used 24 green castings.

The results of the experiment indicated that a blade speed of 400 rpm produced significantly less acceptable voids, while mixing times of 30 and 40 seconds produced significantly less unacceptable voids. Also, there were fewer unacceptable voids at 400 rpm, but the difference was not significant.

None of the 24 castings fractured or had cracks or black streaks. This result strengthened the idea that the combination of blade depth and turntable speed was the most important factor.

Experiment 4 - The last experiment was designed to investigate four levels of blade speed (400, 800, 1,200, and 1,600 rpm) while the mixing time was held fixed at 30 seconds. The remaining factors were held fixed as in the third experiment, but a change was made in the chemicals. Thus, the results of this experiment are valid only for the new chemical composition. The design used a total of 24 castings.

The results of this experiment indicated that high-quality castings could be made with blade speeds of 400 to 800 rpm, but that the quality dropped off sharply for blade speeds in the range of 1,200 to 1,600 rpm.

Valid statistical significance statements could not be made in regard to the effect of chemical changes. However, subjective comparisons could be made based on the part of the previous experiment, conducted when the blade speed was set at 400 rpm. This subjective comparison indicated that chemical changes produced little change in the quality of the castings.

INTRODUCTION

Production of carbon-foam castings is beset with various problems which lead to the rejection of many of the castings at various stages in the process. Many of the castings are rejected because of four types of failures which occur in the production of the green castings, namely: (1) large, cigar-shaped voids in the interior of the castings; (2) streaks of unmixed material running through the castings (black streaks); (3) cracks, both inside and on the top of the castings; (4) fractures; that is, some castings break into two pieces.

In order that a higher percentage of acceptable green castings can be made, controlled experiments were needed to conduct a statistical investigation of the known controllable factors which affect the production of green castings. With the exception of one experiment, all were to follow standard designs such as may be found in "Design and Analysis of Industrial Experiments".⁽¹⁾

Initial discussions with both production and research personnel led to a long list of controllable and uncontrollable factors of the process. This list is given in the Appendix.

The first experiment was designed only to be a screening experiment from which the apparently more important factors were to be selected. Then, a more detailed series of experiments would be run to conduct a thorough statistical investigation of the much smaller list of factors.

In order that each casting made during the experiments would be evaluated in the same manner, the following procedure was adopted: Each casting was to be sliced into a series of one-inch panels and responses were to be observed on only one side of the panel. From each casting, five responses were to be recorded: (1) the number of cigar-shaped voids which are within specifications (less than 0.1 in^2 in area); (2) the dimensions of each cigar-shaped void which exceed specifications; (3) the number of panels on which black streaks occur; (4) the number of panels in which cracks occur; (5) the occurrence of a fractured casting.

A short description of the production process of green castings, as it was proposed at the beginning of this series of experiments, will be given here. This is being done to illustrate some of the variables of the process, both controllable and uncontrollable.

The first step in the process was to form a premix of urethane and related chemicals in a 50-gallon drum. The amount of each chemical was predetermined, but there may have been slight variations in the composition of the chemicals due to variations in the manufacturing processes. The premix was constantly mixed so that the chemicals could not separate. The mixing process possibly caused temperature changes in the premix, which could affect the reaction time of the chemicals. Also, various chemical changes could possibly occur as the age of

the premix increased. Some attempts to correct these changes, such as adding water and a catalyst to the premix, were made at various times.

When a casting was to be made, a predetermined amount of the mixture needed for one casting was drawn from the drum into a mixing container of suitable size. The mixing can was then placed on a turntable where the correct amount of additional chemicals, necessary for the foaming process, was added to the mixture. Next, the proper type of mixing blade was lowered to a specified depth in the mixture and the turntable and the mixing blade rotated in opposite directions at the required speed and for a set time period.

Following the mixing process, the mixture was poured in the correct manner into the desired type of mold which had been heated in a predetermined manner. During the pouring step, the mold may or may not have been agitated in a specified manner.

Finally, the mixture foamed in the mold, creating the green casting.

DESCRIPTION OF THE EXPERIMENTS

THE SCREENING EXPERIMENT

The initial investigation of the process of making green castings of carbon foam led to the long list of conceivable variables given in the Appendix. This list contained 14 variables which could be controlled at the time. From these 14 controllable variables, 11 factors were selected or constructed for an initial screening experiment. For each of the 11 factors, two levels were selected. A list of the factors and their levels is given in Table 1. The levels of the factors were selected so that they would cover the region where the factor was thought to have an effect on the process.

Table 1
FACTORS AND THEIR LEVELS FOR THE SCREENING EXPERIMENT

Factor	Level One	Level Two
Type of Mold	Single-Unit Mold	Double-Unit Mold
Heating of Mold	Heat Bottom of Mold Only	Heat Both Sides and Bottom of Mold
Type of Mixing Blade	Turbine Conn Blade Only	Two Blades—Turbine Conn Blade on Top and Standard Conn Blade on Bottom
Diameter of Blade and Rotation Speed	6 Inches at 300 rpm	4 Inches at 800 rpm
Distance of the Mixing Blade from the Bottom of the Mixing Can ⁽¹⁾	1/2 Inch	1 1/2 Inches
Time of Mixing	30 Seconds	60 Seconds
Turntable Speed	10 rpm	40 rpm
Position of the Mixing Can on the Turntable	On Center	Off Center
Speed of Pouring the Mixture from the Mixing Can into the Mold	Slowly	Quickly
Manner in which the Mixture is Poured from the Mixing Can into the Mold	Onto a Single Spot	In a Circular Manner
Hitting the Mold Against the Floor	No	Yes

(1) Applied only to the bottom blade when two blades were used. The top blade, when used, was set at a fixed depth.

The statistical design of the experiment was based on the theory and the applications given by Plackett and Burman⁽²⁾ and Stowe and Mayer⁽³⁾, respectively. The design required that 16 castings be made under controlled conditions.

Since this design was meant for screening experiments only, the results of the experiment could only be used to see if a factor had a statistically significant effect on the

process and could not be used to consider the effects of interactions between the factors. Thus, the results of this experiment will not be discussed in detail.

The results indicated that only five of the eleven factors had a statistically significant effect on one or more of the five responses, namely: (1) heating of the mold; (2) distance of the mixing blade from the bottom of the mixing can; (3) time of mixing; (4) turntable speed; (5) speed of pouring the mixture from the mixing can into the mold.

INVESTIGATION OF THE FIVE SIGNIFICANT FACTORS

Based on the information gained from the screening experiment, the decision was made to investigate the five significant factors in a more detailed manner. Again, each of the factors was permitted to assume only two levels, and the same levels used in the screening experiment were considered appropriate. The remaining six factors were held at the levels given in Table 2.

Table 2
LEVELS OF THE FACTORS HELD CONSTANT

Factor	Level
Type of Mold	Double-Unit Mold
Type of Mixing Blade	Standard Conn Blade
Size and Speed of Blade	6-Inch Blade Rotated at 300 rpm
Position of the Mixing Can on the Turntable ⁽¹⁾	On Center
Manner in which the Mixture is Poured from the Mixing Can into the Mold	In a Circular Manner
Hitting the Mold Against the Floor	No

(1) The turntable was moved. Thus, while the mixing can was on center in relation to the turntable, it was off center in relation to the mixing blade.

In order that all the main effects and interactions of the five factors could be considered, a total of 32 castings would have been required. But, at that time, the research and production personnel could not produce a total of 32 castings in one day. Thus, to avoid a day-to-day difference which would confound the estimates of all the effects, a design was chosen which only confounded the estimate of the fifth-order interaction with the day-to-day difference. The remaining estimates of the interactions and of the main effects of the five factors would be unaffected by any day-to-day effect.

This design required that 16 castings be made on each of two days under controlled conditions. In order that a better estimate of the random variation present in the process could be obtained, the experiment was replicated twice. Thus, a total of 64 castings (at a rate of 16 per day for four days and made under controlled conditions) were required for this experiment.

Since each casting was evaluated for five separate responses, the results of this experiment will be considered initially in five parts: (1) acceptable voids, (2) unacceptable voids, (3) black streaks, (4) cracks, and (5) fractures.

Acceptable Voids

The results of the experiment indicated that none of the five factors significantly affected the number of acceptable voids in the 64 castings. This result may have been due to a trend over several days which indicated that the number of acceptable voids was decreasing with time. Although this trend was not statistically significant, it may have been large enough to mask the effect of some of the factors or some of their interactions.

Unacceptable Voids

Mixing time was indicated as the only factor or interaction which significantly affected the presence or degree of unacceptable voids. This result was illustrated by the fact that only two of the 32 castings made at a mixing time of 30 seconds had unacceptable voids in them, while 18 of the 32 castings made at a mixing time of 60 seconds had unacceptable voids in them. This result indicated that as far as unacceptable voids were concerned, the 30-second mixing time appeared to be the better of the two levels of mixing time considered.

Black Streaks

The presence and the degree of black streaks in the castings was indicated to have been significantly affected by the two factors, blade position and turntable speed, and also by their interaction. An illustration of these effects is given in Table 3. If the interaction between the two factors is not considered, the best results seem to occur when the turntable speed is at 10 rpm and the blade position at 1 1/2 inches from the bottom of the mixing can. However, when interaction effects are considered, the combination of 10 rpm and a 1/2-inch blade position seems to be superior.

Cracks

Analysis of the presence and number of cracks in the castings produced results which were very similar to the analysis of black streaks. Again, the two factors (blade position and turntable speed) and their interaction were indicated as significant effects. Table 4 summarizes the results of those effects.

Table 3
NUMBER OF CASTINGS WITH BLACK STREAKS

Turntable Speed (rpm)	Blade Position (inch)		Total
	1/2	1 1/2	
10	0 of 16	5 of 16	5 of 32
40	15 of 16	7 of 16	22 of 32
Total	15 of 32	12 of 32	27 of 64

Again, the combination of a 10-rpm turntable speed and a blade position of 1/2 inch from the bottom of the mixing can was indicated as superior. Also, as with black streaks, consideration of only the main effects would have again led to conclusions which would not have been as good as the one indicated when the interaction was considered.

Table 4
NUMBER OF CASTINGS WITH CRACKS

Turntable Speed (rpm)	Blade Position (inch)		Total
	1/2	1 1/2	
10	1 of 16	4 of 16	5 of 32
40	13 of 16	6 of 16	19 of 32
Total	14 of 32	10 of 32	24 of 64

Fractures

Results of the experiment indicated that the mixing-time and turntable-speed factors and the interaction of turntable speed and blade position had significant effects on the presence of fractured castings. Effect of the mixing time was illustrated by the fact that of the 32 castings which were made at a mixing time of 30 seconds, 22 fractured. Only seven of the 32 castings made at the mixing time of 60 seconds fractured. Thus, of the two levels of mixing time considered, the 60-second mixing time was indicated as superior with regard to the fracturing of castings.

Table 5 shows the effect of the interaction between the turntable speed and blade position.

Again the combination of 10 rpm for the turntable speed and 1/2 inch for the blade position was indicated as superior.

An analysis of the five responses indicated that the interaction between blade position and turntable speed could possibly be used to control the presence of cracks, black

Table 5
NUMBER OF CASTINGS FRACTURED

Turntable Speed (rpm)	Blade Position (inch)		Total
	1/2	1 1/2	
10	2 of 16	4 of 16	6 of 32
40	14 of 16	9 of 16	23 of 32
Total	16 of 32	13 of 32	29 of 64

streaks, and fractures in castings, while not significantly affecting the presence of voids in the castings. However, the analysis indicated that the level of the mixing time which gave the best results for unacceptable voids gave the worst results for the fractures. Thus, it was apparent at that time that the factor of mixing time would have to be investigated in greater detail.

INVESTIGATION OF THE MIXING TIME AND BLADE SPEED

Since the results of the previous experiment indicated that a problem existed in regard to the amount of time required to mix the chemicals, the possibility was suggested that rotating the mixing blade at a higher speed might permit the chemicals to be properly mixed in a shorter time period. By doing this, it might be possible to resolve the conflict between voids and fractures with regard to the mixing time.

To investigate the mixing time more extensively, along with the new factor of blade speed, a new design was considered. In this design, four levels of mixing time were used (30, 40, 50, and 60 seconds) and two levels of the new factor—blade speed (300 and 400 rpm). The previous experiment had used a blade speed of 300 rpm. This design required that eight castings be made.

Again, in order that a better estimate of the random variation present could be obtained, the design was replicated three times. Thus, a total of 24 castings, at a rate of eight castings per day for three days, were made under controlled conditions.

The levels of the four other factors used in the previous experiment were fixed at the levels shown in Table 6.

Table 6
LEVELS OF THE FACTORS HELD CONSTANT

Factor	Level
Blade Position	1/2 Inch from the Bottom of the Mixing Can
Turntable Speed	10 rpm
Mold Heating	Bottom Only
Pouring Speed	Quickly

Results of this experiment will be considered in three sections: (1) number of acceptable voids, (2) presence and degree of unacceptable voids, and (3) number of cracks, black streaks, and fractures.

Number of Acceptable Voids

Only the blade speed tended to have a significant effect on the number of acceptable voids in the casting. The results of the experiment indicated that a blade speed of 400 rpm appeared to produce far fewer acceptable voids than a blade speed of 300 rpm.

Presence and Degree of Unacceptable Voids

Again, as in the previous experiment, the factor of mixing time proved to have a significant effect on the presence and degree of unacceptable voids. Also, as before, the longer mixing times produced more castings with unacceptable voids than did the shorter mixing times. This result was illustrated by the fact that of the seven castings which had unacceptable voids, six occurred at mixing times of 50 and 60 seconds. The seventh casting, made at a mixing time of 40 seconds, had a minimal void in it. Also, there was a significant day-to-day effect. But, there was no trend apparent since the second day was the worst.

Number of Cracks, Black Streaks, and Fractures

The impression gleaned from the previous experiment—that the combination of a 10-rpm turntable speed and a blade position 1/2 inch from the bottom of the mixing can reduces the number of castings with cracks, black streaks, and fractures—was greatly strengthened. This conclusion was reached because none of the 24 castings made in this experiment exhibited cracks, black streaks, or fractures.

The results of this experiment indicated rather strongly that the combination of turntable speed and blade position had a much more decisive effect on the control of cracks, black streaks, and fractures than did the mixing time. Since there was a significant difference between the effects of the two blade speeds, another experiment was considered to investigate the factor of blade speed in greater detail.

INVESTIGATION OF HIGHER BLADE SPEEDS WITH A CHANGE IN CHEMICALS

The previous experiment yielded indications that blade speeds had a significant effect on the number of acceptable voids in a casting. To further investigate the effect of the blade speed on the quality of a casting, an experiment was designed to compare four blade speeds: 400, 800, 1,200, and 1,600 rpm. The factor of mixing time, which was varied in the last experiment, was held fixed in this experiment at 30 seconds. The remaining factors were held fixed as before, except that the amount of chemicals

added to the mixing container just before the mixing was begun was increased by 10 percent.

This design required that four castings be made, one at each of the different blade speeds. As before, the design was replicated three times to give a better estimate of the variation present. Thus, this experiment required that 12 castings be made under controlled conditions. In this case, all three replicates were completed in one day.

Since a change in chemicals was made, the results of this experiment are valid only for the new chemical composition. However, subjective comparisons may be made in the case of the blade speed of 400 rpm, since that blade speed has appeared in a previous experiment with the lesser amount of the chemical. But, the point must be stressed that statistical significance statements cannot be made about this subjective comparison.

The results of this experiment will be discussed in two cases: (1) the number of acceptable voids, and (2) the presence and degree of unacceptable voids, black streaks, and fractures.

Number of Acceptable Voids

The results of this experiment indicated that blade speed significantly affects the number of acceptable voids in a casting. The castings made at 400 and 800 rpm were highly superior to those made at 1,200 and 1,600 rpm. Table 7 points out the difference.

Table 7
AVERAGE NUMBER OF ACCEPTABLE VOIDS PER CASTING

Blade Speed (rpm)	Number of Castings	Average Number of Acceptable Voids per Casting
400	3	123
800	3	122
1,200	3	1,167
1,600	3	1,500

Presence and Degree of Unacceptable Voids, Black Streaks, and Fractures

None of the castings exhibited unacceptable voids, black streaks, or cracks; however, one casting made at 1,600 rpm did fracture.

Based on the results of this experiment, indications were that a blade speed in the range of 400 to 800 rpm should be considered and that all thoughts of much higher blade speeds should be forgotten.

In regard to the change in the chemicals used, the blade speed of 400 rpm used in the previous experiment produced castings with an average of 120 acceptable voids per casting, a result that compared favorably with the average number of acceptable voids found in this experiment at blade speeds of 400 and 800 rpm. But, statistical significance statements may not be made regarding this comparison.

CONCLUSIONS

This series of experiments strongly indicates that carbon-foam green castings can be made that are relatively free of unacceptable voids, cracks, black streaks, and fractures. Also, indications are that the number of acceptable voids can be reduced.

The results of these experiments indicate that of the eleven factors considered, the most important are: (1) combination of turntable speed and blade position; (2) time used in mixing the chemicals; (3) rotation speed of the mixing blade.

The levels of these four factors which give the highest quality castings are given in Table 8.

Table 8
INDICATED LEVELS OF THE MOST IMPORTANT FACTORS

Factor	Level
Turntable Speed	10 rpm
Blade Position	1/2 Inch from the Bottom of the Mixing Can
Mixing Time	30 Seconds
Blade Speed	400 to 800 rpm

The levels of the other factors were fixed at various stages of this series of experiments. These levels are given in Table 9.

Table 9
LEVELS OF THE LESS IMPORTANT FACTORS

Factor	Level
Type of Mold	Double-Unit Mold
Mold Heating	Bottom Only
Blade Type	6-Inch Standard Conn Blade
Position of Mixing Can on the Turntable ⁽¹⁾	On Center
Pouring Speed	Quickly
Pouring Manner	In a Circular Manner
Hitting the Mold Against the Floor	No

(1) The turntable was placed off center in relation to the mixing blade.

REFERENCES

- (1) Davies, O. L., Editor; Design and Analysis of Industrial Experiments; Hafner Publishing Company, New York, New York (1960).
- (2) Plackett, R. L. and Burman, J. P.; "The Design of Optimum Multifactorial Experiments", Biometrika, 33, pp 305-325 (1946).
- (3) Stone, R. A. and Mayer, R. P.; Use of the Plackett-Burman Design for the Screening of Process Variables in Catalyst Preparation, Manuscript of an Unpublished Paper Presented at the Eighth Annual Fall Conference of the American Society for Quality Control, Chemical Division, Gatlinburg, Tennessee; November 5 and 6, 1964.

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APPENDIXCONCEIVABLE VARIABLES^(a)

I. MIXING OF CHEMICALS

1. Type of Blade (c)
 - a. Standard Conn
 - b. Turbine Conn
 - c. Propeller
 - d. Two Blades
2. Diameter of Blade (c)
3. Blade Immersion Depth (c)
4. Rotation Speed of Blade (c)
5. Time of Mixing (c)
6. Diameter of Mixing Can (c)
7. Rotation Speed of Turntable (c)
8. Position of Mixing Can on Turntable (c)
9. Method of Scraping the Sides of the Mixing Can During the Mixing of the Chemicals (c)

II. VARIABILITY OF URETHANE

1. Manufacturer (c)
2. Variability of R Component (u)
3. Variability of T Component (u)

(a) Those variables marked with (c) were controllable at the beginning of this series of experiments and those marked with (u) were not.

4. Variability of Surfactant (u)

5. Variability of Catalyst (u)

III. VARIABILITY OF VARCUM

1. Hydroxyl Number (u)

2. Acid Number (u)

3. Viscosity (u)

4. Variability of Polymer Composition, Molecular Weight (u)

IV. TEMPERATURE

1. Ambient

2. Chemicals (u)

3. Heating of Mold (c)

V. TECHNIQUE OF POURING CHEMICALS FROM THE MIXING CAN INTO THE MOLD

1. Speed of Pouring (c)

2. Location of Pour into Mold (c)

3. Time Elapse between Termination of Mixing and Beginning of the Pour (c?)