fectively to keep the products under control within the system. If at the same time the technician lacks confidence in the testing and acceptance procedures, the system virtually disintegrates.

Under these circumstances, when the acceptance point is at the plant, the propensity for graft is greatly increased. When the acceptance is more distant (as in the case of cores taken from the finished product and tested in central laboratories), more involved legal battles are often encountered. In any event, the theory and practice of good statistically based quality control are completely undermined. I feel that this was the status of the Addenda A specification just before the release of the 1970 yellow Addenda A.

It is important that good delineation and coordination be established between acceptance testing and quality control testing. A good quality control program should be somewhat independent of the acceptance system. Under the existing Addenda A, acceptance testing dominates and indeed, in most cases, overpowers what I consider to be good quality control testing. In plants that have lower rates of production, there is a tendency not to do any testing until a "lot sample is due" because of the strong emphasis on acceptance samples. Indeed, if tolerances were properly established and confidence in correlation with central laboratory testing was ensured, I would rather see acceptance testing performed by the central laboratory from field samples. However, I do not wish to minimize the problem of developing such a system (especially the problem associated with a central laboratory type of operation such as that used in New Jersey in recent years). If such a system could be effectively developed, however, a more comprehensive quality control program could be used at the plant where the technician could monitor the entire operation and not just some narrow aspect of it.

Essentially, a statistically based quality control program is a vast improvement over the typical one-sample (pass or fail) system of the past. If it is to be truly effective in maintaining the quality of the product, confidence in the system must be upheld by the establishment of realistic tolerances and testing methods. It is essential that all of the involved parties thoroughly understand the theory and application of the system.

REFERENCES

1. K. Afferton. New Jersey Department of Transportation Standard Specification Analysis—1969 Addenda A. New Jersey Department of Transportation, Jan. 1970.
2. K. Afferton. Composition and Air Void Requirements for Bituminous Mixtures. New Jersey Department of Transportation, Memorandum Rept., July 7, 1972.

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Process Control of Mineral Aggregates

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An aggregate process control program currently used by a multiplant aggregate producer is described. The success of the program is credited to the rapid feedback of test data directly to plant management. The program uses district and plant laboratories staffed with from one to three technicians for conducting daily tests for gradation control and a central laboratory for determining other important properties of aggregates and the products in which they are used. Benefits of the program—including savings that result from minimizing rejections, improved customer relations, and other services performed by the responsible department—are emphasized. The importance of a working knowledge of basic statistical concepts by both aggregate technicians and plant management is stressed.

The process control system described in this paper is used to control the quality of aggregates at 21 plants of the Standard Slag Company. These include 11 blast furnace slag plants, 5 limestone plants, and 5 sand and gravel plants. The program is directed by the Materials Control and Research Department with a staff of 20 full-time and 5 part-time employees. Testing facilities include six district and plant laboratories, each staffed with from one to three technicians and equipped to conduct daily determinations for gradation and unit weight, and a central laboratory equipped for determining most physical and chemical properties specified for the aggregates as well as the performance of the finished products in which the aggregates are used.

Since gradation is the primary aggregate property over which the plant manager has control and since failure to comply with the specified gradation is the primary cause for rejecting aggregate from approved sources, this paper deals primarily with the control of aggregate gradation during production, handling, and recovery from stock.

The founders of our organization realized more than 50 years ago the benefits of producing quality aggregates in terms of a favorable return on investment and repeat sales. During our first encounter with statistical or end-result specifications during the late 1960s, it became apparent that increasing the effectiveness of our process control system would be a sound investment in terms of minimizing costly rejections and product liability claims and improving customer relations by supplying aggregates that have a minimal variation in specified properties. Accomplishing this meant devising a system of rapid testing and reporting that would provide immediate feedback of production control test results to plant management so that process adjustments, when necessary, could be implemented and checked for their effectiveness before a sizable quantity of nonspecification material was produced. The system now in effect was presented to the company's executive committee and received their total support.

The basic procedure used for gradation control is shown in Figure 1. Basically, each aggregate size processed in each operation is sampled in accordance with a prescribed sampling plan that stipulates sampling frequency and location and the minimum sample size. If the gradation of the sample complies with that specified, no adjustment is made. If the first sample fails to comply, a second sample is immediately selected to verify the results of the first and, at the same time, to

Figure 1. Procedure for gradation control.

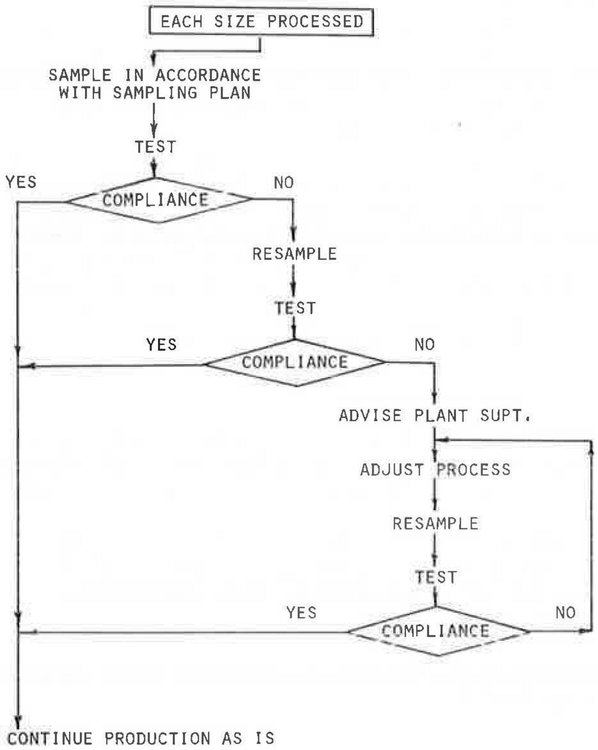


Figure 2. Responsibilities of district laboratory technicians.

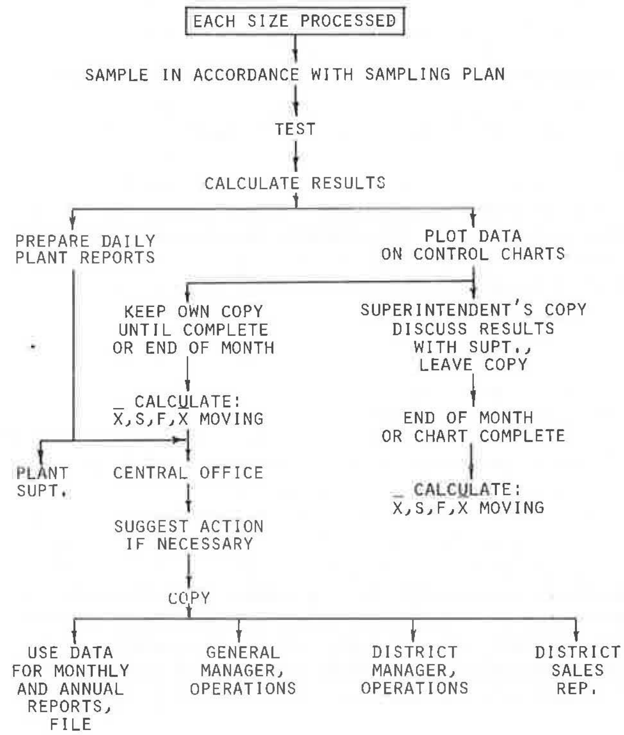


Figure 3. Plant aggregate report.

Report No. 122 Date DECEMBER 21, 1977
Material A. C. B. F. SLAG Plant 15
Sampled by R.J.M. Tested by R.J.M.

Source (mill or stock)	Sieve Analysis									
	M	M			M	M				
Sample No.	243	244			245	246				
Size No.	57	57	SPEC.		8	8	SPEC.			
Sieve Size	Total Percent Passing Square Opening Sieves									
4"										
3½"										
3"										
2½"										
2"										
1½"	100	100	100							
1"	96	97	90-100							
3/4"										
1/2"	42	45	25-60		100	100	100			
3/8"					94	93	85-100			
No. 4	4	5	0-10		21	18	10-30			
No. 6										
No. 8	2	2	0-5		4	3	0-10			
No. 10										
No. 16					2	1	0-5			
No. 20										
No. 30										
No. 40										
No. 50										
No. 60										
No. 80										
No. 100										
No. 200										
F.M.										
% Wash Loss	0.6				1.0					

Weight, lb/cu ft										
Loose (Dry)	78				76					
Compact (Dry)	85				84					
Loose (Damp)										
Compact (Damp)										
% Moisture										

Sample Wt., lbs	34	31			18	15				
Approx. tons rep.	250	250			110	110				

Shipped Via:										

REMARKS:

Figure 4. Control chart.

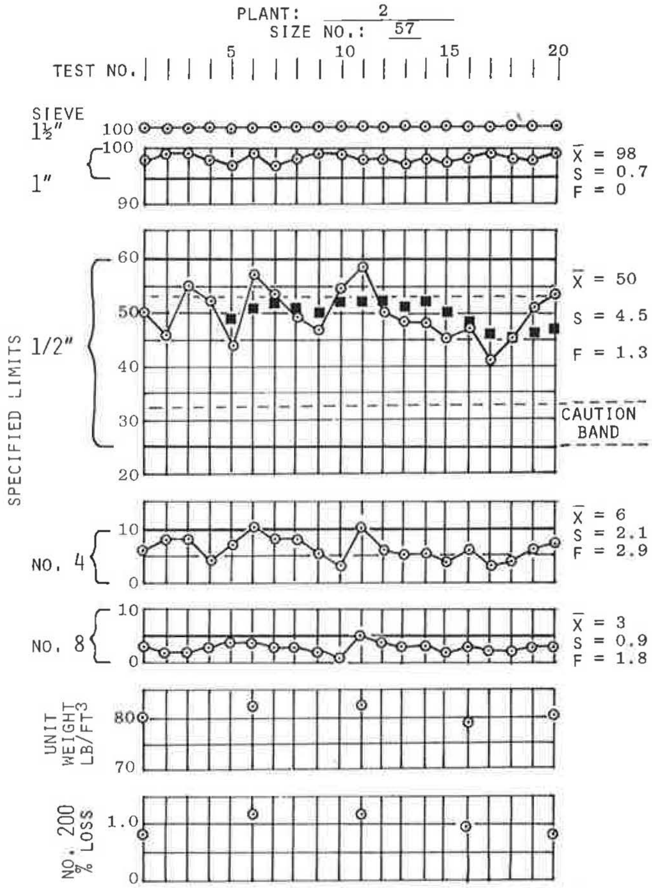
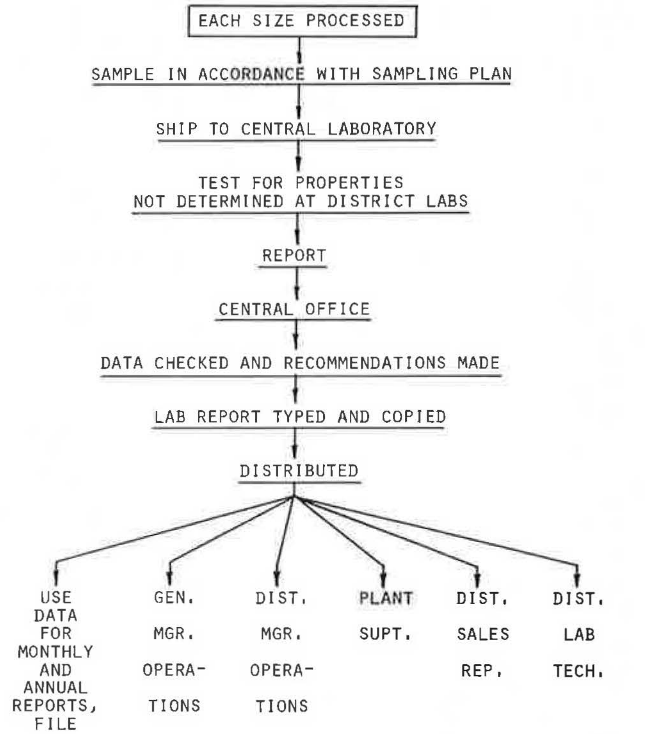


Figure 5. Sampling procedure for central laboratory tests.



reduce sampling or testing error. If the second sample also fails to comply with the specified gradation, the technician advises the plant superintendent that an adjustment in the process is necessary. Once the adjustment is made, the aggregate is resampled to confirm that the adjustment corrected the condition. If it did not, the adjustment process is continued until compliance with the specified gradation is achieved.

Figure 2 shows an outline of the responsibilities of the district laboratory technicians. It should be noted that sampling and testing encompass all of the steps outlined in Figure 1.

District technicians are responsible for calculating the test data and preparing two reports. The daily plant report (Figure 3) is a comparison of the gradations of current production with the specified gradings (because the reports cited here use U.S. customary units of measurement, no SI equivalents are given). To provide immediate feedback of test results, the technician discusses the results and supplies the plant superintendent with his or her copy immediately after completing the daily tests. The technician also sends a copy to the central office for further action and distribution as shown in Figure 2. In addition, immediately after completing the daily tests, the technician brings the control charts up to date. The control charts (Figure 4) show up to 25 sieve analyses of a given aggregate size and provide the plant superintendent with a running account of the variation of each size processed.

Again, to provide the necessary immediate feedback of test results to the plant superintendent, the technician keeps the superintendent's copies of the control charts in a looseleaf binder in the plant office and brings them up to date on the day the tests are conducted. The technician also brings his or her own copies up to date at the same time. Note that, besides the upper and lower specification limits for each sieve, caution bands are included to alert the superintendent that he or she may be operating too close to the specified limits.

In preparing the control charts, a circle is plotted for each test result. Also, starting with the fifth test result, a square is plotted on the control sieve to represent the moving average of five results. The moving average reduces the variation of individual test results and is used to predict causes of potential problems, such as wear of production components.

At the end of each month, the technicians calculate the average, standard deviation, and potential failure for each sieve specified based on a normal curve. These figures are shown at the right of each plot. Each technician is provided with a statistical calculator for ease in determining these parameters. The technicians then send their copies to the central office (Figure 2) where, if necessary, further action is suggested. Copies are then distributed to the general manager of operations, the district manager of operations, and the district sales representative.

District technicians also select samples of all sizes produced at each operation at prescribed intervals and ship these to the central laboratory (Figure 5) to be tested for specified properties not determined at the district level. A typical laboratory report is shown in Figure 6.

The quality control program generates five reports. In addition to the daily plant report, the laboratory report, and the control charts already mentioned, the information from the daily plant reports are tabulated by the department secretaries on a monthly report (Figure 7). The average, standard deviation, minimum, maximum, range, and potential percentage of failure are computed by using a tape-programmed calculator. During December of each year, the data from the monthly

Figure 6. Interoffice aggregate report.

Report Number 412 — Date 11-14-77
Sample of Limestone C.P. — Date Rec'd 10-14-77
Source 22 — Sampled by Shelly 10-10-77

Sample No.		1146	1147	1148	
Size No.		8	10	610	
	SIEVE ANALYSIS, TOTAL PER CENT PASSING				
4"					
3½"					
3"			(a)	(a)	
2½"					
2"					
1½"				100	
1"				89	
¾"				71	
½"		100		52	
⅜"		92	100	39	
No. 3(¼")					
No. 4		11(c)	99	23	
No. 6					
No. 8		3	83	17	
No. 10				16	
No. 16		2	60	14	
No. 20					
No. 30			44	12	
No. 40			37	11	
No. 50			32	10	
No. 60					
No. 100			22	9	
No. 200			15.7	7.2	
F.M.					
PHYSICAL PROPERTIES					
Wt. lbs./ft.³ Dry loose		84.6	99.2	93.8	
Wt. lbs./ft.³ Dry compact		95.0	107.0	109.8	
Moisture as received %					
Absorption 24 hours %		0.83	1.11		
Bulk sp. gr. dry		2.65	2.64		
Wash test No. 100 Sieve %					
Wash test No. 200 Sieve %		2.1			
DELETERIOUS MATERIAL					
Limonites Soft Centers %					
Limonites Solids %					
Limonites Shells %					
Total Chert %					
Deleterious Chert %					
Shale %		0.4			
Coal and Lignite %					
Color Plate No.					
Thin & Elongated %		16.5			

Sample No.	1146	1147
Soundness		
	Loss %	
1½" - ¾"		
¾" - ⅜"		
⅜" - No. 4	7.3	
No. 4 - 8		10.2
No. 8 - 16		6.3
No. 16 - 30		5.6
No. 30 - 50		4.2
Wtd. Avg.	7.3	5.1

Sample No.	1146	
Grading	Los Ang. Abrasion % Loss	
C	24.2	

Sample No.		
Test	Crushed Pieces	
1 Face		
2 Faces		

Sample No.		
Test		

Moisture Density

Method	698D	1557D
Sample No.	1148	1148
Stability	Good	Good
lbs/ft³		
Wet	142.4	152.8
Dry	135.0	145.4
% Moist.	5.5	5.1

KEY
(a) Complies with specified requirements.
(b) Fails to comply with specified limits.
(c) Borderline in complying with specified limits.
(d) Fails to comply with any standard grading.
(e) Exceeds maximum limit for intended use.
(f) Borderline in complying with maximum limit for intended use.
(g) Fails to comply with minimum limit.
(h) Borderline in complying with minimum limit.
(j) Difference between samples exceeds 0.2 maximum permitted.
(k) Should be reduced, may cause staining if used in concrete flatwork.
(m) Indicates a considerable amount of organic material.
(n) Note amount of magnetic particles.
(p) Fails to comply with minimum amount required.
(r) Borderline in complying with minimum amount required.
(s) Fails to comply with minimum amount required for bituminous surface aggregate.
(t) Borderline in complying with minimum amount required for bituminous surface aggregate.
(u) Laboratory compacted grading indicated to be stable.
(v) Laboratory compacted grading indicated to be unstable.
(w) Not necessarily indicitive of in place density.
(x) Coarse grading of sand may make concrete difficult to finish.

Mgr., Materials Control and Research Dept.

Figure 7. Monthly gradation report.

PLANT: 3
SIZE: 57

SPECIFICATION SIEVE SIZE DATE	NO.	100 1 1/2"	95-100 1"	3/4"	25-60 1/2"	3/8"	0-10 #4	0-5 #8	MOIS-TURE	WASH LOSS
7-20	26	100	100	80	44	18	2		6.0	
"	27	100	98	74	42	17	1			
"	28	100	98	72	40	13	2			
"	29	100	99	82	44	16	3	2		1.2
"	30	100	99	67	34	14	2			
"	31	100	99	81	35	15	7			
"	32	100	99	83	40	18	3			
"	33	100	100	88	41	18	1			
"	34	100	99	85	39	17	1			
"	35	100	99	86	43	13	4	2	6.0	1.5
7-25	36	100	99	79	25	11	3	3		
	$\bar{X}$	100	99	79	41	21	3	2	6.0	1.4
	S	0	0.6	4.5	8.8	8.0	2.3	0.5	0.7	0.2
	F	0	0	--	5	--	0	0	--	--
	HI	100	100	88	53	38	8	3	7.0	1.6
	LO	100	98	67	34	11	0	2	5.0	1.2
	R	0	2	21	19	27	8	1	2.0	0.4
	N =	(36)	(36)	(36)	(36)	(36)	(36)	(4)	(5)	(4)

Figure 8. Annual aggregate report.

LIMESTONE

PLANT: 18 MATERIAL SOURCE: 2

Material Size	57 Hi	57 Low	57 Avge.	8 Hi	8 Low	8 Avge.
Physical Properties						
Unit Weight, lb/ft^3						
Dry Loose	87.8	83.6	85.7	82.0	80.2	81.2
Dry Compact	98.0	93.6	95.6	91.8	89.6	90.7
Specific Gravity,						
Bulk Dry	2.52	2.45	2.49	2.48	2.42	2.46
Absorption, %	3.80	2.93	3.27	4.55	3.75	4.12
Moisture as Rec'd., %	7.0	4.0	5.6	8.0	5.0	6.7
Los Angeles Abrasion, % Loss						
B Grading	31.3	26.3	28.6			
C Grading				31.5	27.7	29.3
Soundness, % Loss	5.5	1.5	3.6	6.7	2.5	5.1
Shale, %	0	0	0	0	0	0
Thin & Elongated, %	3.2	1.6	2.4	9.3	5.0	7.5

Chemical Properties

Constituents	57 Total % by Wt.	8 Total % by Wt.
SiO_2	3.30	3.28
Al_2O_3	0.19	0.19
CaO	33.77	34.63
MgO	16.85	16.96
S	0.084	0.100
Fe_2O_3	0.12	0.15
Ign. Loss	44.61	44.38

Average Gradation — 57: N = 220; 8: N = 108

Sieve Size	57 Spec	57 Avge.	57 Hi	57 Low	57 R	57 S	57 F	8 Spec	8 Avge.	8 Hi	8 Low	8 R	8 S	8 F
1 1/2"	100	100	100	100	0	0	0							
1"	95-100	99	100	95	5	0.9	0							
3/4"		79	99	66	33	4.6								
1/2"	25-60	42	59	26	33	6.2	1	100	100	100	100	0	0	0
3/8"		18	43	5	38	5.8		85-100	95	99	88	10	1.7	0
#4	0-10	2	9	0	9	1.2	0	10-30	17	25	9	14	3.1	2
#8								0-10	3	5	2	3	1.0	0
#16								0-5	1	1	1	0	0	0
Wash Loss, %														
200 Sieve		1.1	1.3	0.7					1.0	1.6	0.5			

TOTAL PERCENT PASSING

Figure 9. Example control charts used in training sessions.

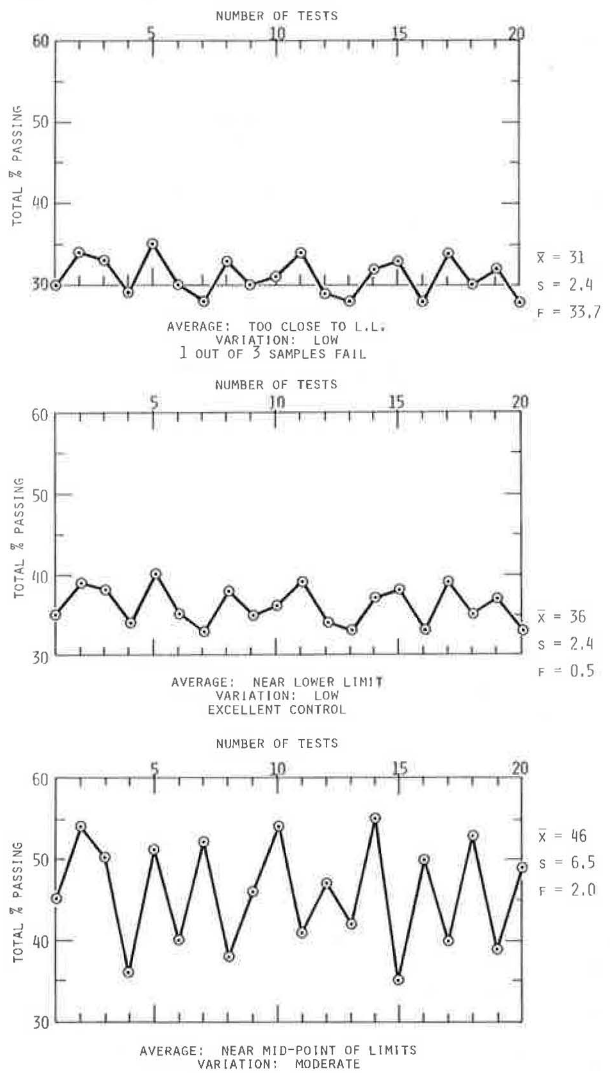
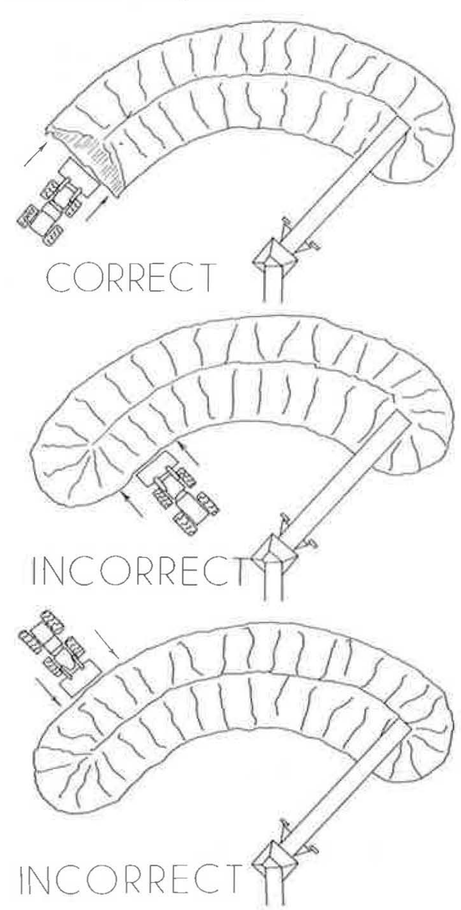


Figure 10. Example stockpile-recovery training aids used in training sessions.



reports are used to construct an annual report for each plant (Figure 8). This report, which shows the yearly average and the variation of properties of each size aggregate processed at each plant, provides valuable data to the marketing, operations, and plant engineering departments as well as a comparison of the capability of each operation to maintain or upgrade the quality of its products.

As a means of continually upgrading the quality control program, all technicians and other members of the Materials Control and Research Department are required to annually attend a 2½-d seminar conducted at the central laboratory that includes sessions on new and proposed aggregate specifications, sampling and testing techniques, and basic statistics and reporting techniques. The technicians also attend seminars sponsored by state aggregate associations and qualify as registered technicians in those states that require certification.

So that the test data that result from the program are thoroughly understood, several half-day seminars that are conducted annually by personnel of the Materials Control and Research Department are held on a district basis for operating personnel and cover such areas as understanding control charts and stockpile recovery to minimize segregation. Typical training aids used in these sessions are shown in Figures 9 and 10.

In an effort to reduce sampling and testing time, we have incorporated automatic sampling and testing in our largest operation, which loads aggregate into lake vessels at 1090 Mg/h (1200 tons/h). At the touch of a button, a sample that weighs approximately 227 kg (500 lb) is sliced from a conveyor-belt transfer point, conveyed to a testing tower, split, sieved, and weighed in separate size fractions. In less than 10 min from the time the sample is taken, the technician has a printout of the gradation. In several of our district laboratories, we dry fine aggregate samples by using microwave ovens that reduce the drying time to about one-third of that required when an electric oven is used. We have recently incorporated the pycnometer method for determining the material finer than the 0.075-mm (No. 200) sieve, which eliminates the necessity for drying the aggregate and saves considerable time.

At this point, the question probably arises, What return on investment can I expect from an efficient process control program? Our experience has demonstrated that the cost of this program ranges between \$0.02 and \$0.03/Mg (\$0.018 and \$0.027/ton). After recently reviewing the program, the chairman of the board of the Standard Slag Company stated that "quality control is the most economic insurance we can purchase."

If a quantity of aggregate is rejected because of failure to comply with the specified gradation after it is incorporated in a project, the aggregate producer could at least incur the cost of production, transportation to the project, placement, and removal. These costs could well exceed the selling price of the aggregate by five or more times. On the other hand, applying process control to one of our plants that produced a large riprap order last year resulted in our technicians handling and testing samples that weighed 2727 kg (6000 lb) or more, but also resulted in shipping more than 272 700 Mg (300 000 tons) of this material without a single rejection.

Additional savings result from having process control personnel perform other services within the organization, such as the following:

1. Testing of equipment performance, which would include analyzing the input and output of crushers to determine their effectiveness in size reduction and reduction of deleterious material to provide the necessary particles with one or more fractured faces and to produce the desired particle shape;
2. Analyzing material from prospective deposits;
3. Providing technicial service for customers; and
4. Management of air and water quality.

In summary, an effective process control program in a corporation must have at least the following essential elements:

1. The total backing of top management,
2. The cooperation of plant production personnel who should immediately report malfunctions in production or loading components since it is not possible for the materials technician to be at all points of production or loading at one time, and
3. Rapid sampling, testing, and reporting procedures to provide immediate feedback of test results to the plant superintendent so that when a process adjustment is necessary the superintendent can rapidly determine whether the adjustment produced the desired effect.

Publication of this paper sponsored by Committee on Quality Assurance and Acceptance Procedures.

Probabilistic Model of Aggregate Plant Production Systems

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A probabilistic model that could be used to evaluate the product characteristics of an aggregate processing plant was developed by combining several theories and mathematical models. The model interest was confined to crushing and screening subsystems. The final model is in the form of a computer programming model that is ready for application to similar plant systems. The computer model will store and compile a series of subroutines; each subroutine performs a specific function, and the whole model analysis procedure is controlled by a main program. A simulator is used to generate desired data to provide for the evaluation of the statistical nature of the output products. Through the use of the high-speed computer, parameters of plant production control—such as raw material feed rate, crusher settings, screen mesh sizes, combining and splitting of certain production flow streams, and appropriate production demand schedules—can be easily evaluated. By varying the data on raw feed material, the model evaluates the tonnage and gradation of the flow streams in the production plant as well as variability.