PHYSICAL AND IMAGE ANALYSIS SIZING OF MINE RUN TACONITE ORE

Coleraine Minerals Research Laboratory

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ABSTRACT

The United States Bureau of Mines (USBM) has developed an image analysis system to determine the size distribution of mine-run taconite ore. The results can be used to evaluate fragmentation so that blasts can be designed for better productivity. The Coleraine Minerals Research Laboratory (CMRL) has been testing the system at Minntac with apparent success, but there was no method available for testing the accuracy of size distributions determined by image analysis. The Iron Ore Cooperative Research Committee approved and funded a project to screen mine-run ore and compare the results to sizing by image analysis.

Three samples, about 2500 tons each, were sized on 6 and 12 inches in a contractor's vibrating grizzly plant at Minntac. Size analyses were extended to 65 mesh by sizing samples of minus-6 inch at the Coleraine laboratory. Between 30 and 60 plus-12 inch pieces from each bulk sample were measured to provide thickness-width-length aspect ratios and to indicate large-fragment dimensions and weights that are encountered in mine-run ore. The average ratio of thickness to width to length was 1.00:2.20:3.21. Fragment volumes ranged from 4 to 80 cubic feet. Weights of these would be approximately 800 pounds and 16,000 pounds.

After the size fractions had been weighed, they were recombined, each sample was loaded into rail cars, and they were dumped at number one primary crusher. The USBM

and CMRL video-taped the ore as it was dumped and processed the tapes through a computer to produce an image analysis size distribution for each of the three samples.

Because of a large discrepancy between the contractor's and the track scale weights, the size analysis of sample number one was not acceptable. The physical size analyses of samples two and three and their corresponding image analysis size distributions were nearly identical for fragment widths of at least 12 inches. Size distributions of mine-run ore by the image analysis system have been proven reliable for evaluating the effective fragmentation of individual blasts for sizes down to 12 inches in width.

ACKNOWLEDGEMENTS

This project was accepted and funded by the Iron Ore Cooperative Committee. Steve Grannes of the USBM developed the entire image analysis system, set up temporary video taping installations for the project, processed video tapes for computer analysis, and wrote special computer programs for image analyses. At Minntac, Tom Kingston, Dennis Hendricks, and mine operations personnel approved, contracted for, scheduled, and performed the bulk sampling, sizing, train loading, and dumping phases of the project.

INTRODUCTION

The Coleraine Minerals Research Laboratory (CMRL) of the Natural Resources Research Institute (NRRI), the United States Bureau of Mines (USBM), and United States Steel (Minntac) have been conducting a project to determine size distributions, or fragmentation, of mine-run ore by computer image analysis. A camera-computer system using USBM software at Minntac's number one primary crusher has been gradually developed since 1990.

The image analysis (I.A.) system produces a size distribution of fragments dumped from each car into the crusher. These data are processed at CMRL to provide a cumulative percent passing distribution based on fragment widths for each train. Train size distributions are traced back to shovel numbers and, therefore, to blast numbers. After being filed by blast number, the size distributions are given to the blasting engineer at Minntac to provide a method to evaluate the effectiveness of each blast. These data provide the best available information with which to evaluate the effects of changes in blast design to improve fragmentation and, therefore, mine and crusher costs and productivities.

Because the image analysis system was new and unproven technology, a method was required to verify the size distribution data as being absolute or to apply corrections to correlate the data to known fragment sizes. Obviously, physical size analyses of material either before or after image analyses would provide the best method of system calibration. However, physical sizing of mine-run taconite ore is difficult and expensive and these measurements have been rare. A screening test on mine-run ore to calibrate the image analysis system was proposed in 1991 by Minntac as a cooperative project with the USBM and CMRL. The project was accepted and $25,000.00 was funded by the Iron Ore Cooperative Research Committee.

MATERIALS AND EXPERIMENTAL WORK

In December, 1991, Minntac trucked two samples, approximately 2500 tons each, to a cleared, level area just north of the rail tracks at the far west ramp and dumped them into separate piles. Sample number 1 was from a lower cherty (LC) blast (91051) being worked by the number 15 shovel, and sample number 2 was from a nearby lower slaty (LS) blast (90067). In January, 1992, another 2500-ton sample was taken from blast number 91051.

Between December 9, 1991 and January 27, 1992, each of the three samples was sized on 6 and 12 inches in a contractor's vibrating grizzly sizing plant. The minus-6 inch and the plus-6 minus-12 inch products from samples 1 and 2 were weighed on a belt scale on the undersize conveyor. The plus-12 inch products from samples 1 and 2 and all three size fractions from sample 3 were weighed on a platform scale with a front end loader. The loader bucket was used to take 10-second cuts of minus-6 inch at the conveyor discharge once an hour. These samples were dumped into drums to provide minus-6 inch composites for sizing on 4, 3, 1-1/2, 3/4, and 1/2 inch and 3, 6, 10, 35, and 65 mesh at CMRL. The contractor reported the weights in plus-12, minus-12 plus-6, and minus-6 inch fractions for each of the three samples. Sizes smaller than 6 inches were normalized, using the contractor's weight percent passing 6 inches, to conform to the contractor's size analysis of each bulk sample.

During sizing operations the CMRL measured lengths (L), widths (W), ar thicknesses (T) of a number of pieces in the plus-12 inch fraction from each bulk sample. These data were used to calculate L to W to T ratios that indicate the degrees of tabularity of larger pieces in each sample. Approximate volumes and weights of these pieces were also calculated for indications of loading and crushing problems that could be encountered with these materials.

Each bulk sample was sized, the fractions weighed and recombined into a stockpile, then loaded into side-dump rail cars and taken to number one primary crusher. Tonnages from the track scale were recorded, and the cars were dumped into the crusher. The USBM and CMRL used three cameras to videotape each car as it was dumped. Two camcorders were used, one with wide-angle lens and the other on a telescopic setting. The electronic camera was used on its normal lens setting.

The videotapes of each sample were processed to obtain a tape of still pictures showing ore being dumped from each car. This tape was then analyzed by image analysis computer software developed by USBM to produce a size distribution, based on particle widths, for each bulk sample.

RESULTS AND DISCUSSION

Physical Sizing of Bulk Samples

The weights, in long tons, of minus-6, 6- by -12, and plus-12 inch fractions determined for the three bulk samples are shown in Table 1. Originally, sizing was planned for only samples 1 and 2. However, because of the unacceptably large weight discrepancy between the contractor and track scale weights of sample 1, bulk sample 3 was taken from the same blast as sample 1. Total contractor and track scale weights and the differences between them are given in Table 1. The reason for the 650-ton difference in weights for sample 1 could not be determined so the size distribution was assumed to be incorrect. A comparison of weights in size fractions of the three samples indicates that most of the missing sample 1 weight could be from the minus-6 inch fraction but such an assumption could not be justified for use in the ensuing calibration of the image analysis system.

The complete size analyses, by the contractor and CMRL (on minus-6 inch), are given in Table 2. Samples 2 and 3 contained surprisingly high percentages of minus-6 inch and even minus-3 inch material. Because these two samples are from different blasts and different geologic units, it appears that percentages of minus-6 inch higher than 40 may be quite common in Minntac blasts.

Sizes and Aspect Ratios of Plus-12 Inch Fragments

The plus-12 inch material was removed from each sample, stockpiled, and CMRL measured the lengths, widths, and thicknesses of a number of pieces larger than 18 inches in width. These measurements were compiled in Tables 3, 4, and 5 for bulk samples 1, 2, and 3, respectively. The only pieces measured were exposed on the surfaces of the plus-12 inch stockpiles and no reasonable estimate of the total numbers or weight percentages in each pile could be made. However, the pieces measured may be quite representative of fragments more than 18 inches wide. Average thicknesses, widths and lengths and their ranges are given at the ends of the tables. All three averages were largest for the pieces measured in sample 2.

Thickness, width, and length measurements were reduced to ratios by normalizing thicknesses to unity and dividing widths and lengths by measured thicknesses. Width and length ratios are listed in Tables 3, 4, and 5, and their means and ranges are given at the ends of the tables. Fragments measured in samples 1 and 3 were more tabular than those in sample 2, evidently because sample 2 is an "interbedded chert" subunit in the lower slaty unit. The overall average ratio of thickness to width to length for the 3 bulk samples is 1.00:2.20:3.21. This is quite close to the generally assumed ratio of 1:2:3.

Approximate volumes and weights of the fragments were also calculated and are listed in Tables 3, 4, and 5. Average volumes and weights and their ranges are given at the ends of the tables. These averages for bulk sample 2 are double those for samples 1 and 3. The smallest fragment volume measured was 4 cubic feet. At 11 cubic feet per long ton its weight was about 800 pounds. The largest piece measured was 80 cubic feet which would weigh about 7.2 long tons or 16,000 pounds. The measurements and calculations in Tables 3, 4, and 5 provide general sizes, weights and shapes of the larger fragments that can be expected in normal run-of-mine ore loaded at Minntac. The largest fragments that were cast aside for secondary breakage are not included, especially in samples 1 and 3. Sample 2 was removed by loader from a blast that had not been worked by shovel. Much of the material that was in frozen blocks made up of wide ranges of fragment sizes. Some of the largest pieces probably would have been sorted by a shovel.

<u>Size Distributions by Image Analysis</u>

The three bulk samples were sized, the fractions recombined in stockpiles, loaded into trucks, and then taken to the far west ramp pocket, where they were loaded into rail cars to be dumped at number one primary crusher. The ramp pocket was emptied as much as possible and trucks dumped all of each sample at the same pocket location to reduce contamination by remnant ores. The train information for the three samples, including the numbers of rail cars and train and total tons, are given in Table 6.

As the cars were dumped at the crusher, it was observed that much of the ore was not free-flowing but broke out as large lumps that consisted of larger fragments packed together by fines. These lumps may have resulted from size segregation during train loading, packing, and possibly freezing the moist fines. This "packed lump" phenomenon has not been observed by CMRL during normal car dumping at the primary crushers.

The still-picture video tape from the wide lens camera at the crusher was run through the image analysis program at CMRL to provide size analyses of all cars for each sized sample. The cumulative size distributions are plotted as percent passing particle widths, in inches, in Figures 1, 2, and 3 for samples 1, 2, and 3, respectively. The numbers of rail cars processed for each sample were 29, 31, and 28. The contractor-CMRL size analyses of samples 2 and 3 are plotted with their imaged analyses for comparison. Because bulk samples 1 and 3 were from the same blast, and the contractor size analysis of sample 1 is not considered valid, the physical size analysis of sample 3 is plotted for reference in Figure 1. Image analysis size distributions for all three samples, using all cars dumped, are coarser than the physically sized reference distributions. However, when the video tape was processed through image analysis using only the rail cars from which material flowed freely (without significant "packed lumps"), finer size distributions were determined for all three samples. These are plotted on the graphs for 10, 3, and 21 cars. The percentages passing 12 inches by physical sizing and by image analysis were nearly identical for samples 2 and 3. These numbers are given in Table 7. The data in the graphs and the table show that system resolution is not generally reliable at fragment widths smaller than 6 to 10 inches. However, the major concern in evaluating blast fragmentation is the amount of larger rock fragments that remain, possibly plus-15 or plus-18 inches in width. The I.A. size distributions for samples 2 and 3 appear to be identical to physical size analyses projected to sizes larger than 12 inches. Physical size analyses of samples 2 and 3 are distinctly different in slope at 12 inches, and the I.A. distributions also demonstrate this difference.

To confirm the validity of I.A. at sizes larger than 12 inches, the fragment widths at 80 percent passing (s80) calculated for sample 2 and 3 physical size distributions were compared with the I.A. sizes at 80 percent passing. These s80 numbers provide an index with which to quantify the comparisons between physical and I.A. size distributions. The physical size analyses for 1.5 inches and larger were plotted on log-log paper and, because both distributions appeared to be linear, linear regression equations were calculated using the logarithms of particle width (X) and cumulative percent passing (Y). Figure 4 shows the plotted points, regression equations and the regression lines. Calculated percentages passing 80 percent are 21.6 and 14.1 inches for samples 2 and 3, respectively. The I.A. s80 particle sizes, by measurements on Figures 2 and 3, are 22.6 and 14.9 inches.

Image analysis at the primary crusher has been proven by the data above to be an accurate determination of the weight percentages of plus-12-inch wide fragments in mine-run ore. The system is in continuous use at one primary crusher at Minntac to accumulate size distributions of blasts for evaluation of blasting effectiveness.

The video camera-image analysis system is recommended to other taconite producers for evaluating blasting practices and possibly reducing drilling, explosives, loading, crushing, and secondary breakage costs.

Table 1

Minntac Bulk Sample Sizing Test

Contractor Size Analyses

Fragment Size, inches	Sample No. 1 Weight Long Tons	Sample No. 1 Weight %	Sample No. 2 Weight Long Tons	Sample No. 2 Weight %	Sample No. 3 Weight Long Tons	Sample No. 3 Weight %
Minus 6	559.38	32.52	1093.39	44.39	1133.63	47.02
6 by 12	447.77	26.03	365.18	14.82	589.41	24.45
Plus 12	713.20	41.45	1004.79	40.79	687.81	28.53
Total	1720.35		2463.36		2410.85	
Track Scale Weights	2370.64		2314.71		2360.36	
Difference, Track Scale Minus Contractor	+650.29		-148.65		-50.49	
% Difference	27.43		6.42		2.14	

Table 2

Physical Size Analyses of Minntac Bulk Samples
Contractor Weights and CMRL Analyses of Minus 6 Inch

Size	Sample 1* Wt % On	Sample 1* Cum Wt % Passing	Sample 2 Wt % On	Sample 2 Cum Wt % Passing	Sample 3 Wt % On	Sample 3 Cum Wt % Passing
12 Inches	41.5	58.5	40.8	59.2	28.5	71.5
6 Inches	26.0	32.5	14.8	44.4	24.5	47.0
4 Inches	8.8	23.7	8.6	35.8	11.5	35.5
3 Inches	5.0	18.7	5.9	29.9	6.5	29.0
1.5 Inches	6.8	11.9	7.8	22.1	10.0	19.0
0.75 Inch	4.0	7.9	5.0	17.1	6.5	12.5
0.5 Inch	1.4	6.6	2.0	15.1	2.3	10.2
3 Mesh	1.9	4.7	2.9	12.3	3.1	7.1
6 Mesh	1.7	3.0	2.8	9.5	2.2	4.9
10 Mesh	0.7	2.3	2.6	6.8	1.5	3.4
35 Mesh	1.5	0.8	4.0	2.9	2.0	1.4

* Sample 1 is included in this table although the observed size distribution is apparently erroneous.

Table 3

Sizes and Aspect Ratios of Measured
Plus-12 Inch Fragments, Bulk Sample 1

Measurements, inches			Aspect Ratio			Volume	Weight,
Thick.	Width	Length	Thick.	Width	Length	Cu Feet	Long Tons
12	38	48	1.0	3.2	4.0	13	1.2
12	31	38	1.0	2.6	3.2	8	0.7
14	56	69	1.0	4.0	4.9	31	2.8
18	32	45	1.0	1.8	2.5	15	1.4
11	21	45	1.0	1.9	4.1	6	0.5
11	24	37	1.0	2.2	3.4	6	0.5
9	22	38	1.0	2.4	4.2	4	0.4
10	29	44	1.0	2.9	4.4	7	0.7
12	20	32	1.0	1.7	2.7	4	0.4
10	28	34	1.0	2.8	3.4	6	0.5
17	38	53	1.0	2.3	3.1	20	1.8
16	32	50	1.0	2.0	3.1	15	1.3
16	37	42	1.0	2.3	2.6	14	1.3
17	37	53	1.0	2.2	3.1	19	1.8
11	24	51	1.0	2.2	4.6	8	0.7
8	37	55	1.0	4.6	6.9	9	0.9
15	32	40	1.0	2.1	2.7	11	1.0
11	28	48	1.0	2.5	4.4	9	0.8
15	44	60	1.0	2.9	4.0	23	2.1
9	45	57	1.0	5.0	6.3	13	1.2

Table 3 - Continued

	Measurements, inches			Aspect Ratio			Volume	Weight,
	Thick.	Width	Length	Thick.	Width	Length	Cu Feet	Long Tons
	17	40	50	1.0	2.4	2.9	20	1.8
	15	29	44	1.0	1.9	2.9	11	1.0
	12	41	63	1.0	3.4	5.2	18	1.6
	11	41	51	1.0	3.7	4.6	13	1.2
	21	56	73	1.0	2.7	3.5	50	4.5
	13	52	61	1.0	4.0	4.7	24	2.2
	15	42	59	1.0	2.8	3.9	22	2.0
	30	36	47	1.0	1.2	1.6	29	2.7
	15	41	53	1.0	2.7	3.5	19	1.7
	16	43	52	1.0	2.7	3.2	21	1.9
	23	44	52	1.0	1.9	2.3	30	2.8
	8	35	45	1.0	4.4	5.6	7	0.7
	22	39	42	1.0	1.8	1.9	21	1.9
33 Fragments							Total	48
Average	14.3	36.2	49.4	1.00	2.70	3.74	15.9	1.45
Range								
From	8	20	32		1.2	1.6	4	0.4
To	30	56	73		5.0	6.9	50	4.5

Table 4

Sizes and Aspect Ratios of
Measured Plus-12 Inch Fragments, Bulk Sample 2

Measurements, Inches			Aspect Ratio			Volume	Weight,
Thick.	Width	Length	Thick.	Width	Length	Cu Feet	Long Tons
21	36	48	1.0	1.7	2.3	21	1.9
27	32	47	1.0	1.2	1.7	24	2.1
23	44	67	1.0	1.9	2.9	39	3.6
17	42	62	1.0	2.5	3.6	26	2.3
29	33	39	1.0	1.1	1.3	22	2.0
30	41	48	1.0	1.4	1.6	34	3.1
12	44	50	1.0	3.7	4.2	15	1.4
17	44	73	1.0	2.6	4.3	32	2.9
31	48	57	1.0	1.5	1.8	49	4.5
13	34	64	1.0	2.6	4.9	16	1.5
15	27	49	1.0	1.8	3.3	11	1.0
22	46	72	1.0	2.1	3.3	42	3.8
23	29	61	1.0	1.3	2.7	24	2.1
32	50	86	1.0	1.6	2.7	80	7.2
19	46	58	1.0	2.4	3.1	29	2.7
21	37	77	1.0	1.8	3.7	35	3.1
11	36	50	1.0	3.3	4.5	11	1.0
25	48	70	1.0	1.9	2.8	49	4.4
15	50	53	1.0	3.3	3.5	23	2.1
16	58	110	1.0	3.6	6.9	59	5.4

Table 4 - Continued

Measurements, inches			Aspect Ratio			Volume	Weight,
Thick.	Width	Length	Thick.	Width	Length	Cu Feet	Long Tons
18	33	41	1.0	1.8	2.3	14	1.3
15	45	45	1.0	3.0	3.0	18	1.6
19	31	53	1.0	1.6	2.8	18	1.6
21	35	43	1.0	1.7	2.0	18	1.7
27	36	51	1.0	1.3	1.9	29	2.6
23	29	37	1.0	1.3	1.6	14	1.3
28	30	53	1.0	1.1	1.9	26	2.3
24	32	40	1.0	1.3	1.7	18	1.6
29	32	35	1.0	1.1	1.2	19	1.7
48	50	55	1.0	1.0	1.1	76	6.9
29	42	64	1.0	1.4	2.2	45	4.1
20	54	64	1.0	2.7	3.2	40	3.6
21	35	53	1.0	1.7	2.5	23	2.0
27	37	37	1.0	1.4	1.4	21	1.9
30	31	42	1.0	1.0	1.4	23	2.1
21	43	52	1.0	2.0	2.5	27	2.5
22	28	50	1.0	1.3	2.3	18	1.6
20	34	38	1.0	1.7	1.9	15	1.4
19	35	49	1.0	1.8	2.6	19	1.7
19	28	29	1.0	1.5	1.5	9	0.8
27	48	55	1.0	1.8	2.0	41	3.7
32	40	43	1.0	1.2	1.3	32	2.9
11	31	50	1.0	2.8	4.5	10	0.9
22	47	77	1.0	2.1	3.5	46	4.2
18	58	78	1.0	3.2	4.3	47	4.3

Table 4 - Continued

	Measurements, inches			Aspect Ratio			Volume,	Weight,
	Thick.	Width	Length	Thick.	Width	Length	Cu Feet	Long Tons
	21	60	109	1.0	2.9	5.2	79	7.2
	18	54	78	1.0	3.0	4.3	44	4.0
	28	40	72	1.0	1.4	2.6	47	4.2
	21	24	38	1.0	1.4	1.8	11	1.0
	21	27	46	1.0	1.3	2.2	15	1.4
	19	31	35	1.0	1.6	1.8	12	1.1
	23	34	63	1.0	1.5	2.7	29	2.6
	33	34	56	1.0	1.0	1.7	36	3.3
	33	46	52	1.0	1.4	1.6	46	4.2
	15	51	75	1.0	3.4	5.0	33	3.0
	25	54	54	1.0	2.2	2.2	42	3.8
	19	44	48	1.0	2.3	2.5	23	2.1
	29	45	90	1.0	1.6	3.1	68	6.2
	23	51	71	1.0	2.2	3.1	48	4.4
59 Fragments							Total	167
Average	22.7	40.1	57.0	1.00	1.92	2.74	31.1	2.83
Range								
From	11	24	29		1.0	1.1	9	0.8
To	48	60	110		3.7	6.9	80	7.2

Table 5

Sizes and Aspect Ratios of
Measured Plus-12 Inch Fragments, Bulk Sample 3

Measurements, inches			Aspect Ratio			Volume,	Weight,
Thick.	Width	Length	Thick.	Width	Length	Cu Feet	Long Tons
17	38	70	1.0	2.2	4.1	26	2.4
18	42	43	1.0	2.3	2.4	19	1.7
11	27	44	1.0	2.5	4.0	8	0.7
14	44	61	1.0	3.1	4.4	22	2.0
28	38	81	1.0	1.4	2.9	50	4.5
19	21	55	1.0	1.1	2.9	13	1.2
24	42	62	1.0	1.8	2.6	36	3.3
14	24	50	1.0	1.7	3.6	10	0.9
21	41	49	1.0	2.0	2.3	24	2.2
10	31	35	1.0	3.1	3.5	6	0.6
8	25	50	1.0	3.1	6.3	6	0.5
17	40	64	1.0	2.4	3.8	25	2.3
13	28	39	1.0	2.2	3.0	8	0.7
11	30	35	1.0	2.7	3.2	7	0.6
10	38	52	1.0	3.8	5.2	11	1.0
19	28	53	1.0	1.5	2.8	16	1.5
17	26	54	1.0	1.5	3.2	14	1.3
22	26	58	1.0	1.2	2.6	19	1.7
11	25	43	1.0	2.3	3.9	7	0.6
14	24	35	1.0	1.7	2.5	7	0.6
16	23	48	1.0	1.4	3.0	10	0.9
18	20	44	1.0	1.1	2.4	9	0.8
17	22	36	1.0	1.3	2.1	8	0.7
13	24	38	1.0	1.8	2.9	7	0.6
19	21	40	1.0	1.1	2.1	9	0.8

Table 5 - Continued

	Measurements, inches			Aspect Ratio			Volume,	Weight,
	Thick.	Width	Length	Thick.	Width	Length	Cu Feet	Long Tons
	12	30	30	1.0	2.5	2.5	6	0.6
	13	32	36	1.0	2.5	2.8	9	0.8
	18	24	67	1.0	1.3	3.7	17	1.5
	22	48	84	1.0	2.2	3.8	51	4.7
	15	27	28	1.0	1.8	1.9	7	0.6
	25	38	41	1.0	1.5	1.6	23	2.0
	16	32	57	1.0	2.0	3.6	17	1.5
	17	36	56	1.0	2.1	3.3	20	1.8
	14	19	39	1.0	1.4	2.8	6	0.5
	19	41	58	1.0	2.2	3.1	26	2.4
	15	42	48	1.0	2.8	3.2	17	1.6
	13	38	43	1.0	2.9	3.3	12	1.1
	15	32	36	1.0	2.1	2.4	10	0.9
	14	20	56	1.0	1.4	4.0	9	0.8
	16	31	48	1.0	1.9	3.0	14	1.3
	17	39	54	1.0	2.3	3.2	21	1.9
	15	28	70	1.0	1.9	4.7	17	1.5
	24	34	60	1.0	1.4	2.5	28	2.6
	16	32	42	1.0	2.0	2.6	12	1.1
	13	24	51	1.0	1.8	3.9	9	0.8
	18	18	29	1.0	1.0	1.6	5	0.5
46 Fragments							Total	65
Average	16.3	30.7	49.4	1.00	1.98	3.16	15.5	1.40
Range								
From	8	18	28		1.0	1.6	5	0.5
To	28	48	84		3.8	6.3	51	4.7

Table 6

Sized Bulk Samples Dumped at No. 1 Crusher

Sample	Date	Engine No.	Number of Cars	Track Scale Weight, tons	Begin Dumping Time
1	12/19/91	949	10	825.51	1215
		1210	10	827.83	1240
		1207	9	717.3	1430
	Total Tons			2370.64	
2	1/10/92	959	10	735.98	1405
		958	10	750.02	1545
		959	10	743.71	1708
		1210	1	85.00	1855
	Total Tons			2314.71	
3	2/4/92	967	8	656.78	1417
		1212	9	758.58	1515
		958	8	688.00	1534
		965	3	257.00	1640
	Total Tons			2360.36	

Table 7

Size Distributions of Bulk Samples by
Image Analysis and Physical Sizing

Cumulative Percent Passing

Sample No.	Sizing Method	Amount of the Sample	Fragment Width 2.5 in.	6.0 in.	7.5 in.	12.0 in.	15.0 in.	20.0 in.	25.0 in.
1	I.A.	29 Cars	6.5	32.8	44.0	66.0	74.9	85.4	91.1
1	I.A.	10 Cars	8.8	44.4	58.2	81.9	90.4	96.8	100.0
2	I.A.	31 Cars	4.3	22.4	31.0	53.1	62.7	73.7	83.5
2	I.A.	3 Cars	4.4	23.6	33.3	58.1	67.2	76.3	81.6
2	Physical	All	27.3	44.4	48.2	59.2			
3	I.A.	28 Cars	4.6	26.1	37.2	60.8	72.3	84.4	89.6
3	I.A.	21 Cars	5.8	29.9	40.7	67.4	80.2	91.4	95.1
3	Physical	All	25.7	47.0	53.1	71.5			

Figure 1

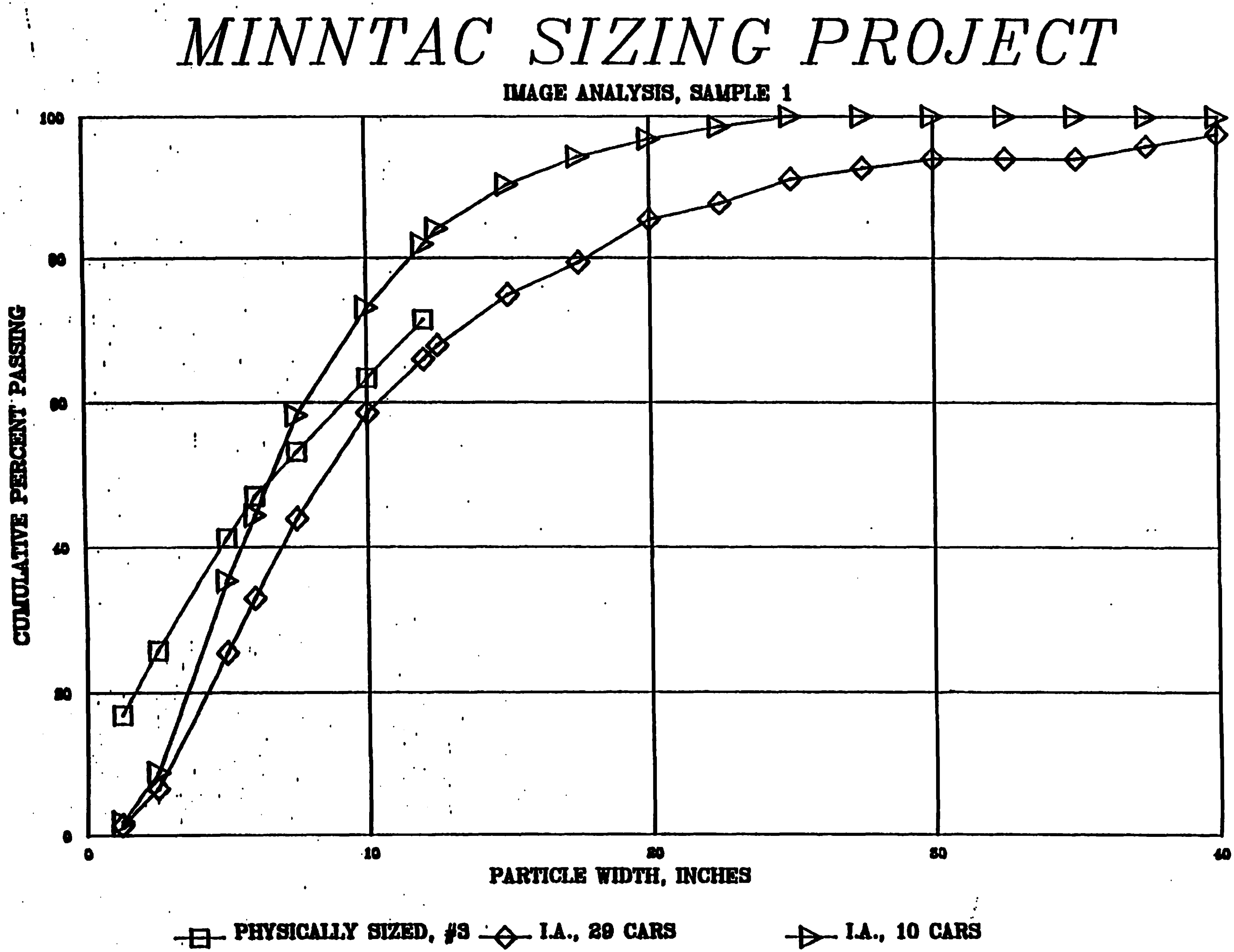
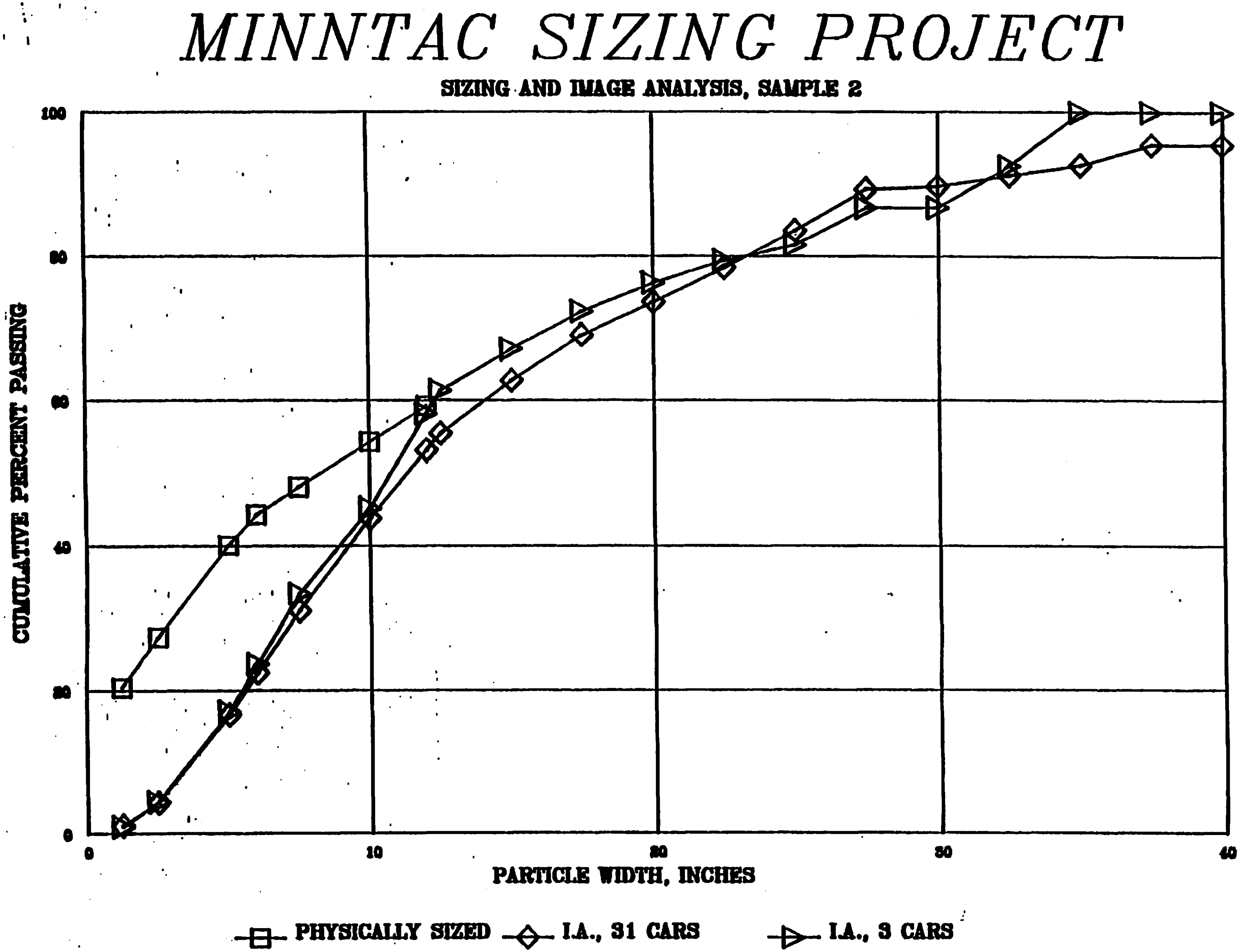

MINNTAC SIZING PROJECT
IMAGE ANALYSIS, SAMPLE 1
CUMULATIVE PERCENT PASSING
PARTICLE WIDTH, INCHES
PHYSICALLY SIZED, #3
I.A., 29 CARS
I.A., 10 CARS

Figure 2



MINNTAC SIZING PROJECT
SIZING AND IMAGE ANALYSIS, SAMPLE 2
CUMULATIVE PERCENT PASSING
PARTICLE WIDTH, INCHES
PHYSICALLY SIZED
I.A., 31 CARS
I.A., 3 CARS

Figure

MINNTAC SIZING PROJECT

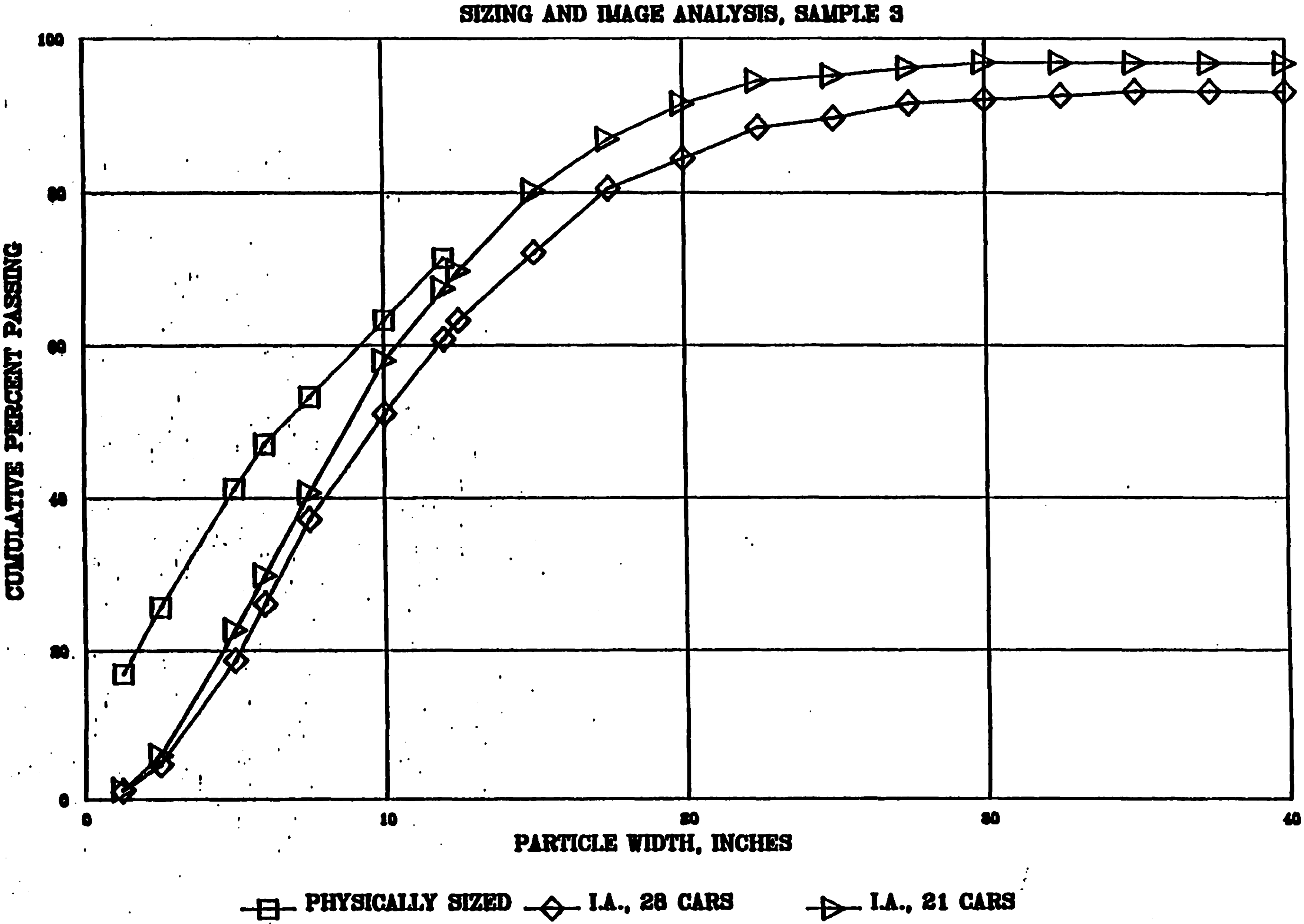
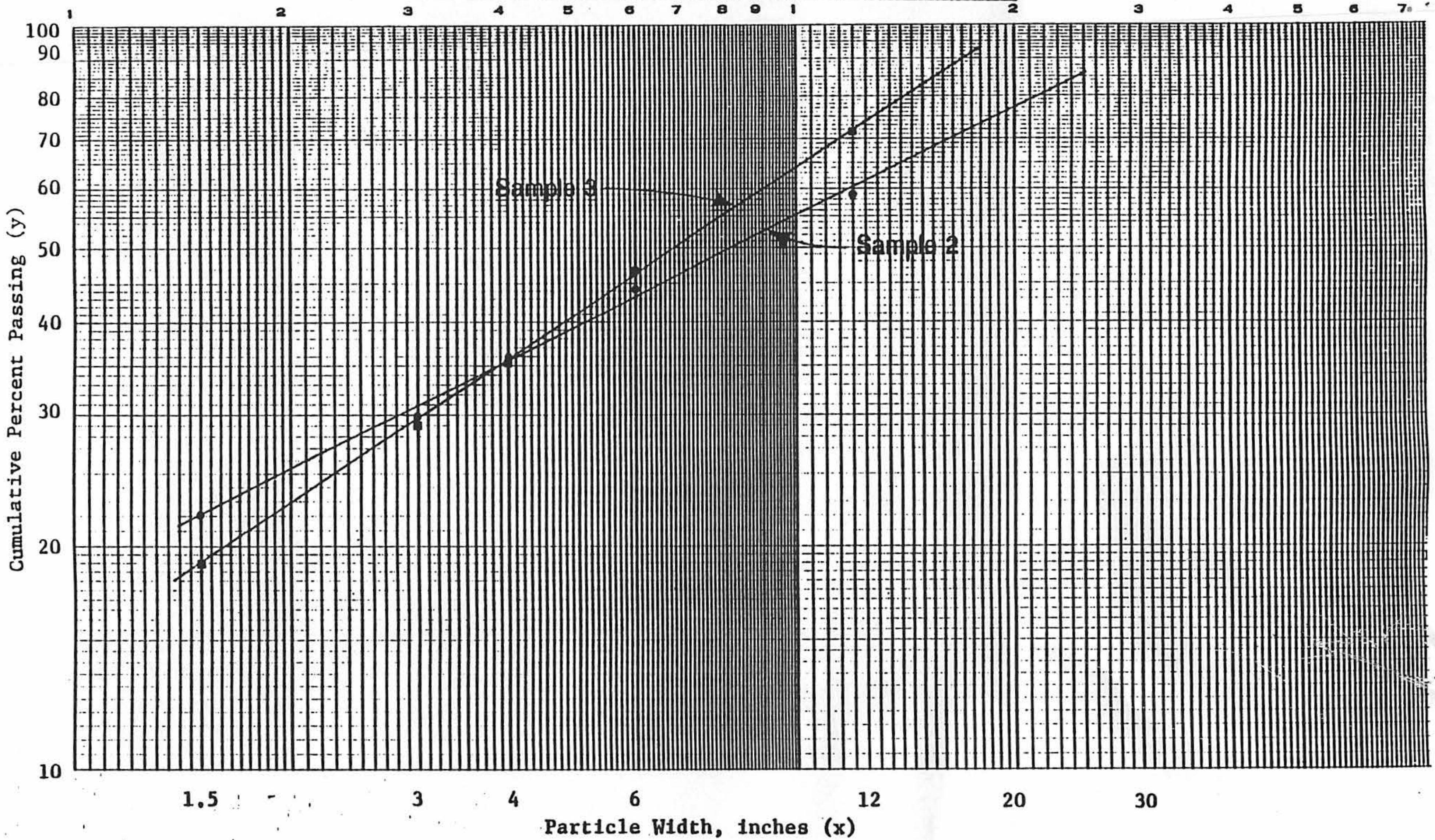


Figure 4

LOG LOG PLOTS OF PHYSICALLY SIZED SAMPLES



Linear Regressions

Sample 2 log y = log 18.1098 + log 3.0424 · log x, x = 21.6 inches at 80 percent passing.
Sample 3 log y = log 14.5585 + log 4.3980 · log x, x = 14.1 inches at 80 percent passing.