Bituminous Mix Design Using Rubber Additives

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ABSTRACT

The work involved design of open-graded bituminous mix with rubber added as: (1) replacement of part of the aggregate and (2) as an additive to a "regular" open graded mix. Reclaimed ground (crumb) rubber and latex were incorporated in the mix and Marshall size specimens were used for high temperature stability (140F) comparison and low temperature (0F) tensile strength evaluation. The rubber additives significantly changed the properties of the mixes with general trend towards reduction of strength with increase in rubber content. The coarser the rubber, the more reduction in strength of the compacted mix.

ACKNOWLEDGEMENT

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The laboratory help given by Daniel E. Etelamaki and other staff members of the Michigan Department of State Highways and Transportation Testing Laboratory is gratefully acknowledged.

DISCLAIMER

Introduction

The main purpose of the research summarized in this report was to examine the design of open-graded bituminous mixes incorporating reclaimed ground rubber and latex rubber additives. Such mixes would be used for the wearing surface on highways to provide increased skid resistance and to reduce hydroplaning. It was hoped that addition of reclaimed ground rubber would improve the mix properties and, in this way, use could be made of the large available quantities of waste rubber.

The control used in this investigation was an open-graded bituminous mix which was selected from a previous report by Tons et al (1).* The control mix was changed by replacing aggregate fractions with similar amounts of rubber. The replacement was done on a substitution basis using the packing volume and rugosity concepts developed by Tons et al (1, 2, 3). Two types of rubber were used; reclaimed ground or crumb rubber and latex. Two different sizes of crumb rubber were involved.

The researchprogram involved the testing of Marshall specimens using the Marshall and split cylinder tests. The Marshall test was used to test specimens at high temperatures (140 F) while the split cylinder was used at low temperatures (0 F). The variables determined were the Marshall stability, flow, split cylinder tensile strength, work energy to failure and air voids.

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* Numbers in parenthesis refer to the references at the end of the report.

Literature Review

The use of rubber as an additive to improve the properties of asphalt is not new. As pointed out by Kaliin (4) the natural rubber companies were experimenting with the addition of rubber to asphalt in the early 1930's. This early work was done with powdered rubber. The development of synthetic rubber made it possible to custom make a latex for a particular use. Kaliin reports that the addition of the proper rubber to asphalt increases the adhesion and cohesion, the low temperature durability and flexibility, and the stability at elevated temperatures.

In Massachusetts (5) during the period from 1949 to 1952 a considerable number of miles of old portland cement concrete pavements were resurfaced with a Standard Class I mix and the same mix treated with three rubber additives: (a) emulsified rubber (latex), 5 percent by weight of asphalt; (b) GRS synthetic rubber powder, 100% passing the No. 20 sieve, 7.5 percent by weight of asphalt; and (c) natural rubber crumbs, 5.75 to 7.5 percent by weight of asphalt. A number of field surveys were made with the main emphasis on crack development. The results after four to seven years of exposure indicated that the performance of the rubber additives did not justify the increase in cost. The Class I mix was a dense mix with low void content and such mixes may not be helped much by the small amounts of rubber added.

Thompson (6) described the work done by the Road Research Laboratory of Great Britain. Ten years (1953-63) of experience using rubberized asphalt and tars in surfacing materials is discussed. In general, the addition of rubber was beneficial. In the case of rolled asphalt surfacings, the addition of 10 percent rubber to the asphalt gave much better results as to crack reflections than the addition of 5 percent.

An investigation carried out at the University of Connecticut by Stephens and Mokrzewski (7) determined that the addition of the proper amount of rubber to dense graded surface mixes did not diminish the performance of the pavement and improved the low temperature performance. There was some loss in Marshall stability as the percent of rubber increased but the stability was always greater than the minimum required. They found that the best mix contained 6.25 percent asphalt and 2 percent reclaimed rubber by weight of aggregate or about 32 percent by weight of asphalt.

During the 1960's and 1970's, rubber was also tried in sealcoats. The work of the Arizona Department of Transportation as reported by Morris and McDonald (8) is especially significant. The paper presented the state-of-the-art as to the design and construction of Arizona's "asphalt-rubber stress absorbing membranes." The membrane utilizes a composition of 25 percent ground tire rubber and 75 percent asphalt. This membrane has been used for seal coats, stress absorbing interlayers and waterproofing membranes. Morris and McDonald reviewed the results from some 2000 lane miles of construction. In general, Arizona's experience with this material has been very satisfying. Beneficial results have been obtained from adding rubber to those mixes and sealcoats.

The use of rubber in open-graded bituminous mixes is relatively new and much has to be learned about the possible benefits. The present investigation was conducted to determine the effect of adding rubber to open-graded-mixes. The Michigan Department of State Highways and Transporation (MDSHT) have made plans for two trial field installations using latex as an additive (9) and a project on ground rubber and reclaimed rubber from old tires (10). This research is intended to compliment the current work by the MDSHT.

Materials Used

In the course of the Laboratory testing program, two series of tests were run. In the first series (Series A) the aggregate was MDSHT 31A crushed gravel remaining from a previous investigation (1). The aggregate used in the second series (Series B) was also MDSHT 31A crushed gravel sieved to have the same size distribution as in Series A. Sand dust was used in Series A while slag filler was used in Series B. The asphalt cement was 85-100 penetration grade.

Two types of rubber were involved in the study, crumb and latex. Two different sizes of crumb rubber were used and are referred to as coarse rubber (No. 4 - No. 16 sieves) and fine rubber (No. 16 - No. 100). Pertinent properties of all materials are given in Tables 1 and 2.

Specimen Preparation

Each specimen, whose uncompacted weight was 1000 grams, was made in a standard Marshall mold using 30 blows of the MDSHT compactor. The asphalt content for the control specimens was 7.2 percent by weight of the total mix, where as for the specimens with rubber the asphalt content varied slightly from 7.2 percent because rubber does not have the same rugosity properties as the aggregate.

The packing volume and rugosity concepts were used in the substitution of rubber for aggregate. In this connection, the FHWA vibratory compaction technique was simulated so that already available data (1) for the MDSHT 31A crushed gravel aggregate could be used. Certain assumptions were made with regard to the necessary rugosity properties of the rubber (Table 2). The amount of flow asphalt was held constant at 3 percent by volume. A sample calculation is given in Appendix A.

In this study there was no emphasis in how the asphalt and rubber might be approximately blended to make the best use of the rubber properties. Instead the crumb rubber was treated as part of the aggregate and the mixing time was the same for both the rubberized and control mixes. For the latex mixes, 15 seconds was allowed to pre-mix the asphalt and natural aggregate before adding the latex. In general, the mixing procedure was that of the MDSHT while the mix design procedure developed by Tons et al (1) was adopted.

Difficulty during mixing was encountered in the high rubber content mixes of Series A. The mixes containing crumb rubber were very tender. Those with latex had rather low workability due to an increase in the viscosity of the asphalt.

Testing

The Marshall and split cylinder tests were used to evaluate the effect of rubber on the mixes. The standard Marshall test procedures were employed. The University of Michigan's testing device was utilized for Series A. Series B were run using the MDSHT's machine which produces a load-deformation record. The tests were conducted at a temperature of 140°F.

The split cylinder test were run on the Baldwin universal testing machine in the MDSHT's testing laboratory. In Series A the loading rate was 6000 pounds per minute. Series B was tested under a controlled deformation of 0.2 inches per minute. Also a load-deformation curve was recorded for this series. The testing temperature for both series was 0 F.

The load-deformation plots obtained for the Series B tests were integrated by means of a planimeter to give the work energy to failure. The energy involved in the Marshall tests for Series A was estimated by assuming a straight line relationship between load and deformation. No attempt was made to estimate this energy for the Series A split cylinder tests.

Each data point is the average of three specimens. The complete testing results are shown in Table 3.

Series A Results

Series A mixes were made treating the rubber particles as aggregate pieces. Thus the total volume (packing volume) of the aggregates and the rubber was always constant while the relative amount of rubber and aggregate particles varied. The results are shown in Figures A-1 through A-6.

Up to 5 percent rubber by volume of aggregate or 25 percent by weight of asphalt was tried in this series. Only the coarse rubber was used at the maximum of 5 percent because of the previously mentioned mixing difficulties. The latex and fine rubber were limited to 1 and 3 percent by volume of aggregate, or 5 and 15 percent by weight of asphalt, respectively.

The Marshall test results are shown in Figures A1 through A4. As can be seen from Figure A1, the latex had negligible effect on the air voids. Both fine and coarse rubber resulted in substantial increases in air voids with the greatest change caused by the coarse rubber. The effect on flow values followed the same trend as the air voids as indicated in Figure A2. All three resulted in decreases in stability as can be seen in Figure A3. The coarser the rubber and the greater the percent of rubber, the larger the decrease. The decrease was very substantial for the 3 and 5 percent rubber contents. The estimated work energy to failure (Figure A4) followed the same trend as the stability. Figure A5 and A6 give the results of the split cylinder tests. As with the Marshall tests, the air voids increased with the percentage and coarseness of the rubber. In this case, the latex specimens also exhibited a small increase in air voids (Figure A5). The ultimate tensile strength results are indicated in Figure A6. The general trend is for a decrease in tensile strength as the percentage and coarseness of the rubber increases.

Series B Results

The results from Series A indicated that the substitution of rubber for aggregate did not show improvement in the properties of the mixes as measured by the Marshall and the split cylinder (indirect tension) tests. Also, the higher percentages of rubber substitution resulted in substantial loss in strength and caused mixing difficulties. Therefore, in Series B a more "conventional" approach was used. The rubber was used as an additive without any aggregate being replaced and the quantities of rubber solids were reduced to 0.3 and 1.0 percent by volume of the actual aggregates. These quantities are close to those used in some of the experimental work by MDSHT Laboratory personnel, especially for the specimens with 0.3% rubber additive.

The results of Series B are presented in Figure B1 through B8. As in Series A, the air voids in both the Marshall and the split cylinder tests increased with the crumb rubber while the latex had very little effect as shown in Figures B1 and B5. As can be seen in Figure B2, the flow values increased with coarse rubber exhibiting the greatest change and latex the least. Again all three rubbers caused a decrease in stability with the crumb rubbers having the greatest effect as indicated in Figure B3. The Marshall energy is shown in Figure B4. The results for this series are somewhat different than for Series A. While the energy to failure decreased as before for the crumb, there was a slight increase in the energy for the latex. In this connection, it must be remembered that the energy was estimated for Series A while it was determined from the load-deformation plot for Series B and is more accurate for this series.

The effect of rubber on the tensile strength from the split cylinder tests is indicated in Figure B6. For this series, the results show a small increase in strength for the latex. Both crumb rubbers caused a decrease in strength with the coarse rubber resulting in the greatest change. As can be seen in Figure B7, this split cylinder energy followed the same trends as the strength.

Discussion of Results

It is evident from the results that crumb rubber effectively increases the air voids and flow values accompanied by a reduction in Marshall stability and energy at 140 F as well as reductions in the ultimate tensile strength and energy at 0 F. The effect varies directly with the size and quantity of the crumb used. The explanation for this behavior lies with the fact that the presence of crumb rubber creates a three layer system between aggregate, rubber and asphalt. The relative thickness of the rubber layer explains why coarse rubber as well as more rubber has greater influence on the behavior of the mixes.

Latex rubber behaves much the same way but because of its "size," which is considered similar to filler, the results are somewhat different from the crumb rubber. The latex had very little effect on the air voids. While the effect on flow values is on the positive side it was only a small increase compared to that caused by the crumb rubber. Both the Marshall stability and ultimate tensile strength did not vary significantly from the control in Series B. Series A results showed a greater variation but a much less reduction than for the crumb rubber. This seems reasonable considering the similarity in air voids.

The small increase in energy in Series B is the result of a small increase in flow values in combination with little or no change in stability. Similar results are seen for the low temperature energy. It should be noted that for crumb rubber, in spite of large increases in flow values, the energy decreased. This is because the corresponding strength values were too low to benefit from the increases in plastic flow at high temperatures or from the elastic strain at low temperatures.

There is a question as to what minimum value in Marshall stability could be tolerated for open-graded thin surface mixes. If such a mix is placed over an existing underlying surface of high stability (in Marshall terms), mixes with quite low stabilities may serve well. This is due to the fact that the relatively thin open-graded friction course will be "confined" between the tire and the underlying stronger layer. There may be some problems at intersections, however, due to the horizontal breaking force induced by trucks. If Marshall stability is used as a guide, additional research work is needed to define reasonable values for open-graded friction surface mixes.

Finally, it must be pointed out that the Marshall method and the split cylinder test was used in this evaluation because of their simplicity and relative popularity. The addition of the rubbers described did not show much improvement in the mix properties. There is no claim that other types of tests could not be found to show improvement.

Conclusions

The following conclusions are based on the work done with the open-graded bituminous mix and the procedures presented in this report and are not for other mixes in general. The most important conclusions resulting from this study are:

(1) Latex rubber had little or modest effect on the air voids, flow, Marshall stability and ultimate tensile strength. It had a positive effect on the work energy to failure for both high and low temperature conditions. The gain was a direct result of an increase in plastic flow and elastic strain for the high and low temperatures, respectively.

(2) Crumb rubber resulted in significant increases in the air voids and flow properties but at the expense of modest decreases in energy and ultimate strength, and a considerable decrease in stability.

(3) If crumb rubber (similar to the one applied in this experiment) is to be used for reasons other than significant improvement of mix properties as measured by Marshall and split cylinder tests, the maximum amount is probably around one percent by the volume of the aggregates.

(4) The results so far indicate that better results with rubber are obtained if it is used as an additive rather than replacement for aggregate.

Recommendations

The following recommendations are offered:

(1) Since latex showed some improvement in energy-to-failure, further laboratory work using higher percentages of rubber solids may be of interest. Also field installations could be tried.

(2) Since the smaller particle size crumb rubber showed better adaptability to the use in open-graded mix, more work should be done with still finer ground rubber. Also field installations with up to 1 percent of the finer rubber could be tried.

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TABLES

TABLE 1

SOME PROPERTIES AND COMPOSITION OF CONTROL MIX

Fraction	SG	B_{rw}	B_{ag}*	% by weight
#1 (3/8"-#4)	2.67	7.72	0.55	53.94
#2 (#4-#16)	2.67	11.55	0.50	30.66
#3 (#16-#100)	2.67	12.03	0.87	2.79
Slag Filler (-#100)	2.80		2.35	5.41
Asphalt	1.02			7.20
				100.00

*% by weight of aggregate

Note: B_{rw} = amount of asphalt lost by rugosity, % by weight.

B_{ag} = amount of asphalt absorbed.

SG = bulk specific gravity.

TABLE 2

RELEVANT INFORMATION ON RUBBER

Type	Size	SG	B_{rw}	B_{ag}	Water Content (% dry weight)
Crumb	#4-#16	1.16	13.95	-	-
Crumb	#16-#100	1.19	9.94	-	-
Latex		0.976	-	-	46.29

Note:

1. #4-#16 crumbs, referred to as coarse rubber, consists of 70.7% from #4-#8 and 29.3% from #8-#16.
2. #16-#100 crumbs, referred to as fine rubber, consists of 60.3% from #16-#30 and 39.7% from #30-#100.
3. The purpose of above fractioning was to match the aggregate size being replaced.
4. Assumptions were made concerning B_{rw} by examining the rubber under microscope and comparing its roughness with known aggregate of similar size.
5. It was assumed also that rubber does not absorb asphalt during mixing and testing.

TABLE 3

AVERAGE TEST RESULTS FOR MIXES

1. Series A

Mixes	Marshall				Split Cylinder	
	V %	F 1/100 in.	S lb.	E_M in.-lb.	V %	US lb.
Control	15.1	8.0	710	33.7	15.1	4600
1% CR	17.2	14.7	365	26.5	18.6	3380
1% FR	16.0	13.7	410	27.6	17.2	3950
1% L	15.2	8.5	665	28.2	15.7	4280
3% CR	21.6	18.8	125	11.7	20.4	3350
3% FR	19.0	17.3	240	20.8	19.0	3300
3% L	15.2	8.0	675	27.3	16.7	3520
5% CR	22.7	20.0	100	9.6	-	-

2. Series B

Mixes	Marshall				Split Cylinder		
	V %	F 1/100 in.	S lb.	E_M in.-lb.	V %	US lb.	E_T in.-lb.
Control	15.1	9.2	650	40.1	15.2	5220	144.3
0.3% CR	16.6	12.7	430	30.9	16.6	4830	126.4
0.3% FR	15.8	11.7	510	35.1	15.7	4957	136.2
0.3% L	15.1	9.2	625	44.0	15.6	5275	168.5
1% CR	18.1	21.1	195	25.7	17.4	4090	116.4
1% FR	16.4	18.9	245	31.1	16.5	4525	127.5
1% L	14.9	10.2	620	47.2	15.1	5395	184.1

Note: V = Voids
F = Flow
S = Stability
US = Ultimate Strength
E_M = Marshall Energy
E_T = Split Cylinder Energy
CR = Coarse Rubber
FR = Fine Rubber
L = Latex

FIGURES

SERIES A

- Marshall and Split cylinder data
- Open-graded, 30 blows (MDSHT compactor)
- The University of Michigan testing machine for Marshall data
- MDSHT testing machine for Split cylinder data
- 31A Green Oak

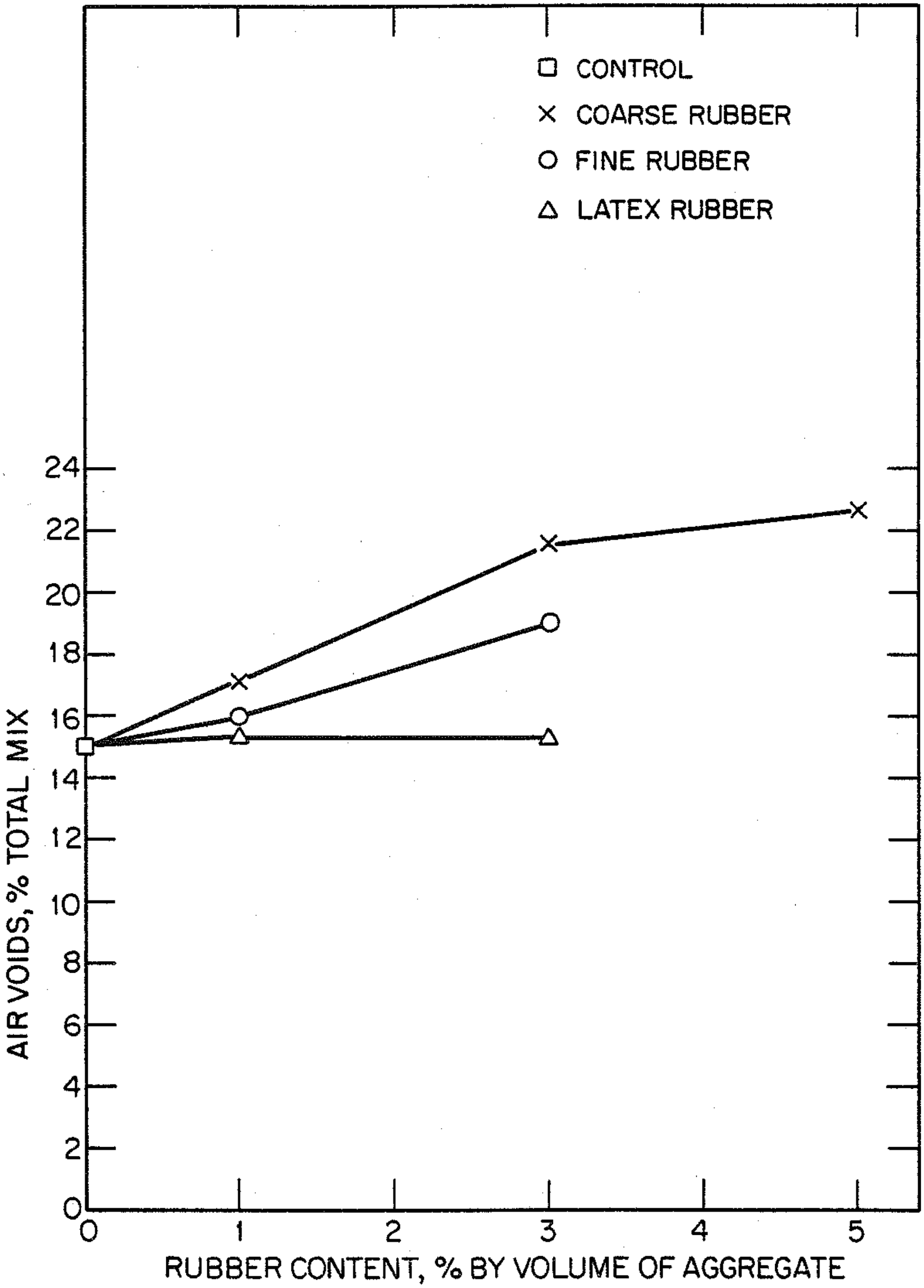

Figure A1. Effect of rubber on voids in Marshall specimens (30 blows).

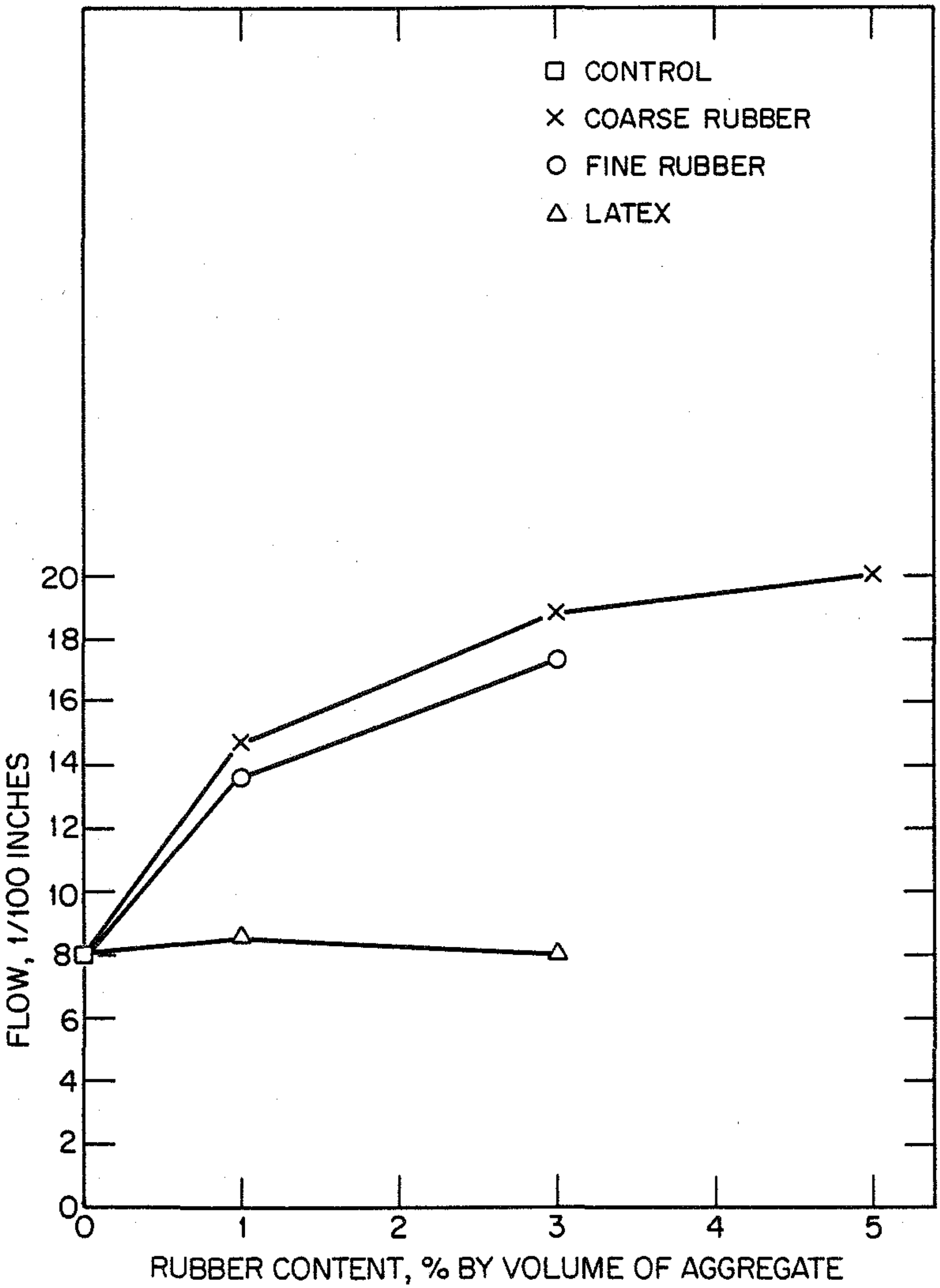

Figure A2. Effect of rubber on flow values from Marshall specimens
(30 blows)

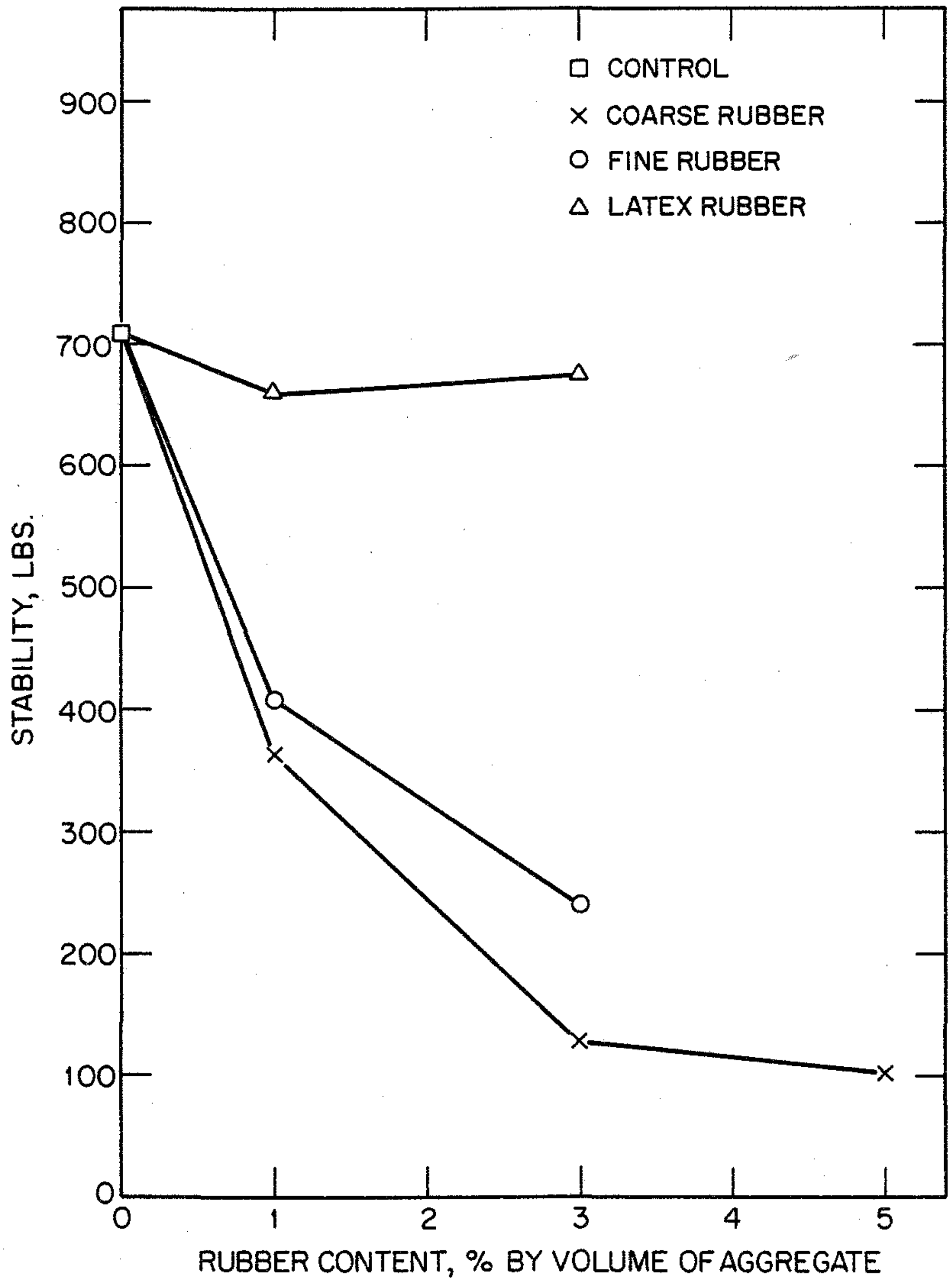

Figure A3. Effect of rubber on Marshall stability (30 blows)

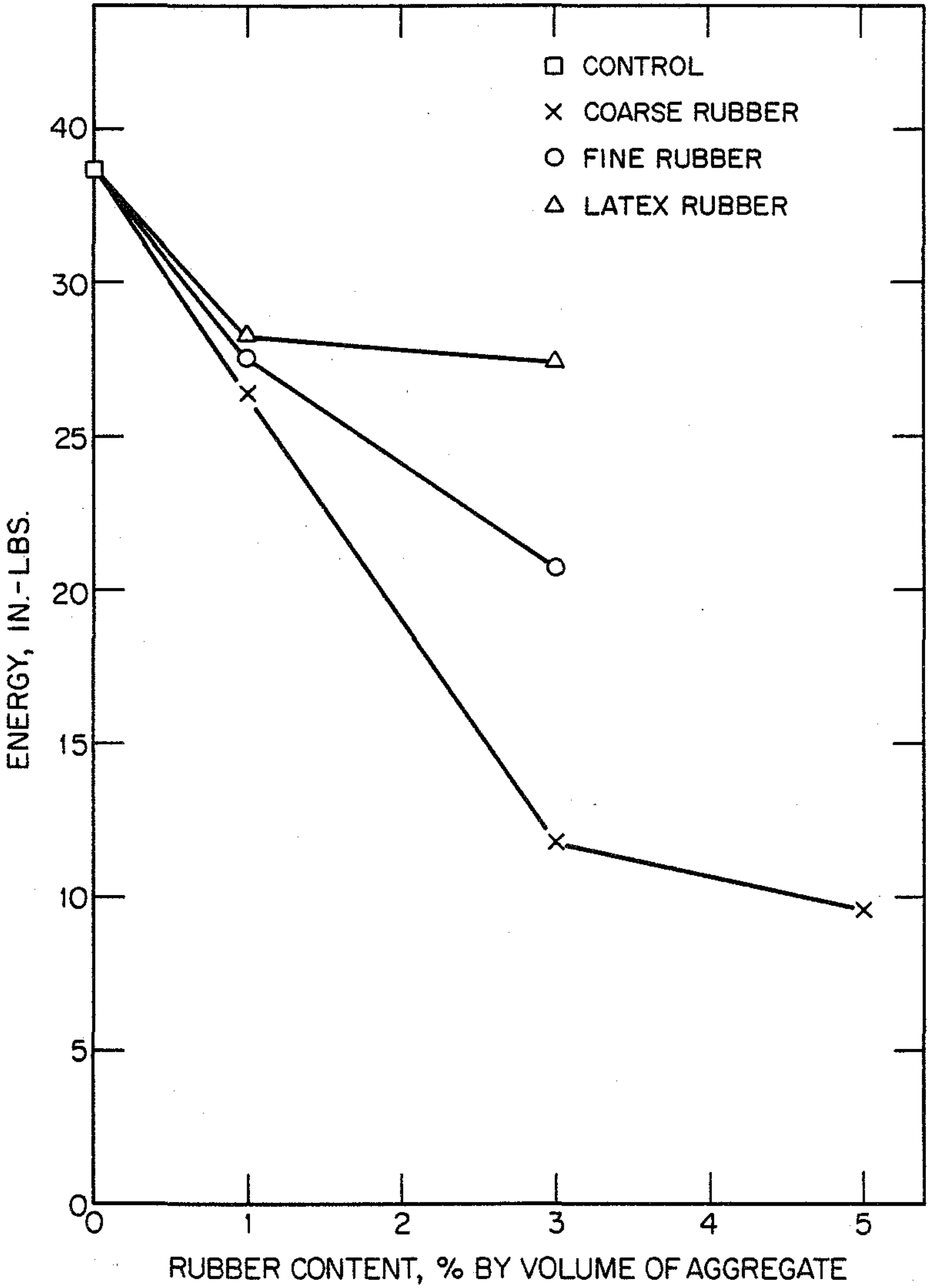

Figure A4. Effect of rubber on Marshall energy (30 blows).

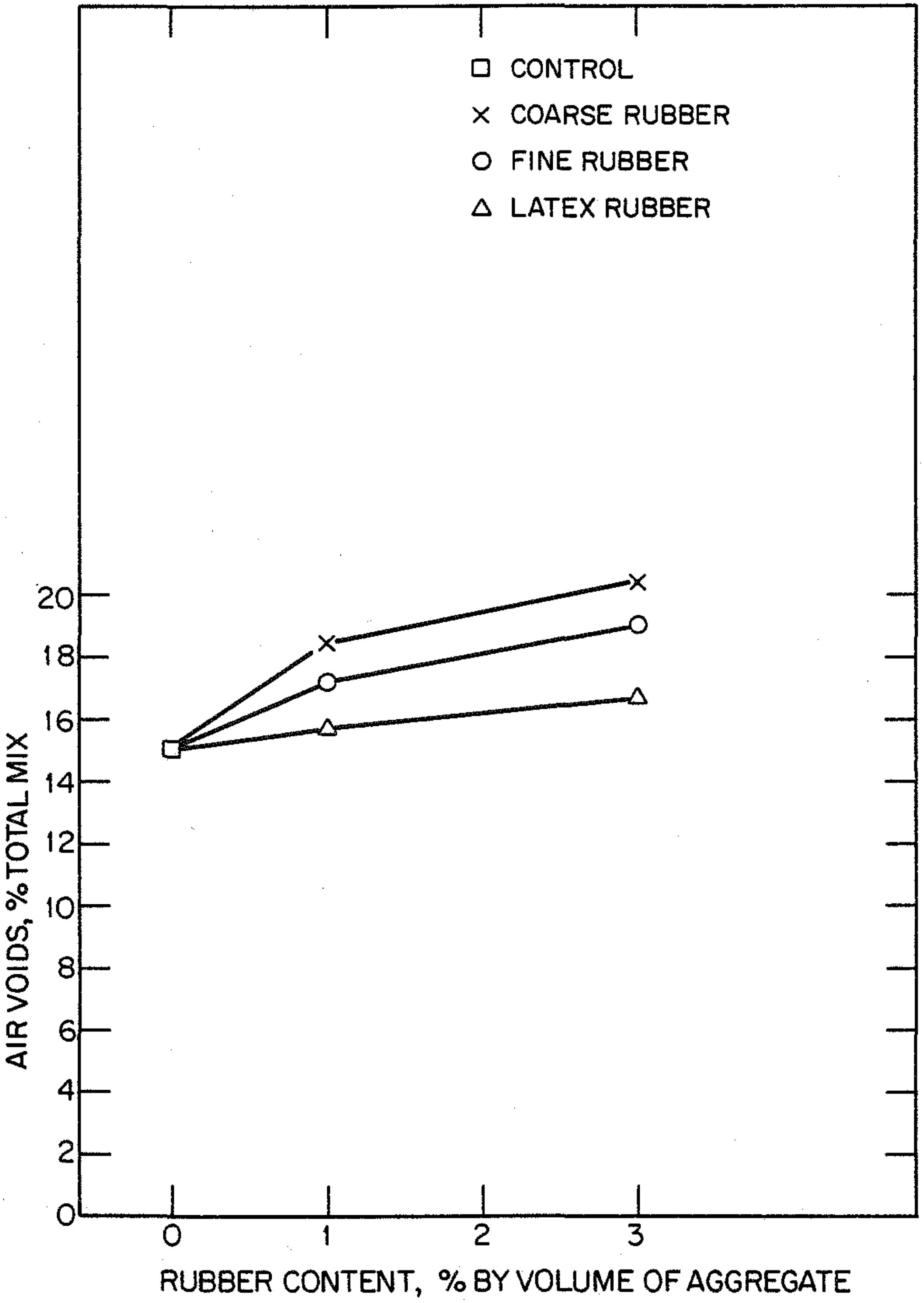

Figure A5. Effect of rubber on voids in split cylinder specimens (30 blows)

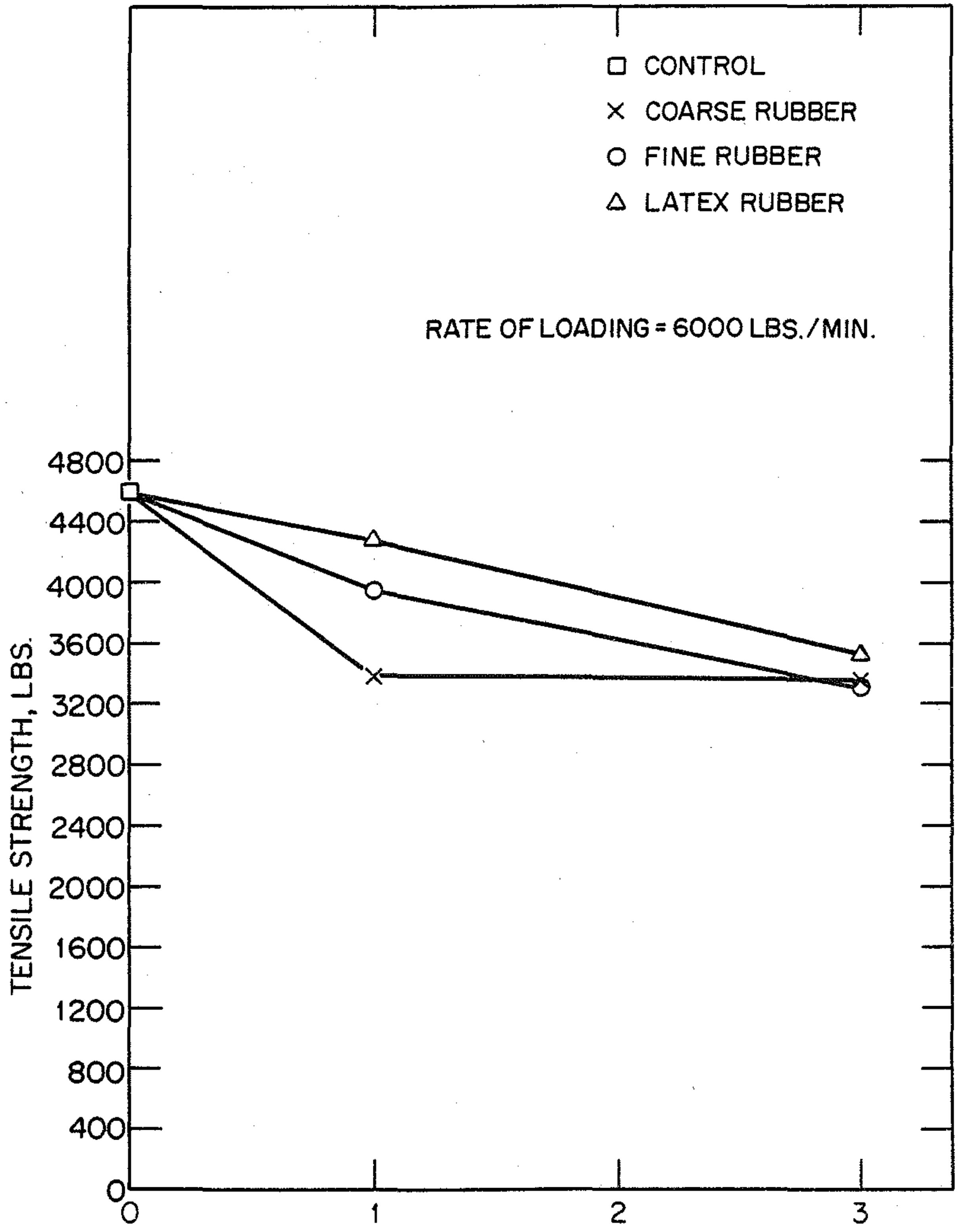

Figure A6. Effect of rubber on ultimate tensile strenght, from split cylinder specimens (30 blows).

FIGURES

SERIES B

- Marshall and Split cylinder data
- Open-graded, 30 blows (MDSHT compactor)
- MDSHT testing equipment
- 31A Green Oak aggregate with slag filler

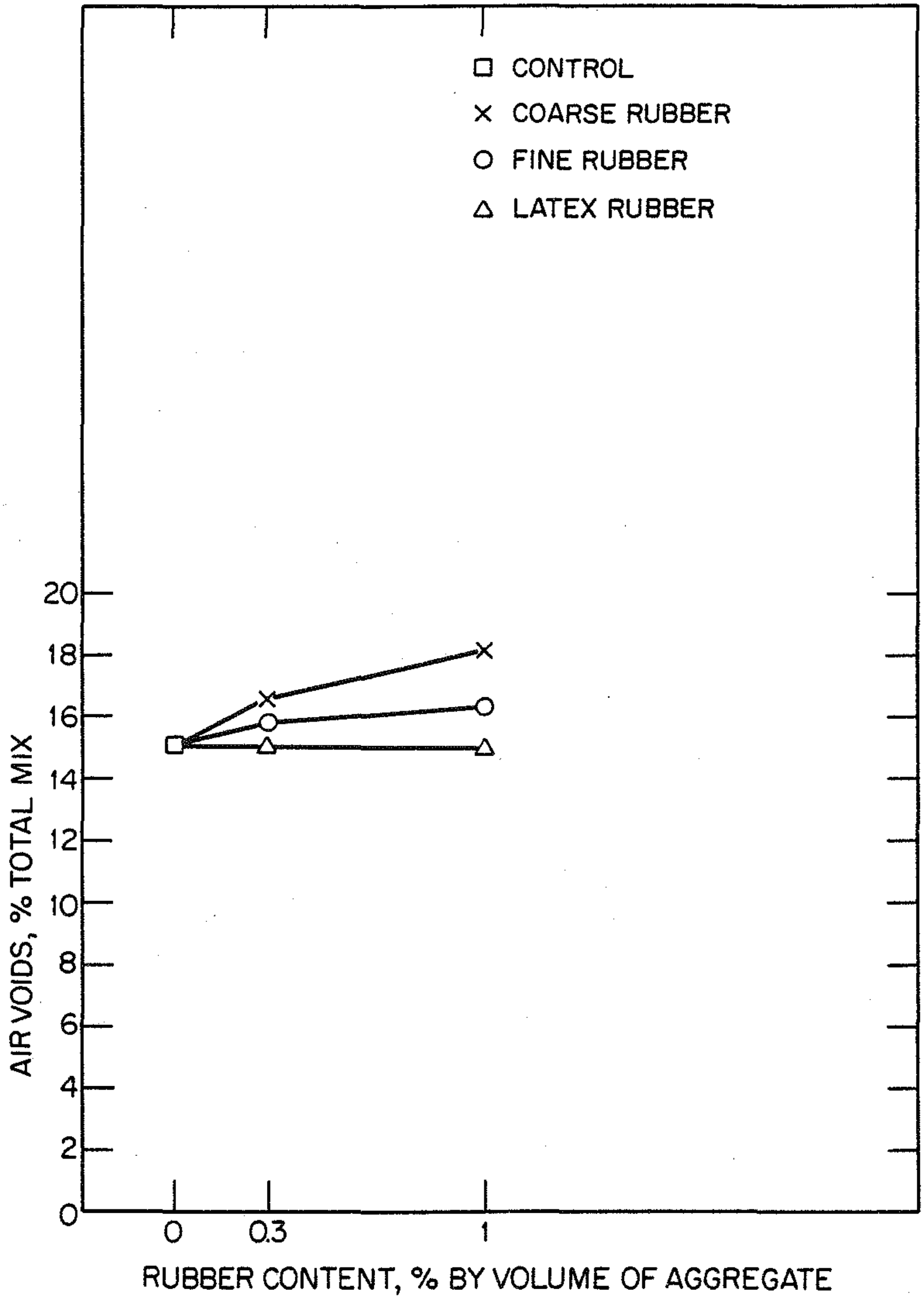

Figure B1. Effect of rubber on voids in Marshall specimens (30 blows).

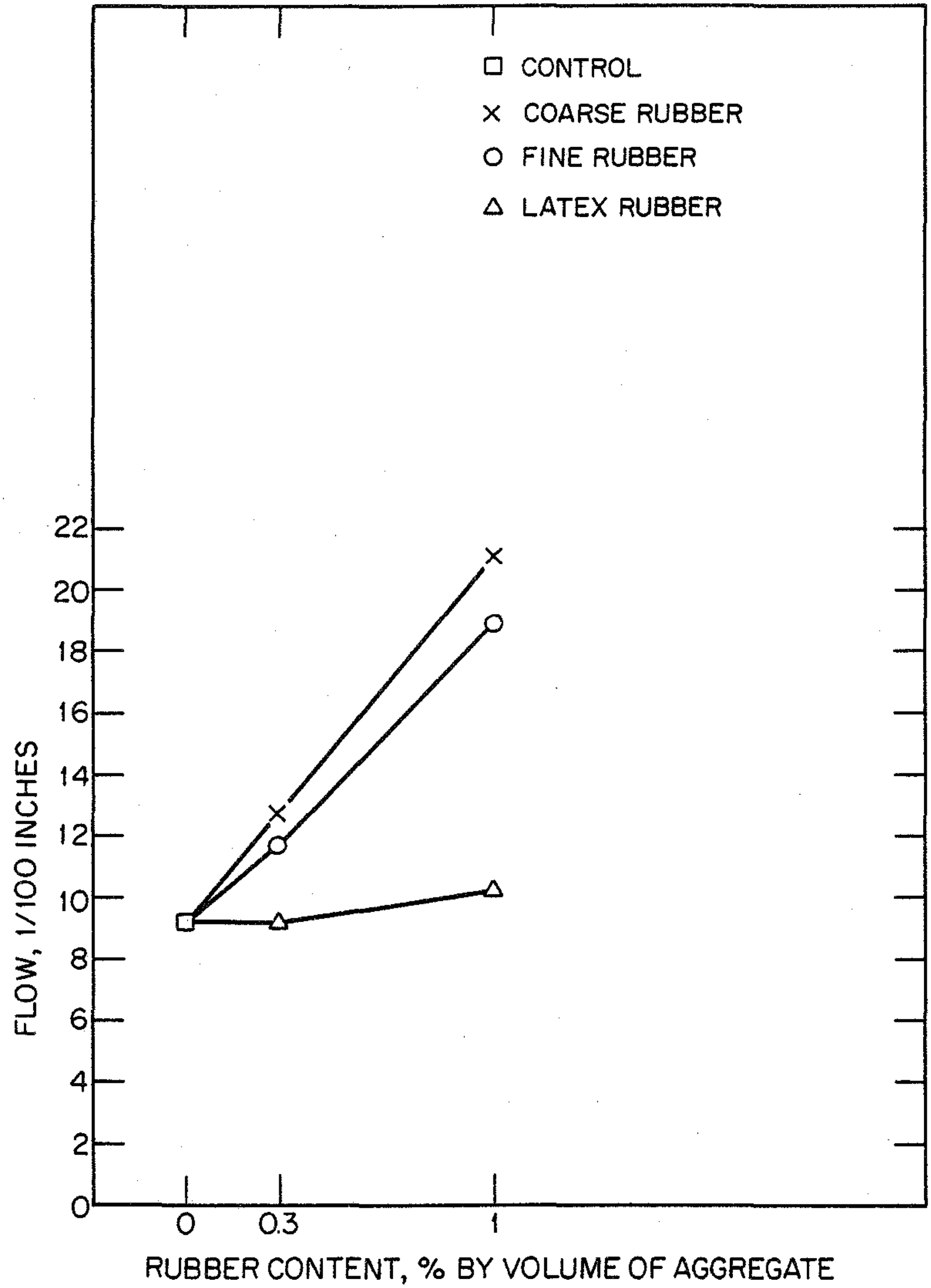

Figure B2. Effect of rubber on flow values from Marshall specimens (30 blows).

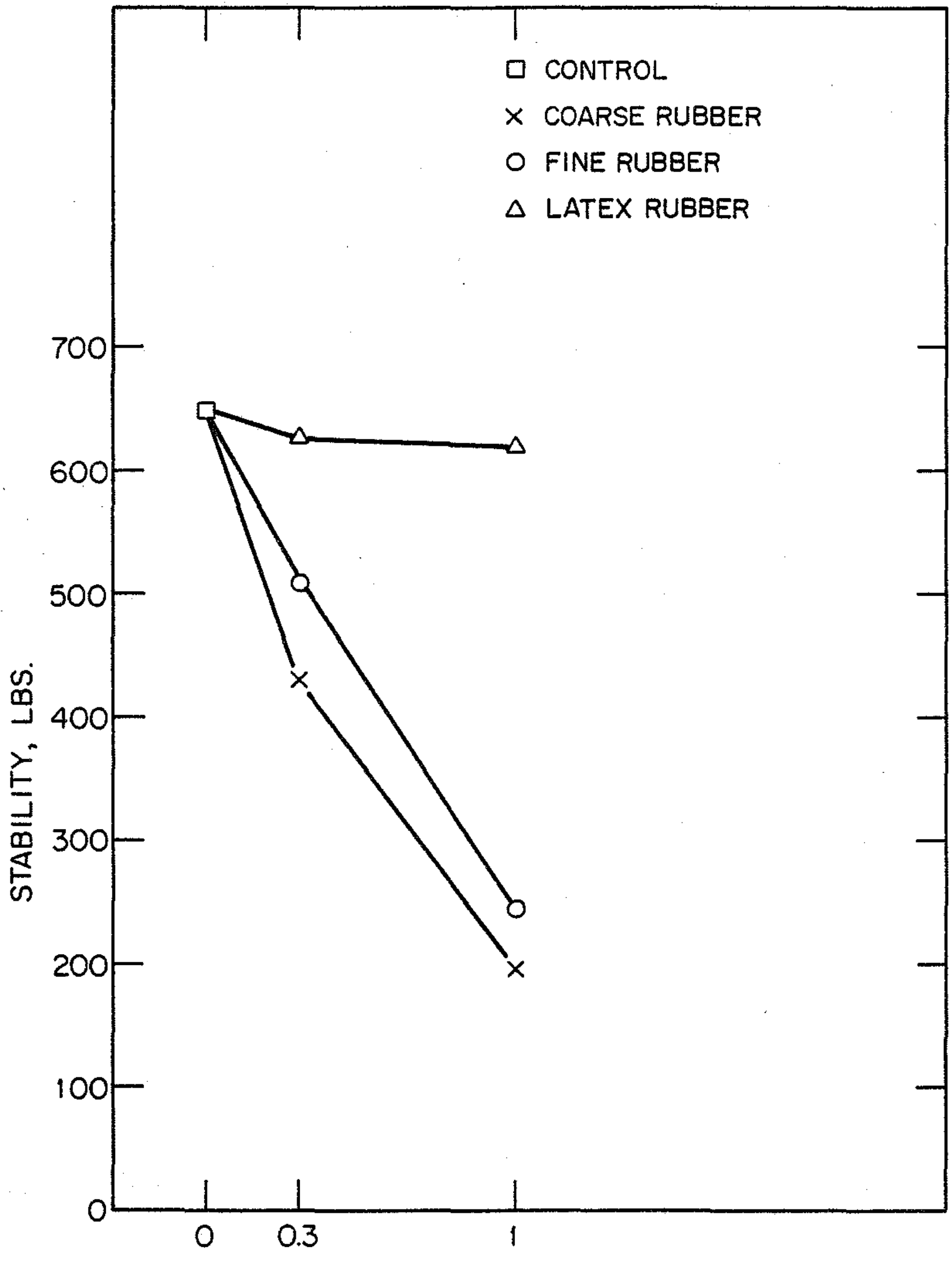

Figure B3. Effect of rubber on Marshall stability (30 blows).

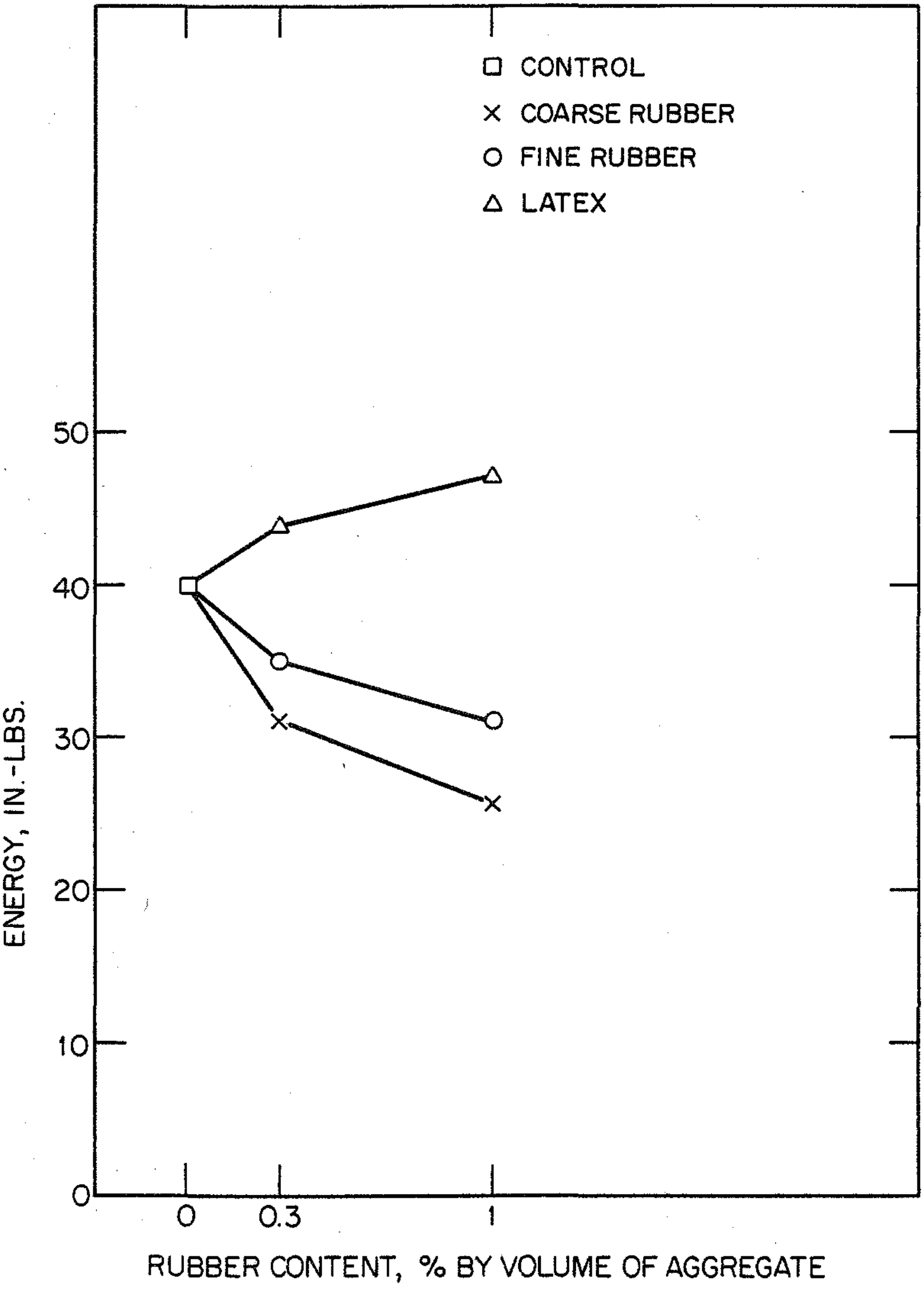

Figure B4. Effect of rubber on Marshall energy (30 blows).

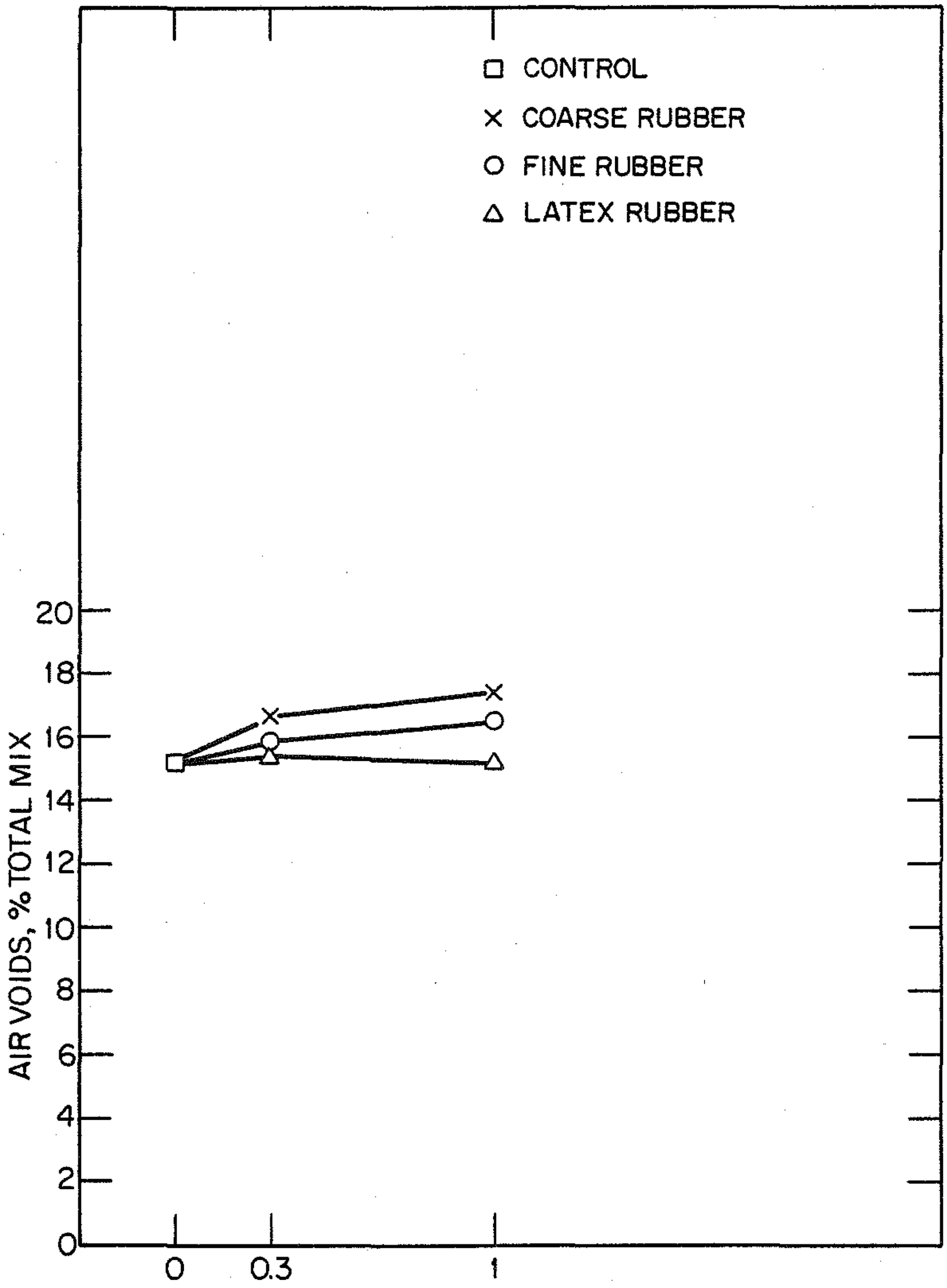

Figure B5. Effect of rubber on voids in split cylinder specimens (30 blows).

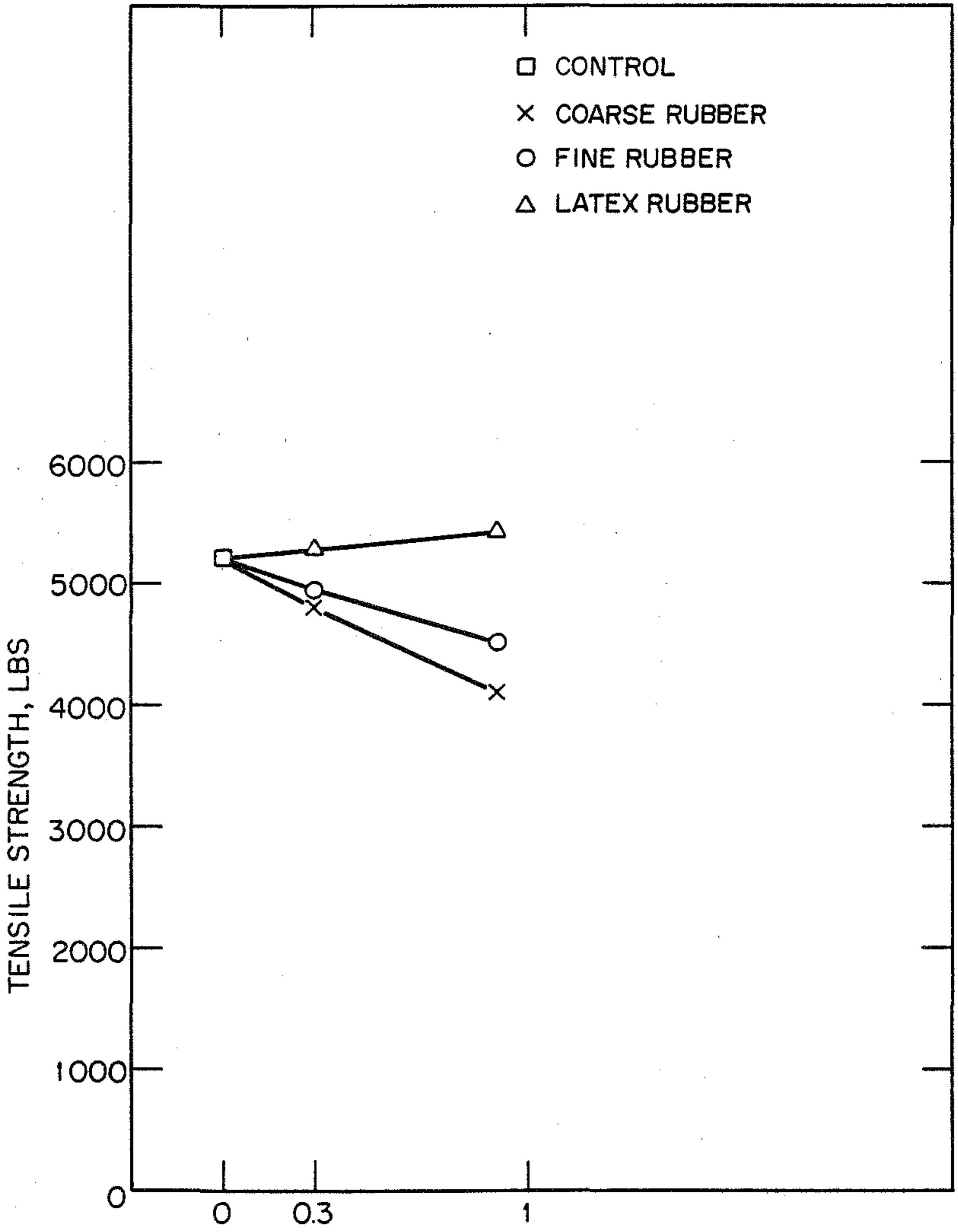

Figure B6. Effect of rubber on ultimate tensile strength, from split cylinder specimens (30 blows).

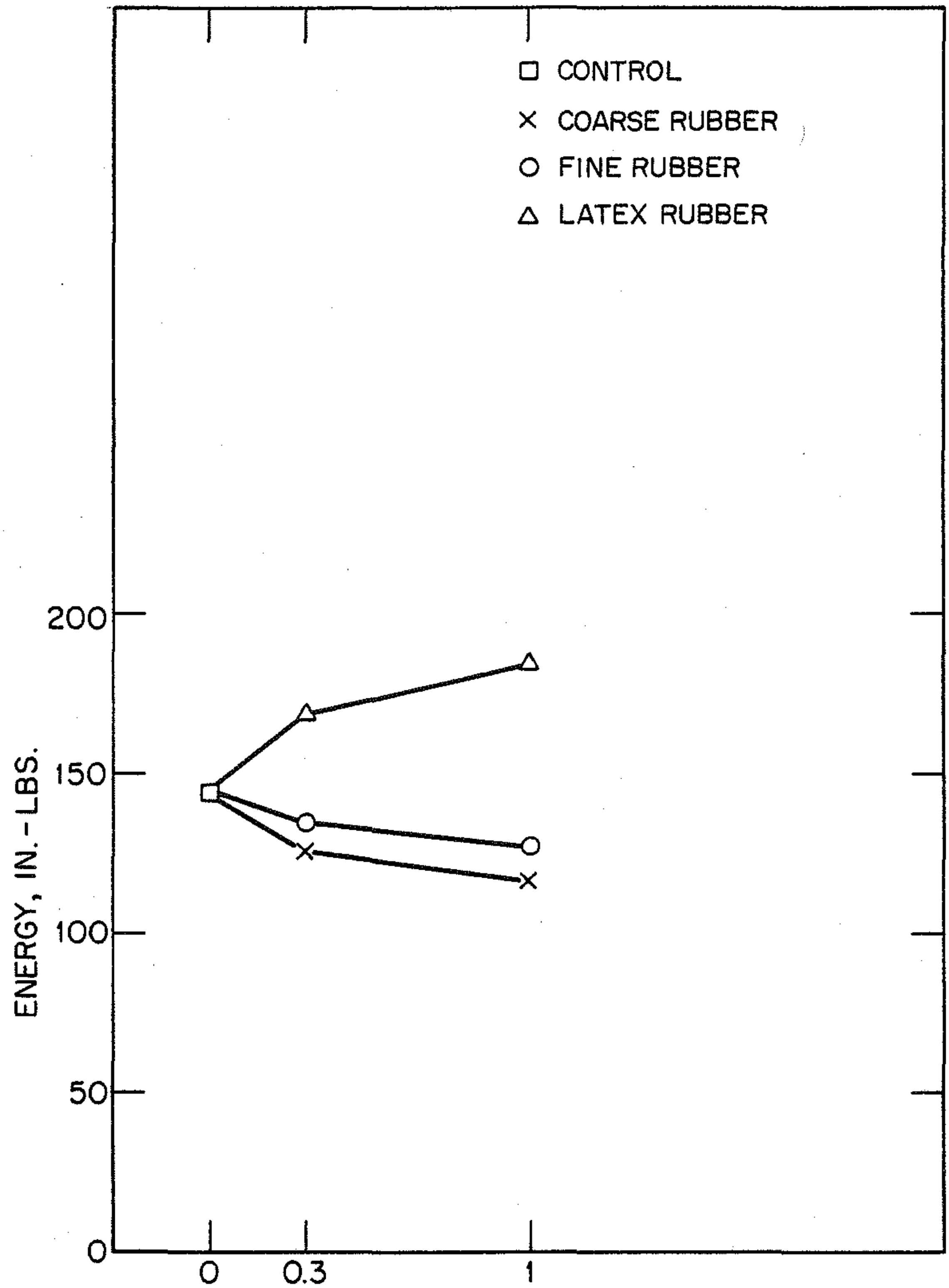

Figure B7. Effect of rubber on split cylinder energy (30 blows).

APPENDIX A

I. Aggregate Proportions for Control Mix

The proportions (by volume) of aggregate were taken from a previous report (1) as follows:

Fraction	Size	% by Vol.
#1	3/8" - #4	61.73
#2	#4 - #16	35.08
#3	#16 - #100	3.19
		100.00

Void content or porosity for the dry aggregate blend above was determined using 1-minute vibratory compaction as in previous work (1). The voids were 36.71% which gives the following volumetric proportions for the dry aggregate:

Fraction #1	39.06 cc
Fraction #2	22.21 cc
Fraction #3	2.02 cc
Total Aggregate	63.29 cc
Air	36.71 cc
	100.00 cc

II. Sample Calculation

A. Control Mix

Fraction	V_s(cc)	V_s(%)	W(g)	(Mic+Mac)AC(g)	(Mic)AC(g)
1	39.06	61.72	164.79	12.72	0.91
2	22.21	35.09	93.69	10.82	0.47
3	2.02	3.19	8.52	1.02	0.07
	63.29	100.00		24.56	1.45=<u>1.42 cc</u>

Mac void = (24.56-1.45)/1.02 = 22.66 cc

Flow AC = 3% by volume of V_s = 3.00 cc

(Flow + Mac) Vol.$_{1,2,3}$ = 25.66 cc

(Flow + Mac) $AC_{1,2,3}$ = 25.66x0.77 = $\underline{19.76 \text{ cc}}$

Filler vol. = 25.66x0.23 = 5.90 cc
= 16.52 g

Mic AC in filler = 16.52x0.0235 = 0.39 g
= $\underline{0.38 \text{ cc}}$

Total AC = (Flow+Mic+Mac)$AC_{1,2,3}$+(Mic)AC_{filler}
= 1.42+19.76+0.38 = 21.56 cc
= 21.99 g

Absorbed AC = (Mic)$AC_{1,2,3,filler}$
= 1.42+0.38 = 1.80 cc
= 1.84 g

Fraction	W(g)	W(%)
1	164.79	53.94
2	93.69	30.66
3	8.52	2.79
Filler	16.52	5.41
AC	21.99	7.20
	305.51	100.00

Note:
1. (Mic)AC = micro asphalt
2. (Mic+Mac)AC = micro plus macro asphalt
3. Filler/Asphalt ratio (by volume) = 0.3. This means the binder contains about 77% pure asphalt and 23% filler by volume.
4. V_s = volume of solids
5. W(g) = weight in grams

B. Replacing 1% of Fraction 2 by Coarse Rubber

Fraction	V_s (%)	V_{s+r} (%)	W(g)	(Mic+Mac)AC(g)	(Mic)AC(g)
1	61.72	61.72	164.79	12.72	0.91
2	35.09	34.09	91.02	10.51	0.46
Rubber	-	1.00	1.16	0.16	-
3	3.19	3.19	8.52	1.02	0.07
	100.00	100.00		24.41	1.44=1.41 cc

Mac void $= \frac{24.41-1.44}{1.02}$ = 22.52 cc

Flow AC = 3% by volume of V_s = 3.00 cc

(Flow + Mac) $\text{Vol.}_{1,2,3,R}$ = 25.52 cc

(Flow + Mac) $\text{AC}_{1,2,3,R}$ = 0.77x25.52 = 19.65 cc

Filler Vol. = 0.23x25.52 = 5.87 cc
= 16.43 g

Mic AC in filler = 0.0235x16.43 = 0.39 g
= 0.38 cc

Total AC = 1.41+19.65+0.38 = 21.44 cc
= 21.87 g

Absorbed AC = 1.41+0.38 = 1.79 cc
= 1.83 g

Fraction	W(g)	W(%)
1	164.79	54.25
2	91.02	29.96
3	8.52	2.80
Filler	16.43	5.41
Rubber	1.16	0.38
AC	21.87	7.20
	303.79	100.00

For abbreviations see page 30.