RESEARCH REPORT
TR-6-74

IMPACT TESTING OF GLASS FIBER REINFORCED CONCRETE

by Ernest L. Buckley, P.E., Ph.D.

CONSTRUCTION RESEARCH CENTER

The University of Texas at Arlington
Arlington, Texas

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Section I

Introduction:

Early research efforts that have been completed by the Construction Research Center at the University of Texas at Arlington have shown that short glass fibers can favorably alter the performance characteristics of concrete. A relatively small volume of fibers from ½" to 1½" in length increases flexural strength and fracture toughness.

Impact resistance can also be substantially increased.[1]

Significant increases in impact resistance would be of particular interest to concrete product manufacturers. The reinforcement is lighter in weight and the improvement of resistance to impact would reduce the rejection rate of pre-cast structural components produced. Normally, plain concrete used from pre-cast operations frequently suffers damage in handling. Glass fibers added to the Portland cement concrete matrix could have a favorable effect in reducing the number of cracks and spalled corners that occur in normal

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(1) Buckley, Ernest L.; Investigations of Alternate Fiber Reinforcements for Portland Cement Mortar and Concrete; TR-2-72; Construction Research Center, University of Texas at Arlington, Arlington, Texas.

handling on the job site.

In order to evaluate the impact resistance capacity of the concrete specimens, a test procedure needed to be developed. Various approaches have been taken to the problem of measuring impact resistance and, since no general standard has been agreed upon, it is difficult to compare data developed with that reported by other researchers. It was, therefore, the objective of the research reported here to measure increases of impact resistance gained by the addition of glass fibers and at the same time, to develop a viable testing procedure that could be recommended for general use.

A design for modification of an impact test machine of the type used for Izod tests and Charpi tests was developed and the tests were conducted upon concrete specimens of nominal cross-sectional dimensions of $1\frac{1}{2}$ x 4 inches.

Concrete specimens were prepared with glass fiber content ranging from 0 to 2.0 percent by volume. For each batch a minimum of 14 specimens were prepared and tested after at least 28 days of curing.

The test results show that the impact resistance appears to increase linearly with the increase in fiber content. The magnitude of performance improvement appears to correlate directly with the increase in modulus rupture for fiber reinforced concrete. Previous studies[2] have developed the analytical means for predicting the flexural strength, f_r, (modulus of rupture) for fiber reinforced mortar or concrete.

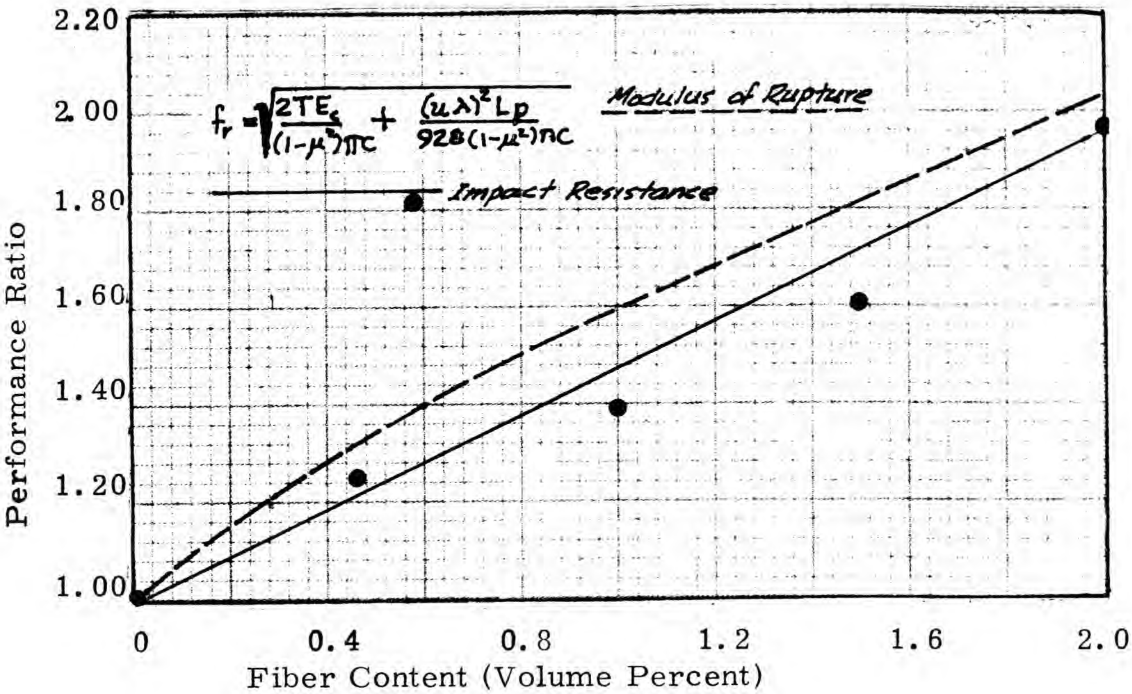

Figure 1: CORRELATION OF IMPACT RESISTANCE WITH PREDICTED FLEXURAL STRENGTH

The related values of flexural strength, f_r, and impact resistance I_c are shown graphically by Figure 1 above. It is apparent that the impact resistance can be doubled by the addition of the glass fibers. The desirability of glass fiber material used in this fashion has been positively shown. It is recommended that additional tests be performed so that the mix design for pre-cast concrete product applications can be optimized.

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(2) Buckley, E. L.; op. cit.

Section II

Background:

Investigation of fiber reinforced concrete and mortar has been carried on at the University of Texas at Arlington for the past four years. The physical properties and performance characteristics of this new building material have been partially established.[3] Laboratory tests have shown that the composite material, glass fiber and concrete matrix, has superior performance in terms of flexural strength and fracture toughness. Earlier tests have also given some indication that the impact resistance is substantially increased.

Other researchers have experimented with small, short, steel wire fibers as a concrete reinforcement. It has been shown that flexural strength and shear strength can be increased in full scale service tests of pavements, floor slabs, and structural members. Difficulties have been experienced in handling and placing the steel fibers. There are hazards to the workmen because of the stiff, needle-like characteristics of the fibers. After placement, any exposed concrete reinforcement with steel wire would represent a hazard to the public or to the user of the facility.

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(3) Buckley, E. L.; op. cit.

Glass fiber of an alkali resistant formula produced by Owens-Corning Fiberglas has been shown to be a practical reinforcement for pavement[4] and for concrete products such as glass reinforced concrete pipe.[5] Up to this time, however, no work has been done that established quantitatively the impact resistant characteristics of fibrous concrete.

It was the purpose of the test reported herein to develop a method of test and to investigate impact resistance, in terms of energy required per square inch of cross-sectional area, to fracture a specimen. It was assumed that impact resistance, as accurately measured, would be a function of the flexural strength of the glass fiber reinforced concrete. For predicting the flexural strength, the following equation was developed and its validity was established:

$$f_r = \sqrt{\frac{2TE_c}{(1-\mu^2)\pi c} + \frac{(u\lambda)^2\ Lp}{928(1-\mu^2)\ nc}}$$

where T is the surface energy absorbed in the formation of cracks per unit of crack area

E_c is the elastic modulus of the composite material determined by calculations based upon the "theory of mixtures"

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(4) Buckley, E. L.; Accelerated Trials of Glass fiber Reinforced Rigid Pavements, Research Report TR-3-74, Construction Research Center, University of Texas at Arlington, Arlington Texas; April 12, 1974.

(5) Buckley, E. L.; Unpublished reports of tests made for Can-Tex Industries, a Division of HARSCO in 1972 and 1973.

μ is Poissons ratio for the concrete matrix.

c is the half-crack length of the critical crack or flaw

u is the unit bond stress

λ is the aspect ratio or length of the fiber over its effective diameter.

L is the length of fiber

p is the fiber content expressed as a percent of total volume

n is the modular ratio, the Young's modulus of the reinforcement (E_r) over the modulus of the concrete or mortar matrix (E_m).

The validity of the equation, using the typical properties of concrete shown by Table 1, has been established by extensive tests, within the following limits:

1) The aspect ratio is limited to values of about 100 for laterally stiff fibers. For glass fibers, aspect ratios up to about 135 (L=1.5 inches) have been used, and the upper limit may be assumed to be about 2 inches.

2) The volume percentage p is limited by the adsorption characteristics displayed by all fibers which affects workability. Values of p up to 4 or 5 percent have been used in the laboratory. Fiber content of from 1.0 to 2.0 percent by volume appears to be the practical limit for field applications.

3) Developable bond stress in steel wire fibers may be about 400 psi. Values of u for glass fibers have been approximated at about 200 psi, by indirect methods. Work is continuing to change surface chemistry and increase the bond.

4) The modular ratio in the denominator indicates that low modulus materials, like glass, are superior to high modulus fibers. The lower limiting value would be when $E_r = E_m$ or n = 1.

TABLE 1

TYPICAL PROPERTIES OF CONCRETE

Ultimate Compressive Strength f'_c (psi)	Modulus of Elasticity E (psi x 10^6)	Poissons Ratio μ	Surface Tension T (in lbs/in^2)	Critical Half-crack Length c (inches)
2000	2.58	0.20	0.015	0.637
4000	3.64	0.16	0.035	0.641
6000	4.46	0.12	0.042	0.598
8000	5.15	0.11	0.050	0.538

The characteristic increase in impact resistance that results from the addition of increasing volumes of glass fibers, suggests a number of practical applications. Precast concrete products are subjected to handling in the casting process and at the job-site during erection. Damage to precast units often results in their rejection. Structural elements made of material of higher impact resistance will decrease the frequency of cracked units, spalled corners and other handling damage. This apparent advantage would be of value in all kinds of concrete product manufacture.

Section III

Impact Tests and Results:

The program of testing that is reported here was begun in late 1973 and continued through the winter and spring of 1974. The original test plan called for the use of an Izod/Charpi test machine with modifications made to the specimen-holding jig to accomodate 3" x 4" specimens. A substantial number of specimens were cast and allowed to cure for 28 days. However, when the specimens were subjected to tests, it was found that the test machine did not have adequate capacity to break the glass reinforced specimens. Failure could be induced in an unreinforced specimen but not in those with glass reinforcement. These results were encouraging from a qualitative standpoint but did not provide any quantitative information.

It was then decided to further modify the specimen holding jig on the Izod/Charpi machine and to make forms with which to cast specimens of $1\frac{1}{2}$" x 4" cross-section dimensions. Some 70 specimens were cast using the batch proportions shown in Table 2. All specimens were cured in a moist room at 70°F and 90-100% relative humidity for 28 days or more.

Other specimens were furnished by Owens-Corning Fiberglas, the characteristics of which are described by Table 3.

TABLE 2

BATCH PROPORTIONS AND TIME DATA

Batch No.	Date Cast	Mix Proportions (lbs.)				Fiber Content	Test Date
		Gravel	Sand	Cement	Water		
1	5-10	47.96	53.85	27.85	16.66	0.0	6-21
2	5-13	"	"	"	"	0.5	6-24
3	5-14	"	"	34.80	20.90	1.0	6-24
4	5-17	"	"	"	"	1.5	6-25
5	5-21	"	"	41.75	24.99	2.0	6-26

TABLE 3

SPECIMEN DATA

Owens-Corning Flexural Specimens, Half-sawn

Sample No.	Casting Date	Volume % Fiber	Fiber Length
334	5/21/74	0	-
458	4/04/74	0.25	1"
361	3/05/74	0.50	1"
362	3/05/74	1.00	1"
363	3/07/74	1.50	1"
462	4/10/74	0.25	$1\frac{1}{2}$"
356	4/02/74	0.50	$1\frac{1}{2}$"
357	4/03/74	1.00	$1\frac{1}{2}$"
358	4/03/74	1.50	$1\frac{1}{2}$"

Note: All made with 8 sacks Type III cement/yard, 50/50 coarse/fine aggregate ratio, masons sand, 0.50 water/cement ratio and 204 filament/bundle glass fibers.

The head of the hammer of the Izod/Charpi machine was also modified to provide a striking surface that would produce a shearing force along a lateral line at the top of the holding jig. The modification resulted in a small increase in the potential energy of the hammer, raised to the Charpi position, of 0.1 ft-lb. In the Charpi position, the total potential energy of the hammer is 264.1 ft-lb. See Figure 2.

Specimens were inserted in the jig with the 4" dimension oriented laterally to the plane in which the hammer swung. The impact blow of the face of the hammer contacts the specimen across its full width as shown by Figure 3.

After impact, the amount of energy expended in fracturing the specimen and in throwing its fragments is read directly from a calibrated guage on the machine. The distance that the fragment was thrown was therefore measured. When more than one fragment was produced, the distance to the center of mass was measured as accurately as possible. In Figure 4, this measured distance is identified as "fragment distance" and the same notation is used in Tables 4 and 5, where the data related to each specimen tested is tabulated.

Fragments were weighed and also recorded. The impact energy expended on each break was then adjusted to account for the energy

Figure 2: IMPACT TEST MACHINE AND SPECIMEN SET UP

Figure 4: AFTER IMPACT, DISTANCE TO FRAGMENT WAS MEASURED

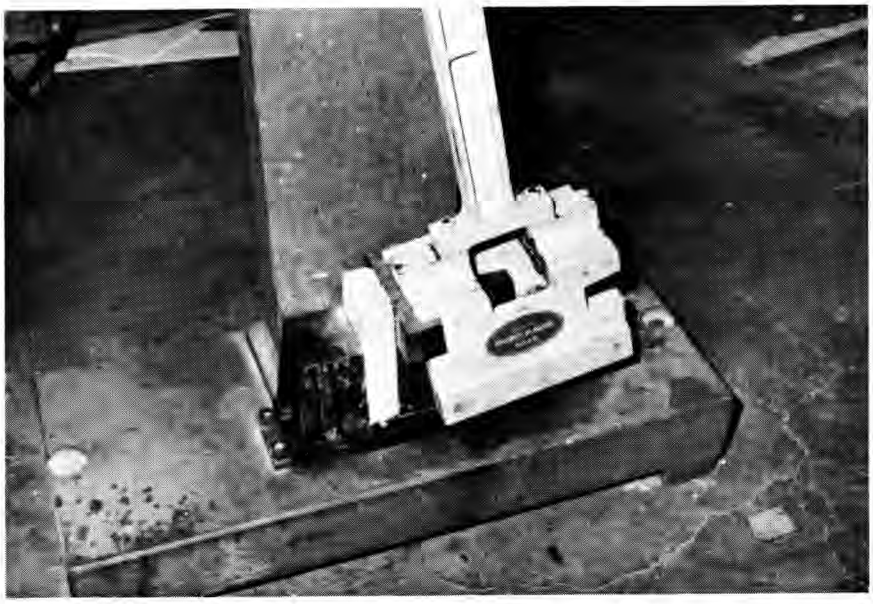

Figure 3: MODIFIED IZOD HAMMER AT INSTANT OF CONTACT WITH SPECIMAN

expended in throwing the fragments and the minor adjustment that was due to the increased hammer weight.

Each specimen cast was of a nominal dimension of $1\frac{1}{2}$" x 4" x 16" long. The specimen in its full length was subjected to impact, producing the results identified as "a" for each specimen in the tabulations of Tables 4 and 5. The "b" specimen was the largest fragment remaining after the initial break of the "a" specimen. Thus we were able to get two data points from each specimen cast.

In addition to the specimens cast in the Civil Engineering Concrete Laboratory at the University of Texas at Arlington, 18 specimens were shipped from the Owens-Corning Fiberglas Technical Center in Granville, Ohio. These specimens were fragments of flexural specimens that had been tested to failure in bending by Owens-Corning. The 3" x 4" flexural specimen fragments had been sawn longitudinally, producing two specimens, nominally $1\frac{1}{2}$" x 4", from each of the flexural fragments. In the sawing it was found that, for each pair of specimens, one had a cross-section of six square inches and the other 5.25 square inches. In each case, then, the largest specimen was subjected to impact first and is designated "a" in Table 5. The specimen with the smaller cross-section is designated "b" and was tested second. Results of these tests are tabulated in Table 5.

TABLE 4

TEST AND TEST RESULTS OF PERFORMANCE UNDER IMPACT TEST

(Glass Fiber Reinforced Concrete Specimens)

Cross Section Area = 6.0 in^2.   Hammer Wt. Adjustment = +0.1

Specimen No.		Impact Reading (ft-lbs)	Fragment Distance (ft)	Weight Fragment (lbs)	Adj. (ft-lbs)	Impact Energy (ft-lbs)	Impact Resistance $\left(\frac{ft\text{-}lb}{in^2}\right)$
0-1	a	141	13	5.75	75	66	11
	b	182	15	1.00	15	167	28
0-2	a	167	14.8	4.85	71	96	16
	b						
0-3	a	139	11	5.8	64	75	13
	b	136	21.7	1.75	38	98	16
0-4	a	136	9	5.1	46	90	15
	b	122	15.6	2.35	37	85	14
0-5	a	165	6.0	5.1	31	134	22
	b						
0-6	a	186	9	5.47	49	137	23
	b	112	16.1	2.2	36	76	13
0-7	a	172	10.1	5.65	58	114	19
	b	140	19.8	1.85	37	103	17
0-8	a	150	9	5.95	54	96	16
	b	130	17.2	1.1	19	111	19
0-9	a	139	10.0	5.35	54	85	14
	b	117	13.2	2.75	36	81	14

TABLE 4 (Cont'd.)

Specimen No.		Impact Reading (ft-lbs)	Fragment Distance (ft)	Weight Fragment (lbs)	Adj. (ft-lbs)	Impact Energy (ft-lbs)	Impact Resistance $\left(\frac{ft\text{-}lb}{in^2}\right)$
0-10	a	167	11.6	5.25	61	103	17
	b	113	22.4	0.9	20	93	16
0-11	a	178	8.0	5.8	46	132	22
	b	142	9.6	2.15	21	121	20
0-12	a	142	7.6	5.8	44	98	16
	b	145	17.3	1.85	32	113	19
0-13	a	178	8.2	4.55	37	141	24
	b	120	23.6	2.4	57	63	11
0-14	a	180	6.9	5.3	37	143	24
	b	132	22.7	2.35	53	79	13
0.5-1	a	163	9	5.3	48	115	19
	b	135	11.8	2.85	33	102	17
0.5-2	a	153	10.1	5.95	61	92	15
	b	164	21	2.45	51	115	19
0.5-3	a	166	12.2	5.85	71	95	16
	b	153	26.2	2.54	67	86	14
0.5-4	a	190	7.5	5.3	40	150	25
	b	175	17	2.65	45	130	22
0.5-5	a	193	10.2	5.2	53	140	23
	b	184	13.3	2.25	30	154	26
0.5-6	a	199	7.5	4.7	35	164	27
	b	142	12.1	3.25	40	102	17

TABLE 4 (Cont'd.)

Specimen No.		Impact Reading (ft-lbs)	Fragment Distance (ft)	Weight Fragment (lbs)	A dj. (ft-lbs)	Impact Energy (ft-lbs)	Impact Resistance $\left(\frac{\text{ft-lb}}{\text{in}^2}\right)$
0.5-7	a	177	7.1	5.83	42	135	23
	b	161	7	2.05	14	147	25
0.5-8	a	182	9	4.9	44	143	24
	b	132	15	2.5	38	94	16
0.5-9	a	192	6	5.45	34	158	26
	b	168	14	2.35	33	135	23
0.5-10	a	179	7	5.8	41	138	23
	b	186	14	2.45	34	152	25
0.5-11	a	162	8	5.15	41	121	20
	b	170	11	2.8	31	139	23
0.5-12	a	179	9	4.8	43	136	23
	b	163	16.5	2.25	37	126	21
0.5-13	a	168	9.2	5.55	51	117	20
	b	181	7.5	3.1	23	158	26
0.5-14	a	192	10	5.6	56	136	23
	b	191	12	2.8	34	157	26
1-1	a	191	10	5.5	55	136	23
	b	181	11.5	3.1	36	145	24
1-2	a	172	11	5.55	61	111	19
	b	190	18	2.55	46	144	24
1-3	a	204	6	5.9	35	169	28
	b	216	18	2.5	45	171	29

TABLE 4 (Cont'd.)

Specimen No.		Impact Reading (ft-lbs)	Distance Fragment (ft)	Weight Fragment (lbs)	Adj. (ft-lbs)	Impact Energy (ft-lbs)	Impact Resistance $\left(\frac{ft\text{-}lb}{in^2}\right)$
1-4	a						
	b	185	13	2.9	38	147	25
1-5	a	186	7	5.7	40	146	24
	b	186	14.5	3.15	46	140	23
1-6	a	193	7	5.75	40	153	26
	b	214	12	3.15	38	176	29
1-7	a	175	10.5	5.5	58	117	20
	b	134	10	3.1	31	103	17
1-8	a	207	8.5	6.0	51	156	26
	b	174	8	3.4	27	147	25
1-9	a	222	7	5.7	40	182	30
	b	183	14	2.55	36	147	25
1-10	a	196	7	5.80	41	155	26
	b	170	12.5	2.6	32	138	23
1-11	a	216	6	6	36	180	30
	b	198	11	3.45	38	160	27
1-12	a	201	10	5.9	59	142	24
	b	142	18	2.65	48	94	16
1-13	a	186	8	5.35	43	143	24
	b	162	18	3	54	108	18
1-14	a	174	7.8	5.6	44	130	22
	b	154	8	3.2	26	128	21

TABLE 4 (Cont'd.)

Specimen No.		Impact Reading (ft-lbs)	Distance Fragment (ft)	Weight Fragment (lb)	Adj. (ft-lbs)	Impact Energy (ft-lbs)	Impact Resistance $\left(\frac{\text{ft-lb}}{\text{in}^2}\right)$
1.5-1	a	221	6	5.8	35	186	31
	b	181	8.5	3.4	29	152	25
1.5-2	a	217	7	5.7	40	177	30
	b	204	11	3.2	35	167	28
1.5-3	a	209	5	5.6	28	181	30
	b	221	8.5	3.2	27	194	32
1.5-4	a	235	5	5.5	28	207	35
	b	196	10	3.0	30	166	28
1.5-5	a	211	5.5	5.6	30	181	30
	b	226	13	3.3	43	183	31
1.5-6	a	235	6	6.1	37	198	33
	b						
1.5-7	a	183	10	5.6	56	127	21
	b	172	9	3.2	29	143	24
1.5-8	a	161	7	5.5	39	122	20
	b	204	11	3.15	35	169	28
1.5-9	a	194	9	5.55	50	144	24
	b	193	13.5	3.15	43	150	25
1.5-10	a	207	5	5.76	29	178	30
	b	258	15	3.23	48	210	35
1.5-11	a	246	5.5	5.7	31	215	36
	b	202	13.5	3.25	44	158	26

TABLE 4 (Cont'd.)

Specimen No.		Impact Reading (ft-lbs)	Distance Fragment (ft)	Weight Fragment (lb)	Adj. (ft-lbs)	Impact Energy (ft-lbs)	Impact Resistance $\left(\frac{ft\text{-}lb}{in^2}\right)$
1.5-12	a	204	6.5	5.72	37	167	28
	b	153	11	3.33	39	114	19
1.5-13	a	173	9	5.53	50	123	21
	b	189	8	3.0	24	165	28
1.5-14	a	226	7.5	5.53	41	185	31
	b	204	8.5	3.12	27	177	30
2-1	a	189	5.5	5.80	32	157	26
	b	192	12.0	3.25	39	153	26
2-2	a	186	7.0	5.60	39	147	25
	b	252	11.0	3.23	36	216	36
2-3	a	210	4.0	5.60	22	188	31
	b	262	6.0	3.15	19	243	41
2-4	a	264	3.5	5.78	20	244	41
	b	264	6.2	3.45	21	243	41
2-5	a	256	3.5	6.15	22	234	39
	b	264	11.0	3.20	35	229	38
2-6	a	244	3.0	5.8	17	227	38
	b	225	11.5	3.3	38	187	36
2-7	a	246	5.0	5.95	30	216	36
	b	221	9.0	3.35	30	191	32
2-8	a	180	6.0	5.55	33	147	25
	b	251	6.0	3.35	20	231	39

TABLE 4 (Cont'd.)

Specimen No.		Impact Reading (ft-lbs)	Distance Fragment (ft)	Weight Fragment (lbs)	Adj. (ft-lbs)	Impact Energy (ft-lbs)	Impact Resistance $\left(\frac{ft\text{-}lb}{in^2}\right)$
2-9	a	240	6.5	5.75	37	203	34
	b	230	6.5	3.20	21	209	35
2-10	a	240	4.5	5.80	26	214	36
	b	264	10.5	3.35	35	229	38
2-11	a	260	3.5	6.05	21	239	40
	b	254	13.0	3.50	46	208	35
2-12	a	254	4.5	5.53	25	229	38
	b	256	7.5	3.40	26	230	38
2-13	a	220	6.5	5.48	36	184	31
	b	191	10	3.0	30	161	27
2-14	a	226	5	5.54	28	198	33
	b	214	8	3.20	27	187	31

TABLE 5

TEST AND TEST RESULTS OF GLASS FIBER REINFORCED CONCRETE PERFORMANCE UNDER IMPACT TEST

(Owens-Corning Technical Center Specimens)

Hammer Wt. Adjustment = +0.1
Cross Section Area for A = 6.0 in^2; for B = 5.25 in^2.

Specimen No.		Impact Reading (ft-lbs)	Distance Fragment (ft)	Weight Fragment (lbs)	Adj. (ft-lbs)	Impact Energy (ft-lbs)	Impact Resistance $\frac{ft\text{-}lb}{in^2}$
357	a	163	15	2.0	30	133	22
	b	152	19	2.2	42	110	21
358	a	201	18	1.5	27	174	29
	b	183	17.5	1.4	25	158	30
361	a	162	17.5	1.4	25	137	23
	b	124	18	1.15	20	104	20
363	a	210	9	1.25	11	199	33
	b	170	18	1.0	18	152	29
334	a	186	21	1.97	42	144	24
	b	134	18	3.0	36	98	19
458	a	206	21	1.6	34	172	29
	b	197	19	2.0	38	159	26
362	a	204	14.5	1.94	28	176	29
	b	188	13.5	2.0	27	161	31
462	a	180	22	1.38	30	150	25
	b	178	17	1.67	28	150	29
356	a	214	17.5	1.39	24	190	32
	b	182	20.5	1.58	32	150	29

Section IV

Findings and Conclusions:

The data acquired and reported under Section III has been subjected to analysis. The results of the test of specimens cast at the University of Texas at Arlington, in terms of mean impact resistance in foot/pounds of energy absorbed per square inch of cross-sectional area, are plotted in Figure 5. Upper and lower limits are also shown so that the magnitude of deviation from the mean can be seen. The impact resistance appears to increase linearly as the fiber content increases.

The impact resistance, expressed as a performance ratio, comparing the performance of glass fiber reinforced specimens with that of unreinforced concrete, is shown by Figure 6. The relationship of impact performance to fiber content again appears to be approximately linear. Close correlation to predicted flexural strength is seen. It may, therefore, be preliminarily concluded that glass fiber reinforcement can produce predictable increases in impact resistance with increased capacity under impact loads of up to 100 percent for concrete of ultimate compressive strength of about 4,000 psi.

Perhaps, just as important as the test results, is the demonstration of a feasible method of test that can be recommended for adoption.

Impact tests made with the Izod/Charpi test hammer, with the hammer raised to the Charpi position, can produce repeatable results that will permit parallel effort on the part of two or more researchers. Their results can then be directly compared.

It should be noted that the problem of concrete consistency, workability, becomes a serious problem at fiber content of 1.5 percent or more by volume. Further work contemplated at the University of Texas at Arlington, will be done using a vibrating table to facilitate specimen casting. Problems of maldistribution and malorientation of fibers, that was evident on the fracture surfaces of some specimens tested, could be avoided. High energy vibration is necessary to produce effective compaction of concrete with a high fiber content. Since this is necessary in the laboratory, it is implied that high energy, external vibration of forms will be necessary for field placement of glass fiber reinforced concrete or in the casting of pre-cast glass reinforced concrete products.

The results of impact tests made on half-sawn flexural specimen fragments furnished by Owens-Corning Fiberglas Technical Center, tabulated by Table 5 in Section III, are shown graphically by Figure 7. Impact resistance, plotted to compare the performance of glass fiber reinforced specimens to those that were unreinforced, is shown by Figure 8. The effect of fiber length cannot be determined with the small number of specimens tested. It is believed that valuable results could be

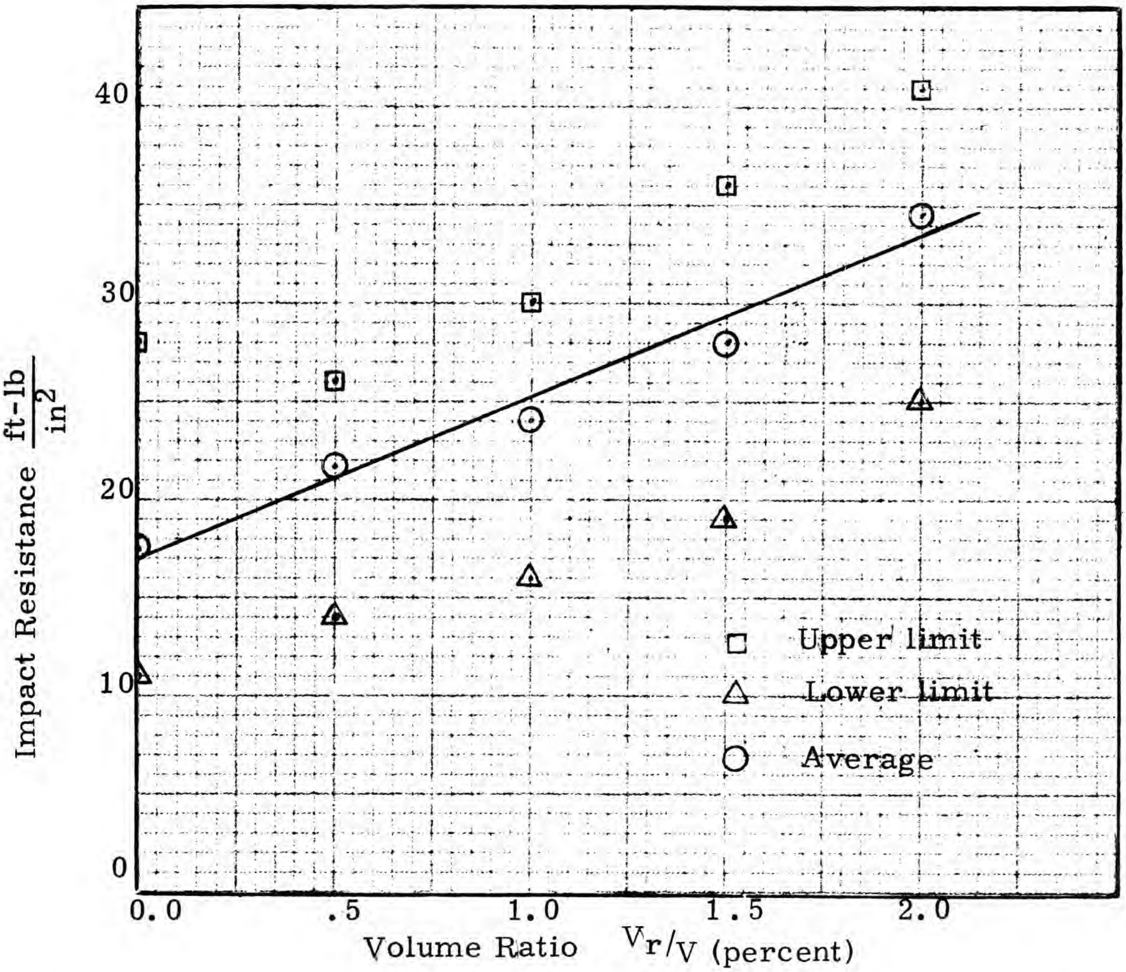

Figure 5: IMPACT RESISTANCE VERSUS FIBER CONTENT OF REINFORCED PORTLAND CEMENT CONCRETE

produced by testing a significant number of these sawn specimens. Care should be taken in the sawing to accurately produce equal halves of each flexural fragment.

The limited objectives of the test program reported here have been met. The introduction of short, randomly oriented glass fibers has a positive and predictable influence upon the impact resistance of concrete. This property would be of significant value in many

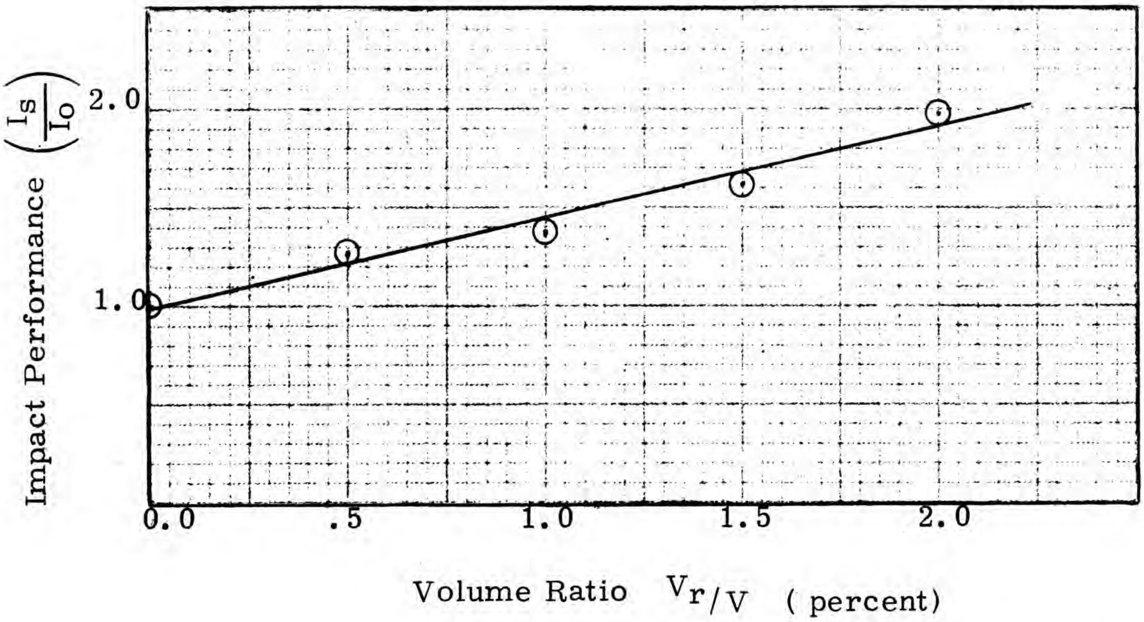

Figure 6: IMPACT PERFORMANCE VERSUS FIBER CONTENT OF REINFORCED PORTLAND CEMENT CONCRETE

applications. Further research should be accomplished to determine the influence of other variables and, thus, to develope the criteria for design.

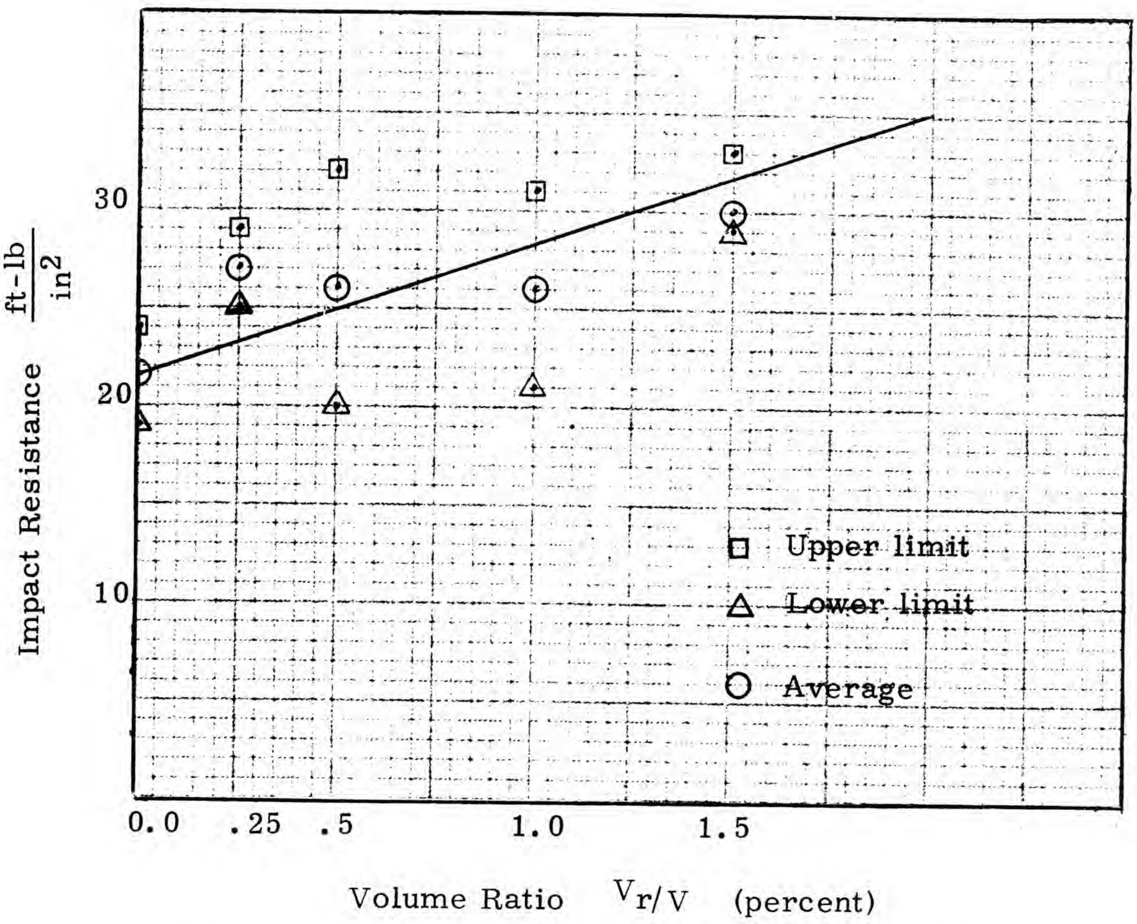

Figure 7: IMPACT RESISTANCE VERSUS FIBER CONTENT OF REINFORCED PROTLAND CEMENT CONCRETE (SPECIMENS CAST BY OWENS-CORNING TECHNICAL CENTER)

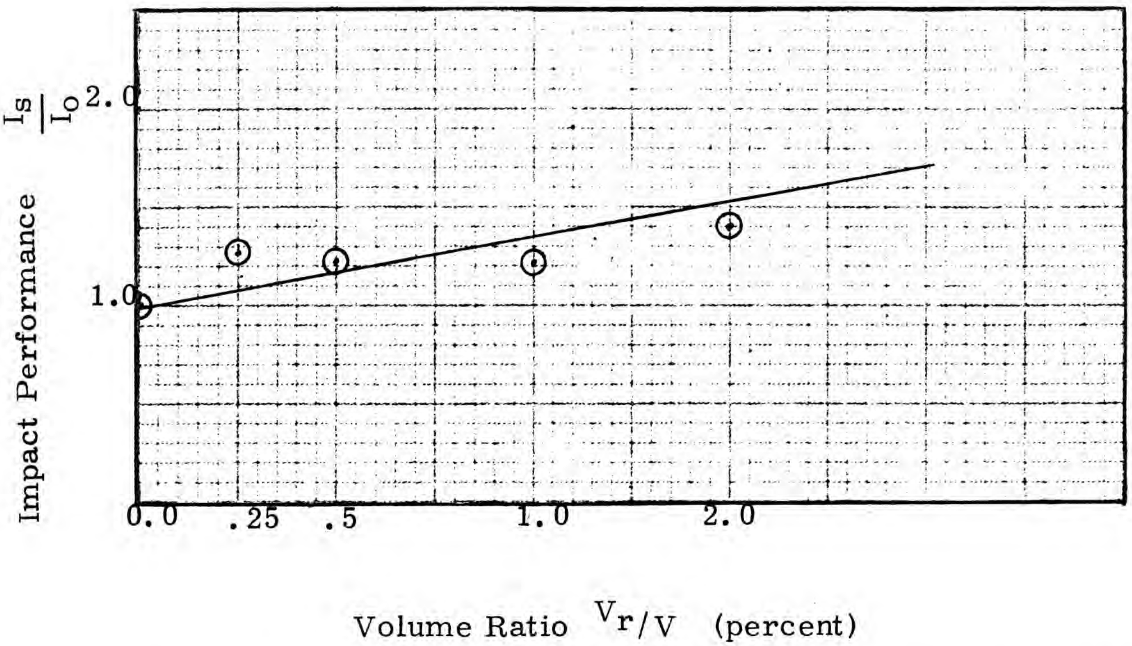

Figure 8: IMPACT PERFORMANCE VERSUS FIBER CONTENT OF REINFORCED PORTLAND CEMENT CONCRETE (SPECIMENS CAST BY OWNES-CORNING TECHNICAL CENTER)