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MODIFIED ACI DROP-WEIGHT IMPACT TEST FOR CONCRETE

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Biography:

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ABSTRACT

The ACI Committee 544 repeated drop-weight impact test for concrete is often criticized for large variations within the results. This paper identifies the sources of these large variations and accordingly suggests modifications to the ACI test. The proposed modifications were evaluated and compared to the current ACI test by conducting impact resistance tests on 40 specimens from two batches of polypropylene fiber reinforced concrete (PPFRC). The results obtained from both

1 methods were statistically analyzed and compared. The variations in the results were investigated
2 within the same batch and between different batches of concrete.

3
4 The impact resistance of PPFRC specimens tested with the current ACI test exhibited large
5 coefficients of variations of 58.6% and 50.2% for the first-crack and the ultimate impact resistance,
6 respectively. The corresponding coefficients of variations for PPFRC specimens tested according to
7 the modified technique were 39.4% and 35.2%, indicating that the reliability of the results was
8 significantly improved.

9
10 It has been shown that, using the current ACI test, the minimum number of replications needed per
11 each concrete mix to obtain an error below 10% was 41 compared to 20 specimens for the modified
12 test. Although such large number of specimens is not good enough for practical and economical
13 reasons, the reduction presents a good step on the development of a standard impact test.

14

15 **Keywords:** impact resistance; statistical variation; fiber reinforced concrete.

16

17

INTRODUCTION

18 Despite the significant increase in the impact resistance of concrete due to the addition of fiber
19 reinforcement [1-3], researchers and designers are not able to utilize impact resistance as a design
20 parameter, simply because it cannot be fully quantified due to the lack of a standard impact test for
21 concrete. The absence of a standard impact test prompted researchers to propose their own impact
22 tests to estimate the impact resistance of concrete either quantitatively or qualitatively [3-7]. Some of
23 these tests are relatively difficult to perform and require sophisticated equipments. However, none
24 of these tests have been claimed to be a standard test due to the lack of statistical data on the
25 variation of the results. In this regard, the ACI Committee 544 [8] has proposed a drop weight
26 impact test to demonstrate the relative brittleness and to quantify the impact resistance of fiber

1 reinforced concrete (FRC). The test is widely used since it is simple and economical. However, the
2 results obtained from this test are often noticeably scattered [9]. The large variation in impact
3 resistance as determined from this test is reported in the literature for different types of FRC [10-11].
4 However, large variation is a common problem in impact testing; and it is difficult to devise
5 systems that give reproducible results [7]. This might be attributed to the nature of the impact
6 process itself and the number of factors controlling the impact resistance compared with other
7 mechanical properties. In a previous study [12], the first author has highlighted the need for
8 modifying the ACI test in such a way that increases its accuracy and reduces the large variation in
9 results in order to adopt it as a standard test.

10

11 **RESEARCH SIGNIFICANCE**

12 The statistical variation in a mechanical property is the main factor in deciding the minimum
13 number of test results necessary for measuring such material property. Large variation indicates that
14 reliability is questionable; and necessitates large number of specimens to be tested to keep the error
15 under a certain limit.

16

17 The reported coefficient of variation of impact resistance of FRC specimens tested according to the
18 current ACI impact test is about 50 to 60%, which requires between 40 and 50 specimens to be
19 tested to keep the error under 10% [10-12]. This research identifies the sources of variations and
20 introduces modifications to reduce these sources in order to pave the way for the development of a
21 standard impact test.

22

23 **THE CURRENT ACI IMPACT TEST**

24 **Test procedures**

25 According to the current recommendations of the ACI Committee 544, the test is to be carried out
26 by dropping a hammer weighing 44.7 N from a height of 457 mm repeatedly on a 63.5 mm

1 diameter hardened steel ball, which is placed on the top of the centre of a 150 x 63.5 mm cylindrical
2 concrete specimen (disc) as shown in Fig. 1. The steel ball is free to move vertically within
3 a 63.5 mm cylindrical sleeve.

4

5 ~~The test should continue until complete failure. For each specimen, two values should be identified~~
6 ~~corresponding to initial and ultimate failure. The former value measures the number of blows~~
7 ~~required to initiate a visible crack, whereas the latter measures the number of blows required to~~
8 ~~initiate and propagate cracks until ultimate failure. The ultimate failure occurs when sufficient~~
9 ~~impact energy is supplied to spread the cracks enough so that the test specimen touches the steel~~
10 ~~lugs, which are located at a distance of 5 mm from the specimen.~~

11

12 The test should continue until complete failure. For each specimen, the number of blows required to
13 cause a visible crack and to propagate cracks until ultimate failure should be measured. The
14 ultimate failure is declared when the cracked test specimen touches the steel lugs located at a 5 mm
15 distance from the specimen due to the impact energy supplied by the dropped hammer.

16

17 The results can be evaluated on the basis of averaging the obtained values. Five specimens are
18 recommended for replications. The highest and lowest values should be discarded and the impact
19 resistance is the average of the remaining three [9].

20

21 **Sources of large variations and discrepancy in test results**

22 The sources of large variations in results obtained from the current ACI impact test can be
23 summarized as follows:

24 1. Allowing cracks to occur anywhere and in any direction: This increases the subjectivity of
25 the test and also makes the visual identification of the first crack very difficult.

- 1 2. Using a single point of impact: This increases the possibility of false results, as it might
2 happen that this point is a hard particle of coarse aggregate or a soft area of mortar.
- 3 3. Absence of criteria for preparing test specimens: thus specimens may have trowled, cut or
4 smooth mould-faced surfaces.
- 5 4. Definition of the ultimate failure by the touching of the specimen to the lugs of the
6 apparatus: This might lead to continuing impacting specimens, which has already failed by
7 complete separation or excessive crack width.
- 8 5. Absence of criteria for accepted or rejected failure mode: This increases the scatter of the
9 results.

10

11 **Suggested modifications**

12 The following suggested modifications are proposed to reduce the sources of variations:

- 13 1. Forcing cracks to occur in a predefined path by using a notched specimen; two 25 mm
14 triangular notches located at the ends of the specimen diameter is suggested, as shown in Fig. 2.
- 15 2. Using a 50 mm line of impact instead of a single point reduces the possibility of false results,
16 as it will probably act upon more representative area of concrete that contains hard particles of
17 coarse aggregate as well as soft areas of mortar.
- 18 3. All specimens should have similar surfaces. Either all specimens ~~is~~ are to be cast in identical
19 moulds with exact dimensions so that all of them have smooth bottom and trowled faces; or all
20 surfaces should be cut faces; i.e. neither the trowled top nor the smooth bottom faces can be used, as
21 shown in Fig. 3.
- 22 4. Ultimate failure should be declared if the specimen is separated completely into halves
23 before touching the lugs; or the specimen touches two opposite lugs of the apparatus, whichever
24 takes place first.
- 25 5. Only specimens failed by cracking through the line of impact and the two notches are
26 accepted; any other pattern of cracking should be rejected (For example, see Fig. 4(b)).

1

2 In addition, using a 50 mm thick notched specimen instead of the 63.5mm un-notched specimens
3 reduces the time and effort required to test a single specimen as the 50 mm specimen requires less
4 number of blows allowing for testing more replications. Additional benefit from reducing the
5 number of blows is the reduction of noise pollution and making the test more environmentally
6 friendly.

7

8

EXPERIMENTAL INVESTIGATION

9 The effectiveness of the modified technique was evaluated by testing 40 PPFRC specimens from
10 two batches; 20 specimens from each batch. Additional counterpart 40 specimens were tested
11 according to the current ACI impact test, for the sake of comparison. Compressive strength was
12 determined at the age of 28 days, as a measure of quality control.

13

14 **Materials**

15 Table 1 presents the Chemical composition of the ordinary Portland cement (OPC) used in this
16 study, as given by the supplier. It is conforming to BS 12: 1996. Quartzite natural gravel of 10-mm
17 nominal maximum size was used as coarse aggregate. The fine aggregate was quartzite sand, with
18 grading conforms to zone M of BS 882, 1992. Its specific gravity and water absorption were 2.66
19 and 0.17 percent, respectively. A superplasticizer based on naphthalene sulfonates polymer was
20 added to the concrete mix to enhance workability. Virgin polypropylene fiber was used. The
21 physical properties and dimensions of this fiber are presented in Table 2.

22

23 **Mixing and preparation of specimens**

24 The mix proportions are given in Table 3. A conventional rotary drum concrete mixer was used.
25 The coarse aggregate, cement and sand were first mixed in the dry state for one minute before
26 adding about half of the mixing water. After two minutes of mixing, the remaining mixing water

1 and superplasticizer were added. Mixing was continued for another three minutes before adding the
2 polypropylene fibers. The fibers were slowly added to the running mixer to avoid clumping. Mixing
3 was continued for further five minutes to achieve uniform distribution of the fiber. Workability of
4 the fresh concrete was assessed using the slump test according to BS 1881: Part 102, 1983. The
5 slump values were 80 and 105 mm for the first and second batches, respectively.

6
7 Concrete specimens were prepared from two different batches of identical composition but cast in
8 two different occasions. Enough standard cylinders with a diameter of 150 mm and a height of 300
9 mm were cast from each batch to prepare 40 specimens for the impact test. Half of them were tested
10 according to the ACI current method, whereas the other half was tested following the proposed
11 modified technique. However, allowance for rejected results was made. Ten 100-mm cubes were
12 prepared from each batch according to BS 1881: Part 108: 1983 for the compressive strength test.

13
14 After casting, the concrete specimens were compacted using a vibrating table. The specimens were
15 covered with wet hessian and polyethylene sheets overnight. They were then de-molded after 24
16 hours and cured in a fog room with curing conditions conform to BS 1881: Part 111: 1983 (20 ± 2 °C
17 and 97 ± 3 % relative humidity) for 7 days, after which the cylinders were cut using a diamond saw
18 to get specimens for the impact test, from each cylinder as shown in Fig. 3. All specimens and
19 cubes were then transferred to an environmental chamber maintained at 38 ± 2 °C and 45 ± 5 %
20 relative humidity, until testing at the age of 28 days.

21

22

TEST PROCEDURES

Compressive strength

24 Compressive strength of the hardened concrete cubes was determined according to BS 1881: Part
25 116: 1983. The tests carried out using a digital automatic testing machine of a 3000 kN capacity. A
26 total of 20 cubes (10 x 2 batches) were tested at the age of 28 days.

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Impact resistance

The impact resistance of PPFRC at the age of 28 days was determined according to the test procedures explained earlier for the current ACI impact test and the modified method. The impact blows were applied and counted mechanically using a standard soil compaction machine shown in Fig. 5. The following changes are introduced in the proposed modified technique:

- 1- Specimens were 50 mm thick for the modified method instead of 63.5 mm as shown in Fig. 3.
- 2- Notched specimens were used as shown in Fig. 2.
- 3- Hardened steel bar, shown in Fig. 6, of a 13 mm diameter x 50 mm length attached to a 50 mm hardened steel cylinder with a height of 50 mm is used instead of the steel ball.

The main differences between the two methods are summarized in Table 4.

Forty specimens (2 batches x 20 specimens) of PPFRC were tested according to the current ACI impact test. However, larger number of specimens, 24 and 25 specimens from the first and second batches, respectively, had to be tested to determine the impact resistance using the modified method to achieve 20 accepted results from each batch. Four and five results were rejected from the first and second batches, respectively as they failed by cracking away from the predefined cracking path, as shown in Fig. 4.

EXPERIMENTAL RESULTS AND DISCUSSION

Compressive strength

Summary of statistical parameters for the results of the compression test, carried out at the age of 28 days, is given in Table 5.

1 The average 28-day compressive strength, standard deviation and coefficient of variation were 41.3
2 MPa, 4.17 MPa and 10.09%, respectively. The mean compressive strengths within batches were
3 38.6 and 44.1 MPa with standard deviations of 2.80 and 3.46 MPa, respectively. The corresponding
4 coefficients of variation within batches were 7.26% and 7.85%.

5
6 Fig. 7 presents the histogram of the 20 results obtained from the compressive strength tests. The
7 figure shows that the results are almost normally distributed and fit well with the superimposed
8 normal distribution curve of the same mean and standard deviation as the compressive strength
9 results.

10
11 The overall standard deviation and the standard deviations within batches indicate good quality
12 control over the production of the concrete specimens. A figure of 4 to 6 MPa is considered
13 acceptable in the UK [13]. The values of the coefficient of variation provide further evidence of
14 good quality control. The overall coefficient of variation (10.09 %) is much lower than a limit of
15 15 % suggested by Swamy and Stavrides [14] for good quality control; even though the coefficients
16 of variation within batches are higher than the 5% limit suggested by them. However, Day [13]
17 suggested that a coefficient of variation between 5 and 10 % generally represents a reasonable
18 quality control.

19 20 **Impact resistance**

21 Table 6 presents the impact resistance results (total number of blows) for the first-crack (FC) and
22 the ultimate impact resistance (UR) values for the two methods of testing; i.e. the current ACI and
23 modified test methods. The values are sorted in ascending order with respect to the first crack
24 values.

25

1 Table 6 indicates that the results obtained using the current ACI method are inconsistent. While the
2 first crack impact resistance is sorted in ascending order, the corresponding ultimate impact
3 resistance does not follow the same trend. For example, comparing specimens number 13 and 11 of
4 the first batch, it can be seen that specimen number 13 has much lower UR (89 blows compared to
5 100 blows for specimen number 11) despite that its FC resistance is significantly higher than that of
6 specimen 11 (67 compared to 54 blows). Other examples such as specimens 8 versus 9 of the first
7 batch and specimens 7 versus 8 of the second batch are emphasized in Table 6. On the other hand,
8 the results obtained using the proposed modified method are consistent. It can be seen from Table 6
9 that the ultimate impact resistance follows the same trend of ascending order as did the first crack
10 impact resistance, i.e. Specimens exhibited higher first crack resistance would have higher ultimate
11 impact resistance.

12
13 Table 7 gives the mean, standard deviation and coefficient of variation for all samples and within
14 batches obtained from the ACI and modified test methods. This table clearly indicates that the
15 standard deviation and coefficient of variation for all specimens and within the two batches
16 calculated for the ACI method are much higher than those obtained for the proposed modified
17 method.

18
19 The overall average of the ultimate impact resistance, as determined by the current ACI method,
20 was 80 blows with a standard deviation of 40.4, which makes a coefficient of variation of more than
21 50.2 %. The counterpart values, as determined by the proposed modified method, were considerably
22 less than those values determined by the current ACI method, with a mean, standard deviation and
23 coefficient of variation of 55 blows, 19.4 blows and 35.2 %, respectively.

24
25 As expected, the mean obtained for the ACI method is higher than that for the proposed modified
26 method due to the effect of the notches and reduction of the specimen size. The overall FC mean

1 reduced by about 22 %, whereas, the overall UR mean reduction was more than 30%. Similar
2 figures of reductions were obtained within individual batches.

3
4 The standard deviation values obtained using the proposed modified method were 17.3 and 19.4 for
5 the overall FC and UR, respectively. These values are almost half the counterpart values obtained
6 using the current ACI test. This was true for the overall standard deviations and within batches, for
7 FC and UR. In addition, the standard deviation values obtained using the proposed modified
8 method compare favorably to those reported in the literature for different types of FRC tested
9 according to the ACI test. Values of 59 and 66 were obtained by Nataraja et al. [11] for steel fiber
10 reinforced concrete. However, unlike compressive strength, it is not realistic to use the standard
11 deviation to judge or compare the impact resistance results. This is because the impact test is not a
12 standard test. In such cases it is more appropriate to use the coefficient of variation.

13
14 The coefficient of variation is considered a more meaningful index of variability because it accounts
15 for the mean as well as the standard deviation. Day [13] stated that several ACI committees
16 including ACI committees 212 (Mixture Proportioning), 214 (Evaluation of Test Results) and 363
17 (High Strength Concrete) adopted the coefficient of variation as a measure of variability rather than
18 the standard deviation. The impact resistance of specimens tested with the current ACI test
19 exhibited large coefficients of variations of 58.6% and 50.2% for the overall first-crack and the
20 ultimate impact resistance, respectively. The corresponding coefficients of variations for specimens
21 tested according to the modified technique were 39.4% and 35.2%, indicating that the reliability of
22 the results was improved by about 30%.

23
24 The coefficient of variations obtained for PPFRC in this study using the current ACI method is in
25 the same order of magnitude as reported for other fiber reinforced composites. Values of 54.6 and
26 57.3 were reported by Soroushian et al. [10] for carbon fiber reinforced composites and Nataraja et

1 al. [11] for steel fiber reinforced concrete, respectively. Therefore, the reduction obtained using the
2 proposed modified method would be expected for other types of FRC.

3
4 Figures 8, 10 and 12 show the histogram distribution of the ultimate impact resistance results with
5 the normal distribution curve overlapping them for the ACI method for all test specimens, batch 1
6 and batch 2, respectively. The corresponding distributions for the proposed method are given in
7 Figures 9, 11 and 13. These figures show that the scatter of distribution for the proposed modified
8 method is closer to the ideal normal distribution than that for the ACI method. Similar conclusions
9 can be drawn for the distribution of first-crack impact resistance but charts are not presented here.

10
11 The normal probability plots of all results for the ACI and proposed modified test methods are
12 presented in Figures 14 and 15, respectively. Straight lines have been drawn through the plotted
13 points to represent the normal distribution. It can be seen that the results for FC and UR obtained
14 from the current ACI method are not as close to straight lines as the results of the modified method,
15 indicating larger scatter of the ACI method.

16

17 **Goodness-of-fit test**

18 The goodness-of-fit test was performed to compare the variations for the two test results obtained
19 from the ACI and modified test methods. It was concluded that a much better fitness of the impact
20 resistance test results to normal distribution at 95% of confidence is obtained from the proposed
21 modified method than that for the ACI method.

22

23 **Minimum number of replications**

24 The coefficients of variation of the test results introduced in Table 7 can also be used to determine
25 the minimum number of tests, n , required in order to guarantee that the percentage error in the

1 measured average is below a specified limit, e , at a specific level of confidence [14], as given by
2 Equation (1) below.

3

$$4 \quad n = t^2 v^2 / e^2 \quad (1)$$

5

6 where:

7 v = coefficient of variation

8 t = value of t -student distribution for the specified level of confidence and is dependent on the
9 degree of freedom, which is related to the number of tests.

10

11 For a large sample size, “ t ” approaches 1.645 and 1.282 at 95 and 90 % level of confidence,
12 respectively [15-16]. Table 8 presents the number of samples required to keep the error under
13 various limits between 10 and 50 %, at 95 and 90 % level of confidence.

14

15 It can be seen that for the UR obtained using the ACI method, if the error is to be kept under 10%,
16 the minimum number of tests should be 68 and 41 at 95 and 90 % level of confidence, respectively.
17 These values are double of that required by the proposed modified method, which are 34 and 20
18 specimens. The number of replications is even reduced in case of FC, as it can be seen from
19 Table 8.

20

21 Moreover, the table shows that if five samples are used to determine the impact resistance, then the
22 error in the measured value according to the ACI method could be between 30 to 40% depending on
23 the level of confidence. In the proposed modified method, the corresponding errors are between 20
24 to 25 %.

CONCLUSIONS

The present paper has identified the sources of variations and discrepancy in the current ACI impact test method and suggested a proposed modified method for the impact test of concrete. The following conclusions may be drawn:

1. The proposed modified method improved the reliability of the results; made the test easier to be carried out; reduced the time required for testing and made the test more environmentally friendly.
2. The reliability of the results obtained using the modified technique was improved by about 30% compared to the results obtained using the current ACI method. The impact resistance of PPFRC specimens tested with the current ACI test exhibited large coefficients of variations of 58.6% and 50.2% for the first-crack and the ultimate impact resistance, respectively. The corresponding coefficients of variations for PPFRC specimens tested according to the modified technique were 39.4% and 35.2%.
3. It has been shown that if the error is to be kept below 10%, the minimum number of replications needed per each concrete mix was 41 using the current ACI test compared to 20 specimens for the modified test.
4. With the current common practice of using five specimens for the determination of impact resistance of concrete mixes the error in the measured value obtained using the current ACI test could be between 30 and 40 % depending on the level of confidence. The corresponding error values using the modified test would be reduced to 20 to 25 %.

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Table 1- Chemical Composition of the Cement

<i>Oxide</i>	<i>Content %</i>
CaO	63.28
SiO ₂	20.77
Al ₂ O ₃	4.93
Fe ₂ O ₃	3.06
MgO	2.42
Na ₂ O	0.28
K ₂ O	0.7
L.O.I.	0.81

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Table 2- Physical Properties and Dimensions of PPF

<i>Physical Properties</i>	
Specific gravity	0.91
Melting point	160-170 °C
Ignition point	590 °C
Tensile modulus	4.1 GPa
Tensile strength	560 MPa
<i>Dimensions</i>	
Length	12 mm
Nominal Diameter	18 μm

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Table 3- Mix Proportions

<i>Constituent</i>	<i>Content per m³ of Concrete</i>
Cement	410 kg
Coarse aggregate	1000 kg
Fine aggregate	800 kg
Water	185 liter
Superplasticizer	4.1 liter
Polypropylene fiber	3 kg

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Table 4- Main Differences between the ACI and Proposed Modified Methods

	ACI Method	Proposed Modified Method
Test specimens (Figures 2 & 3)	<ol style="list-style-type: none">1. 63.5 mm thick cylinder2. Un-notched specimen3. Top and/ or bottom surfaces could be trowled, cut or smooth	<ol style="list-style-type: none">1. 50 mm thick cylinder2. Notched specimen3. All specimens should have cut faces
Load application (Figures 1 & 6)	Point load; applied through a hardened steel ball of 63.5mm diameter	Line load; applied using a hardened steel bar of a 13 mm diameter x 50 mm length
Failure criteria (Fig. 4)	No criteria	Only specimens failed by cracking through the line of impact and the two notches are accepted; any other pattern of cracking should be rejected

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Table 5- Compressive Strength Test Results

No.	Batch 1	Batch 2	Overall
Mean (MPa)	38.6	44.1	41.3
SD (MPa)	2.80	3.46	4.17
CoV (%)	7.26	7.85	10.09

SD= Standard Deviation; CoV= Coefficient of Variation

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Table 6- Results from Impact Test (total number of Blows as measured from tests)

Specimen	Current ACI Method				Proposed Modified Technique			
	Batch 1		Batch 2		Batch 1		Batch 2	
	FC	UR	FC	FC	FC	UR	FC	UR
1	11	18	9	16	12	23	13	15
2	12	27	12	20	20	29	19	24
3	17	30	14	25	22	34	23	29
4	26	38	15	28	27	38	26	33
5	28	40	24	43	32	41	29	38
6	32	41	33	52	34	43	32	40
7	34	65	43	74	39	48	34	43
8	43	73	47	63	40	53	37	47
9	46	60	55	79	43	54	39	50
10	53	89	56	73	45	57	42	52
11	54	100	58	89	45	58	42	55
12	65	95	64	95	48	61	43	56
13	67	89	66	81	49	63	44	58
14	77	121	68	101	52	68	47	64
15	79	121	70	85	54	72	52	65
16	81	104	76	98	59	73	55	68
17	97	135	76	103	62	78	57	70
18	99	127	90	141	66	81	64	73
19	108	141	109	129	74	87	73	82
20	148	173	118	134	77	96	79	86

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Table 7- Statistical Parameters for Impact Tests

Method	Parameter	Batch 1		Batch 2		Overall	
		FC	UR	FC	UR	FC	UR
Current ACI Method	Mean (Blow)	59	84	55	76	57	80
	SD (Blow)	36.2	43.9	31.2	37.3	33.4	40.4
	CoV (%)	61.4	52.1	56.6	48.7	58.6	50.2
Proposed Modified Technique	Mean (Blow)	45	58	43	52	44	55
	SD (Blow)	17.6	19.8	17.3	19.1	17.3	19.4
	CoV (%)	39.1	34.3	40.7	36.5	39.4	35.2

SD= Standard Deviation; CoV= Coefficient of Variation

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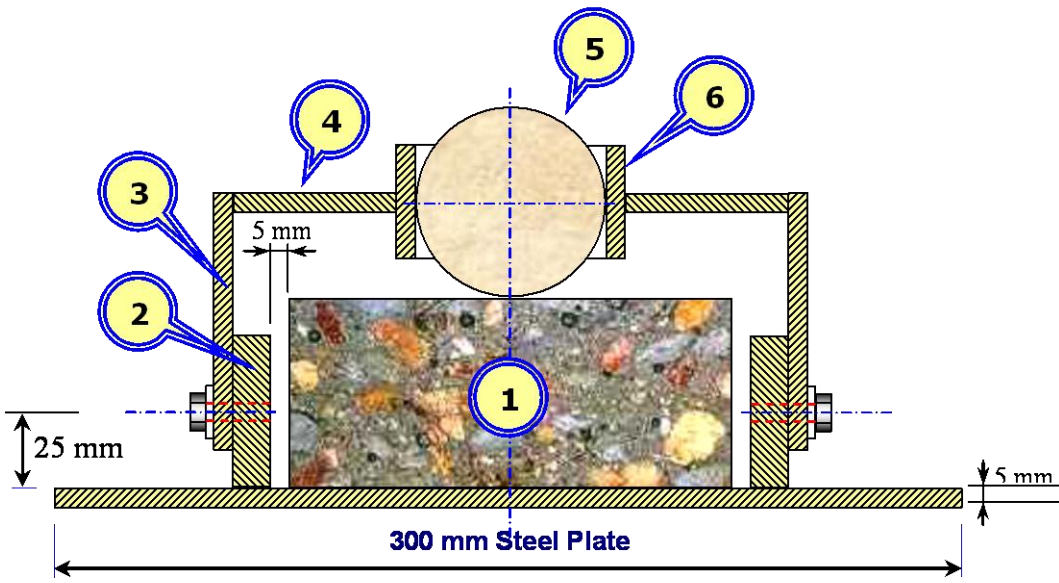
Table 8- Number of Replications Required to Keep the Error under a Specific Limit

Level of confidence	Current ACI Method				Proposed Modified Technique			
	95%		90%		95%		90%	
	FC	UR	FC	UR	FC	UR	FC	UR
10	93	68	56	41	42	34	26	20
15	41	30	25	18	19	15	11	9
20	23	17	14	10	11	8	6	5
25	15	11	9	7	7	5	4	3
30	10	8	6	5	5	4	3	2
40	6	4	4	3	3	2	2	1
50	4	3	2	2	2	1	1	1

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- 1. Concrete Specimen 150 x 63.5 mm
- 2. Steel Plate 50 x 50 x 13 mm
- 3. Steel Plate 50 x 86 x 5 mm
- 4. Steel Plate 55x 5 mm
- 5. Hardened Steel Ball 63.5 mm
- 6. Steel Pipe 63.5 mm Diameter

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Fig. 1- Impact Test Apparatus with the Concrete Disc in Place

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Fig. 2- Notched Specimens: Two 25 mm Triangular Notches

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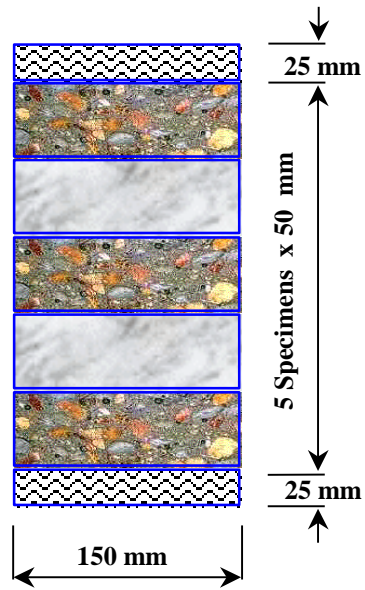
14

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Fig. 3- Concrete Specimens for Impact Test Obtained from Concrete Cylinders

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(The trawled top and the smooth bottom faces are discarded)

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(A) Accepted failure

(B) Rejected failure

Fig. 4- Examples of Accepted and Rejected Failures

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Fig. 5- Impact Testing Machine

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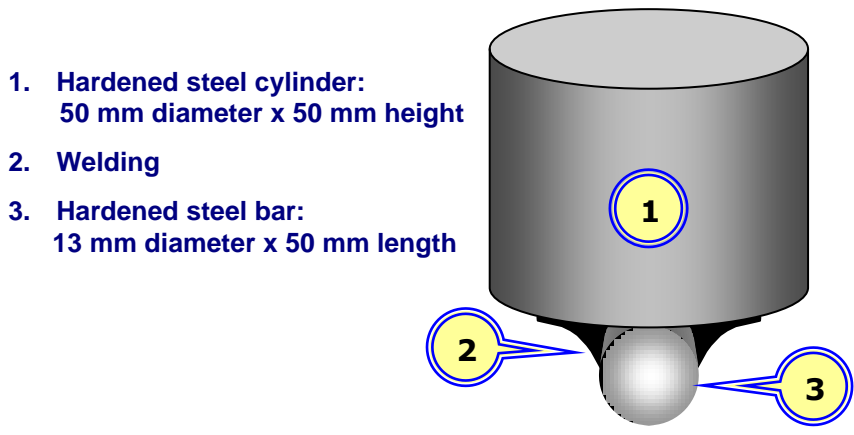


Fig. 6- Impact Testing Line Load

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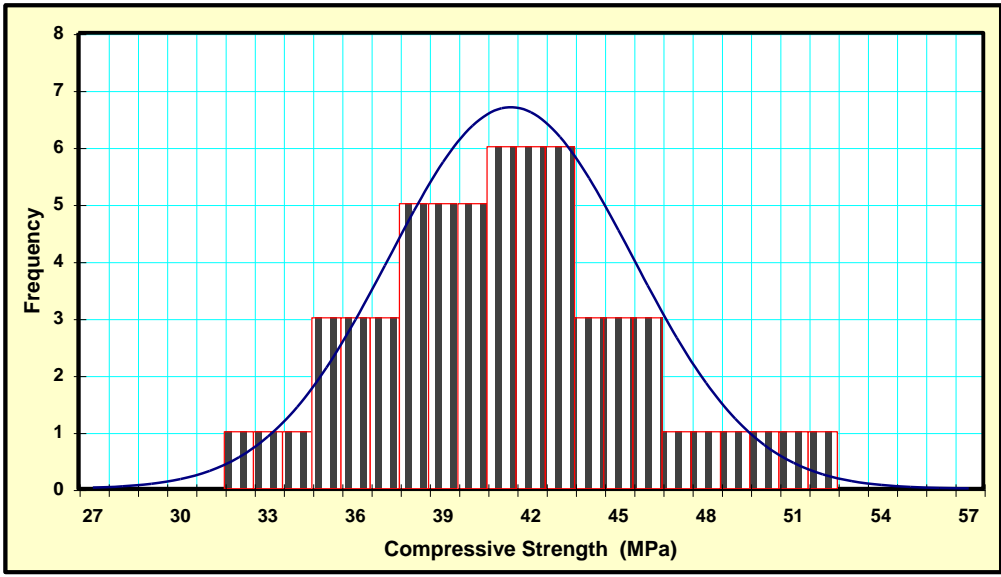


Fig. 7- Distribution of Compressive Strength Test Results

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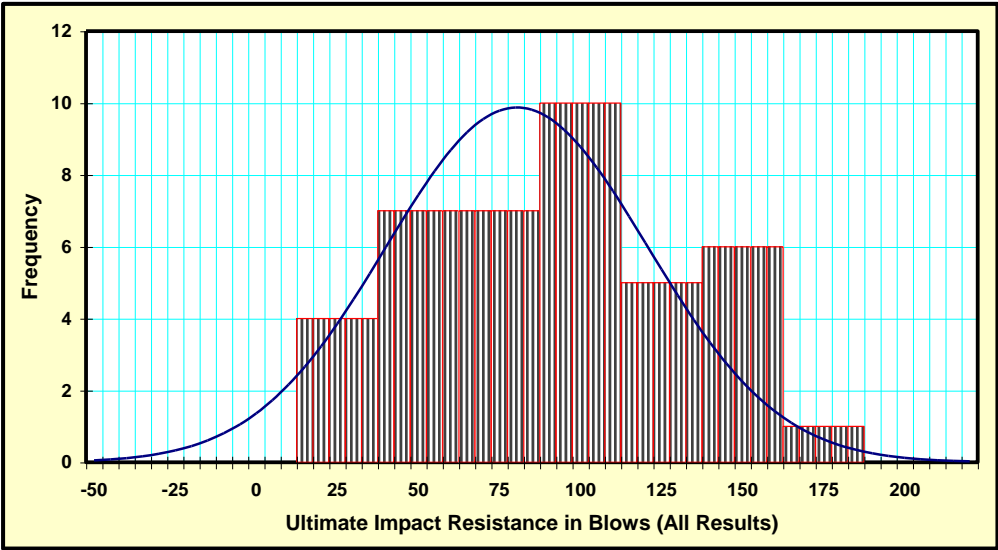


Fig. 8-Distribution of the Ultimate Impact Resistance (Current ACI-All Results)

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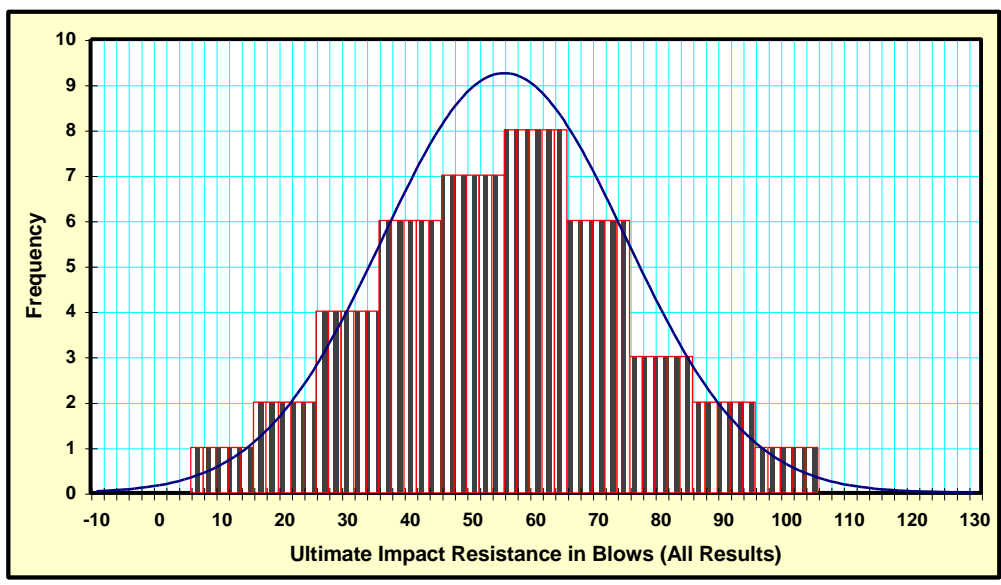


Fig. 9- Distribution of the Ultimate Impact Resistance
(Proposed Modified Technique -All Results)

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Fig. 10- Distribution of the Ultimate Impact Resistance (Current ACI-Batch 1)

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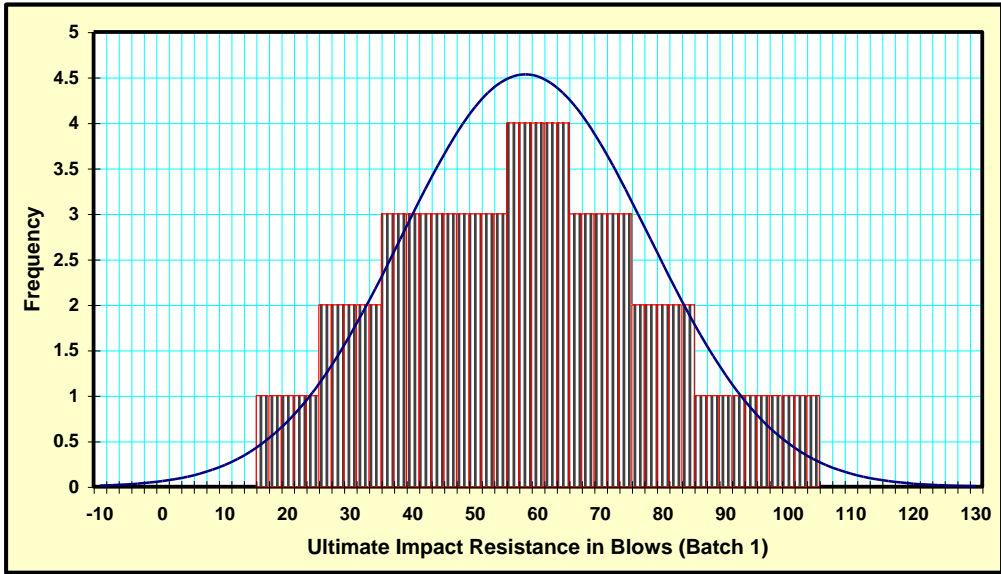


Fig. 11- Distribution of the Ultimate Impact Resistance
(Proposed Modified Technique -Batch 1)

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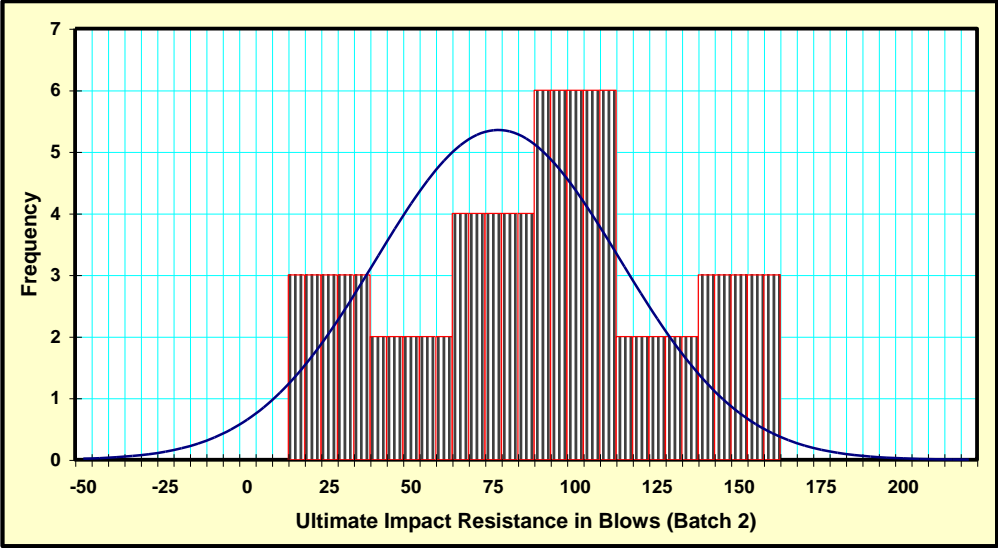


Fig. 12- Distribution of the Ultimate Impact Resistance (Current ACI-Batch 2)

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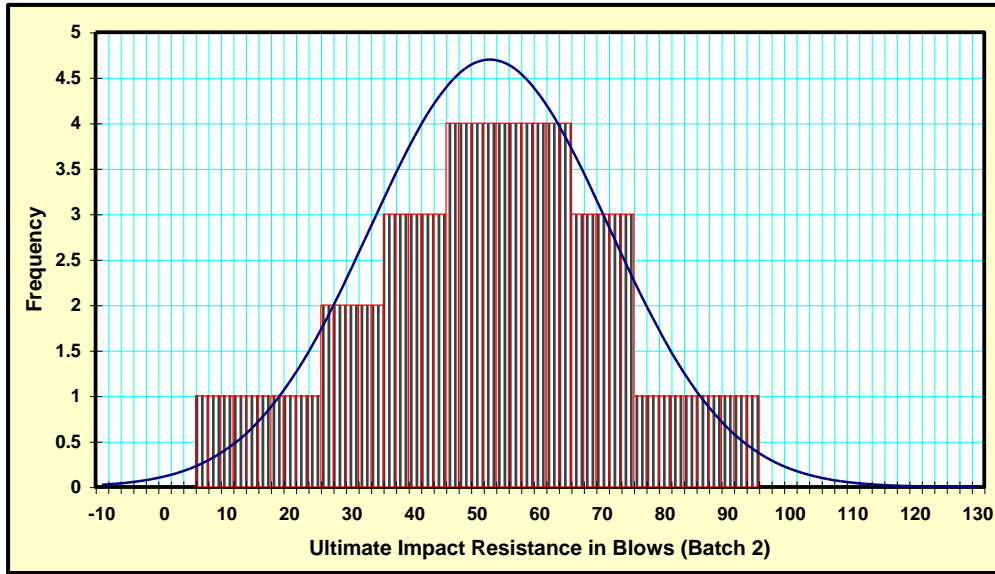


Fig. 13- Distribution of the Ultimate Impact Resistance
(Proposed Modified Technique -Batch 2)

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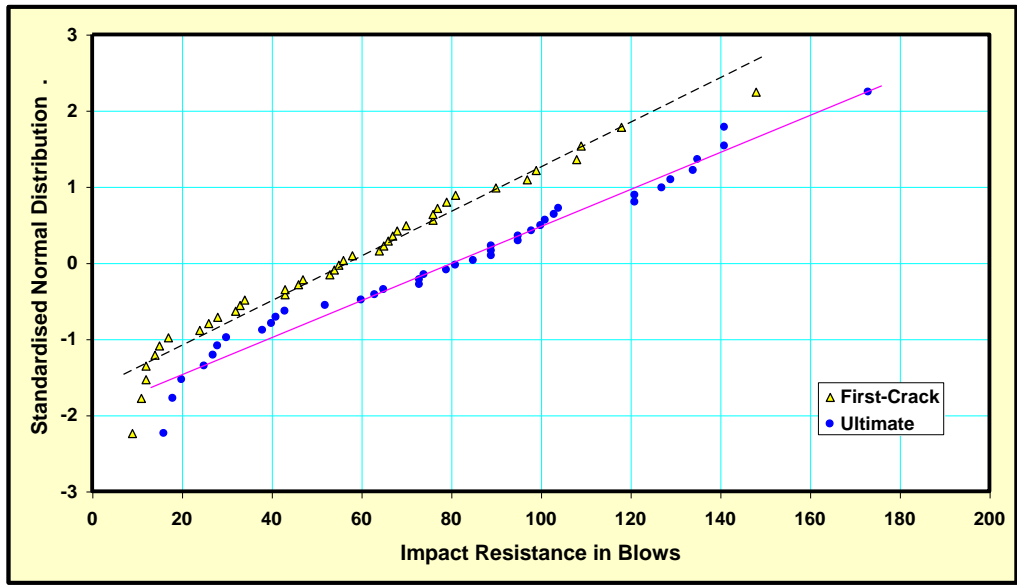


Fig. 14- Normal Probability Plot of All Results (Current ACI)

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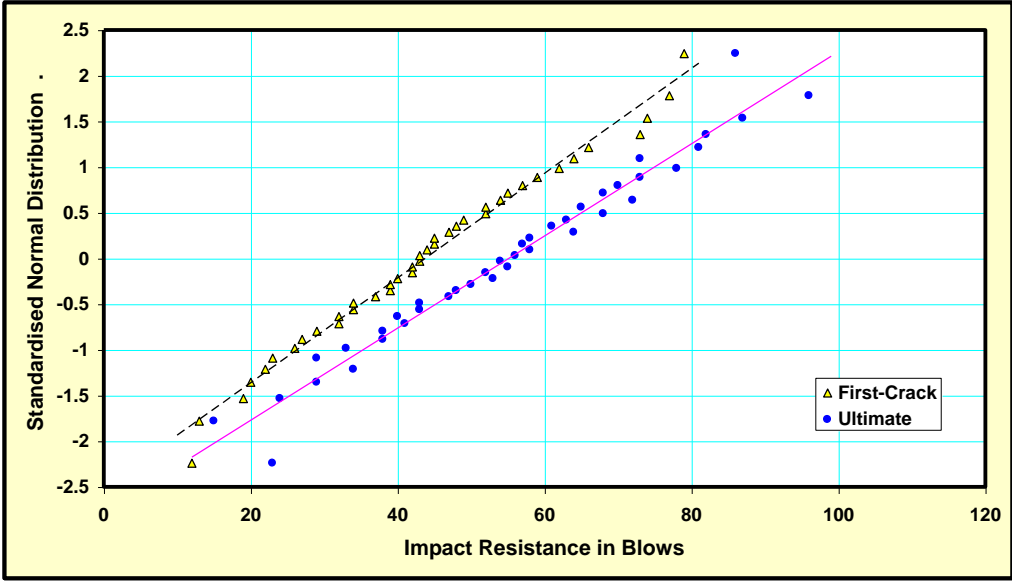


Fig. 15- Normal Probability Plot of All Results (Proposed Modified Technique)