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Correlation between Destructive and Non-Destructive Strengths of Concrete Cubes Using Regression Analysis

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Abstract

In this study, the destructive and non-destructive tests were performed on totally 120 laboratory-made concrete cubes. Regression analysis using MATLAP software was carried out. Simple relationships were determined and correlated between non-destructive testing (NDT) named as Schmidt rebound hammer test and concrete destructive compression test. The Schmidt rebound hammer is principally a surface hardness tester with an apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. Schmidt hammer was applied in both vertical and horizontal positions. The standard concrete cubes were prepared with various mix proportions that yielded standard cubes crushing strengths (f_{cu}) within a range of 10 to 35 MPa.

Keywords: Non-destructive testing- Crushing Strength-Structure Evaluation-Rebound Index – Concrete Quality

1. Introduction

Concrete is the most commonly used construction material in structures. Determination of compressive strength has become the most important concern of researchers since its usage and usually regarded as the main criteria to judge the quality of concrete. Various destructive and non-destructive test (NDT) methods have been developed for determining the compressive strength. The aim of these tests is to control concrete production and determine under service loads deteriorations in buildings on time. Nevertheless, the destructive methods are expensive

and time consuming. In addition, cube and cylinder concrete specimens prepared in laboratory are not represented in situ concrete. Furthermore, getting core specimens from structural element reduces the load carrying capacity of construction elements (2).
Actually, non-destructive testing may be applied to both new and existing structures. With respect to new structures the principal application is for quality control, whereas for existing structures non- destructive testing is carried out to assess structural integrity(2,3).

This experimental study consists of non-destructive testing on standard concrete cubes using Schmidt hammer, and thereafter destructive testing of same cubes using compression testing machine. The standard concrete cubes were prepared with various mix proportions that yielded standard cubes crushing strengths (f_{cu}) within a range of 10 to 35 MPa.

1.1 NDT Testing of Concrete Using Schmidt Hammer

Among the available non-destructive methods, the Schmidt Hammer test is the most commonly used one in practice. It has been used world-wide as an index test for a testing equipment to estimate strength of concrete due to its rapidity and easiness in execution, simplicity, portability, low cost and non-destructiveness. The rebound hammer test is described in ASTM C805 (1993), BS 1881: Part 202 (1986). The test is classified as a hardness test and based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The energy absorbed by the concrete is related to its strength (ACI, 2011). Despite its apparent simplicity, the rebound hammer test involves complex problems of impact and the associated stress-wave propagation (Akashi and Amasaki, 1984). The test method starts by the careful selection and preparation of the concrete surface to be tested and a fixed amount of energy is applied by pushing the hammer against the test surface. The plunger must be allowed to strike perpendicularly to the surface, as the angle of inclination of the hammer affects the results. After impact, the rebound number should be recorded by taking at least 10 readings from each tested area . Although there is no unique relation between hardness and strength of concrete, experimental data relationships can be obtained from given specimens.

However, this relationship is dependent upon the concrete surface effecting factors, such as degree of saturation, carbonation, temperature, surface preparation, and type of surface finish. The result is also affected by type of aggregate, mix proportions, hammer type and inclination. Areas exhibiting honey-combing, scaling, rough texture or high porosity must be avoided. Amasaki (1991) presented the effect of carbonation on rebound number. Grieb (1958) showed the effect of type of aggregates on rebound number and hence estimated strength. Earlier researches (2 - 9) on finding the correlation between concrete strengths and NDT were generally limited to the specimens prepared in laboratory conditions.

1.2 Experimental Program

This research aimed to obtain simple correlations used by engineers who work on-site. Samples were made from ordinary Portland cement and aggregate of local natural sources or crushed hard limestone. Various concrete mixes were used to prepare the standard cube specimens (15 × 15 × 15 cm) in the laboratory to compare with Schmidt hammer rebound strength.

One hundred and twenty concrete cubes, with a wide range of crushing strengths f_{cu} (10 to 35 MPa), were prepared for testing. After 28 days from the casting date and in accordance with B.S 1881. Twelve hammer impacts were equally distributed on two opposite sides of each specimen that is sides which have been lying sideward during concreting. The Schmidt hammer rebound number was calculated as the average of the twelve readings. The Schmidt hammer test was first used while kept in a horizontal position to test opposite cube surfaces been placed in vertical direction, and then kept in a vertical position to test opposite cube surfaces been placed horizontal direction. Finally, the same cubes were destructively tested to obtain crushing strengths using standard compression machine. Figure 1. shows the cube specimen placed in the testing machine.

Figure 1: The cube specimen placed in the testing machine.

2. Tests Results

The test hammer was first used while kept in a vertical position to test opposite cube surfaces been placed in horizontal direction, and then kept in a horizontal position to test opposite cube surfaces been placed vertical direction. Finally, destructive testing was carried out for the same cubes to obtain its crushing strengths using standard compression testing machine.

The tests results for both positions are given in Tables 1 and 2.

Table 1: Destructive, None-destructive and Predicted Crushing Strength of Standard Concrete Cube *(f_{cu})* (Schmidt Hammer in Vertical Position)

Concrete cube N0.	Rebound Value (MPa)	Crushing Strength f_{cu} (MPa)	Predicted Concrete Strength f_{cu} (MPa)		
			Linear Relation	Quadratic Equation	Cubic Equation
1	28.6000	12.6000	14.0427	13.4077	13.9009
2	30.8000	13.5000	16.2180	15.9896	15.5307
3	33.0000	13.0000	18.3933	18.4614	17.7071
4	34.1000	16.0000	19.4810	19.6559	18.9370
5	31.3500	12.5000	16.7618	16.6179	16.0315
6	29.7000	12.6000	15.1304	14.7124	14.6348
7	30.2500	12.5000	15.6742	15.3545	15.0641
8	30.1400	12.4000	15.5654	15.2266	14.9751
9	29.9200	12.7800	15.3479	14.9701	14.8018
10	29.8100	12.9600	15.2391	14.8414	14.7175
11	27.5000	13.5000	12.9551	12.0754	13.3543
12	37.4000	14.4000	22.7439	23.0744	22.8890
13	38.5000	18.3000	23.8315	24.1588	24.2094
14	27.0000	11.7000	12.4607	11.4607	13.1747
15	25.0000	12.3000	10.4832	8.9451	12.9432
16	31.9000	13.3200	17.3057	17.2393	16.5633
17	35.2000	16.4000	20.5686	20.8230	20.2275
18	32.4500	13.5900	17.8495	17.8538	17.1229
19	30.8000	13.9500	16.2180	15.9896	15.5307
20	35.2000	16.0000	20.5686	20.8230	20.2275
21	30.8000	15.3000	16.2180	15.9896	15.5307
22	37.4000	14.8500	22.7439	23.0744	22.8890
23	33.0000	14.4000	18.3933	18.4614	17.7071
24	30.8000	15.3000	16.2180	15.9896	15.5307
25	38.5000	16.0200	23.8315	24.1588	24.2094
26	36.3000	16.2000	21.6562	21.9624	21.5533
27	34.6500	16.2000	20.0248	20.2429	19.5763

28	31.9000	14.7600	17.3057	17.2393	16.5633
29	29.7000	14.9400	15.1304	14.7124	14.6348
30	27.5000	14.6700	12.9551	12.0754	13.3543
31	29.7000	15.3000	15.1304	14.7124	14.6348
32	41.8000	21.0000	27.0945	27.2467	27.8246
33	39.6000	19.2000	24.9192	25.2156	25.4890
34	28.6000	16.3800	14.0427	13.4077	13.9009
35	35.2000	16.5600	20.5686	20.8230	20.2275
36	37.4000	16.5600	22.7439	23.0744	22.8890
37	28.6000	16.7400	14.0427	13.4077	13.9009
38	29.7000	16.8200	15.1304	14.7124	14.6348
39	36.3000	22.1000	21.6562	21.9624	21.5533
40	34.1000	16.3800	19.4810	19.6559	18.9370
41	44.0000	21.1500	29.2698	29.1675	29.6931
42	39.6000	27.0000	24.9192	25.2156	25.4890
43	35.2000	18.0900	20.5686	20.8230	20.2275
44	29.7000	17.6400	15.1304	14.7124	14.6348
45	27.5000	14.5800	12.9551	12.0754	13.3543
46	35.2000	17.4600	20.5686	20.8230	20.2275
47	38.5000	27.6000	23.8315	24.1588	24.2094
48	36.3000	23.8000	21.6562	21.9624	21.5533
49	34.1000	26.0000	19.4810	19.6559	18.9370
50	34.7600	25.0000	20.1335	20.3595	19.7057
51	30.8000	18.0000	16.2180	15.9896	15.5307
52	44.0000	22.3200	29.2698	29.1675	29.6931
53	36.3000	19.1700	21.6562	21.9624	21.5533

54	39.6000	21.0000	24.9192	25.2156	25.4890
55	35.2000	19.0800	20.5686	20.8230	20.2275
56	36.3000	19.0800	21.6562	21.9624	21.5533
57	30.8000	17.4600	16.2180	15.9896	15.5307
58	31.9000	19.2600	17.3057	17.2393	16.5633
59	39.6000	19.2600	24.9192	25.2156	25.4890
60	40.7000	22.0000	26.0068	26.2449	26.7025
61	33.0000	19.8000	18.3933	18.4614	17.7071
62	44.0000	23.4000	29.2698	29.1675	29.6931
63	37.4000	19.9800	22.7439	23.0744	22.8890
64	37.4000	20.2500	22.7439	23.0744	22.8890
65	37.4000	20.7000	22.7439	23.0744	22.8890
66	37.4000	20.3400	22.7439	23.0744	22.8890
67	37.4000	21.1500	22.7439	23.0744	22.8890
68	37.4000	20.7000	22.7439	23.0744	22.8890
69	37.4000	20.3400	22.7439	23.0744	22.8890
70	37.4000	20.6100	22.7439	23.0744	22.8890
71	35.2000	21.6000	20.5686	20.8230	20.2275
72	44.0000	22.9500	29.2698	29.1675	29.6931
73	38.5000	23.4000	23.8315	24.1588	24.2094
74	39.6000	21.6000	24.9192	25.2156	25.4890
75	35.2000	20.7000	20.5686	20.8230	20.2275
76	42.9000	25.2000	28.1821	28.2209	28.8299
77	34.1000	21.6900	19.4810	19.6559	18.9370
78	33.0000	19.5300	18.3933	18.4614	17.7071
79	40.7000	21.7800	26.0068	26.2449	26.7025

80	40.9200	21.7800	26.2244	26.4475	26.9350
81	35.2000	22.5000	20.5686	20.8230	20.2275
82	48.4000	28.0800	33.6203	32.6788	31.2180
83	39.6000	23.4000	24.9192	25.2156	25.4890
84	38.5000	24.0300	23.8315	24.1588	24.2094
85	43.1200	23.3100	28.3996	28.4124	29.0147
86	37.4000	22.5000	22.7439	23.0744	22.8890
87	36.3000	24.3000	21.6562	21.9624	21.5533
88	34.1000	24.7500	19.4810	19.6559	18.9370
89	41.8000	25.2000	27.0945	27.2467	27.8246
90	39.6000	25.3800	24.9192	25.2156	25.4890
91	35.2000	25.2000	20.5686	20.8230	20.2275
92	50.6000	31.1600	35.7956	34.2691	30.4688
93	44.0000	26.4100	29.2698	29.1675	29.6931
94	38.5000	27.5500	23.8315	24.1588	24.2094
95	33.0000	21.5700	18.3933	18.4614	17.7071
96	40.7000	25.6500	26.0068	26.2449	26.7025
97	41.2500	27.5500	26.5506	26.7492	27.2765
98	41.8000	25.6500	27.0945	27.2467	27.8246
99	45.1000	26.7900	30.3574	30.0867	30.3889
100	37.4000	27.0800	22.7439	23.0744	22.8890
101	37.4000	25.3000	22.7439	23.0744	22.8890
102	44.0000	27.5500	29.2698	29.1675	29.6931
103	46.2000	27.9300	31.4451	30.9783	30.8918
104	40.7000	26.6000	26.0068	26.2449	26.7025
105	48.4000	28.5000	33.6203	32.6788	31.2180

106	35.7000	22.8000	21.0630	21.3443	20.8273
107	47.2500	28.0300	32.4833	31.8036	31.1688
108	33.6000	22.3000	18.9866	19.1164	18.3689
109	46.4100	30.2000	31.6527	31.1453	30.9638
110	49.3500	34.8600	34.5597	33.3790	31.0383
111	38.8500	28.5000	24.1776	24.4980	24.6221
112	45.2600	30.4000	30.5156	30.2181	30.4746
113	44.1000	30.8700	29.3686	29.2522	29.7637
114	39.9000	31.2000	25.2158	25.4991	25.8275
115	36.7500	25.8000	22.1012	22.4206	22.1000
116	39.9000	30.6000	25.2158	25.4991	25.8275
117	48.3000	32.5800	33.5215	32.6039	31.2249
118	37.8000	28.5000	23.1394	23.4719	23.3723
119	36.7500	26.6000	22.1012	22.4206	22.1000
120	40.9500	31.1600	26.2540	26.4750	26.9664

Table 2: Destructive, None-destructive and Predicted Crushing Strength of Standard Concrete Cube *(f_{cu})* (Schmidt Hammer in Horizontal Position)

Concrete cube N0.	Rebound Value (MPa)	Crushing Strength f_{cu} (MPa)	Predicted Concrete Strength f_{cu} (MPa)		
			Linear Relation	Quadratic Equation	Cubic Equation
1	26.0000	14.0000	15.4611	13.4077	13.9009
2	28.0000	15.0000	17.5612	15.9896	15.5307
3	30.0000	14.5000	19.6613	18.4614	17.7071
4	31.0000	13.8000	20.7114	19.6559	18.9370
5	28.5000	13.9000	18.0863	16.6179	16.0315
6	27.0000	14.0000	16.5112	14.7124	14.6348
7	27.5000	13.9000	17.0362	15.3545	15.0641

8	27.4000	13.8000	16.9312	15.2266	14.9751
9	27.2000	14.2000	16.7212	14.9701	14.8018
10	27.1000	14.4000	16.6162	14.8414	14.7175
11	25.0000	15.0000	14.4111	12.0754	13.3543
12	34.0000	16.0000	23.8615	23.0744	22.8890
13	35.0000	15.5000	24.9116	24.1588	24.2094
14	22.5000	13.0000	11.7859	11.4607	13.1747
15	21.5000	11.0000	10.7359	8.9451	12.9432
16	29.0000	14.8000	18.6113	17.2393	16.5633
17	32.0000	14.8000	21.7614	20.8230	20.2275
18	29.5000	15.1000	19.1363	17.8538	17.1229
19	28.0000	15.5000	17.5612	15.9896	15.5307
20	32.0000	14.9000	21.7614	20.8230	20.2275
21	28.0000	17.0000	17.5612	15.9896	15.5307
22	34.0000	16.5000	23.8615	23.0744	22.8890
23	30.0000	16.0000	19.6613	18.4614	17.7071
24	28.0000	17.0000	17.5612	15.9896	15.5307
25	35.0000	17.8000	24.9116	24.1588	24.2094
26	33.0000	18.0000	22.8115	21.9624	21.5533
27	31.5000	18.0000	21.2364	20.2429	19.5763
28	29.0000	16.4000	18.6113	17.2393	16.5633
29	27.0000	16.6000	16.5112	14.7124	14.6348
30	25.0000	16.3000	14.4111	12.0754	13.3543
31	27.0000	17.0000	16.5112	14.7124	14.6348
32	38.0000	20.0000	28.0617	27.2467	27.8246
33	36.0000	18.0000	25.9616	25.2156	25.4890

34	26.0000	18.2000	15.4611	13.4077	13.9009
35	32.0000	18.4000	21.7614	20.8230	20.2275
36	34.0000	18.4000	23.8615	23.0744	22.8890
37	26.0000	18.6000	15.4611	13.4077	13.9009
38	27.0000	18.8000	16.5112	14.7124	14.6348
39	33.0000	19.0000	22.8115	21.9624	21.5533
40	31.0000	18.2000	20.7114	19.6559	18.9370
41	40.0000	23.5000	30.1618	29.1675	29.6931
42	36.0000	20.0000	25.9616	25.2156	25.4890
43	32.0000	20.1000	21.7614	20.8230	20.2275
44	27.0000	19.6000	16.5112	14.7124	14.6348
45	25.0000	16.2000	14.4111	12.0754	13.3543
46	32.0000	19.4000	21.7614	20.8230	20.2275
47	35.0000	19.6000	24.9116	24.1588	24.2094
48	33.0000	19.3000	22.8115	21.9624	21.5533
49	31.0000	19.7000	20.7114	19.6559	18.9370
50	31.6000	19.8000	21.3414	20.3595	19.7057
51	28.0000	20.9000	17.5612	15.9896	15.5307
52	40.0000	24.8000	30.1618	29.1675	29.6931
53	33.0000	21.3000	22.8115	21.9624	21.5533
54	36.0000	20.8000	25.9616	25.2156	25.4890
55	32.0000	21.2000	21.7614	20.8230	20.2275
56	33.0000	21.2000	22.8115	21.9624	21.5533
57	28.0000	19.4000	17.5612	15.9896	15.5307
58	29.0000	21.4000	18.6113	17.2393	16.5633

59	36.0000	21.4000	25.9616	25.2156	25.4890
60	37.0000	21.8000	27.0117	26.2449	26.7025
61	30.0000	22.0000	19.6613	18.4614	17.7071
62	40.0000	26.0000	30.1618	29.1675	29.6931
63	34.0000	22.2000	23.8615	23.0744	22.8890
64	34.0000	22.5000	23.8615	23.0744	22.8890
65	34.0000	23.0000	23.8615	23.0744	22.8890
66	34.0000	22.6000	23.8615	23.0744	22.8890
67	34.0000	23.5000	23.8615	23.0744	22.8890
68	34.0000	23.0000	23.8615	23.0744	22.8890
69	34.0000	22.6000	23.8615	23.0744	22.8890
70	34.0000	22.9000	23.8615	23.0744	22.8890
71	32.0000	24.0000	21.7614	20.8230	20.2275
72	40.0000	25.5000	30.1618	29.1675	29.6931
73	35.0000	26.0000	24.9116	24.1588	24.2094
74	36.0000	24.0000	25.9616	25.2156	25.4890
75	32.0000	23.0000	21.7614	20.8230	20.2275
76	39.0000	28.0000	29.1118	28.2209	28.8299
77	31.0000	24.1000	20.7114	19.6559	18.9370
78	30.0000	21.7000	19.6613	18.4614	17.7071
79	37.0000	24.2000	27.0117	26.2449	26.7025
80	37.2000	24.2000	27.2217	26.4475	26.9350
81	32.0000	25.0000	21.7614	20.8230	20.2275
82	44.0000	31.2000	34.3621	32.6788	31.2180
83	36.0000	26.0000	25.9616	25.2156	25.4890

84	35.0000	26.7000	24.9116	24.1588	24.2094
85	39.2000	25.9000	29.3218	28.4124	29.0147
86	34.0000	25.0000	23.8615	23.0744	22.8890
87	33.0000	27.0000	22.8115	21.9624	21.5533
88	31.0000	27.5000	20.7114	19.6559	18.9370
89	38.0000	28.0000	28.0617	27.2467	27.8246
90	36.0000	28.2000	25.9616	25.2156	25.4890
91	32.0000	28.0000	21.7614	20.8230	20.2275
92	46.0000	32.8000	36.4622	34.2691	30.4688
93	40.0000	27.8000	30.1618	29.1675	29.6931
94	35.0000	29.0000	24.9116	24.1588	24.2094
95	30.0000	22.7000	19.6613	18.4614	17.7071
96	37.0000	27.0000	27.0117	26.2449	26.7025
97	37.5000	29.0000	27.5367	26.7492	27.2765
98	38.0000	27.0000	28.0617	27.2467	27.8246
99	41.0000	28.0000	31.2119	30.0867	30.3889
100	34.0000	28.5000	23.8615	23.0744	22.8890
101	34.0000	28.8000	23.8615	23.0744	22.8890
102	40.0000	29.0000	30.1618	29.1675	29.6931
103	42.0000	29.4000	32.2619	30.9783	30.8918
104	37.0000	28.0000	27.0117	26.2449	26.7025
105	44.0000	30.0000	34.3621	32.6788	31.2180
106	34.0000	30.2000	23.8615	21.3443	20.8273
107	45.0000	29.5000	35.4121	31.8036	31.1688

108	32.0000	28.0000	21.7614	19.1164	18.3689
109	44.2000	30.2000	34.5721	31.1453	30.9638
110	47.0000	36.7000	37.5122	33.3790	31.0383
111	37.0000	30.0000	27.0117	24.4980	24.6221
112	43.1000	32.0000	33.4170	30.2181	30.4746
113	42.0000	32.5000	32.2619	29.2522	29.7637
114	38.0000	32.8000	28.0617	25.4991	25.8275
115	35.0000	31.9000	24.9116	22.4206	22.1000
116	38.0000	32.2000	28.0617	25.4991	25.8275
117	46.0000	34.3000	36.4622	32.6039	31.2249
118	36.0000	30.0000	25.9616	23.4719	23.3723
119	35.0000	28.0000	24.9116	22.4206	22.1000
120	39.0000	32.8000	29.1118	26.4750	26.9664

2.2 Data Analysis

Linear nonlinear regression analysis were conducted using MATLAP software to study the correlation between and rebound index and crushing strength of standard concrete cube for the both positions under consideration.

1-Schmidt Hammer in Vertical Position

The scatter plot (Figures 2, 3 and 4) representing the rebound index versus concrete cubic compressive strength could give the following three equations (Linear, quadratic and cubic) were concluded for the predicted **v**alues of the concrete cubic compressive strength f **(MPa) :**

$$f = 0.9888x_1 - 14.2361$$

$$f = 0.0114x_1^2 + 0.8497x_1 - 30.1834$$

$$f = -0.0032x_1^3 + 0.3497x_1^2 - 11.6296x_1 + 134.7075$$

Where: x_1 is the Schmidt hammer rebound strength (MPa)

The predicted values of the concrete cubic compressive strength are given in Table 1.

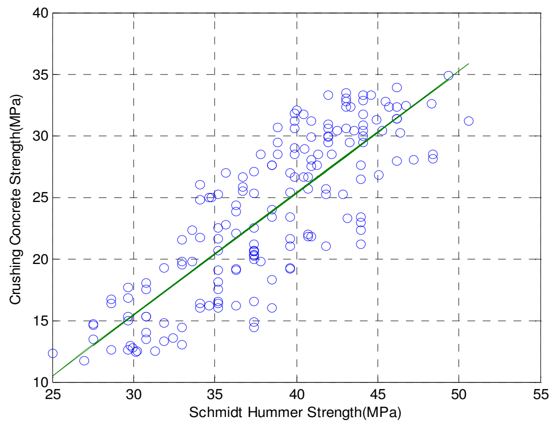

Figure 2: Rebound index versus concrete cubic compressive strength (Linear Equation)

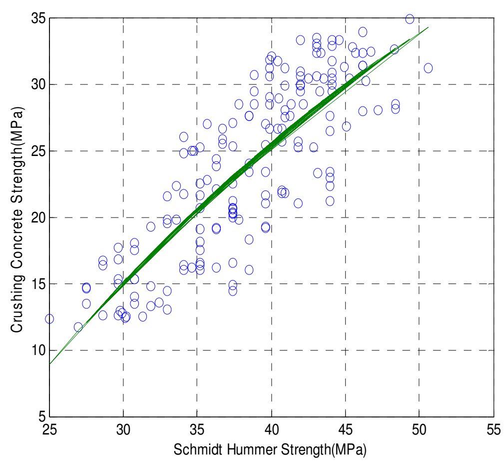

Figure 3: Rebound index versus concrete cubic compressive strength (Quadratic Equation)

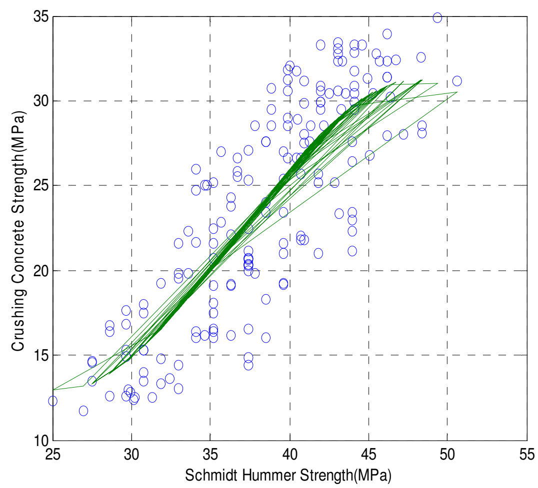

Figure 4: Rebound index versus concrete cubic compressive strength (Cubic Equation)

2-Schmidt Hammer in Horizontal Position

The scatter plot (Figures 5, 6 and 7) representing the rebound index versus concrete cubic compressive strength could give the following three equations (Linear, quadratic and cubic) were concluded for the predicted **v**alues of the concrete cubic compressive strength f **(MPa) :**

$$f = 1.0501x_1 - 11.8402$$

$$f = -0.0078x_1^2 + 1.5979x_1 - 21.1986$$

$$f = -0.0029x_1^3 + 0.2975x_1^2 - 8.8004x_1 + 94.4267$$

Where: x_1 is the Schmidt hammer rebound strength (MPa)

The predicted values of the concrete cubic compressive strength are given in Table 2.

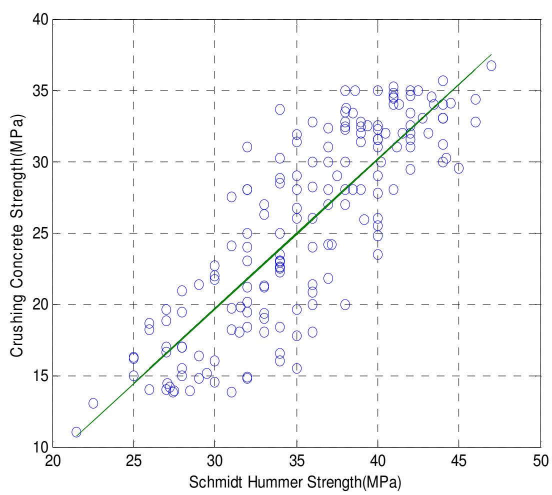

Figure 5: Rebound index versus concrete cubic compressive strength (Linear Equation)

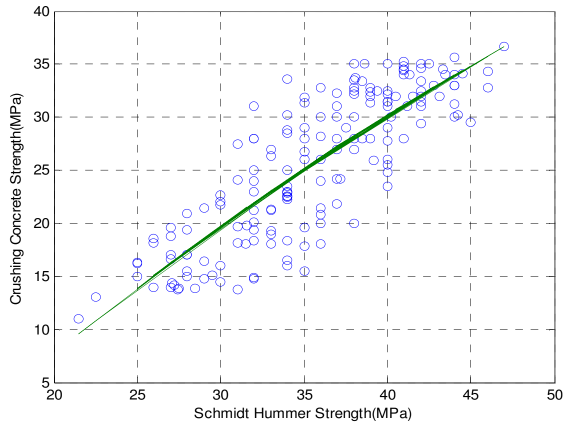

Figure 6: Rebound index versus concrete cubic compressive strength (Quadratic Equation)

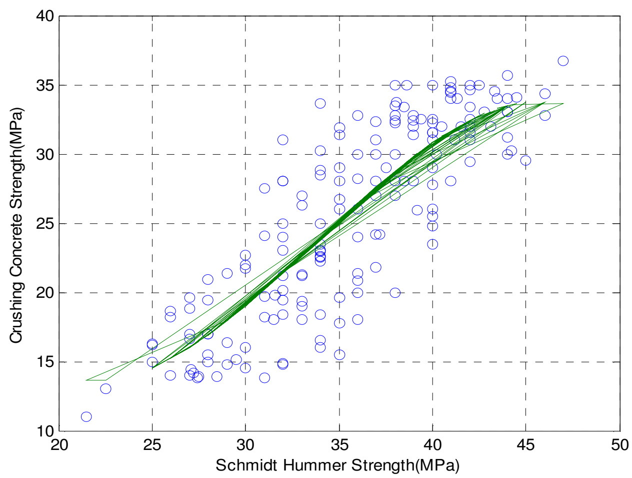

Figure 7: Rebound index versus concrete cubic compressive strength (Cubic Equation)

3. Conclusions

The correlation among the strength values obtained by destructive and NDT test methods on laboratory-made concrete has been established. Schmidt Hammer test method has been used as a non-destructive test. The following principal conclusions have been drawn:

1. The use of rebound hammer test method on concrete cubes is not suitable to estimate its strength. Direct use of rebound hammer demonstrates high variations, which makes engineering judgment quite difficult. The Schmidt Hammer method could only be used as a reliable instrument to calculate the compressive strength

2. The Presents study puts forward a useful mathematical linear nonlinear relationships that help the engineer to predict confidently the crushing strength of standard concrete cubes, by measuring the rebound index by means of Schmidt hammer. The mathematical expression is applicable for a wide range of concrete strengths.
3. Schmidt Hammer test results can be influenced by many factors; such as the characteristics of the mixture, surface carbonation, moisture condition, rate of hardening and curing type. Therefore, the correction factors have to be used to allow this effect for existing concrete.

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