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Non-destructive Testing of Replacing Virgin Aggregates by Recycled Aggregate Concrete Cluster Using Schmidt Rebound Hammer and Ultrasonic Pulse Velocity

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Abstract: The Schmidt hammer and Ultrasonic pulse velocity are the main importance to testing hardened concrete structures after the concrete has gain the strengths, which checking is necessary weather the concrete structure is suitable for designed use. Broken concrete and re-sized output are called recycled aggregate concrete cluster (RACC) owing to mix of mortar and aggregate. Lack of information on recycling and reuse of recycled aggregate concrete cluster combined with construction demolition waste. Thus, the main aim of this research was to study the effect of replacement of virgin aggregate (VA) by possible extent inclusion of recycled aggregate concrete cluster with C-30 grade concrete mix design having water to cement ratio 0.435 and slump of 25~100mm at replacement levels of 10%, 20%, 30%, 40% and 50% virgin aggregate by recycled aggregate concrete cluster. Finally, comparison of properties between virgin aggregate and recycled aggregate concrete cluster was recognized to verify the suitability of recycled aggregate concrete cluster to replace virgin aggregate. The results shows that almost at par, else proximate engineering parameter values of recycled aggregate concrete cluster with Virgin aggregate offered momentum for twenty percent objective scope. It is suggested that recycled aggregate concrete cluster recycling needs policy makers' attention.

Keywords: Hardened Concrete, Recycled Aggregate Concrete Cluster, Non–destructive, Virgin Aggregate

1. Introduction

Non–destructive test is the method of inspecting, testing and evaluating materials, components or assembly of hardened concrete performance without destroying the serviceability of parts or systems. It is implying that also the technique of evaluating the quality of concrete in civil structures is to test samples casting simultaneously for compressive and flexural strengths [1]. All aggregates are not suitable for producing concrete, due to the strength of aggregates may control the ultimate strength of concrete once they are crushed apart before the failure of cement paste [2]. Recycled aggregates and recycled concrete aggregate cluster are usually not suggested in creating concrete. Owing to drastic effect of reduced concrete performance, due to high level amount of cement pastes [3]. The rate of recycled aggregate concrete cluster using Schmidt rebound hammer ultrasonic pulse velocity decrease that is proportional to the decrease of compressive strength. For normal concrete, Schmidt rebound hammer ultrasonic pulse velocity testing strength are about one-tenth of compressive strength. However, for replacing of virgin aggregate within recycled aggregate concrete cluster, it is drop to 5% of normal concrete strength and though, re-sizes and use of recycled aggregate concrete cluster can be significantly reduced resulting in s cost of virgin aggregates up to 10% [4]. Moreover, owing to a low virgin aggregate content of concrete, it provided creep and shrinkage increases. To decrease the content of recycled aggregate concrete cluster concrete, varying 25MPa to 35MPa, it definitely helps in improving the structural performance of the structure by producing a denser, more durable and higher load capacity concrete [5]. However, with an increase in concrete strength, the cement content is increased and this leads to higher performance of concrete. Consequently, additional reinforcement has to be introduced to control these additional cracks caused by the increase in concrete strength. Attention should be paid during the design of concrete to increase the strength of concrete is suggested [6]. There is lack of information on recycling and reuse of recycled aggregate concrete cluster combined with construction demolition waste by replacement of virgin aggregates in the Ethiopian construction industry. Thus, the main aim of this research was to study the effect of replacement of virgin aggregate (VA) by possible extent inclusion of recycled aggregate concrete cluster in the Ethiopia construction industry.

2. Literature Reviews

2.1. Ultrasonic Pulse Velocity Testing

Ultrasonic pulse velocity test used on site and in laboratory application for exploratory the quality of concrete, which measure the velocity of an ultrasonic pulse passing through concrete structure inspection. A control unit measures the time (t) in micro-second, it takes for the pulse to travel between two transducers. The distance between the transducers was measured and divided by the pulse travel time and the result was reported as the ultrasonic pulse velocity (*V*) measured in m/s [7].

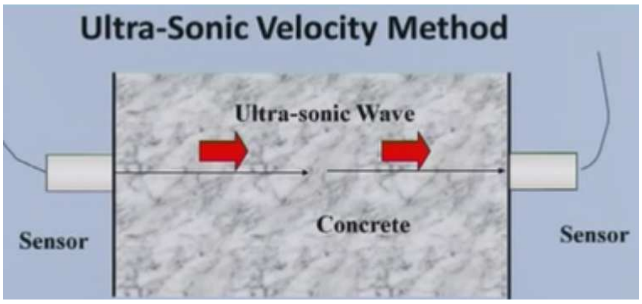

Figure 1. *Direct transition ultrasonic pulse velocity testing.*

Higher ultrasonic pulse velocity indicates concrete's good quality and lower one implies crack or voids**.** Currently, the ultrasonic pulse velocity testing has the top potential for testing concrete strengths on site. Pulse velocity tests also can be investigated in laboratory size samples and on-site concrete structures [8]. Under this test, the quality of concrete by states in below.

1) Greater than 4500 m/s an excellent;
2) Range in between 3500~4500 m/s a good;
3) Range in between 3000~3500 m/s a doubtful;
4) Range in between 2000~3000 m/s a poor;
5) Less than 2000 m/s a very poor.

ASTM C597 standards is also to assess the ultrasonic pulse velocity in concrete based on the principle that velocity of sound in a solid can be measured by measuring the travel time of short pulses of compressional waves through a test object [7]. The pulse velocity is affected greatly by the amount and type of aggregate and to a minor degree by the w/c. If internal defects are present in the test object, the actual pulse path length and pulse travel time were be increased.

2.2. Schmidt Rebound Hammer Testing

Schmidt rebound hammer testing is non -destructive testing methods of concrete which provide a convenient and rapid indication of the concrete strengths. An empirical association has been established between Schmidt rebound number and strengths of concrete. The known instrument to make use of the rebound principle of the concrete strengths testing is the Schmidt hammer, which weight 1.8kg and it is used for both in laboratory and site work. It includes of a spring controlling hammer mass, which is slide on a plunger within a tubular specimen, then the hammer forced against surface of the concrete by the spring and distance of rebound is measured on a scale [9]. The test surface may be vertical, horizontal and any angle.

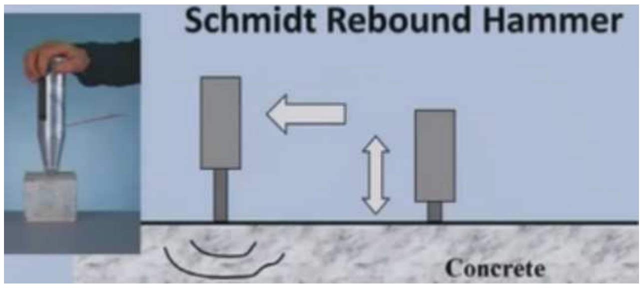

Figure 2. *Vertical Schmidt rebound hammer test.*

2.3. Importance and Needed of Non–destructive Testing

Non –destructive testing is the main importance to tests concrete structures after the concrete has gain the strengths, which checking is necessary weather the concrete structures are suitable for designed use [10]. This test would be completed without destroyed the concrete and it is also consisting of the fundamentals parameters tests such as density, strengths, and elasticity modules as well as also surface hardness and surface absorption in laboratory [11]. It is similarly possible to check the quality of workmanships and structural integrity by the ability to detect voids, cracking and delamination. The Monte Carlo simulation methods are to refer the practical randomly assigning a value to any underlying random variable and observing the outcomes of the process of comforts [12]. The general scheme of the Monte Carlo methods was as follows

1) To find the MIN and MAX values of non-destructive test.
2) To generate random value for each of recycled aggregate concrete replacement levels.
3) The expected values nondestructive test is average value of these test results.

2.4. Correlation Between Destructive and Nondestructive Strength

In destructive testing the specimens are destroyed, in order to gain the specimens quality or the materials behaviors under different applied loads but non-destructive testing is the process of inspecting, testing or evaluating the behaviors of materials, components or assembles without destroying the serviceability parts of specimens. There is not too much literature available on the effect of recycled aggregate concrete cluster as a partial replacement of virgin aggregate on correlation between destructive and non-destructive strength of concrete [13].

3. Materials and Methods

3.1. Materials

To producing suitable mix design for the concrete making, the physical characteristics of cement, fine aggregate, coarse aggregate, water and admixture used for the research were examined.

1) Cement

Portland Pozzolana cement was used for this particular research a (PPC) CEM-IV-32.5 for normal strength concrete.

2) Fine Aggregate

Natural sand commonly known as konso sand, which is extracted from konso area found in southern national part of Ethiopia was used to prepare the concrete samples. all fine aggregate which was retain on 9.5mm sieve size were no longer relevant, and all the passing fine aggregate were used for experimentation.

3) Virgin coarse aggregate

The virgin coarse aggregate used for this research was purchased from aggregate crushed production sites of Arba Minch sekele around Mikael church area. The following tests were conducted for virgin coarse aggregates.

4) Recycled aggregate concrete cluster

The recycled aggregate concrete cluster used for this research was collected from deposit site waste of Arba Minch University, around Main Campus of institute of technology of area and broken to resize as per standard of aggregate s [14]. The following tests were conducted for virgin coarse aggregates and recycled aggregate concrete cluster.

Figure 3. *Gradation of virgin aggregates and recycled aggregate concrete cluster.*

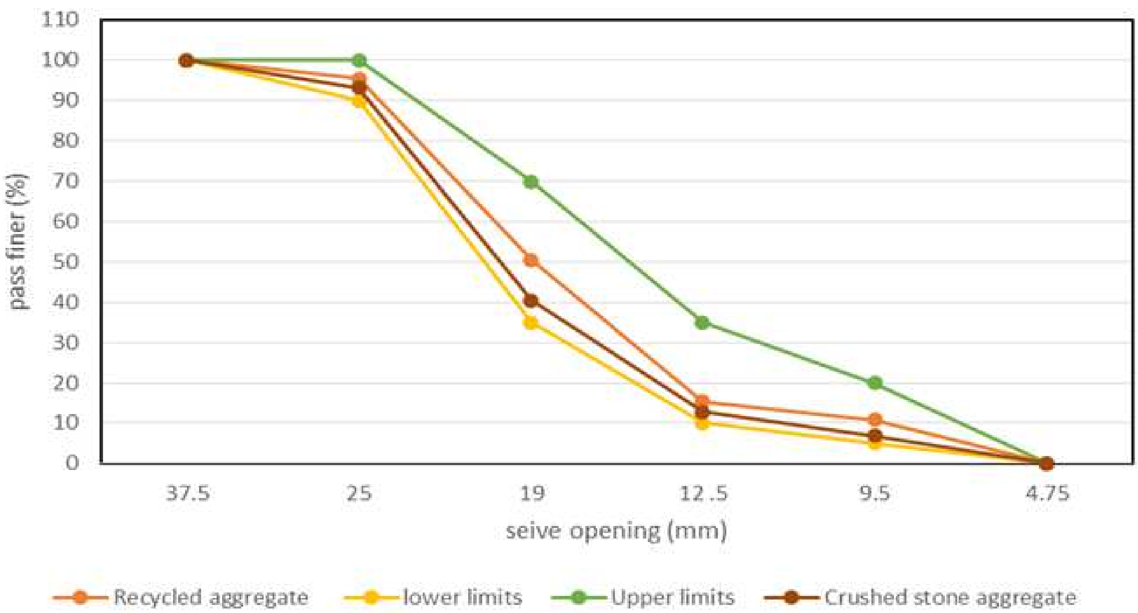

Figure 4. *Gradation of virgin and RACC.*

Comparison of Aggregate Properties and Testing Procedures

To comparing the engineering properties of virgin aggregate and recycled concrete aggregate cluster meant for mix concrete preparation as per ASTM standard [14-18]. Different types of tests were carried out on virgin aggregates and recycled aggregate concrete cluster. The tests done and the procedures or reference standards used is explained below Table.

Table 1. *Test of physical and chemical properties of anticipated aggregates.*

Types of Tests	Test methods	Samples per test	Total quantity of aggregates (kg) (RACC&CSA)
Physical properties			
1. Grading& fineness modules	ASTM C33	3	30
2. Compact & loose unit weight	ASTMC29	3	174.96
3. Specific gravity 4. Water absorption	ASTMC127	3	12
5. Flakiness	BS812	3	12
6. Elongation	BS812	3	12
7. Soundness	ASTMC88	3 (Cycles)	1
Mechanical properties			
1. loss Abrasion angles Value	ASTMC 31	3	40
2. Impact value	BIS 812	3	12
3. Crushing value	BIS812	3	12

As results presented in the table above, the values of quality stating physical and mechanical properties values for recycled aggregate concrete cluster were lower mostly by thirteen~ fifteen percent than crushed stone aggregate, but their absolute values were acceptable for structural concrete as per ASTM and BS.

3.2. Methods

3.2.1. Mix Design of Concrete

Ethiopian building code of standard (EBC2, 1995) has not justified local trial mixes design procedure. Thus, mix design process as per ACI 211.1-91 was followed for design C-30 concrete grade as well as target slump was 25~100mm and necessary precautions to possible extent were be incorporated against variations from standard with respect to concrete ingredients [18]. The concrete mixes prepared from replacement of virgin aggregates with recycled aggregate concrete cluster are given in table below.

Table 2. *Details of RACC trail concrete mix.*

Trail Mix	M1	M2	M3	M4	M5	M6
Content	0%	10%	20%	30%	40%	50%

Figure 5. *Mixing ingredients of concrete.*

3.2.2. Casting and Curing Specimen

Prepared mix design concrete is poured in well lubricated mold. The compaction of concrete is achieved through compaction table vibrator. Casting of 0.15*0.15*0.15m of cubes for Schmidt hammer and ultrasonic velocity testing, curing at 56th days of cubes for testing the properly. The mold along with casted concrete was covered with wet hessian cloth to retain the design mix water. Demolding of the concrete specimen was done after 24 hours and specimens were kept immersed under fresh water for curing. Curing water was changed every week.

3.2.3. Experimental Procedures

As per objective of this research work that concrete properties were immediately examined after mixing of concrete as per standard test procedures and the hardened properties of concrete test was done also as per standard specifications or procedures. At specified interval time curing session, specimen was withdrawn from water bath, wiped to have surface dry specimen and tests were done as mentioned below table.

Figure 6. *For Schmidt rebound hammer and ultrasonic pulse velocity testing at 56th day.*

Table 3. *Hardened properties of concrete test methods.*

Test Types	Methods	Specimen	curing	samples	Totals
Ultrasonic Test	ASTMC597	cubes	56	3	18
Hammer Test	ASTMC5805	cubes	56	3	18

3.2.4. Method of Data Analysis

Analysis of the performance of concrete (fresh and hardened) were done by the MONTE CARLO SIMULATION and EXCEL PACKAGE were used for found the optimum arguments of concrete hardened properties in which virgin aggregates are replaced partially by recycled aggregate concrete cluster.

4. Results and Discussion

4.1. Ultrasonic Pulse Velocity Test

The Ultrasonic Pulse Velocity test was carried out as per ASTM [7]. On the two appropriate sides of specimens (0.15*0.15*0.15) M^3 by using direct transmission. The concrete testing by ultrasonic pulse velocity tests is presented in table below.

Table 4. *Simulation of Ultrasonic Pulse Velocity for all mixes of concrete at 56th days.*

Ultrasonic Pulse Velocity of concrete properties (m/s)						
	Replacement levels of recycled aggregate concrete cluster					
	0%	10%	20%	30%	40%	50%
Min	3723.62	3673.60	3507.54	3424.00	3298.87	3240.00
Max	3740.42	3698.78	3549.41	3451.43	3382.22	3287.53
Expected average given probability of Ultrasonic pulse velocity test (m/s)						
	3731.947	3661.806	3531.319	3425.618	3329.251	3270.591

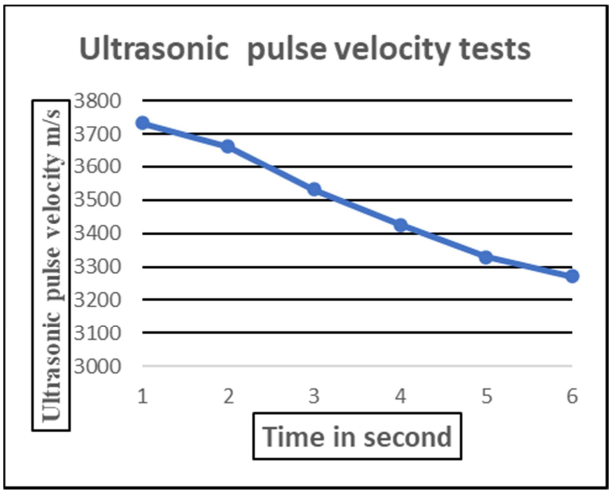

Figure 7. *Ultrasonic pulse velocity variation range.*

The Figure and Table above implies that the ultrasonic pulse velocity variation range through normal concrete has minimum range for a given average probability, whereas through concrete having recycled aggregate concrete cluster, ultrasonic pulse velocity variation range too wide for a given average probability. This indicates that the density homogeneity gets affected to a greater extent when recycled aggregate concrete cluster are included because of drastic density difference between mother aggregate and mortar attached around it. The variation in density values throughout normal concrete is less than the concrete which has recycled aggregate concrete cluster. Thus, ultrasonic pulse has to pass through minimum density variable media in normal concrete and wider density variable media in recycled aggregate concrete cluster. Apart from this density variation, concrete with recycled aggregate concrete cluster has more interfacial transition zones like solid aggregate stone, mortar around recycled aggregate concrete cluster, new cement pastes around recycled aggregate concrete cluster and new cement-sand mortar media.

4.2. Schmidt Rebound Hammer Test

The test was carried out as per ASTM and the concrete specimens were placed in the center of hydraulic machine press and the continuous load was applied and maintained [9]. The rebound hammer test was carried out on ten different points, space at 1.5cm on faces of cubes specimens. The cubes unmovable during test and care should be taken during test by rebound hammer test, means that not hit once place twice times. The Monte Carlo simulation provide an estimate of expected value of a random variable by Schmidt rebound hammer tests are presented in Table below.

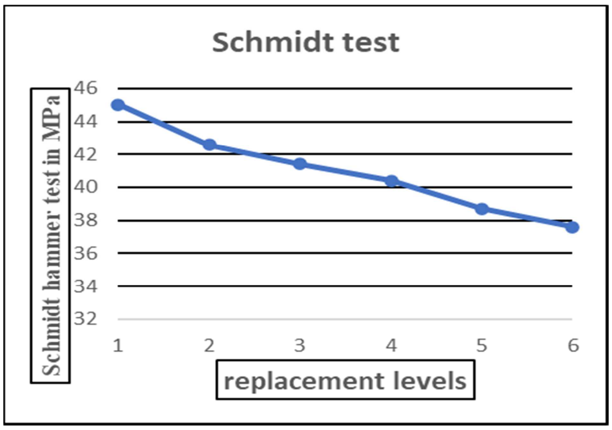

Figure 8. *Schmidt rebound hammer test results of different concrete mixes at 56th day.*

Table 5. *Schmidt rebound hammer test results of different concrete mixes at 56th day.*

Schmidt rebound hammer test (MPa)						
	Recycled aggregate concrete cluster replacement levels					
	0%	10%	20%	30%	40%	50%
Min	43.56	43.37	40.00	39.53	37.94	36.91
Max	46.44	44.59	42.73	41.43	39.38	38.26
Expected average given probability of Schmidt rebound hammer value (MPa)						
	45.03	42.57	41.41	40.40	38.71	37.60

Table and Figure above imply that the Monte Carlo simulation provides an estimate of expected value of a random variable process was repeated several times the number of iterations to obtain the average probability of expected rebounded hammer value in MPa. The multiples of specimen tested at any stages of loading to the total number of simulations at that stage of loading. So, this trend is same as detected in case of ultrasonic pulse velocity test. Thus, similar discussion should be done in this case also, as that of ultrasonic velocity test. The average probability distribution for Schmidt rebound hammer test variation in density values through-out normal concrete is less than the concrete which has recycled aggregate concrete cluster.

4.3. Correlation Between Rebound Hammer and Crushing Strength

Under this section the correlation among the strength obtained by non-destructive and destructive methods on laboratory made concrete cubes has established. The Schmidt rebound hammer test methods has used as non – destructive test. Hence, the relationship between rebound hammer test and compressive strength of concrete along with coefficient of determination results are presented in Table below.

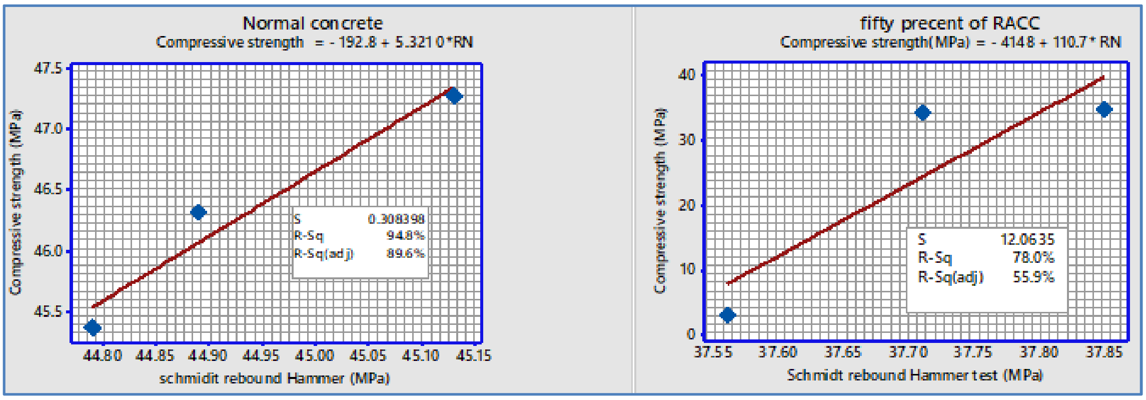

Figure 9. *Concrete cubes crushing strength versus Schmidt rebound hammer test.*

Table 6. *Schmidt rebound hammer and crushing strength tests results at 56th day.*

Recycled aggregate concrete cluster						
	0%	**10%**	**20%**	**30%**	**40%**	**50%**
AV (Mpa)	46	45	44	40	37	34

The Schmidt rebound number value versus the compressive strength results at 56 days age for normal concrete and fifty percent virgin aggregate replacement by recycled aggregate concrete cluster tested on multiple specimens is presented in Table 6 and Figure 9 respectively. The regression correlation coefficient has best value of, R^2=0.95 for normal concrete where as good value of R^2=0.78 for fifty percent crushed stone aggregate replacement by recycled aggregate concrete cluster samples.

5. Conclusion

It resolved that the correlation coefficient for crushed stone aggregate and recycled aggregate concrete cluster were R^2=0.95 and 0.78, which depict total crushed stone aggregate concrete to have more uniform strength while fifty percent recycled aggregate concrete cluster concrete to have non uniform Schmidt rebound hammer value with greater standard deviation. The Schmidt rebound hammer and ultrasonic pulse velocity test results variation range widens as recycled aggregate concrete cluster inclusion increases in hardened concrete, which implies increment of heterogeneity and varied nature ITZ as recycled aggregate concrete cluster inclusion increases. Series of Schmidt rebound hammer test and ultrasonic pulse velocity test actual results and their random simulation are helpful to depict the variation in media heterogeneity as recycled aggregate concrete cluster inclusion increases. Engineering properties-wise categorized recycled aggregate concrete cluster recycling organizations need to be promoted through policy makers and further study.

References

[1] R. Rumbayan and A. Ticoalu, "A study into flexural, compressive and tensile strength of coir-concrete as sustainable building material," vol. 11, 2019.

[2] A. C. I. E. Bulletin, "ACI Education Bulletin E1-07."

[3] Y. B. Raghavendra, R. R. Y, N. Hossiney, and H. T. Dinesh, "Properties of high strength concrete with reduced amount of Portland cement – a case study Properties of high strength concrete with reduced amount of Portland cement – a case study," 2021, doi: 10.1080/23311916.2021.1938369.

[4] "A study on recycled concrete aggregates," vol. 118, no. 18, pp. 3239–3263, 2018.

[5] H. E. M. Sallam and M. H. Seleem, "Mechanical Properties of NSC and Hsc Effect of Coarse Aggregate Type And Specimen Geometry on Mechanical Properties Effect Of coarse Aggregate Type And Specimen," no. December 2016, 2007.

[6] A. Hidayat, J. Puspowardojo, and F. Abdul, "The Influence of Graded Concrete Strength on Concrete Element," *Procedia Eng.*, vol. 125, pp. 1023–1029, 2015, doi: 10.1016/j.proeng.2015.11.157.

[7] P. Velocity and T. Concrete, “Pulse Velocity Through Concrete 1,” pp. 4–7, 1989.

[8] W. and Namboonruang, “The Concrete Testing by Ultrasonic Pulse Velocity (UPV),” *Web Conf. 61*, vol. 05017, pp. 1–4, 2016.

[9] B. Statements and R. Superficial, “Standard Test Method for Rebound Number of Hardened Concrete 1,” pp. 2–4, 2002.

[10] J. Malek and M. Kaouther, “Destructive and Non-destructive Testing of Concrete Structures,” vol. 8, no. 4, pp. 432–441, 2014.

[11] C. C. Test, A. Content, M. Rooms, and P. Concrete, “Standard Practice for Making and Curing Concrete Test Specimens in the,” vol. 04, pp. 1–8, 2002.

[12] M. Carlo and S. Formula, “Monte Carlo Simulation Formula in Excel – Tutorial and Download What is Monte Carlo Simulation? Describe Monte Carlo,” pp. 1–12, 2019.

[13] J. S. Gosavi and U. R. Awari, “A Review on High-Performance Concrete,” pp. 1965–1968, 2018.

[14] T. Size, “Standard Practice for,” vol. 04, pp. 1–5, 2003.

[15] T. Size and B. Statements, “Standard Test Method for Bulk Density (‘ Unit Weight ’) and Voids in Aggregate 1,” vol. 97, no. Reapproved, pp. 3–6, 2003.

[16] R. Structural, S. Bars, A. Machine, and B. Statements, “Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine 1,” vol. 04, pp. 4–7, 2003.

[17] B. Statements, T. Size, and C. Aggregate, “Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption,” pp. 3–8, 2001.

[18] T. Size, “Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated,” vol. 04, pp. 1–4, 1999.