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Damage Detection Recycled Coarse Aggregate Using Ultrasonic Pulse Velocity

[1]Suraj Gupta, [2]Alka Tomar

[1]Student, [2]Assistant Professor

[1]Department of Civil Engineering Parul Institute of Technology Faculty of Engineering and Technology

[1]Parul Institute of Engineering and Technology, Vadodara, Gujarat 391760, India

Abstract: Ultrasonic pulse velocity is a non-destructive method that is used to measure the properties of concrete and detect the damage of recycled aggregates and natural coarse aggregates concrete such as cracks. Due to the demolition of old concrete structures, waste concrete generates an environmental problem. To solve this problem, it is necessary to recover the recycled aggregates from concrete waste. The natural coarse aggregates is replaced by recycled coarse aggregates with the help of crushing the waste concrete and providing new concrete, but there should be a change in the compressive strength and damage occur within the concrete cube. The ultrasonic pulse velocity method was used to detect the damage of concrete such as cracks in the natural coarse aggregate and recycled coarse aggregates concrete. The specimen was a 150x150x150 mm cube concrete specimen. Each concrete cube was examined for velocity readings in sound, modulus of elastic and detected the concrete damaged by applying different loads on natural and recycled concrete. The damage level increases as the ultrasonic pulse velocity decreases. After analysis, the compressive strength of natural coarse aggregate is higher than recycled coarse aggregate concrete and the velocity of natural coarse aggregate is around 19.34% higher than recycled concrete and cracks occur more in recycled concrete as compared to natural coarse aggregate concrete. The higher reduced velocity shows crack formation. The main role of this work lies in comparative study of NCA and RCA, also determining the mechanical properties of concrete including young's modulus of concrete and detecting the damage within concrete through the help of the ultrasonic pulse velocity method.

Index Terms **- Ultrasonic pulse velocity, Non-destructive test, Recycled coarse aggregate, Dynamic young's modulus**

I. INTRODUCTION

The concrete is a strong hard building material which is use in construction site like dams, channel and other structure. The material is cement, sand and stone is used in concrete all materials are mixed with water [1]. Concrete is important material which is mixed together and used on construction sites. The characteristics of concrete depend upon process of mixing, handling, curing of concrete, and vibration that help to gain the strength of concrete.[2]. Natural aggregate is used in many construction sites; dams, buildings, channels and bridges. Most old buildings are demolition where waste is obtained from old buildings directly thrown on land. However, that waste generates an environmental problem [3]. This leads to an increase in construction and demolition waste (C&DW), which is a serious environmental problem and has a huge impact on natural resources. Recycling Coarse aggregate plays an important role in recycling concrete waste from landfills. Within a few years, concrete recycling will play a major role in reducing total natural resources [4]. In India, construction and demolition of almost twenty-three million tons per year and there will be more next year and most of the land is covered by waste concrete by using the construction waste for recycling. We can protect natural resources and reduce waste in landfills [5]. The high pulse velocity is obtained from fresh concrete and provides high modulus elastic [6]. The most popular methods are ultrasonic pulse velocity and ultrasonic pulses generated by electrical transducers to detect flaws in concrete specimens. The ultrasonic wave transfers pulse through a transducer which doesn't travel through air or vacuum, so grease is used to get the transducer in contact with a concrete cube [7]. In the Ultrasonic Pulse Velocity Test, a wave pulse passing through concrete is generated by a transducer on a concrete surface and this wave or signal is received by a receiver transducer on another surface to measure the travel time of the wave between points. The length of the wave path between the two sensors is measured and helps determine the velocity [8]. The ultrasonic pulse velocity also changed under the influence of frost. Under the condition of frost, high measuring value of ultrasonic pulse velocity are detected during concrete curing [9]. The ultrasonic pulses velocity is used to measure the properties of clay bricks and to obtain large amounts of information such as elastic modulus and internal cracks in wood, metal and concrete [10]. Ultrasonic method is used to identify the damage any types of concrete structure and determine its properties. If any damage occurs inside the concrete, such as a crack with the help of a pulse can easily determine the depth of the crack inside the concrete. The damaged concrete shows a low velocity as compared to plain concrete. The reflection of the technique depends on the travel time of the wave and the type of concrete on which the signal passing through the transducer is measured [11].

Formulation

According to IS code 13311 (Part 1): 1992

- Modulus of elasticity of concrete calculated using IS code 13311 (Part 1) 1992 for non-destructive testing of concrete.

$$E=\frac{Q(1+\mu)(1-2\mu)v^2}{(1-\mu)}$$

- Formula for the velocity of ultrasonic pulse to characterize the concrete properties [12]

$$1.\ Calculated\ Velocity = \frac{Expected\ Distance\ of\ travel\ by\ the\ waves}{Time\ Recorded}$$

2.Actual Distance travelled= (Average velocity of waves get undamaged cube)*(Time recorded)

Where,

E = Young's modulus of elasticity of concrete (MPa)

Q = density of concrete (kg/m^3)

V = Ultrasonic velocity of concrete (km/s)

Table 1. Guideline Concrete Based On UPV Test Results.

S.N	Cross Probing pulse velocity	Quality of concrete
1	Below 3.0	Unsure, bad and loss of integrity exist.
2	3 to 3.5	Medium, OK, but suspect loss of integrity
3	3.5 to 4.5	Good, slight porosity may exist.
4	Above 4.5	Excellent

II. MATERIAL USED

- **Cement**

In this study, OPC 53 grade cement was used which has high strengths and is more durable and the relative density for cement is 3.15.

- **Coarse Aggregate**

The coarse aggregate is a granular material, includes crushed stone, gravel, sand is used for making concrete for construction. In the market, different sizes of aggregate are available, such as 10 mm and 20 mm, but the common size of aggregate that is used in concrete mix is 20 mm because it provides bulk density on concrete.

Table 2. Material Properties of Natural Coarse Aggregate

S.N	Properties	Coarse Aggregate
I.	*Size*	20mm
II.	*Shape*	Angular
III.	*Aggregate Impact Value*	8.34%
IV.	*Relative Density*	2.69
V.	*Water Absorption*	1.3

- **Recycled Coarse Aggregate**

Recycled aggregate is produced by crushing the demolition of old building concrete waste. The serious problem which impacts to our environment is waste concrete. Through recycling, we can reduce the waste concrete or collect the waste concrete from landfill for building construction. At the same time, construction and demolition waste concrete can be reduce by the help of crushing. Recycling processes can be performed on construction and demolition sites. After that, recycled concrete is sent to the construction site.

Table 3. Material Properties of Recycled Coarse Aggregate

S.N	Properties	Coarse Aggregate
I	*Size*	20mm
II	*Shape*	Angular
III	*Relative Density*	13.45%
IV	*Aggregate Impact Value*	2.47
V	*Water Absorption*	4.24

- **Fine Aggregate**

Fine aggregate is a material that is used in concrete mixed for the construction of any structure. Fine aggregate consists of sand which is obtained from rivers or crushed stone particles. The sand is natural material which easily available in market but sand has less workability so bleeding occur more in the concrete. The relative density and fineness modulus are 2.66 and 2.52 respectively.

Table 4. Material Properties of Fine aggregate

S.N	Properties	Coarse Aggregate
I.	*Size*	Less than 4.75 mm
II.	*Zone*	2
III.	*Fineness Modulus*	2.45
IV.	*Relative Density*	2.66
V.	*Percentage of Slit*	5.4%

- **Water**

The W/C ratio used for natural aggregate concrete and recycled coarse concrete is 0.43 according to IS 10262-2019 code.

- **Ultrasonic Pulse Velocity**

Ultrasonic pulse velocity means transit time as the form of a wave of ultrasonic pulse or signal of 50-58kHz, created by a transducer and passing through one surface to another surface. The ultrasonic machine transfers the electrical pulse to the transmitter. It converts the electrical pulse to mechanical energy or signal from inside the concrete reflecting signal received by the receiver converts the signal to an electrical pulse shown on screen. The ultrasonic pulse velocity is used to measure mechanical properties of concrete, modulus of elastic, poisson's ratio and depth of cracks also detect the damage in the concrete, measure the velocity of concrete.

- **Experimental Procedure**

According to IS Code 10262-2019
M_{30} Grade of concrete
Grade of cement = Ultratech 53 Grade OPC cement
Maximum aggregate Dimension is 20 mm use
Water cement ratio from IS code 10262 = 0.43
Target Mean Strength is given as (F_{ck})
F_{ck}=30+1.65(S)
F_{ck}=30+1.65x5
F_{ck}=38.25 N/ sq mm
Water content for concrete =186 litre
Required water content = 186+(0.06*186)=197litre
Weight of cement = 197/0.43= 450kg/ m^3
For Volume of aggregate
Coarse aggregate = 0.64
Fine aggregate = 0.37
Calculation quantity Material
Consider Concrete volume = 1 m^3
Cement Content = 450/3.15*1000= 0.145 m^3
Water content= 197/1000= 0.197 m^3
Vol. of all aggregate = 1-(0.145+0.197)= 0.6 m^3
Weight of Coarse aggregates= 1114kg
Weight of Fine aggregates= 640kg

The NCA and RCA concrete mixed design done according to IS code 10262-2019 by the weight and 0.55 water cement ratio taken for both concrete that given in **Table 4.**

Table 5. Concrete Requirements for Natural Coarse Aggregates and Recycled Coarse Aggregates for 1 m^3

Material	Natural Coarse Aggregates by weight in (Kg)	Recycled Coarse Aggregates by weight in (Kg)
Cement	460	470
Natural Coarse Aggregates	1114	-
Fine Aggregates	640	630
Water required	197litre	202litre
Recycled Coarse Aggregates	-	1008

- **Preparation of Specimens**

The M30 grade of concrete is prepared for concrete tests. The number of specimens for NCA and RCA concrete are given in **Table 2**. All samples are kept in a water tank at room temperature to cure for 7, 14 and 28 days for compressive strength testing and 28 days for ultrasonic pulse velocity testing.

Table 6. Prepared Specimen Assigned to Each Test.

Possessions	Curing Age For test in days	Sample size and shape	Specimens required for test
For Compressive strength of concrete			
Natural coarse aggregate	7,14,28	150x150x150 mm cubes	9
Recycled coarse aggregate			9
For Ultrasonic pulse velocity (UPV)			
Natural coarse aggregate	28	150x150x150 mm cubes	2
Recycled Coarse aggregate			2

III. EXPERIMENTAL SETUP

The M30 grade of concrete size is 150x150x150 mm and is used in testing. The sample of concrete cube for testing curing time reached 28 days and ultrasonic pulse velocity testing consists of two components, a transmitter and a receiver. Transmitters are used to convert electrical pulse to mechanical pulse as a form of signal or waves and receivers are used to convert mechanical pulse to electrical pulse as from a signal that is shown on a monitor. The sound waves are transmitted from sound into material to detect the damage to concrete or properties of concrete. Direct probing is used to measure the properties of concrete, detect the damage of concrete, modulus of elastic. Ultrasonic testing devices are shown in Figure 1.

Figure 1. Ultrasonic testing device

Experiment consists of ultrasonic pulse velocity and compressive test instrument before testing, a thin layer of grease is applied on both sides of the surface of the cube so that it is easy to travel sound waves inside the concrete. After that, the specimen is kept

in the compression testing instrument. The transducer is attached on the both side of the specimen, a transmitter is attached at once to the face of the sample cube and the receiver is used on another face of the specimen it is called direct method. Then the load increases gradually after that increment, a load of 50 KN intervals is applied to concrete by using a compression testing machine. Recorded the time travel it takes for ultrasonic waves in the sample to pass from one surface to another. The transit times of each load increment for different samples are shown in Figure 2.

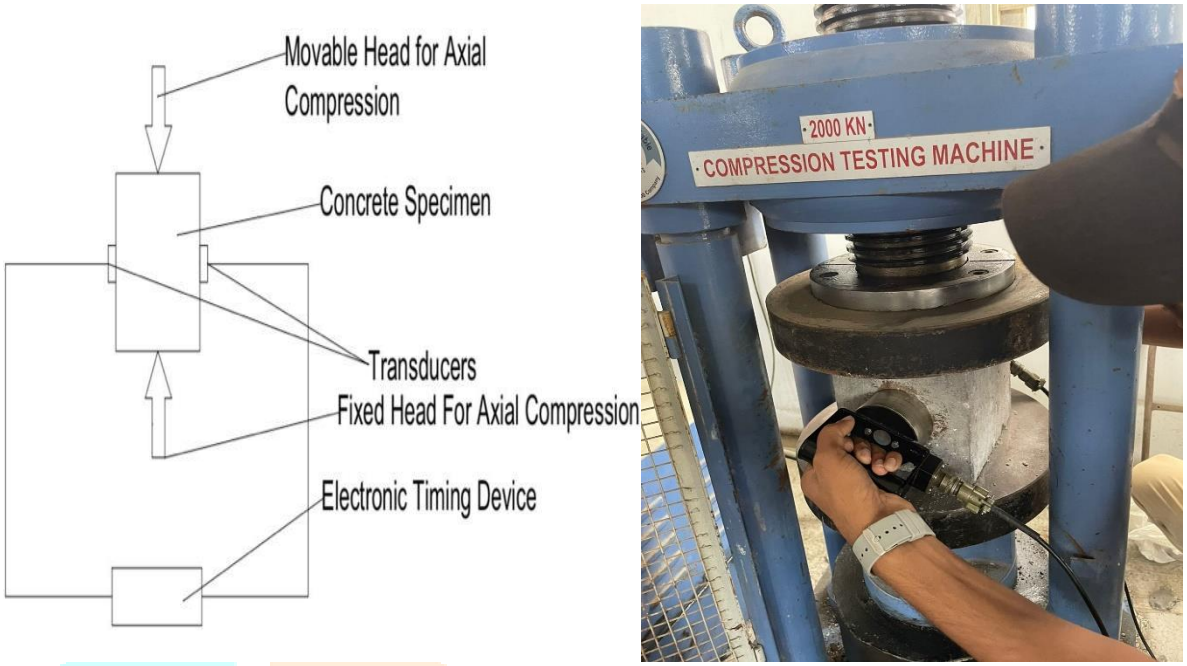

Figure 2. Compression Along with Ultrasonic Pulse Velocity (UPV)

IV. RESULT

- **Compressive Strength of Recycled Coarse Aggregate and Natural Coarse Aggregates Concrete**

First, we had cast the M30 grade of sample cubes for testing in compressive testing machine (CTM) to get strength of concrete and cube size is 150x150x150 mm taken for test. On the based calculation, we used water cement ratio 0.43 from the mix design. We tested the concrete cube for compressive strength with the help of a compressive testing machine (CTM) for 7, 14, 28 days. We cast 18 cubes for NAC and RCA cubes for to get the strength of concrete for 7,14 and 28 days and M_{30} grades of concrete used in concrete preparation. The three samples testing in 7 days and three samples testing in 14 days, remain sample test after 28 days for natural coarse aggregate and same procedure done for recycled coarse aggregate. Compressive strength increases rapidly up to 28 days and velocity of concrete also increases. The recorded observation is shown in Figure 3.

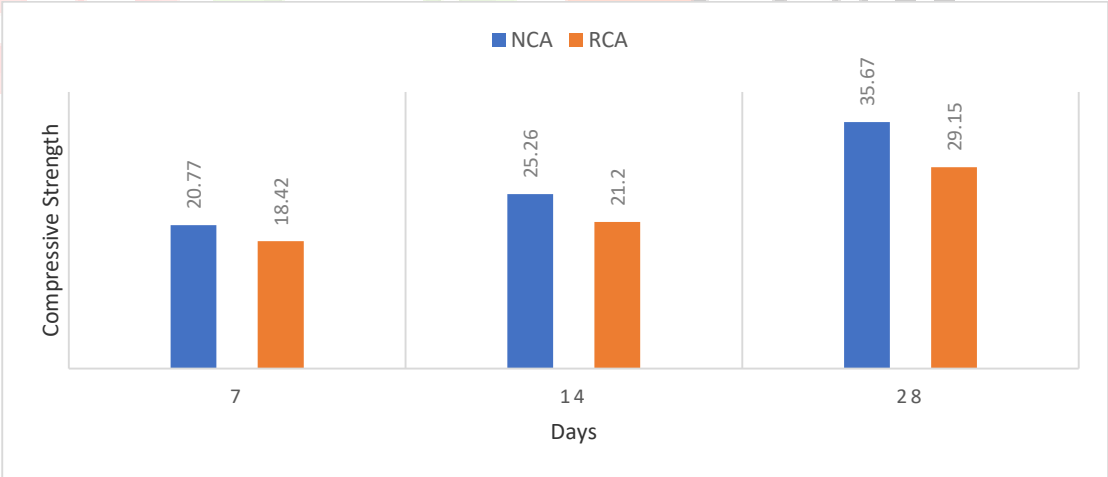

Figure 3. Comparison of Compressive Strength Between RCA and NCA

- **Slump Test for RCA and NCA**

Slump test can be measured on site. It is show the workability of concrete. The workability and quality of concrete depend upon shape of concrete. This method can be easily performed both in the laboratory and on the construction site. The recorded observations are given in Table 7.

Table 7. Slump Value for NCA and RCA

S.N	Material for M_{30}	Slump Value
1	Natural Coarse Aggregates	124 mm
2	Recycled Coarse Aggregates	110 mm

- **Properties of RCA and NCA Concrete using Ultrasonic Pulse Velocity**

The properties of RCA and NCA are determined by the help of the ultrasonic method. Pulse velocity recorded on the cube size is 150x150x150 mm and poisson's ratio is 0.32 from IS code 13311 (Part 1) 1992. The direct method is used to determine the velocity and measure the time travel inside the concrete. The modulus elastic of concrete is determined by the help of equation (1). The elastic modulus of concrete and pulse velocity values recorded are shown in Table 8.

Table 8. Properties of Concrete using Ultrasonic Pulse Velocity

M_{30} grade of concrete	Density of Concrete (kg/m^3)	Velocity (m/s)	Elastic Modulus (Gpa)
Natural Coarse aggregate Without damage	2690	4792.34	42.95
Recycled Coarse aggregate (RCA) without damage	2470	3947.36	26.89

- **Impact of damage level to ultrasonic pulse velocity of natural coarse aggregates and recycled coarse aggregates concrete.**

The load is applied in 50 kN interval to the RCA and NCA concrete cubes and we cast four concrete cubes two cube for natural coarse aggregate and remain cube for recycled coarse aggregate. When loads increase, then cracks also increase in the concrete cubes, so that velocity decreases and develops internal cracks inside the concrete. The ultimate load and Ultrasonic pulse velocity values recorded are shown in Table 8 and load vs ultrasonic pulse velocity under axial compression are shown in Figure 4.

Table 8. Damage Level 50KN Interval in M30 Grade Concrete Strength (MPa)

M_{30} grade of concrete	Load (KN)	Time (µs)	Ultrasonic Pulse Velocity (m/s)	Elastic Modulus (Gpa)
Natural Coarse aggregates concrete (NCA)	0	31.29	4792.34	42.95
	50	32.5	4615.39	40.04
	100	34.4	4360.47	35.75
	150	35.9	4178.28	32.82
	200	37	4043.65	30.74
	250	39.5	3787.88	26.98
	300	41	3658.54	25.17
	350	41.6	3605.77	24.45
	400	43	3488.38	22.88
	450	51.5	2912.63	15.95
	500	67.2	2234.7	9.39
Recycled Coarse aggregates concrete (RCA)	0	38	3947.36	26.89
	50	38.45	3901.17	26.27
	100	39.45	3802.28	24.96
	150	40	3750	24.28
	200	41.2	3640.78	22.88
	250	51.4	2916.2	14.68
	300	55.7	2689.14	12.49
	350	58.5	2564.1	11.35
	400	69.5	2155.18	8.02
	450	76.45	1962.07	6.65
	500	103.76	1445.78	3.67

- **Ultrasonic Pulse Velocity Under Axial Compression**

The time travel by ultrasonic pulse velocity obtained from applying various axial compression loads in NCA and RCA concrete cube are potted.

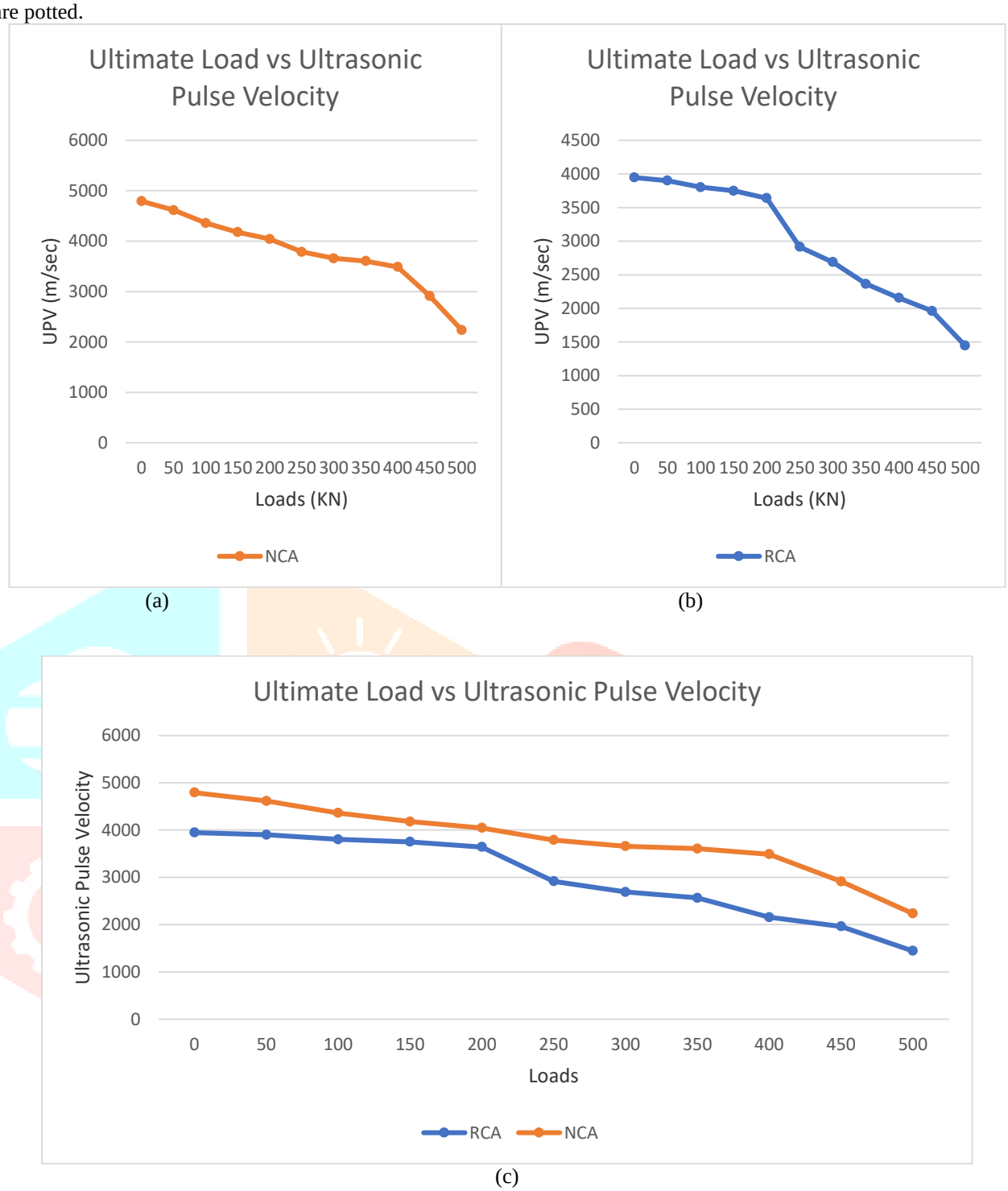

Figure 4. Ultimate load Vs Ultrasonic pulse velocity of RCA and NCA under axial compression load. (a) M30 NCA. (b) M30 RCA. (c) M30 NCA and RCA.

Figure 4. shows the changing of velocity of ultrasonic pulse during axial compression for natural aggregate and recycled coarse aggregate. When load apply slowly the velocity of natural coarse and recycled concrete decrease until concrete failure. It is observed that ultrasonic pulse velocity decreases very slowly. The slow reduction of concrete shows the formation of the initial crack. The velocity is reduced higher when crack formation, but the time travel between one face to another face takes more time as compared to without a crack. For M30 grade concrete, the water cement ratio of RCA is higher than NCA concrete. From the graph, we observed major crack formation after 400KN load applied in natural aggregate and RCA major crack formation from 200KN. Finally, after failure ultrasonic pulse velocity of NCA and RCA concrete values came below 2234.7 m /s and 1445.78 m /s at 500 KN load.

V. CONCLUSION

The ultrasonic pulse velocity and compression test was performance on concrete cube specimens. The direct transmission method carried out to determine characteristics of concrete.

1. Bring the waste concrete into production line, it helps to reduce impact in the environment and it save the cost.
2. The good quality of coarse aggregate help to increase high strength of concrete similarly good quality of recycled aggregate concrete also help to increase high strength of concrete. The velocity of natural coarse aggregate is around 19.34% higher than recycled coarse aggregates concretes
3. The direct transmission method is used to determine modulus of elasticity, properties of concrete damage detection inside the concrete.
4. The compressive strength of natural aggregate is higher than recycled coarse aggregate concrete.
5. If load increases in natural aggregate and recycled coarse aggregate, velocity decreases. The incremental load shows that initial crack formation. The slow reduction of velocity is observed up to the initial crack formation. The velocity reduced more after crack formation. The natural aggregate observed less crack as compared to recycled coarse aggregate.
   Hence, pulse velocity is inversely proportional to the time travel pulse to pass through concrete. Crack formation clearly observed from the graphs

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