

CHARACTERIZATION OF DIFFERENTIAL CONCRETE MIX DESIGNS BY ULTRASONIC PULSE VELOCITY TECHNIQUE

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Abstract: There are many test methods to assess the strength of in situ concrete, such as non-destructive test method namely one such technique was Ultrasonic pulse velocity (UPV). These methods are considered indirect and predicted tests to determine concrete strength at the site. These tests are affected by many parameters that depends on the nature of materials used in concrete production. So, there is a difficulty to determine the strength of hardened in situ concrete precisely by these methods. In this research, the UPV test is used to assess the concrete compressive strength. From the results of this research it is intended to obtain a statistical relationship between the Concrete compressive strength and Ultrasonic pulse velocity. In this research work, UPV test was carried out by considering direct transmission (on opposite faces) method. It's possible to interpret an acceptable equation that can be used to measure the compressive strength from the (UPV) value. This arrangement is the most preferred arrangement in which transducers are kept directly opposite to each other on opposite faces of the concrete. The transfer of energy between transducers is maximum in this arrangement. The accuracy of velocity determination is governed by the accuracy of the path length measurement. Thus the objectives of this present research are threefold. First, this research will examine the influence of conditioning such as drying condition on the results of UPV test performed on concrete cubes with different mixtures proportion. In which Slump, and w/c ratio value was varied with constant compressive strength as in the First case and compressive strength, and w/c ratio value varied with constant slump as in the Second case. Seventy-two concrete cubes (100 mm³) with grades of concrete ranges from 25 to 40 N/mm² were prepared and tested using UPV test. The non-destructive test parameters were related to different mixtures proportion in ordered to characterize mix designs. Second, this research will examine the influence of the UPV value on compressive strength. Third, this research will also aims to develop non-destructive charts for different concrete mixtures proportion. This implied that the developed chart was more suitable for normal strength concrete. As well as can be utilised in minimising inaccuracy in non-destructive tests.

Keywords: Concrete, non-destructive testing, ultrasonic pulse velocity, water-cement ratio, cement content, grades of concrete, slump, compressive strength

1.0 Introduction

An evaluation of concrete properties is of great interest, whether to detect altered areas or to control the concrete quality and estimate its compressive strength (Breyse, 2009). The standard methods used to assess the quality of concrete in concrete structures on specimens cannot be considered. The disadvantage is that results are not immediately known, the number of specimens or samples is insufficient for an economic reason, still does not reflect the reality of the structure (International atomic energy agency, 2001). The main advantage of non-destructive testing method is to avoid the concrete damage on the performance of building structural components. Additionally, their usage is simple and quick. Test results are available on site. Concrete testing in structures is demanding in which the cores cannot be drilled, where the use of less expensive equipment is required (Hobbs and Tchoketch, 2007). Several non-destructive evaluation methods have been developed based on the fact that some physical properties of concrete can be related to the compressive strength of concrete. The non-destructive measurements have proved to be an effective tool for inspection of concrete quality. The non-destructive testing of concrete has a great technical and useful importance. These techniques have been grown during recent years especially in the case of construction assessment. The concrete structures can be evaluated by UPV meter for quality control during construction of new structure and also periodical evaluation of the same member to assess the deterioration of the structures to measure the changes occurring with time in the properties of the concrete and taking a remedial measure immediately without damaging the structure further by which service life of the member is extended. For quality control, results of UPV can be more reliable than usual procedure of sample testing by cubes or cylinders which is basically done in a controlled manner and may not give a true value of the quality of the concrete rather than giving the compressive strength which is only a single factor of quality control. There are so many factors which could not be found out from a cube or cylinder compressive test. Hence, UPV plays an important role for assessing the quality

control of new structure and predicting the deterioration of the structure with time in an extreme environment (Lorenzi Alexandre, 2007). However, there are so many variables which influence the matrix of materials of a heterogeneous concrete for strength, and density which are important factors of a durable concrete. To study the influences of few variables which affects the concrete characteristics a laboratory investigation was made. Some work in previous literature made use of the ultrasonic pulse velocity (UPV) of concrete to predict compressive strength and it is fundamental in such research work to study the relationship between UPV and compressive strength (Sturup, et al., 1984). Pulse velocity is influenced by many variables such as mixtures proportion, aggregate type, age of concrete, moisture content, and others (Popovics, et al., 1990). The factors significantly affecting the concrete strength might have little influence on UPV. As a result, a strength estimate made with the pulse velocity method is not a broad spectrum technique. No clear rules have been presented to describe how the relationship between UPV and the compressive strength of concrete changes with its mixture proportion. Therefore, there exists a high uncertainty when one tries to make use of UPV to predict the strength of concrete in different mixtures proportion. The development of the construction industry has required to elaborating more effective methods of non-destructive inspection and financial control to allow a more efficient and reliable industrial performance. One of these methods is based on the measurement of ultrasonic pulse velocity (Rio, et al., 2004). However, for the application of this method a higher efficient is required to be aware of certain factors that affect, directly or indirectly, the velocity of ultrasonic pulse propagation (Malhotra, and Carino, 1991).

The velocity measurement of Ultrasonic wave propagation through the concrete can inform us about compressive strength. Differences can exist, if various compositions and ages of the concretes are considered, in the relation to ultrasonic velocity/compressive strength. The experimental work was conducted by researcher (Dahiru, 2016) to investigate relationship between ultrasonic Pulse Velocity and concrete cube compressive strength. This was followed by trial mix using a nominal mix of 1:2:4, w/c, ratios of 0.4, 0.5 and 0.6 along with two different consolidation methods such as manual and machine vibrated. Based on the result of trial mix, W/C ratio of 0.5 was used to prepare and cure 150mm x 150mm x 150mm concrete cubes. UPV test result (1-90 days) showed after 1- 90 days curing, an inverse relationship with the crushed concrete compressive strength. In recent decades there are numerous non-destructive methods that were developed. It was, however noted that there are certain problems associated with the NDT of concrete. In fact, there is no standard for acceptance which defines the undesirable characteristics of non-conforming materials. Since, according to researchers (Gupta, and Gupta, 2008; Shetty, 2010; Bungey, et al, 1996; Dalrymple, 2006; Abdul' Azeez, et al, 2012; Lim, and Coa, 2013; and Opoola, 2015), compressive strength is the property most valued by designers and quality control engineers as many of the desirable characteristics of concrete are quantitatively related to it; there is need to develop reliable predictive models to correctly evaluate compressive strength of concrete. This is especially important in case of ultrasonic pulse velocity. Similarly in recent years other researchers also confirmed that, there is the high need to investigate the relationship between UPV, as the most accepted technique, among the popular NDT methods, and compressive strength. In view of the fact that compressive strength is regarded as the single most important quality index of concrete. Thus in present study an attempt was made to interpret the relationships between Ultrasonic pulse velocity and compressive strength for in case of different mixtures proportion, grade of concrete, w/c ratio, cement content, water content, fine aggregate, coarse aggregate, and slump.

2.0 Research objectives

The non-destructive tests are less expensive and easier than destructive. However, the evaluation of the test results is very difficult. There are several studies on the use of non-destructive tests to assess the properties of concrete. On the other hand, investigations on the evaluation of the test results are very scarce in the technical literature. The objectives of this present research are threefold. First, this research will examine the influence of conditioning such as drying condition on the results of UPV test performed on concrete cubes with different mixtures proportion such as w/c ratio, slump, grade of concrete, fine aggregate, coarse aggregate, cement content, and water content under two different conditions such as Slump, and w/c ratio value was varied with constant compressive strength as in the First case and compressive strength, and w/c ratio value varied with constant slump as in the Second case. Second, this research will examine the influence of the UPV value on compressive strength. Third, this research will also aims to develop non-destructive charts for different concrete mixture proportions. This implied that the developed chart was more suitable for normal strength concrete and can be utilised in minimising inaccuracy in non-destructive tests.

3.0 Experimental Program

In the present research work, six different mixtures type were prepared in total as per (BRE code, 1988) standards with a concrete cubes of size (100 mm³). Three of the mixtures type were concrete cubes (100 mm³) with a compressive strength of (40 N/mm²), slump (0-10, 10-30, and 60-180 mm) and different w/c (0.45, 0.44, and 0.43). These mixtures were designated as M1, M2, and M3. Another Three of the mixtures type were concrete cubes with a compressive strength of (25

N/mm², 30 N/mm², and 40 N/mm²), slump (10-30 mm), and different w/c (0.5 0.45, and 0.44). These mixtures were designated as M4, M5, and M6. The overall details of the mixtures proportion were to be represented in Table.1-2. Twelve concrete cubes of size (100 mm³) were cast for each mixtures type. The grade of cement used in this study was 42.5 N/mm². The fine aggregate used was river bed sand sieved with 4.75 mm size and used 600 microns down sand. The coarse aggregate used was crushed stone with maximum nominal size of 10 mm.

Table 1: (Variable: Slump & W/C value; Constant: Compressive strength)

Mix ID	Comp/mean target stg, N/mm ²	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg) 10 mm	Mixture proportions
M1	40/47.84	0-10	0.45	3.60	1.62	5.86	18.60	1:1.63:5.16
M2	40/47.84	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87
M3	40/47.84	60-180	0.43	5.43	2.34	6.42	14.30	1:1.18:2.63

Table 2: (Variable: Compressive strength & W/C value; Constant: Slump)

Mix ID	Comp/mean target stg, N/mm ²	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg) 10 mm	Mixture proportions
M4	25/32.84	10-30	0.50	3.84	1.92	5.98	17.04	1:1.55:4.44
M5	30/37.84	10-30	0.45	4.27	1.92	6.09	16.50	1:1.42:3.86
M6	40/47.84	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87

4.0 Ultrasonic pulse velocity

The Ultrasonic pulse velocity (UPV) is a non-destructive technique involve measuring the speed of sound through materials in order to predict material strength, calculate low-strain elastic modulus and/or to detect the presence of internal flaws such as cracking, voids, honeycomb, decay and other damage. The technique is applicable where intrusive (destructive) testing is not desirable and can be applied to concrete, ceramics, stone and timber. The main strength of the method is in finding general changes in condition such as areas of weak concrete in a generally sound structure. Absolute measurements should be treated with caution. At the same time, the UPV technique is not always practicable in testing sound concrete. Especially in investigation of crack depth, it is ineffective if the crack is water filled. The performance is also often poor in very rough surfaces. Sometimes good contact requires the use of a coupling gel between the transducers and the structure. This may be aesthetically unacceptable on some structures. The schematic diagram of measurement principles of Ultrasonic pulse velocity as shown in Fig.1.

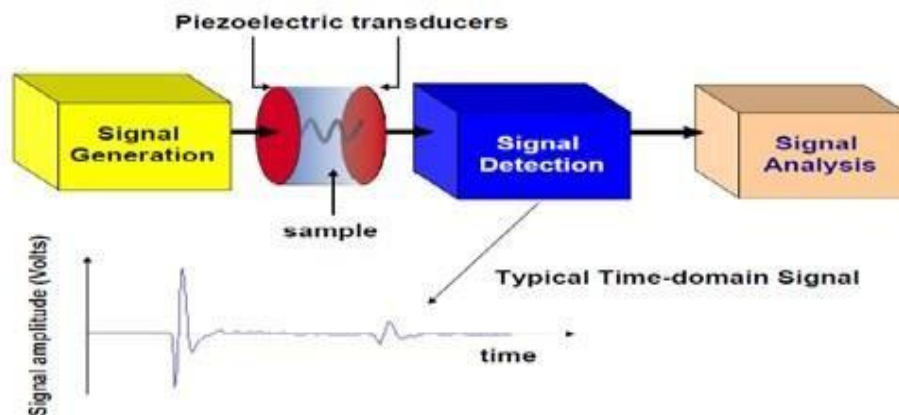


Figure 1: Measurement principles of UPV test

The measurement of the velocity of ultrasonic pulses as a means of testing materials was originally developed for assessing the quality and condition of concrete and the PUNDIT will undoubtedly be used predominately for this purpose. In most of the applications it is necessary to measure the pulse velocity to a high degree of accuracy since relatively small changes in pulse velocity usually reflect relatively large changes in the condition of the concrete. For this reason, it is important that care be taken to obtain the highest possible accuracy of both the transit time and the path length measurements since the pulse velocity measurement depends on both of these. Accuracy of transit time measurement can only be assured if good acoustic coupling between the transducer face and the concrete surface can be achieved. For a concrete surface formed by casting against steel or smooth timber shuttering, good coupling can readily be obtained if the surface is free from dust and grit/covered with a light or medium grease or suitable couplant. A wet surface presents no problem. If the surface is moderately rough, stiffer grease should be used but very rough surfaces require more elaborate preparation. The direction in which the maximum energy is propagated is at right angles to the face of the transmitting transducer. However, it is possible to detect pulses travelling through concrete in some other direction. In other words, it is possible, to make measurements of pulse velocity by placing the two transducers on either as per BS 1881: Part 203:1986 (1) adjacent faces-semi-direct transmission, (2) opposite faces-direct transmission, and (3) same face-indirect or surface transmission. The ultrasonic pulse velocity of concrete can be related to its density and modulus of elasticity. It depends upon the materials and mix proportions used in making concrete as well as the method of placing, compacting and curing of concrete. If the concrete is not compacted thoroughly and having segregation, cracks or flaws, the pulse velocity will be lower as compare to good concrete, although the same materials and mix proportions are used. The quality of concrete in terms of uniformity, can be assessed using the guidelines given in Table.3.

Table 3: Quality of concrete given by (BS, 1881, 1983) as a function of UPV

UPV (m/sec)	Quality of concrete
>4500	Excellent
3500-4500	Good
3000-3500	Medium
<3000	Doubtful

Thus in the present research work an attempt was made to investigate the influence of conditioning such as Drying condition on the results of Ultrasonic pulse velocity test (Direct type), which is performed on concrete cubes with different Mixture proportions. In which Slump, and W/C ratio value was varied with constant Compressive strength as in the First case and Compressive strength, and W/C ratio value varied with constant Slump as in the Second case. In addition to that, this research will aim to examine the influence of the Ultrasonic pulse velocity value on compressive. As concerned to the Ultrasonic pulse velocity apparatus which is manufactured by CNS Farnell, London, derives its name from the initial letters of the full title of "Portable Ultrasonic Non-destructive Digital Indicating Tester" (PUNDIT) was used in this research work, The test equipment provides a means of generating a pulse, transmitting this to the concrete, receiving and amplifying the pulse and measuring and displaying the time taken.

5.0 Results and discussion

The non-destructive testing (NDT) of concrete is of great scientific and practical importance. The subject has received growing attention during recent years, especially the need for quality characterisation of damaged constructions made of concrete, using NDT methods. In fact, none of the available non-destructive methods for testing concrete strength is better. Nevertheless, there are intrinsic and practical factors that may interfere with the determination of concrete strength by ultrasonic means. Concrete is a mixture of four materials: Portland cement, mineral aggregate, water and air. This complexity makes the behaviour of ultrasonic waves in concrete highly irregular, which, in turn hinders non-destructive testing. In the view of the complexities of the problem it would appear to be overly optimistic to attempt to formulate an ultrasonic test method for the determination of concrete strength. However, considering the seriousness of the infrastructure problem and the magnitude of the cost of rehabilitation, major advancement is desperately needed to improve the current situation. For instance, it has been demonstrated repeatedly that the standard ultrasonic method using longitudinal waves for testing concrete can estimate the concrete strength only with $\pm 20\%$ accuracy under laboratory conditions. The interpreted ultrasonic pulse velocity as well as compressive strength are average values taken on three sides of concrete cubes in the present research work with their variation as shown in Figs.2-7. The variation of average compressive strength with ultrasonic pulse velocity, standard deviation, and co-relation equation as well as R^2 value are represented in Table.4. The relationship between ultrasonic pulse velocity and compressive strength of all the

mixtures type was investigated. It is confirmed as a general trend that, the UPV increased with increased compressive strength.

Table 4: Variation of Ultrasonic pulse velocity with Compressive strength

Mix ID	Comp stg, N/mm ²	STD	UPV, m/sec	STD	Co-relation Equation	R ²
M1	32.50	2.09	4347.25	333.21	Y = 0.0046x + 12.70	0.5233
M2	33.59	2.59	4371.91	184.22	Y = 0.0108x - 13.80	0.5915
M3	35.29	2.22	4446.33	268.11	Y = 0.0079x + 0.187	0.9063
M4	27.16	1.61	3528.33	364.93	Y = 0.0031x + 16.19	0.4927
M5	32.43	1.29	3645.91	556.17	Y = 0.0025x + 25.09	0.7515
M6	33.40	1.71	4080.16	483.94	Y = 0.0033x + 19.93	0.8638

It's observed from results that, the ultrasonic pulse velocity was increased with higher compressive strength as well as different slump value for in case of mixtures type (M1-M3). Whereas in mixtures type (M4-M6), the ultrasonic pulse velocity was somewhat decreased with lower compressive strength, and increases with higher compressive strength for constant slump value. The correlation coefficient (R²) as observed from (Figures.2-7) results that its varied from each other in all mixtures type (M1-M6) which was ranges from 52.33%, 59.15%, 90.63%, 49.27%, 75.15%, and 86.38%. This means that there is an excellent relationship between compressive strength and ultrasonic pulse velocity. This in implies that the independent variable (ultrasonic pulse velocity) is a useful predictor of the dependent variable (compressive strength).

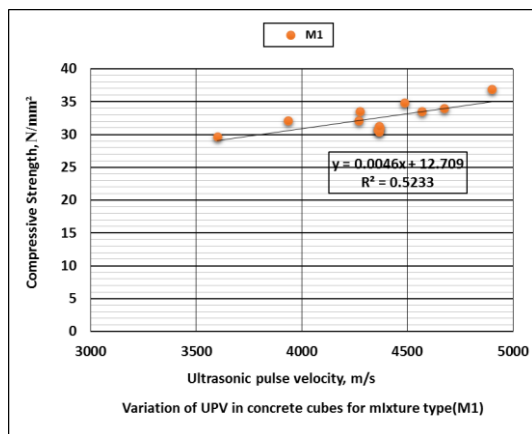


Figure 2: Compressive strength versus UPV in M1

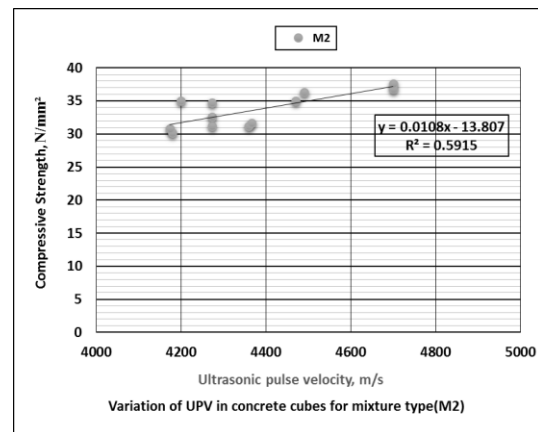


Figure 3: Compressive strength versus UPV in M2

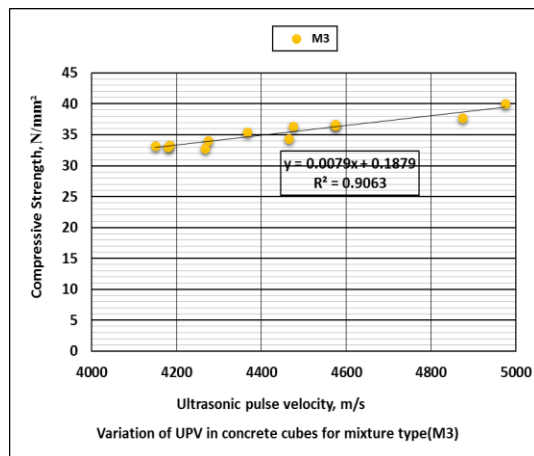


Figure 4: Compressive strength versus UPV in M3

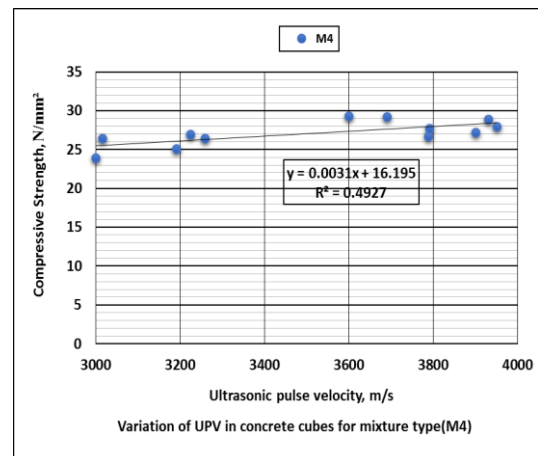


Figure 5: Compressive strength versus UPV in M4

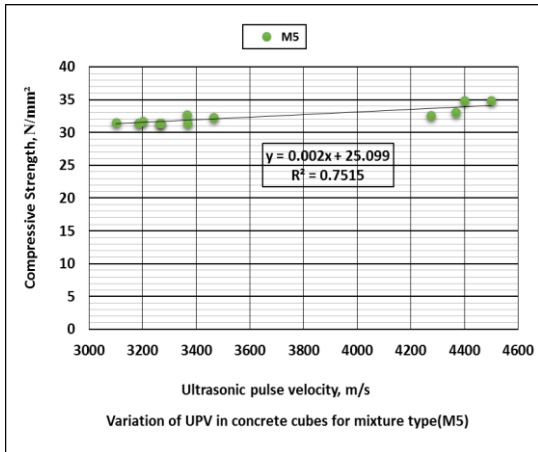


Figure 6: Compressive strength versus UPV in M5

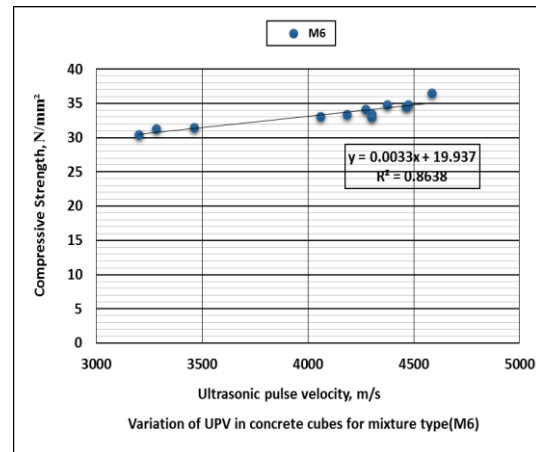


Figure 7: Compressive strength versus UPV in M6

6.0 Conclusions

The concrete is a heterogeneous material and the interpretation of the relationship between strength and UPV is very complex. The results show that there is a good correlation between strength and UPV. The results also show that it is possible to understand how the variations of tests condition affect the results of UPV, which can lead into a decrease of the errors considering the strength estimation. In fact, the UPV tests can provide important data about decision-making of concrete conditions. It can be concluded that, by means of UPV, it is possible to characterize concrete mixtures design and quality of concrete structures. In this study, the ultrasonic pulse velocity technique as a non-destructive testing of concrete was used to characterize concrete mixtures design. It was concluded that increasing the cement content caused a rapid pulse in pundit readings and reducing the w/c ratio, the pulse rate increased in some cases. It was also confirmed that with high concrete slump, the aggregates with different density affect the concrete ultrasonic pulse rate. In fact, there is no clear rules that have been presented to describe how the relationship between UPV and the compressive strength of concrete changes with its mixture proportion. Therefore, there exists a high uncertainty when one tries to make use of UPV to predict the strength of concrete in different mixtures proportion. There are several attempts have been made towards either developing new procedures of estimating the compressive strength and other properties of concrete or towards using the existing methods for getting more reliable and dependable information of the quality of concrete in the years to come without disturbing the structure. This paper investigated the relationship between the UPV value and compressive strength of normal concrete and also shown the influence of the mixtures proportion, w/c ratios and the grade of concrete on the relationship between UPV and compressive strength. Based on the research studies, the following conclusions are drawn:

- [1]. The present study proposed a useful mathematical linear relationship that help the researchers to predict confidently the compressive strength of standard concrete cubes, by measuring the ultrasonic pulse velocity with ultrasonic pulse velocity test. The mathematical expression is applicable for a wide range of normal concrete strengths.
- [2]. The ultrasonic pulse velocity and compressive strength of normal concrete with low w/c ratio are higher than those with high w/c ratio, in turn its because of the denser structure of concrete with lower w/c ratio.
- [3]. The interpretation of correlation equation, however, is not unique, but rather depends particularly on the mixtures proportion, cement type and type of aggregate, water-cement ratio, and grade of concrete used for a particular type of mixtures design.
- [4]. The ultrasonic pulse velocity was increased with increased grade of concrete as well as varied slump value and decreases with lower grade of concrete.

Conflict of Interest statement

This is the original research conducted by me M.N. Balakrishna under the guidance of the above mentioned other authors. Moreover, I am self-funded student for my entire study, and lab work. I am not at all applying for any funding or any university or organisation. In which I am spending my own money for study, accommodation, and travel, and food at Nottingham Trent University, UK. In fact there is no conflict of interest in any matter.

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