NDT ASSESSMENT OF NORMAL CONCRETE WITH AGGREGATE OF DIFFERENT SIZES IN DAMAGED AND UNDAMAGED STATES

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ABSTRACT
Ultrasonic Pulse Velocity (UPV) is one of the Non-Destructive Testing (NDT) methods of assessments concrete properties. This tool is known as an excellent method for determining the quality and uniformity of concrete and its ability to determine the defects on concrete structures. This study was conducted to evaluate the effect of concrete with difference aggregate sizes and curing time by measuring ultrasonic wave velocity and UPV is one of the techniques in the evaluation for determining the damage mechanism in the concrete structure. Therefore, 9 specimens with size 150mm x 150mm x 150 mm cubes were cast for ultrasonic evaluation with different aggregate sizes of 10 mm, 20 mm and 30 mm respectively. Ultrasonic measurements were recorded at 7, 14 and 28 days after concrete has been casting. The results revealed that UPV decreases with the increase aggregate size. It was also found that UPV increases as the concrete curing time increases. Additionally, the compressive strength of concrete was affected by difference aggregate sizes where the strength of concrete increases as the aggregate size decreases.

Keywords: Non-destructive testing, ultrasonic pulse velocity, compressive strength, aggregates sizes.

INTRODUCTION
In construction, concrete is a complex composite material, which begins its life as a mixture of graded stone aggregate particles suspended in a fluid of cement, water and admixture [1]. Coarse aggregates play an important role in such behavior of concrete [2]. Concrete structure needs to be evaluated to get long life performance after construction. The presence of defects in concrete structure may occur due to surrounding environments and ageing of concrete. Therefore, evaluations of concrete performance have been adopted by many Non Destructive Testing methods [3].

NDT is one of the methods that are widely used in industries nowadays as an evaluation technique to determine the properties for any type of component without destroying or changing the characteristics of that component. According to Verma et al. [4], NDT method is useful for evaluating structure by performing indirect assessment of concrete properties. In general NDT is a discrete inspection performed during manufacture at specified intervals during the service of a structure [5].

There are several types of NDT which are Ultrasonic Pulse Velocity (UPV), Acoustic Emission (AE) and others. Even though there are many types of NDT method, no single NDT method will work for all flaw detections or measurement applications. Each method has certain advantages and disadvantages over the others. However, certain NDT methods have their own limitations due to different theoretical principles, and as a result produce different sets of information regarding physical properties of structure [6]. For example, the methods might not be entirely non-destructive and are therefore not applicable in situ and usually the methods have to be manually performed at regular (small) time intervals in order to properly determine early age compressive strength development [7].

Referring to a study done by Lawson et al. [1], the assessment of concrete properties is usually done via the UPV method, where it has the ability to determine internal damage such as voids, honeycombs, decay and other defects. UPV can be effectively used for changes in the structures that occur over time to determine the lifetime of the structure [8]. Besides that, Ultrasonic waves (elastic waves) are used to estimate concrete damage state and detect internal flaws [9]. The measurement of the lifetime of concrete structure is part of the quality control procedure for structure, where NDT is evolving as an integral part of inspection and quality assurance practice in many disciplines of civil engineering [10]. UPV is often used to assess the quality of concrete and to estimate its compressive strength [11].

There are several factors that contribute to UPV measurement such as water-cement ration, aggregate gradation and curing time of concrete. The types of transducer contact and specimen path length also affect the measurement of UPV wave. Therefore, this study focuses on methods to classify the quality of the concrete structure. The study simultaneously measures the pulse velocity and compressive strength of 150 mm cubes at different ages from 1 day to 28 days and revealed a linear relationship between the strength and velocity [12]. However, this research still requires detailed exploration of UPV applications on basic concrete properties.

ULTRASONIC PULSE VELOCITY
Ultrasonic Pulse Velocity (UPV) method can be considered as one of the most promising methods for evaluation of concrete structures as seen in Figure-1 [13]. Furthermore, UPV is one of the most effective tools for
predicting the strength of concrete, determining the extension of cracks in concrete, as well as ascertaining the thickness of surface layers damaged by chemical attacks or fire [14].

Nonetheless, the UPV test involves measuring the time taken to travel through a distance in concrete from which velocity is calculated. The signal that is produced by ultrasonic was generated by a Piezo-electric crystal housed in a transducer, which transforms an electric pulse into a mechanical wave.

Figure-1. Ultrasonic pulse velocity instrument.

Type of waves

According to Muravin et al. [15], the types of compressional waves generated depend on material properties, its mechanical behavior and level of stresses at the source. In the Ultrasonic Pulse Velocity (UPV) device, there are several types of propagation mechanical waves which are P-wave (longitudinal), S-wave (transverse) and R-wave (Rayleigh) as shown in Figure-2. M. Gams [7] explained that the P-wave is usually used to estimate compressive strength of hardened concrete. Besides that, S-wave velocity is governed by the same material property as the compressive strength such as how strongly the individual particles are bonded together [16].

Every wave type propagates with its own characteristic velocity. The velocities of waves depend on the elastic properties as well as the density of the concrete. However, P-wave travels fastest in the direction of the disturbance known as the longitudinal or compression wave. In addition, a UPV wave through the concrete was created at a point on the surface of the test object, and the time of its travel from one point to another point is measured.

Figure-2. (a) P-wave, (b) S-wave, (c) R-wave [7].

Classification of the quality of basis pulse velocity

Qualities of concrete based on longitudinal pulse velocity are classified and summarized in Table-1.

Table-1. Quality of concrete due to pulse velocity.

<table>
<thead>
<tr>
<th>Longitudinal Pulse Velocity (km/s)</th>
<th>Quality of concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;4.5</td>
<td>Excellent</td>
</tr>
<tr>
<td>3.5 – 4.5</td>
<td>Good</td>
</tr>
<tr>
<td>3.0 – 3.5</td>
<td>Doubtful</td>
</tr>
<tr>
<td>2.0 – 3.0</td>
<td>Poor</td>
</tr>
<tr>
<td>&lt;2.0</td>
<td>Very Poor</td>
</tr>
</tbody>
</table>

MATERIALS AND METHODS

This paper is about the fundamental applications of ultrasonic pulse velocity (UPV) testing on concrete structure that was conducted in the laboratory. The strength of the concrete specimen was determined via compressive test and the evaluation of the concrete was conducted using UPV testing. In implementing the procedure for deterioration assessment of concrete, direct transmission was used to measure the strength of concrete with aggregates of different sizes.

Material: The raw material used is Ordinary Portland Cement (OPC) for the coarse aggregate. Three sizes of aggregates which are 10 mm, 20 mm and 30 mm were sieved. The minimum size of fine aggregates of 0.02 mm and clean water were used in the mixture.

Concrete design mix: The cement, aggregate and water content for the concrete were determined by using standard mix design concrete (ODE), with 0.50 water
cement ratio. In this study, three different sizes of aggregates which are 10 mm, 20 mm and 30 mm were used.

**Testing method:** An experiment was carried out to determine the quality and strength of the concrete that contained different sizes of aggregates compared to normal concrete. The concrete specimens used in this research measure 150mm x 150mm x150 mm. There are 12 molds per batch based on the size of the aggregates that were used in the concrete mixture. The strength of concrete was verified at 7, 14 and 28 days of curing time.

The non-destructive testing was conducted by using UPV before (undamaged state) and after (damaged state) compressive strength testing. Pulse velocity was determined by considering the transducer arrangements which are direct transmission, semi-direct transmission and indirect transmission. However, in this study, the pulse velocity, V of concrete was determined using direct transmission of transducer arrangement as shown in Figure-3. Transducer arrangement is one of the factors that affect the pulse velocity in the concrete. However, direct transmission is the most suitable arrangement because the transducer transmitted pulses with the maximum energy with this arrangement. All the tests are based on BS 1881-203:1986 [17]. The pulse velocity for each cube was calculated by using the following equation:

![Figure-3](image_url)

**RESULTS AND DISCUSSION.**

Figure-4 shows the comparison strength of concrete for different aggregate sizes used in concrete mixture. The concrete has the same mold size which is 150 mm x 150 mm x 150 mm and the concrete grade used was grade 35, with aggregates of different sizes. The strength of concrete is influenced by the shape and size of aggregates. Generally, concrete with the smallest size of aggregates gives the highest strength because the smallest size of aggregates is able to fill the voids present in the concrete.

![Figure-4](image_url)

Comparison between the strength of concrete with various sizes of aggregates is shown in Figure-5. The strength of concrete decreases as aggregate size increased. Aggregate size is one of the factors that contribute to the change of strength in concrete.

The usage of smallest aggregate can produce a higher strength of concrete. This is due to the size of aggregate in the mixture. Therefore, the bigger size of aggregate lead to larger space between the particles even though the particles are close together. But, when particles of uniform size are used, the spacing between the particles becomes largest. However, when aggregates of different sizes are used, the void will be filled and it contributed to lower usage of the cement paste.

Figure-5 shows strength against pulse velocity for various aggregate sizes for 7, 14 and 28 days. It shows that the maximum aggregate size is affected by the velocity. In this research, direct transmission method was used to measure the velocity by placing two transducers on either side of the opposite faces (direct transmission).
At the meantime, Figure-5 shows the velocities in the concrete are influenced by the age of the concrete. Pulse velocity rapidly increased during the early age (7 days), and then the velocity continued to increase at a slower rate until it reaches 28 days. Curing time contributed to the increase of pulse velocity in the concrete and can be attributed to the relationship between capillary pores and ultrasound wave velocity. However, compressive strength and pulse velocity of concrete are influenced by many factors such as mixture proportions, aggregate type and so on. In this research, the velocity in concrete decreases as the size of aggregates increases.

Non-destructive test values shown in Table-2 indicate non-uniform quality of concrete for all specimens. Quality of concrete grading is excellent before compressive testing, but after testing via compressive testing, the quality of concrete becomes weaker due to the detection of voids and cracks during the assessment. This is due to the presence of micro cracks when the specimen is subjected to loading. In some cases, many investigators found that pulse velocities decrease significantly when the quality of concrete is doubtful. Besides that, velocity in the concrete decreases due to the presence of defects during the process of placing, compacting and curing of concrete during the research.

Table-2. Difference in the quality of concrete before and after testing.

<table>
<thead>
<tr>
<th>Aggregate size (mm)</th>
<th>Pulse Velocity Before (Km/s)</th>
<th>Quality of concrete</th>
<th>Pulse Velocity After (Km/s)</th>
<th>Quality of concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>4.60</td>
<td>Excellent</td>
<td>3.24</td>
<td>Doubtful</td>
</tr>
<tr>
<td>10</td>
<td>4.69</td>
<td></td>
<td>3.24</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>4.58</td>
<td></td>
<td>3.50</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>4.56</td>
<td></td>
<td>3.23</td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSIONS

The Ultrasonic Pulse Velocity (UPV) is an effective tool to determine the quality of concrete in damaged and undamaged states. This paper validated the fundamentals from previous research by evaluating concrete with different aggregate sizes using non-destructive testing. However, from this research it has shown that the pulse velocity in concrete decreases as the size of aggregate increases. Conversely, the strength of concrete increases as the size of aggregate decreases. Therefore, this research may prove helpful for further research as a guideline in the determination of concrete properties.

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REFERENCES


