DYNAMIC MODULUS OF ELASTICITY OF SUGAR CANE BAGASSE ASH IN FIBER REINFORCED CONCRETE BY USING ULTRASONIC PULSE VELOCITY

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ABSTRACT

This research paper is focused on Nondestructive Techniques for health monitoring of the structural concrete by using the ultrasonic pulse velocity method which is an ideal tool for monitoring the stress intensity for the various mixes of sugar cane bagasse ash based fiber reinforced concrete. It is suitable for existing structures and those under construction industries. The laboratory experimental test results indicated that the compressive, flexural, UPV and also dynamic modulus of elasticity increases as the intensity of stress depends upon the supplementary cementitious materials along with the matrix densification effect on the steel fibers. The comparison of the test results clearly shows that this method can be used effectively to predict the dynamic modulus of elasticity of concrete by using UPV and density of concrete values for the various mixes.

Key words: Compressive strength, Dynamic modulus, Sugarcane bagasse ash, Rebound hammer, Ultrasonic pulse velocity.

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1. INTRODUCTION

The load deformation of a structural concrete specimen is dependent on two factors: The first type of deformation is due to the elastic properties of the concrete and the second type of deformation is due to the inelastic or plastic properties of concrete. In computing the total deformation of a concrete structure, the entire strain, plastic and elastic must be used. If, however, the dynamic response of a concrete structure is desired, the modulus of elasticity, as found by the sonic or vibratory method, would govern the response of the structure and would be considerably differing from that obtained in the static test. It is difficult to define clearly all
the reasons for the difference between the static and the dynamic moduli of elasticity, but the difference is probably in the varying amounts of plastic and elastic deformations that occur. Moreover, because of the stress-strain characteristics of concrete, it is probable that the modulus of elasticity of concrete, regardless of how it is determined, is a function of the stress intensity.

Bagasse plays a major role in the generation of electricity continuously. Dry bagasse is scorched to produce steam. With the help of the steam produced, turbines are rotated to produce power. Approximately, three tonnes of wet bagasse are produced for every 10 tonnes of sugarcane crushed. Bagasse ash refers to the agro waste from sugarcane industry that exhibits pozzolanic activity. Bagasse ash usually contains high amounts of unburnt matter, silicon, aluminium, iron and calcium oxides. The bagasse obtained directly from the mill and burnt under uncontrolled conditions, as they are not reactive. Hence, the ash becomes an industrial waste, there by posing disposal problems.

Quarry dust is a by-product obtained from the crushing process of stones, which are available in an ample manner from rock quarries at a very low cost, being an economic alternative to natural sand. It is easily available than natural sand and cement. Quarry dust, being a volatile material, its inhalation causes respiratory problems when disposed in an ineffective manner. By replacing river sand with quarry dust, the requirement of land fill area can be reduced greatly and can also solve the problem of natural sand scarcity. Quarry dust offers comparatively higher strength than natural sand with or without concrete admixtures. Non-destructive method is one of the widely used technique which is based on the fact that the properties of waves in the media are influenced by the material, homogenies of the structures due to the propagation of cracks [1] and soon transforms the signals in time domain to frequency domain to find the arriving time of reflected wave using peak frequencies [2] and the early damage of concrete using resonance frequencies and ultrasonic pulse velocities were noted [3]. The applied NDT for estimation of compressive strength of concrete made of cementitious materials. Most applications of pulse velocity were on normal concrete and there were few studies on other types of supplementary cementitious materials replaced with cement to produce the structural concrete, which is superior in carbon dioxide to minimize the CO$_2$ emission [4-7].

Compressive strength, heat of hydration, drying shrinkage and durability of concretes containing various replacement levels of Sugarcane bagasse ash with cement were investigated. Oxygen permeability test, rapid chloride penetration test, chloride conductivity test, water sorptivity test, DIN water permeability test and Torrent air permeability tests were carried out to determine the durability assessment. The results reveal that the use of bagasse ash prominently improves the performance of concrete. Bagasse ash blended concrete was observed to have low heat of hydration, as well as additional strength gain due to pozzolanic reaction and also significant reduction in permeability because of pore refinement and similar drying shrinkage behavior than that of the conventional concrete [8-10].

Bagasse ash is left over after squeezing the sugarcane fibres and taking off its juice. It is formed when the fibres are burnt at 1100°C for 1 to 5 hours in a furnace. Scanning electron microscopy and X-Ray diffraction studies were carried out on various parameters such as grain size and the percentage variation of chemical composition. The effect of temperature on weight and density variation in different hours was observed [11-14].

The SCBA replacement up to 20% by weight of cement due to the consumption of large amounts of energy is reduced by cement production. A fibrous matter that remains after the addition of bagasse ash causes reduction in strength of concrete. This can be compensated by the use of fibers in concrete. To compare the influence on concrete, natural and artificial
fibers are added. The replacement of cement with 10% and 20% of SCBA, super plasticizer (0.8% to 1.5% by weight of binder content) added to this. The properties of concrete such as compressive strength, flexural strength were examined. The experimental test results reveal that the percentage addition of SCBA along with different dosage of steel fibers increases the modulus of elasticity of concrete which is suitable for the structural conventional concrete.

2. MATERIALS & EXPERIMENTAL PROCEDURES

2.1. Materials

2.1.1. Cement

The most common type of Ordinary Portland Cement 53 grade was used. The specific gravity value of 3.15 was determined by test in accordance with IS 12269-2013[15].

2.1.2. Fine Aggregate

Fine aggregate which is locally available, free from debris, soil and nearly riverbed sand is used. In the present study the fine aggregate conforms to zone II in accordance with IS 383-2016 [16]. The specific gravity of sand is 2.68 and the average bulk density of fine aggregate (loose state) is 1548.88 kg/m$^3$ and rodded state is 1692.20 kg/m$^3$.

2.1.3. Coarse Aggregate

The crushed 20 mm maximum size of aggregates was used and tested as per Indian standards and results are within the permissible limit. The specific gravity of coarse aggregate is 2.80, the average bulk density of coarse aggregate is 1692.32 kg/m$^3$ and rodded state is 1940.18 kg/m$^3$.

2.1.4. Water

The requirement of water curing for the concrete plays a major role to give the surface treatment as well as maintain the temperature inside the concrete during the hydration process.

2.1.4. Steel Fiber

The discrete types of steel fibers are used with aspect ratio 80, i.e. fiber length equals to 130 mm and 1.6 mm diameter. The addition of dosage level of steel fibers from 0 to 1.5% by volume fraction ($V_f$) for various mixes.

2.1.6. Water Curing

After casting the various mixes of concrete specimens are kept at 27°C and relative humidity of 100% at different curing days.

2.2. Experimental Procedures

2.2.1. Specimen Details and Mix Proportions

The cube specimen size of 150 x 150 x 150 mm was used for compressive strength of concrete at 28 days. The prismatic concrete having dimensions of 100 x 100 x 500 mm were tested and calculated the flexural strength by using the third point loading method in accordance with IS 516-1999 [17] at 28 days for various mixes. Also, the same mix proportion is used for the empirical equation (1) is given below in accordance with IS 456-2000 [18] to calculate the flexural strength for various mixes. The specimen classifications and detailed mix proportions in accordance with IS 10262-2009 [19] are represented in Table 1.

$$\text{Flexural strength} = 0.7 \times \sqrt{f_{ck}} \quad (1)$$
Table 1 Detailed mix proportions

<table>
<thead>
<tr>
<th>Specimen</th>
<th>w/b ratio</th>
<th>Cement</th>
<th>SCBA</th>
<th>Fine aggregate</th>
<th>Quarry Dust</th>
<th>Coarse aggregate</th>
<th>Steel fiber Vt (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>0.47</td>
<td>336</td>
<td>0</td>
<td>834</td>
<td>0</td>
<td>223</td>
<td>158</td>
</tr>
<tr>
<td>M1</td>
<td>0.47</td>
<td>302</td>
<td>34</td>
<td>628</td>
<td>206</td>
<td>223</td>
<td>891</td>
</tr>
<tr>
<td>M2</td>
<td>0.47</td>
<td>302</td>
<td>34</td>
<td>628</td>
<td>206</td>
<td>223</td>
<td>891</td>
</tr>
<tr>
<td>M3</td>
<td>0.47</td>
<td>302</td>
<td>34</td>
<td>628</td>
<td>206</td>
<td>223</td>
<td>891</td>
</tr>
<tr>
<td>M4</td>
<td>0.47</td>
<td>268</td>
<td>68</td>
<td>417</td>
<td>417</td>
<td>223</td>
<td>891</td>
</tr>
<tr>
<td>M5</td>
<td>0.47</td>
<td>268</td>
<td>68</td>
<td>417</td>
<td>417</td>
<td>223</td>
<td>891</td>
</tr>
<tr>
<td>M6</td>
<td>0.47</td>
<td>268</td>
<td>68</td>
<td>417</td>
<td>417</td>
<td>223</td>
<td>891</td>
</tr>
</tbody>
</table>

Note: 12mm: 20mm of coarse aggregate were taken the ratio 20:80 by total of volume coarse aggregate

2.2.2. Schmidt Rebound Hammer Test
The plunger is then held perpendicular to the concrete surface and the body pushed towards the downward direction of the concrete specimens. This movement extends the spring holding the mass to the body during rebound the slide indicator travels with the hammer mass and stops at the maximum distance the mass reaches after rebounding. The average values of rebound hammer numbers are noted and the prescribed chart is referred based on the direction available on the Schmidt instruments and all values are monitored in accordance with IS 13311-1992 (part1) [19].

2.2.3. Ultrasonic Pulse Velocity
The transmitter and receiver were placed at the top and bottom of harden surfaces of concrete cube/prism specimen, in parallel direction to the destructive load. The following equation (2) was used to assess the quality of concrete by the direct transmission method of the pulse to be measured in accordance with IS 13311-1992 (part 2) [20].

\[
Ultrasonic \ Pulse \ Velocity = \frac{L}{t}
\]

Where \(L\) is the knowing the path length and \(t\) is the travel time taken by pulse

The image for experimental test set up how to assess the quality of structural concrete by using direct and indirect method of UPV as shown in Figure 1. Standard rating values are given in Table 2 in accordance with IS 13311-1992 (part 2).
Table 2 Pulse velocity and Quality of concrete

<table>
<thead>
<tr>
<th>Pulse Velocity (km/second)</th>
<th>Concrete Quality (Grading)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 4.5</td>
<td>Excellent</td>
</tr>
<tr>
<td>3.5 to 4.5</td>
<td>Good</td>
</tr>
<tr>
<td>3.0 to 3.5</td>
<td>Medium</td>
</tr>
<tr>
<td>Below 3.0</td>
<td>Doubtful</td>
</tr>
</tbody>
</table>

2.2.4. Elastic Modulus of Concrete (Ec)
The elastic modulus of concrete was evaluated using a concrete specimen of size 150 mm diameter by 300 mm height after capping, the cylindrical concrete specimens were attached with a compressometer at the gauge points about the centre of the specimen. The load was applied up to 40% of the failure load for various mixes and the deformation was recorded at every 5 kN load increment after 28 days of curing. Finally a stress-strain graph is drawn from the observed compression test results and the slope of the line is calculated thereby determining the elastic modulus of the concrete.

Also, the compressive strength test values are used to calculate the modulus of elasticity of concrete for the following equation (3) for various mixes in accordance with IS 456-2000.

\[ E_c = 5000 \sqrt{f_{ck}} \]  
(3)

where \( E_c \) is the elasticity modulus of concrete and \( f_{ck} \) is the characteristic compressive strength of concrete.

2.2.5. Dynamic Elastic Modulus of Concrete (Ed)
The dynamic elastic modulus (Ed) values are calculated from the ultrasonic pulse velocity test values for various mixes in accordance with IS 13311 (Part 1) 1992. The following equation (4) is given below.

\[ Ed = \rho V^2 \]  
(4)

Where \( V \) is the Ultrasonic pulse velocity \( (\text{km/sec}) \) & \( \rho \) is the density of concrete \( (\text{kg/m}^3) \)

3. TEST RESULTS AND DISCUSSION
The laboratory experimental works for destructive and Non-destructive test result values are tabulated for various mixes are represented in Table 3.

The effect of SCBA up to 20% with 1.5% of steel fiber exhibited the high compressive strength of concrete. However, it also reached the target strength of concrete at 28 days for various mixes, when compared to conventional concrete. The schematic rebound hammer test values are noted with reference to the graph the corresponding values of each specimen are given in Table 1. From the test results it can be noted that the higher rebound hammer number up to 36 in case of an M6 mix with corresponding compressive strength 32 MPa was observed at 28 days as shown in Figure 2. It was also noted that there is a decrease of 6 to 21% in compressive strength by using the NDT methods, when compared to experimental test results.
Table 3 Various experimental test results

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Compressive strength at 28 days (MPa)</th>
<th>mass (kg)</th>
<th>Density of concrete (kg/m$^3$)</th>
<th>Flexural strength at 28 days (MPa)</th>
<th>Flexural strength by using empirical formula</th>
<th>Modulus of Elasticity (GPa) at 28 days</th>
<th>Modulus of Elasticity (GPa) by using empirical formula</th>
<th>Rebound hammer with corresponding values</th>
<th>Ultrasonic pulse velocity (km/sec)</th>
<th>Rating (IS 13311 Part 1-1992)</th>
<th>Dynamic Modulus (GPa) in accordance with IS 13311-1992 (part 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>26.5</td>
<td>7350</td>
<td>2177.8</td>
<td>3.85</td>
<td>3.60</td>
<td>31.80</td>
<td>25.74</td>
<td>27</td>
<td>21</td>
<td>3.71</td>
<td>Good</td>
</tr>
<tr>
<td>M1</td>
<td>30.5</td>
<td>7360</td>
<td>2180.7</td>
<td>4.25</td>
<td>3.87</td>
<td>39.50</td>
<td>27.61</td>
<td>30</td>
<td>25</td>
<td>4.12</td>
<td>Good</td>
</tr>
<tr>
<td>M2</td>
<td>31.5</td>
<td>7350</td>
<td>2177.8</td>
<td>4.41</td>
<td>3.93</td>
<td>43.10</td>
<td>28.06</td>
<td>31</td>
<td>26</td>
<td>4.31</td>
<td>Good</td>
</tr>
<tr>
<td>M3</td>
<td>35.1</td>
<td>7360</td>
<td>2180.7</td>
<td>4.25</td>
<td>4.15</td>
<td>42.50</td>
<td>29.62</td>
<td>32</td>
<td>28</td>
<td>4.20</td>
<td>Good</td>
</tr>
<tr>
<td>M4</td>
<td>32.0</td>
<td>7340</td>
<td>2174.8</td>
<td>4.10</td>
<td>3.96</td>
<td>35.50</td>
<td>28.28</td>
<td>34</td>
<td>31</td>
<td>3.95</td>
<td>Good</td>
</tr>
<tr>
<td>M5</td>
<td>34.5</td>
<td>7320</td>
<td>2168.9</td>
<td>4.24</td>
<td>4.11</td>
<td>43.45</td>
<td>29.37</td>
<td>32</td>
<td>28</td>
<td>4.35</td>
<td>Good</td>
</tr>
<tr>
<td>M6</td>
<td>36.4</td>
<td>7360</td>
<td>2180.7</td>
<td>4.50</td>
<td>4.22</td>
<td>45.10</td>
<td>30.17</td>
<td>36</td>
<td>34</td>
<td>4.40</td>
<td>Good</td>
</tr>
</tbody>
</table>

Figure 2 Compressive strength of concrete Vs density of concrete at 28 days

The experimental test results of flexural strength of concrete are given in Table 3 for various mixes. It is clearly noted that the flexural strength increases when the steel fibres increases as shown in Figure 3. The strength increases from 3.85 to 4.50 MPa and thus attributed to the change in the microstructure of the concrete when its compressive strength increases. For example, for specimen consisting 20% of SCBA with 1.5% of steel fiber exhibited the higher bending stress noted up to 4.50 MPa in M6 mix. In this case, the cementitious paste becomes denser and less porous and hence its increase the resistance to crack propagation. However, this increase in the flexural tensile strength is lower than the corresponding increase in the compressive strength. This may be attributed to the difference in the mechanism for lower strength and high strength concrete.
Figure 4 shows the modulus of elasticity of concrete for various mixes at 28 days. From the experimental test results, it is noted that the higher modulus of elasticity is produced in the case of 20% SBCA along with 1.5% of steel fibers. However, while calculating the modulus of elasticity values by the existing standard equation for various mixes, it decreases up to 19 to 33%, which is dependent on the concrete compressive strength.

Figure 5 shows the dynamic modulus of elasticity of concrete at various mixes depends upon the density of concrete with corresponding to ultrasonic pulse velocity of concrete. It is clearly noted the maximum dynamic velocity values are noted in M5 mix 42.22 GPa, when compared to conventional concrete. It is also noted that 10% of SCBA with 1.5% of steel fibers in M2 mix produced up to 40.27 GPa, which depends on the usage of supplementary cementitious materials with effect of steel fibers. The elastic modulus of aggregates is
generally higher than the binder content, providing a reason for higher dynamic modulus. Also, it can be predicted the life span of structures without affecting their lifespan and also assessing the quality of concrete.

![Graph showing dynamic elastic modulus of concrete](image)

**Figure 5** Dynamic elastic modulus of concrete at 28 days

### 4. CONCLUSION

The following conclusion can be drawn from the limitation of the experimental studies:

The compressive strength of concrete value increases up to 21% in the mix M6, when compared to conventional concrete. However, it was noted that the effect of quarry dust plays a major role to minimize the porosity and increase the density of concrete. The higher bending stress is observed in terms of flexural strength of concrete due to addition/effection of steel fibres up to 1.5% of volume fraction. Also, it was observed that the good matrix densification with effect of steel fibres produced the higher flexural strength, when compared to conventional concrete.

In determination of dynamic modulus of elasticity of concrete from ultrasonic pulse velocity test results and also the density of concrete for various mixes.

It was noted that the dynamic modulus of elasticity is slightly lower than the static modulus of concrete.

The prediction made using the proposed methods shows a high degree of consistency with experimentally assessed the compressive strength of concrete specimens used. Thus, the present research work suggests an alternative approach of compressive strength assessment against destructive testing methods.

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