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# 2 **Evaluating Structural Integrity of Green Concrete Modified** 3 **with Supplementary Cementitious Materials Using** 4 **Non-Destructive Testing**

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## 10 **Abstract**

11 The growing demand for environmentally friendly construction materials has led to the  
12 partial replacement of Portland cement with supplementary cementitious materials  
13 (SCMs) such as fly ash and bentonite. This study aims to determine the non-destructive  
14 strength of concrete in which cement is blended with fly ash and varying dosages of  
15 bentonite. The concrete specimens were created, in which cement was replaced with 0%,  
16 10%, 20%, 30%, 40%, and 50% bentonite, along with a constant dosage of 10% fly ash. The  
17 mechanical characteristics of concrete were assessed using non-destructive testing (NDT)  
18 methods, such as Ultrasonic Pulse Velocity (UPV) and Schmidt Rebound Hammer test,  
19 to determine the strength and surface hardness of the concrete specimens. Study shows  
20 that concrete specimens containing 10% fly ash along with 10% bentonite exhibited  
21 higher values of pulse velocity and rebound index, which predicts higher compressive  
22 strength of concrete due to the formation of dense microstructure and refinement of in-  
23 ternal pores of the concrete. However, the specimens containing higher dosages of ben-  
24 tonite and fly ash exhibited a low rebound index, likely due to their porous and loose  
25 microstructure. Therefore, non-destructive testing methods can be effectively used for  
26 monitoring the structural health of sustainable concrete.

27 **Keywords:** Green Concrete; Bentonite; Fly Ash; Non-Destructive Testing

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## 29 **1. Introduction**

30 The rapid development of infrastructure projects around the world has increased  
31 the demand for Portland cement. As a result, the production of Portland cement has also  
32 increased to a massive scale, which is not only harmful for the environment, but the cost  
33 of cement is also gradually increasing. This is particularly important, especially in Paki-  
34 stan, as a developing country. The production of cement contributes almost 7% to the  
35 global carbon dioxide footprint, which has become an important source of global warm-  
36 ing, and Pakistan has recently been experiencing the effects of climate change in the form  
37 of floods [1]. The use of natural pozzolanic materials has received special attention re-  
38 cently due to some special characteristics such as formation of high dense microstructure,

reduction in heat of hydration, improvement in permeability, and enhancement in mechanical properties of concrete [2], [3].

Bentonite is one of the pozzolanic materials that has been available readily in Pakistan, but it has not received significant attention. It is estimated that around 36 million tons of bentonite deposits are available at different locations in Pakistan, and it could have a huge potential as a pozzolanic material, especially in concrete [4]. Bentonite can be used as a partial replacement of cement to enhance the mechanical and chemical characteristics of concrete. Recent studies reveal that a certain proportion of bentonite can reduce micro-pores and create a stronger concrete [4], [5]. The industrial expansion has also led to a rise in the generation of fly ash as a byproduct. Various researchers propose using fly ash as a supplementary cementitious material in concrete for a variety of engineering benefits, including better workability, greater pozzolanic activity, and a decrease in heat of hydration [6], [7], [8], [12].

The combination of fly ash and bentonite influences the hydration mechanics, pore configuration, and texture of concrete, which can have a substantial impact on non-destructive testing (NDT) results. Although ultrasonic pulse velocity and Schmidt hammer tests are commonly employed to examine the quality and strength of ordinary concrete, their application to concrete containing both fly ash and bentonite has not been thoroughly investigated. There are very limited studies that explore the combined effect of fly ash and bentonite on the properties of concrete. Existing studies for regular Portland cement concrete may not correctly reflect the characteristics of blended systems that include clay minerals. As a result, the purpose of this investigation is to assess the performance of ultrasonic pulse velocity and rebound hammer tests in determining concrete incorporating bentonite and fly ash.

## 2. Materials and Methods

### 2.1. Materials

In this study, natural sand and crushed stones (ASTM C33) were transported from Margalla Hills, Islamabad [9]. The cement chosen for this study (ASTM Type I) meets the standards of ASTM C150 and has a specific gravity of 3.14. The maximum and minimum nominal sizes of fine aggregates were 4.75 and 0.075 mm, respectively. The fine aggregates were sieved in accordance with ASTM C136/C136M-19 criteria. The concrete mix ratio of 1:2:4 was used in this study. The chemical composition of cement, bentonite, and fly ash is shown in Table 1.

Table 1. Chemical properties of Ordinary Portland Cement, Bentonite, and fly ash.

Chemicals	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O
OPC	17.4	-	10.2	3.6	1.8	62.3	0.9	1.4
Bentonite	56.8	1.45	15.45	12.27	3.71	0.55	-	-
Fly Ash	55.5	2	24.5	13	3.5	0.5	0.7	0.9

## 2.2. Mix Design and Casting

The controlled sample of concrete was tagged as B0, which contained 100% bentonite was added in remaining mixes, such as B1 (10%), B2( 20%), B3(30), and B4(50%), with constant ratio of 10% fly ash, as shown in Table 2. Different materials such as cement, bentonite, fly ash, and aggregates were mixed in a concrete mixing machine and casting of cubical specimens having a size of 100mm was performed as shown in Figure 1. Afterwards, specimens were subjected to Rebound Hammer and Ultrasonic Pulse Velocity tests.

Table 2. Details of concrete mix design.

Mix ID	Cement (%)	Bentonite (%)	Fly Ash (%)
B0	100	0	0
B1	80	10	10
B2	70	20	10
B3	60	30	10
B4	50	40	10
B5	40	50	10

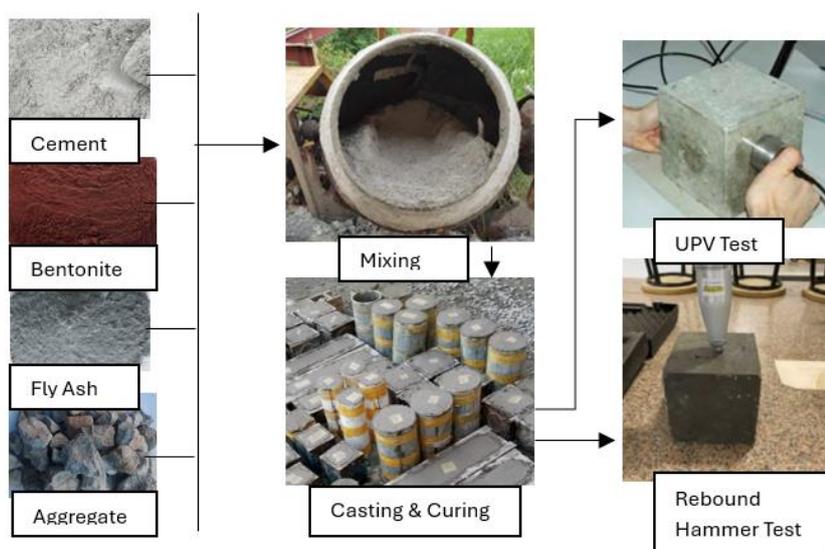


Figure 1. Experimental Program.

## 2.3 Testing Method

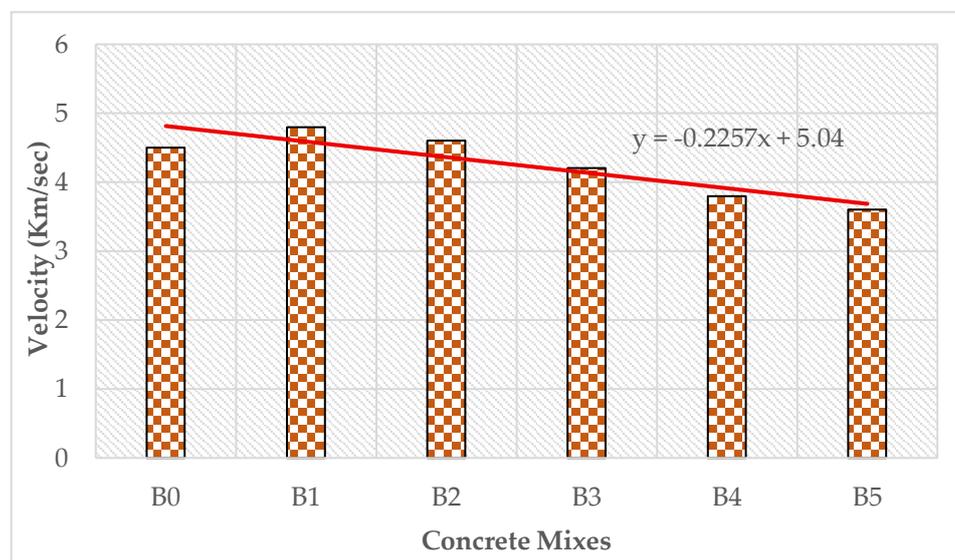
The concrete specimens were subjected to an ultrasonic pulse velocity test according to the specifications defined by ASTM C597/C597M. The Ultrasonic Pulse Velocity (UPV) test apparatus was set up in a way that both faces of cubical concrete specimens were attached with transducers to measure the pulse velocity through the concrete [10]. The signal propagation was directly observed, and the velocity was

94 calculated by measuring the distance between the transducers. The process was applied  
95 to all specimens of concrete. The surface hardness of concrete samples was determined  
96 using the Schmidt rebound hammer test in accordance with ASTM C805/C805M. The  
97 rebound hammer plunger was permitted to come into contact with the concrete surface,  
98 and readings were collected at three different positions on each specimen to determine  
99 the average value of surface hardness.

### 100 3. Results

#### 101 3.1. Ultrasonic Pulse Velocity (UPV)

102 To determine the quality of concrete mixes, a nondestructive UPV test was per-  
103 formed using the direct approach. The pulse time used varies depending on the homo-  
104 geneity, porosity, and fracture availability. The quality of concrete was investigated us-  
105 ing the velocity of waves passing through concrete samples. Velocities were estimated  
106 by dividing pulse distance by transit time. Experimental results showed that the addi-  
107 tion of 10% bentonite and 10% fly ash in concrete mix B1 increased signal velocity to 4.8  
108 km/s compared to the controlled mix sample B0, which had a pulse velocity of 4.5 km/s.  
109 This improvement is attributed to an improvement in matrix density [11], which contrib-  
110 uted to the strength of the concrete. The results showed that adding a small dosage of  
111 bentonite and fly ash enhanced signal velocity. In contrast, samples containing high dos-  
112 ages of bentonite decreased the velocity due to the formation of a porous composition.  
113 The results of the ultrasonic pulse velocity test as illustrated in the Figure. 2.  
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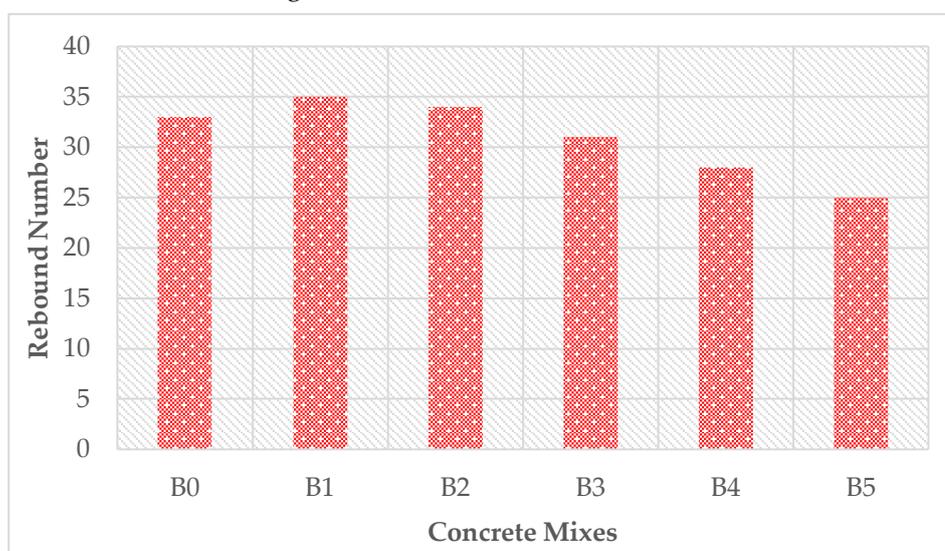
115 **Figure 2.** Results of the ultrasonic pulse velocity test.  
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#### 117 3.2. Schmidt Rebound Hammer Test

118 Results showed that concrete specimens containing 10% bentonite and 10% fly  
119 ash dosage had an apparent impact on the surface hardness of the concrete. Concrete  
120 with 10% bentonite and 10% fly ash had the greatest rebound number of 35, indicating "

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Good Layer" of concrete quality and greater surface hardness. This rise in rebound value is due to the combined micro-filling impact of bentonite and the pozzolanic reaction of fly ash, both of which contribute to matrix densification and refinement of the interfacial transition zone. Similar studies indicate that the presence of can enhance the formation of ettringite, which fills the micropores and solidifies the microstructure of concrete [7], [8]. The rebound value continued to decrease in the concrete mixes containing higher dosages of bentonite. The lowest value of rebound number was 25 for the mix B5 containing 50% bentonite and 10% fly ash, reflecting "Poor Concrete". The high dosages of bentonite reduced packing density and surface porosity, and showed vulnerability to impact energy, resulting in lower readings. The rebound values of different concrete mixes are shown in the Figure. 3.



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**Figure 3.** Rebound values of different concrete mixes.

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#### 4. Conclusion

This study aimed to apply ultrasonic pulse velocity and Schmidt hammer test to evaluate the quality of sustainable concrete developed by using supplementary cementitious materials. The following conclusions are made from this study.

1. The concrete specimens containing 10% bentonite and 10% fly ash exhibited the highest ultrasonic pulse velocity and rebound hammer values, reflecting improved concrete quality and hardness as compared to other samples.
2. The optimum dosages of fly ash and bentonite can enhance the strength of concrete due to the pozzolanic effect of bentonite and fly ash, resulting in the formation of a dense microstructure.
3. The high dosages of bentonite reduced the surface hardness and strength of concrete due to high water demand, formation of voids, and potential clay agglomeration.
4. The study shows that non-destructive testing methods could measure the impact of bentonite and fly ash on concrete performance; however, destructive and microstructural testing of concrete can be carried out to improve the quality of results.

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154 **Conflicts of Interest:** The authors declare no conflicts of interest.

## 155 **Abbreviations**

156 The following abbreviations are used in this manuscript:

UPV	Ultrasonic Pulse Velocity
NDT	Non-Destructive Testing
BN	Bentonite

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