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ENVIRONMENTAL DURABILITY ASSESSMENT OF OPTIMALLY CURED BAGASSE ASH BASED GEOPOLYMER CONCRETE

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ABSTRACT
The growing demand for the infrastructure development in country is also demand for the sustainable construction materials which has accelerated the development of eco – friendly alternative to ordinary Portland cement concrete to geopolymer concrete. As the constructional industry is one of the key factors for the country development, there is increase in the production of the cement also but this led to increase in pollution due to emission of CO_2 during manufacturing process. As this the reason, geopolymer concrete is one of the solution to move towards the sustainability in construction industry. Geopolymer concrete is concrete which uses the industrial and agricultural waste and help to decrease the pollution. In this research paper, study had been done to investigates the environmentally durability of the fly ash based geopolymer concrete incorporating 15% replacement of sugarcane bagasse ash (SCBA) as the optimum replacement for fly ash. Bagasse ash based Geopolymer concrete is prepared using 16M NaOH solution and Na_2SiO_3 alkaline activator. This bagasse ash based geopolymer concrete is oven cured at optimum 100°C temperature for 18hours. At the optimum temperature, curing hours and percentage replacement of bagasse ash durability performance was evaluated under different conditions such as water absorption, water penetration test, ultrasonic pulse velocity (UPV), Rapid Chloride Penetration test (RCPT), acid attack, pull out test and corrosion test. The results shows at optimum percentage replacement of bagasse ash, temperature and curing hours exhibited a dense and homogenous concrete.

KEYWORDS: Geopolymer concrete, Fly ash, Bagasse ash, alkaline activators, curing temperature, Curing Hours, environmental durability

1. INTRODUCTION

Today, there is rapid growth of global construction industry has significantly increased the demand for concrete. Conventional concrete is prepared by OPC as the binding material, due to which there is increase in cement production and this has become a major environmental concern. During the production of cement tonnes of CO_2 emission take place, which effect the environment [2]. Consequently, to reduce the emission of CO_2 during manufacturing of cement, primary objective of sustainable construction is required. This encourages the researcher to develop low carbon cementitious binders that will minimize the environmental impact. [4-5]

One of the sustainable alternatives is geopolymer concrete. Geopolymer is a concept which was introduced by the Sir Joseph Davidovits [2]. Geopolymer concrete is concrete in which cement is completely replaced by the source materials which consist of silica and alumina and can be activated by alkaline liquids to produce a polymeric reaction [2]. As per the precursor composition and production process of geopolymer concrete, approximately 40-80% of the CO_2 emission can be reduce when compare to conventional concrete [4-7].Geopolymer concrete is produced by alkali activation of alumino silicate rich source such as Fly ash, bagasse ash, ground granulated blast furnanace (GGBS),metakaolin, rice husk ash, and palm oil fuel ash using alkaline activators, mostly Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) solutions[1-3-10-16].

According to the previous investigations Fly ash is one of most widely used geopolymer precursors, which shows excellent performance due to its high contents of silica and alumina. Fly ash based geopolymer concrete is most extensively used as a sustainable construction material and also maintains excellent engineering performance [6-8]. Despite of the excellent performance there is also need to identify alternative alumino silicate materials which can partially replacing fly ash because there is gradual decrease in coal –fired power houses in many countries [6]. The alkaline activators type and dosage is also influence the mechanical properties of the geopolymer concrete [11-20]. Curing is one the most important factor which affects the strength of geopolymer concrete. Heat curing shows more strength when combined with the room temperature curing [12].

Agricultural waste is also emerging as alternatives because they are also content considerable silica content. Simultaneously there is an issue of their waste disposal and hence leads to environmental pollution []. Among these agricultural by-products, sugarcane bagasse ash (SCBA), is the one which increasing the attraction of researcher as it have high reactive silica content and enhance the mechanical and durability performance of geopolymer concrete [22].Sugarcane is one of the world's largest production crop in many countries such as India, Pakistan, brazil, China and Thailand [21-24]. During the manufacturing of the sugar, sugarcane bagasse is burned to generate steam and electricity, which produce large amount of sugarcane bagasse ash (SCBA) as a residual waste from industry. Disposal of this SCBA is a challenge as it is dispose in open landfill due to which it generate airbone particulate pollution in the environment[25]. Therefore, SCBA can be utilising as a construction material because it content high silica and significant pozzolanic reactivity [25].SCBA is influenced the workability and mechanical properties of concrete [14-18]. SCBA is primarily depending on the combustion temperature, burning duration and grinding process [15]. In the recent studies, approximately 600 -800°C temperature burning of raw bagasse ash with proper grinding will be rich in reactive silica, making it suitable for supplementary cementitious application in geopolymer concrete [24]. Researchers had investigated that influence of SCBA replacement level, curing conditions , alkaline activator composition and ash quality have effect on the performance of the bagasse ash fly ash based geopolymer concrete[17]. Rihan et.al demonstrated that replacement of SCBA into Fly ash geopolymer concrete can reduce the dependence on prolonged high temperature curing but showed that thermal curing will accelerates Geopolymerization reaction and improved the mechanical performance of the concrete[14]. Apart from strength, durability is also one of the parameter to evaluate suitability of SCBA based geopolymer concrete for structural application. Most of the studies have demonstrated that optimized SCBA geopolymer concrete exhibits reduced water absorption, lower sorptivity, improved acid attack and enhanced resistance to elevated temperatures [19 -23].

2. Experimental

In this paper, fly ash based geopolymer concrete is replaced by optimum percentage bagasse ash and oven cured at optimum temperature and curing hour to determine the behaviour of concrete in different environmental conditions.

2.1 Material

2.1.1 Fly Ash

Fly ash processed to low calcium class F,[13] supplied as POZZOCRETE 60 by Dirk India Private Limited. Fly ash used has a specific gravity of 2.26. The fly ash has a fineness 360 m^2/kg as per Blaine's method.

Fig.1 Fly ash

2.1.2 Bagasse Ash

Raw Sugarcane bagasse ash was collected from Mula Shakari Sakar Kharana, Sonai, District Ahilyanagar, Maharashtra in India. This raw bagasse ash produced in cogeneration plant after the burning of sugarcane bagasse. This ash is firstly sieve through 500µm sieve to remove the residue and collect fine ash [20]. After collection of this fine SCBA, it is calcinsed at temperature 700°C for 2hrs for promoting the pozzolanic reactivity [20]. The specific gravity of this SCBA is 2.56 [20]. This calcinsed SCBA is used for the replacement of fly ash in fly ash based geopolymer concrete to determine the optimum percentage of bagasse ash and oven cured at different temperature for different curing hours.

Fig. 2 Untreated Bagasse ash

Fig. 3 Treated Bagasse ash

2.1.3 Aggregate

Locally available coarse aggregate of 12.5mm and 20mm having specific gravity of 2.7 is used. Locally available river sand having specific gravity of 2.4 for fine aggregate is used.

2.1.4 Activators

Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) as alkaline activators are used. 16M of sodium hydroxide (NaOH) was obtained using 99% pure sodium hydroxide pellets [17]. The alkaline solution ratio, NaOH/ Na_2SiO_3 was 2.5.

Fig. 4 NaOH in pellets form

Fig.5 Na_2SiO_3 in gel Form

2.2 Mixing and Casting

Bagasse ash based geopolymer concrete is prepared as per the conventional method in a concrete mixer. A day before the casting, 16 M NaOH solution was prepared because NaOH liberates heat when mixed with water during the preparation. Initially, in concrete mixer as per the percentage of different bagasse ash, fly ash, and aggregate were dry mixed thoroughly. After that, NaOH and Na_2SiO_3 alkaline solution was gradually added in the mixer so that all the material gets mixed properly and gives a homogenous mixture. Following the mixing, concrete is poured into moulds. After 24 hours, moulds are demoulded for 5%, 10%, 15%, 20%, 25% and 30% replacement of the fly ash by bagasse ash. These all specimens were oven cured for 60℃, 80℃ and 100℃ for 6hrs, 12hrs, 18hrs and 24hrs curing hours for each temperature. Then compressive strength of the specimens was done to obtain the optimum percentage replacement of the bagasse ash, curing hours and temperature. Performances of different environmental conditions were tested on the optimum percentage replacement of bagasse ash, curing hours and temperature.

2.3 Test Conducted

2.3.1 Compressive Strength

Compressive Strength testing of each specimen was conducted on 2000KN capacity of compression testing machine. 03 Cubes Sample for every percentage replacement of fly ash by bagasse ash and each sample is oven cured at different 60℃, 80℃ and 100℃ for 6hrs, 12hrs, 18hrs and 24hrs curing hours were tested to determine the optimum percentage replacement of bagasse ash, temperature and curing hours. At the optimum percentage replacement of bagasse ash, temperature and curing hours different environmental conditions were tested such as water permeability, water absorption test, Rapid chloride penetration test, corrosion test, acid attack test, Pull out test, and ultrasonic pulse velocity.

Fig.6 Testing of Compressive Strength using 2000KN compression testing Machine

2.3.2 Water permeability Test

Water permeability test was conducted on the optimum percentage of bagasse for optimum temperature and optimum curing hours to determine the penetration of water in the concrete. The test was conducted on 150x150x150mm cube specimen after 28 days of curing as per IS 3085:1965 (Method of Test for Permeability of Cement Mortar and Concrete).

2.3.2 Water Absorption

Water absorption test is to study of pore structure and durability of the bagasse ash geopolymer for optimum percentage replacement in fly ash based geopolymer by oven cured at 100°C for 18 hrs. In this test 03 samples were prepared and tested for water absorption after 28days for 0, 25, 50 cycles.

2.3.3 Rapid Chloride Penetration Test (RCPT)

RCPT test was conducted at optimum condition to determine the resistance of chloride ion penetration in the bagasse ash geopolymer concrete. In this method cylindrical specimen of 100X200mm was cast and 50mm thick discs were cut from the cylinder after 28 days. These discs were tested in the RCPT apparatus.

2.3.4 Corrosion Test

Corrosion test was conducted for the optimum condition of bagasse ash geopolymer concrete by casting 03 specimens which are centrally embedded with reinforcing bar in the concrete. After oven cured at 100°C for 18hrs, these were specimens were partially immersed in sodium chloride solution for 28days. After 28 days, corrosion test is to be conduct.

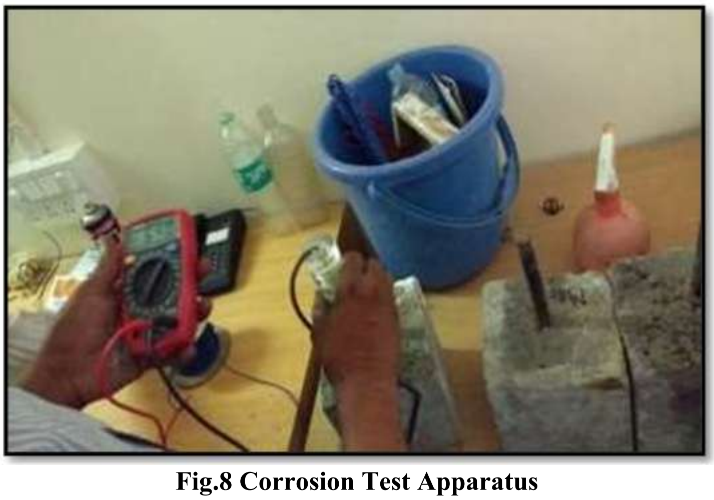

Fig.8 Corrosion Test Apparatus

2.3.5 Acid attack Test

Acid attack test was conducted on 03 specimens of size 150x150x150mm, were casted for optimum percentage replacement of fly ash by bagasse ash and cured at 100℃ for 18hrs. After 28days, these specimens were immersed in 5% H_2SO_4 acidic solution for 28days. By removing from acidic solution, compression testing is done.

Fig. 9 Specimen of Acid Attack Test

2.3.6 Pull out test

Pull out test were conducted on 03 specimen which are centrally embedded with reinforcing bar to determine the bond strength of bagasse ash geopolymer concrete at optimum percentage replacement of bagasse ash and oven cured at100℃ for 18hrs.

Fig.10 Universal Testing Machine **Fig.11 Specimen for Testing**

2.3.7 Ultrasonic Pulse Velocity (UPV)

UPV test was conducted by casting 03 specimen of 150x150x150mm at optimum percentage of replacement by bagasse ash and oven cured at100℃ for 18hrs to determine the quality of the bagasse ash geopolymer concrete.

Fig.12 Ultrasonic Pulse Velocity Apparatus

3. RESULT AND DISCUSSION

3.1 Compressive strength

The Compressive strength of cube specimen of size 150x150x150mm were casted for 5%, 10%, 15%, 20%, 25% and 30% replacement of the fly ash by bagasse ash and oven cured for 60℃, 80℃ and 100℃ for 6hrs, 12hrs, 18hrs and 24hrs curing hours for each temperature. Compressive strength of each percentage replacement of fly ash by bagasse ash at oven cured temperature and curing hours are conducted after 7 days to determine the optimum percentage replacement, temperature and curing hours.

3.1.1 Optimum percentage replacement and curing hours

Following figure 1, 2 & 3 represents the compressive strength of bagasse ash geopolymer concrete for replacement of fly ash by 5%, 10%, 15%, 20%, 25% and 30% and oven cured for 60°C, 80°C and 100°C for 6hrs, 12hrs, 18hrs and 24hrs curing hours.

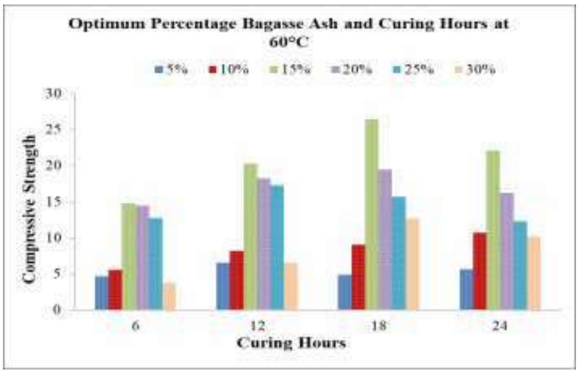

Fig 1. Optimum percentage bagasse ash and curing hours at 60℃

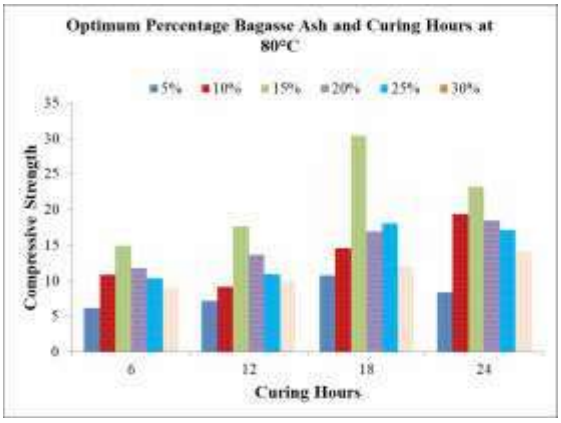

Fig 2. Optimum percentage bagasse ash hours at 80℃

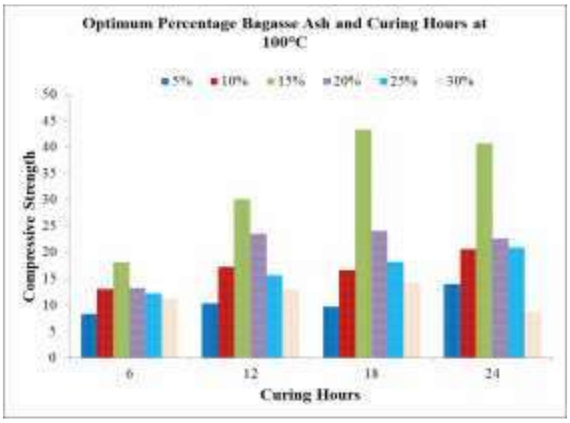

Fig 3. Optimum percentage bagasse ash and curing and curing hours at 100

From above figures 1, 2 & 3 we can conclude that 15% replacement of fly ash by bagasse ash at 18hours of curing hours showing maximum compressive strength for oven cured specimen for 60℃, 80℃ and 100℃.

3.1.2 Optimum temperature of curing

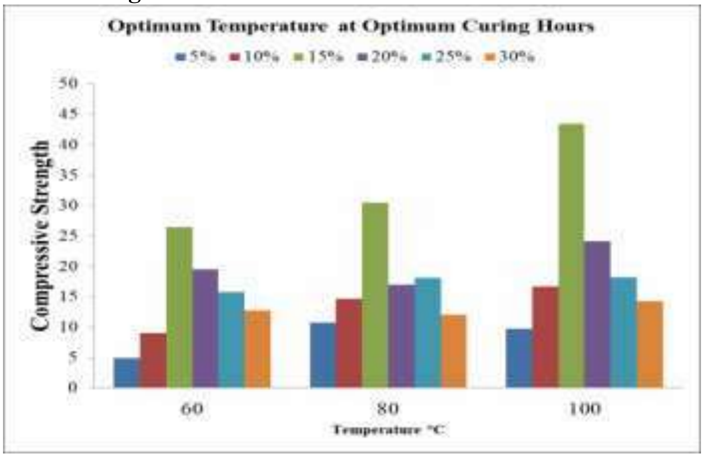

Fig 4 Optimum Temperature at optimum Curing Hour

From the above figure 4, we can conclude that optimum temperature for 5%, 10%, 15%, 20%, 25% and 30% replacement of the fly ash by bagasse ash at optimum curing of 18 hours is 100℃.

3.2 Environmental condition test

3.2.1 Water permeability Test

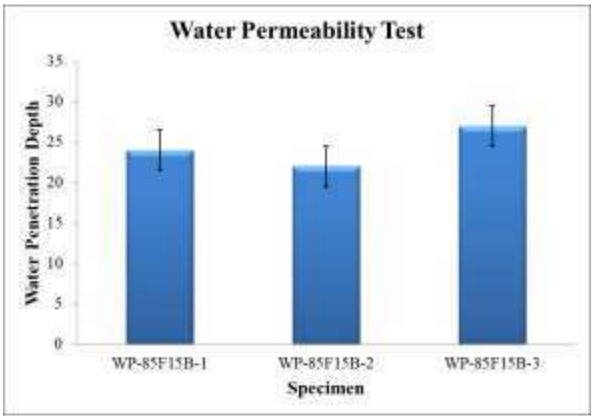

Fig 5 Water Permeability Test

From the fig 5, water permeability test for bagasse ash geopolymer concrete cast at optimum percentage replacement of bagasse ash and cured at optimum temperature for curing hours. As per observation, average of rate of penetration for 03 specimens is 24.35mm. This result indicates moderate resistance of water penetration.

3.2.2 Water absorption test

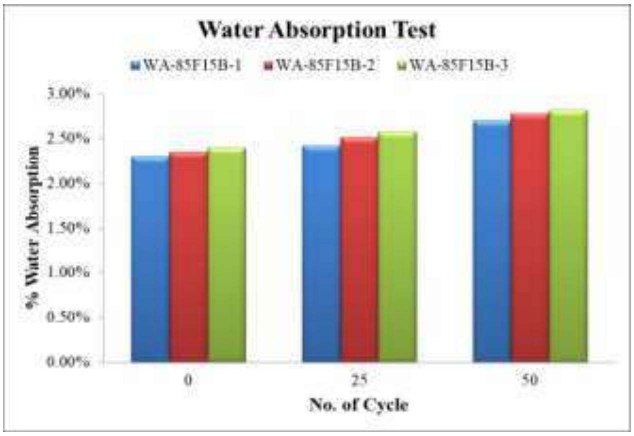

Fig 6 Water Absorption Test

From the fig. 6, water absorption test is conducted for optimum condition for 0, 25 and 50cycles after 28days. As we can observe there is increment in the water absorption as we increase the number of cycle from 2.30% to 2.82%. This increase is due to the increase in capillary pore which allow the moisture to ingress as number of cycles of wet and drying process increases.

3.2.3 Rapid Chloride Penetration Test

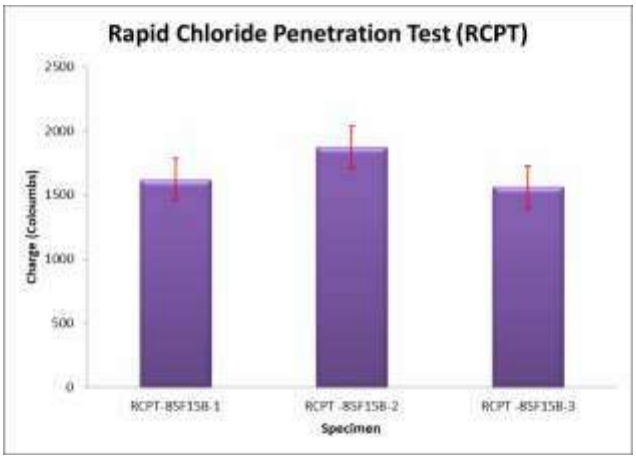

Fig. 7 Rapid Chloride Penetration Test

In fig 7, RCPT test was conducted on the bagasse ash geopolymer concrete as per ASTM C1202-22 at optimum percentage replacement of bagasse ash and oven cured at 100°C for 18hrs curing hours. As per observation, from figure RCPT gives an average of 03 specimens is 1685 Coulombs. According to ASTM C1202-22, charge passed value within the range of 1000-2000 Coulombs corresponds to low chloride ion penetration.

3.2.4 Pull Out Test

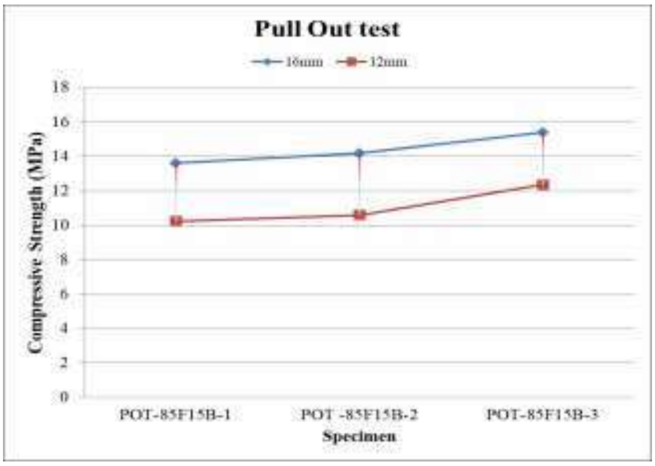

Fig 8 Pull Out test

In fig 8, Pull out test was conducted on the bagasse ash geopolymer concrete as per IS 2770 (Part 1): 1967 for bond strength evaluation at optimum percentage replacement of bagasse ash and oven cured at 100°C for 18hrs curing hours embedded with 12mm and 16mm reinforcing bar. As per observation, for each reinforcing bar 03 specimens were casted and tested after 28 days. The maximum pull out strength is observed in the 16mm bar as compared to the 12mm bar.

3.2.5 Acid attack

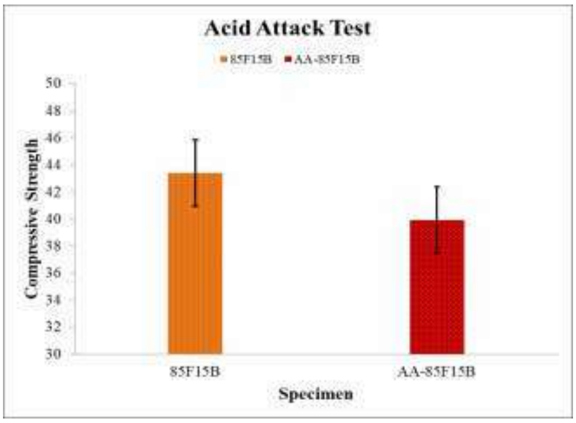

Fig 9 Acid Attack test

In fig 9, Acid attack test was conducted on bagasse ash geopolymer concrete as per IS 516:1959 for compressive strength testing and **IS 12330:1988** for durability assessment of concrete under aggressive environments at optimum percentage replacement of bagasse ash and oven cured at 100°C for 18hrs curing hours. As per observation, excellent acidic resistance for 28 days of immersion in 5% H_2SO_4 solution when compared to the optimum percentage of replacement of fly ash by bagasse ash. There is approximately about 7.99% reduction in the compressive strength of the acidic samples for 28days.

3.2.5 Corrosion test

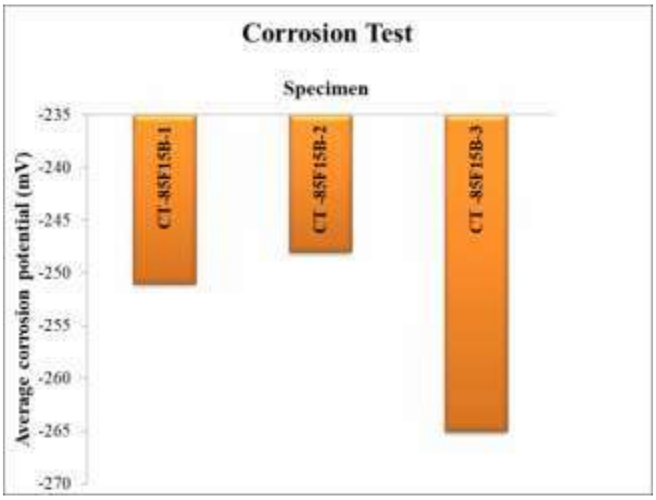

Fig. 10 Corrosion test

In fig 10, Corrosion test was conducted on bagasse ash geopolymer concrete as ASTM G59 and the corrosion rate calculations specified in ASTM G102 for durability assessment and electrochemical evaluation practices. In this test, 03 specimens are casted with centrally embedded reinforcement and immersed in the sodium chloride for 28 days. After 28 days, corrosion test is conducted by corrosion test measurement apparatus to measure the average corrosion potential. As per observation, the average corrosion potential for 3 specimens is -254.66 mV which indicate concrete indicate low corrosion activity.

3.2.6 Ultrasonic Pulse Velocity

In fig 11, UPV test was conducted as per IS 13311 (Part 1): 1992, to determine the quality of bagasse ash geopolymer concrete. After 28 days, ultrasonic pulse velocity test is conducted by ultrasonic pulse velocity test apparatus to measure the time and velocity for the 03 specimen casted for optimum percentage replacement and oven cured at 100°C for 18 hours. As per the observation, bagasse ash geopolymer concrete is good quality of concrete.

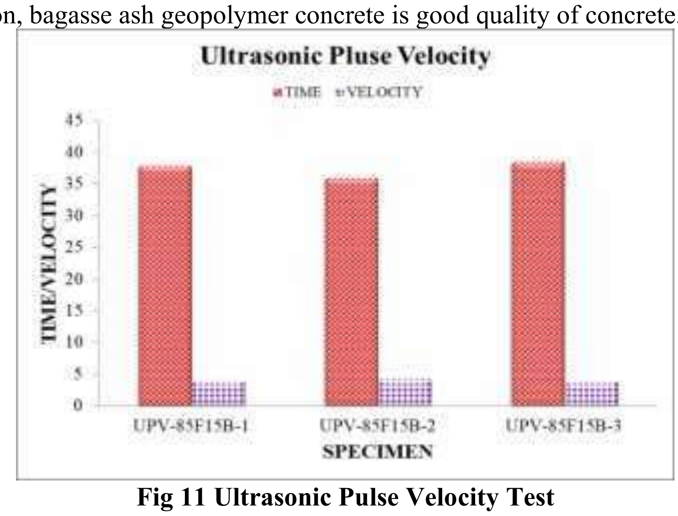

Fig 11 Ultrasonic Pulse Velocity Test

4. CONCLUSION

In this experimental work, investigation of the optimum replacement of bagasse ash for fly ash based geopolymer concrete with optimum curing hours and temperature had been determined. On this optimum percentage replacement of bagasse ash, temperature and curing hours, different environmental conditions are determined for the bagasse ash geopolymer concrete. From all the above experimental work, following can be concluded:

1. The experimental work results shows optimum percentage of replacement of bagasse ash is 15% for the fly ash based geopolymer concrete for oven curing. From the comparison of results for different temperature and curing hours, we can conclude that for 15% replacement of bagasse ash shows good results for 100°C temperature when cured for 18hrs of curing hour.

2. Different environmental conditions were tested at optimum percentage bagasse ash replacement, temperature and curing hours to determine the results.
3. At optimum condition, Geopolymer concrete exhibits low water absorption and water penetration. This results indicate that there improved water resistance and hence enhance long term durability.
4. For Ultrasonic Pulse velocity test, concrete shows good quality according to IS 13311 (Part 1): 1992.
5. For corrosion test, concrete indicated low corrosion activity according to ASTM G59 and ASTM G102.
6. From the RCPT test of concrete, according to ASTM C1202-22 concrete is corresponds to low chloride penetration for optimum condition of concrete.
7. The acid attack test, concrete at optimum condition showing excellent acidic resistance after 28 days of immersion in acid. Approximately about 7.99% reduction of compressive strength was observed when compared with concrete which is not exposed to the acid.
8. The pull out test was conducted for centrally embedded 12mm and 16mm reinforcing bar, comparing results for both reinforcing bar shows that there is good bond characteristics for 16mm reinforcing bar. The overall result for the pull out shows adequate anchorage and good bond strength.

From all the above findings, at optimum percentage replacement of bagasse ash, temperature and curing hours will help to produce good sugarcane bagasse ash as supplementary material for geopolymer concrete. This experimental work also confirms to produce sustainable and durable concrete which will help to reduce the CO_2 emission in the environment.

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Declarations of Conflict Interest
The author declares that there is no conflict of interest

Declarations of Funding
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