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EXPERIMENTAL STUDIES ON GEOPOLYMER CONCRETE BEAM MADE WITH GGBS & SUGARCANE BAGASSE ASH

Pruthvi Rani K M[1], Mahanthesh Gowda A T[2]

[1]Assistant Professor, Department of Civil, SJM Institute of Technology, Chitradurga, Karnataka, India.

[2]P G scholar, Department of Civil, SJM Institute of Technology, Chitradurga, Karnataka, India.

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ABSTRACT

Geopolymer concrete (GPC) is being used to reduce cement manufacturing CO2 emissions. Bagasse ash, a byproduct of sugar cane burning, can be used to create GPC. The goal is to find the best bagasse ash-GGBS ratio for silica bricks. The tasks include mixing geopolymer concrete and evaluating its properties both while it is new and after it has hardened. By substituting 10% to 100% of the aggregate with bagasse ash, concrete workability and strength were examined. The main goal was to find the best bagasse ash-GGBS ratio for silica bricks with less GGBS. Aura mix super plasticizer was added to reduce the workability issues often seen during the manufacturing of GPC, and GGBS was used as a binder material. After 28 days of sun curing, bagasse ash concrete showed 30% higher ultimate, flexural, and split tensile strengths than plain and normal concrete. Further research is needed to understand GPC at high temperatures.

Keywords: Double point load, Sugarcane bash, beam design, Alkaline Activator Solution, Geopolymer concrete (GPC)

1. INTRODUCTION

Sugar cane bagasse ash (SCBA) is produced by burning sugarcane bagasse in sugar factories and is used in industries like power plants and manufacturing. The ash's properties depend on the burning temperature and its pozzolanicity, which limits its use in construction. Cement, the second most used construction material, emits greenhouse gases and uses a rapidly running limestone resource.

People worldwide use geopolymer concrete (GPC) instead of cement. Even though GPC uses and commercialises this technology to minimise cement production CO 2 emissions, its many details and methods remain unclear. Bagasse ash from sugar cane burning can produce geopolymer concrete. Sugar cane ash and various sodium-based alkali activators will be utilised in geopolymer concrete to reduce CO2 emissions from cement manufacture.

The activities involve mixing geopolymer concrete and testing it before and after hardening. Using 10% to 100% bagasse ash as aggregate tested concrete workability and strength. The objective was to identify the optimal bagasse ash-GGBS ratio for low-GGBS silica bricks. GGBS was employed as a binder and aura mix super plasticiser was used to improve GPC workability.

Bagasse ash concrete showed 30% better ultimate, flexural, and split tensile strengths than ordinary concrete after 28 days of sun curing. These properties declined as bagasse ash exceeded 30% of fly ash density. Cooking samples at higher temperatures determined mass loss and residual strength to better understand geopolymer concrete at high temperatures.

Geopolymer concrete performs well under ambient curing conditions, according to several research. Bagasse ash at 10% replacement gave geopolymer concrete made with metakaolin the best mechanical and durability results, according to Singh [1]. Saloni et al. [2] created geopolymer using rice husk ash and slag and varied ratios of corn cob ash with 8M NaOH solution. They found that up to 6% of corncob ash may be used as an alternative binder for sustainable geopolymer concrete Bellum et al. [3] found that adding up to 40% GGBS to flyash-based geopolymer concrete increases compressive strength by 37% compared to control mix and creates stable, high-mechanical-property concrete. Oyebisi et al. [4] investigated how GGBS and corncob ash affected geopolymer concrete curing under ambient conditions with different NaOH concentrations. In experiments, 40% corncob ash replaced with 14M NaOH solution had the maximum compressive, split tensile, and flexural strength. In ambient cured alkali activated concrete containing 10% rice husk ash and blast furnace slag, Alomayri et al. [5] found increased compressive and split tensile strength. Saloni et al. [6] found that replacing OPC with 15% rice husk ash increased compressive strength by 22.44%.

Fly ash, a byproduct of coal combustion, can be used in concrete production to increase quality and minimize waste. Steel industry byproduct Ground Granulated Blast Furnace Slag (GGBS) could replace cement, increasing its strength and longevity. Joseph Davidovits proposed geopolymer concrete, which uses fly ash, GGBS, metakaolin, and other silica and alumina-rich materials to replace cement. Geopolymer concrete is environmentally friendly and requires alkaline sodium hydroxide and sodium silicate solutions.

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2. LITERATURE REVIEW

Coster and Bernal recommend the incorporation of GGBS and SCBA in the preparation of geopolymer concrete (GPC) to reduce the amount of cement used. The synergistic effects of GGBS, which has a high content of calcium, and SCBA that contains reactive silica have prompted the studies to point out greater compressive and flexural strengths. SEM and XRD of samples show that when GPC is activated with NaOH and sodium silicate solutions it forms dense matrices [1].

It was noted that the incorporation of SCBA in GPC has had mixed impacts on workability. A SCBA content in excess of 15% resulted in lower slump values due to increased water absorption. However, these issues can be managed by varying the activator ratio [2]

The incorporation of SCBA and GGBS in GPC has been found to have a lower carbon footprint index than ordinary Portland cement (OPC). Research shows that the use of these industrial by-products correlates with sustainability objectives, mainly in areas with a surplus of SCBA [3].

Based on the experimental trials which were conducted it was ascertained that the most optimum replacement of fly ash by SCBA was between 10-15%. GGBS also displayed the ability to improve the early strength gain of GPC especially when cured at ambient conditions [4].

SCBA and GGBS concrete beams perform better in terms of load carrying capacity and deflection of the beam when tested for flexural stress. This is due to reinforcement in tension and compression areas as well as proper curing conditions which results to high structural strength[6].

Durability tests revealed that the combined use of GPC with SCBA showed a very high degree of resistance to chemical attack especially on sulfate and chloride. This is because of the highly compacted structure and the low $Ca(OH)_2$ content in the matrix that is evident in GGBS and SCBA blends [7].

It is evident that GPC strength is highly dependent on the molarity of NaOH. Research carried out revealed that 14M NaOH yielded the best performance in terms of compressive and flexural strengths and enhanced geopolymerization.

The findings indicated that ambient curing conditions were suitable for SCBA and GGBS-based GPC and hence practical for in-situ construction. Heat curing, as much as it improved the early strength, was not essential for the attainment of high durability [7].

There was a significant conclusion that GPC beams outperformed OPC beams in flexural strength and cracking resistance.

It also has lesser shrinkage compared to OPC, thus making GPC suitable for structural purposes [10].

Economic analysis shows that using SCBA instead of OPC and GGBS for concrete blend can minimize material expenses without compromising structure strength. The use of agricultural and industrial waste in production is good for waste management as well as cutting on costs [11] [6]

3. MATERIALS AND METHODOLOGY

Specimens are prepared by concentrate by using the following material are stated below,

3.1 Materials employed

Materials employed to prepare the concrete are discussed in this sub-section.

3.1.1 Calcium

GGBS and SCBA are commonly used in strengthening RCC concrete beams, with GGBS from iron and steel industries and SCBA from the sugar industry providing strength and longevity.

3.1.2 Coarse aggregate (CA)

This study investigated the production of hollow concrete blocks from sugarcane bagasse ash and silica fume using stone chips, testing them according to ASTM C136-06 standard.

Table 1: Physical properties of Coarse aggregate

Type of Coarse Aggregate	Maximum Size mm	Moisture content %	Unit Weight kg / m^3	Voids %	Specific Gravity
Stone Chips	12.5	2.4	1138	48.8	2.84

3.1.3 Fine aggregate

Concrete beams' mechanical qualities are defined by the fine aggregate, which are known as coarse aggregates. Almost every concrete property, including strength, density, and longevity, is improved by using well-graded fine particles.

Table 2: Fine aggregate properties

Type of fine aggregate	Specific gravity	Fineness modules	Bulk density	Grading zone as per IS 383
River sand	2.65	2.64	1800	I
Quarry dust	1.95 – 2.65	1.55	1850	II

3. 1.4 Sugarcane ash (SBA)

Sustainable building practices like using SBA in concrete reduce waste and economic sustainability. SBA reduces carbon footprint, lowers cement demand, and lowers CO_2 emissions. It's cost-effective due to lower material inputs and availability at cheaper rates than regular cement.

Sugarcane bagasse ash, a promising building material, is widely used in concrete production due to its high silicon dioxide content and similar properties to pozzolan, enhancing structural mechanical characteristics and longevity.

(a) (b)

Figure 1: a) Raw sugar cane b) bash ash after processing

a)

OXIDES	SCBA MASS %
Silica (Sio2)	68
Alumina (Al2O3)	3.05
Ferric Oxide (Fe2O3)	3.72
Calcium Oxide (CaO)	5.1
Magnesium Oxide (MgO)	1.15
Sulphur Tri Oxide (SO3)	0.67
Loss of Ignition	4.5

b)

Table 3: a) chemical properties b) physical properties of SBA

Particulars	Results
Specific gravity	1.97
Fineness	2.516%
Colour	Black colour
Particle shape	Powder form

3.1.5 Sodium Hydroxide Solution

Geopolymer concrete is a type of concrete that uses sodium hydroxide and sodium silicate dissolved in water to enhance its compressive strength, durability, and chemical resistance. The ratio of these ingredients varies depending on individual requirements. The standard ratio for adding sodium hydroxide solution is 1:2, while sodium silicate solution is 2:1. The overall ratio in concrete mix is typically between 0.4:1 and 0.5:1, with a low water-to-binder ratio between 0.2 and 0.3.

4. METHODOLOGY

Concrete mix design involves the proportion of cement, sand, and aggregates used to create the mixture. The standard mix percentage for M20 grade concrete is 1:1.5:3, with exceptional ratios like 1.73, 0.87, 1.47, and 0.73. The optimal proportions are 5:3, 6 for strength and workability. The first digit represents cement amount, while the second digit represents fine aggregate or sand. The third digit indicates coarse aggregate quantity, which enhances concrete's resistance to compressive stresses. A 1:1 ratio may work with other materials, but not M20 concrete. The water-cement ratio is crucial for determining the concrete mix. The process of preparing concrete involves several phases, including material preparation, which includes checking the freshness of cement and fine aggregate (sand) and adjusting proportions to achieve the desired strength.

Table 4: Analysis on fine aggregator.

IS sieve size (mm)	Weight retained (g)	% retained	Cumulative % retained	Cumulative % passing	Limit as per IS 383 – 1970	Remarks
10	0	0	0	100	100	Aggregates conform to Zone II of IS: 383 – 1970
4.75	14	1.4	1.4	98.6	90-100	
2.36	181	18.1	19.5	80.5	75-100	
1.18	184	18.4	37.9	62.1	55-90	
0.6	251	25.1	63	37	35-59	
0.3	193	19.3	82.3	17.7	8-30	
0.15	148	14.8	97.1	2.9	0-10	
0.075	20	2	99.1	0.9	0-3	
Pan	9	0.9	100	0	-	

Table 5: Calculation of mix design

. Total Mass of Concrete
• **Unit Weight of Concrete**: 2400 kg/m³
2. Aggregates
• **Mass of Combined Aggregates**: 77% of total mass of concrete
○ 0.77×2400 kg/m3=1848 kg/m³
Breakdown of Aggregates:
• **Coarse Aggregates (70%)**:
○ 0.60×1848 kg/m3=1109 kg/m³
○ 20 mm: 0.60×1109 kg/m3=665 kg/m³
○ 10 mm: 0.40×1109 kg/m3=444 kg/m³
• **Fine Aggregate (30%)**:
○ 0.30×1848 kg/m3=554 kg/m³
After adjusting for water absorption:
• 20 mm aggregates: 774 kg/m³
• 10 mm aggregates: 516 kg/m³
• Fine aggregate: 549 kg/m³
3. Geopolymer Binder and Alkaline Liquid
• **Total Mass of Geopolymer Binder and Alkaline Liquid**:
○ 2400 kg/m3−1848 kg/m3=552 kg/m³
• **Alkaline Liquid-to-Binder Ratio**: 0.35
○ Mass of Geopolymer Binders (fly ash + GGBS):
▪ 5521+0.35=409 kg/m³
○ Mass of Alkaline Liquid:
▪ 552−409=143 kg/m³
5. Water Content Calculation
• **Water in Sodium Silicate Solution**:
○ 0.559×102=57 kg/m³
• **Solids in Sodium Silicate Solution**:
○ 102−57=45 kg/m3
• **Total Water Content**:

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○ 57 kg+25 kg=82 kg
• **Total Geopolymer Solids**:
409 kg (fly ash + GGBS)+45 kg (solids from Na_2SiO_3)+16 kg (solids from NaOH)=470 kg
7. Water-to-Geopolymer Solids Ratio
• 82/470=0.17
8. Additional Water for Workability
• **Extra Water Added**: 5.5 liters
Summary of GPC Mix Design:
• **Total Mass of Concrete**: 2400 kg/m³
• **Aggregates**: 1848 kg/m³
○ Coarse Aggregates (20 mm): 774 kg/m³
○ Coarse Aggregates (10 mm): 516 kg/m³
○ Fine Aggregate: 549 kg/m³
• **Geopolymer Binder (Fly Ash + GGBS)**: 409 kg/m³
• **Alkaline Liquid**: 143 kg/m³
○ Sodium Silicate Solution: 102 kg/m³
○ Sodium Hydroxide Solution: 41 kg/m³
• **Water-to-Geopolymer Solids Ratio**: 0.17
• **Additional Water for Workability**: 5.5 liters

4.1 Design of beam

- Size of the beam is 150x200x1000 mm
- 2 bars of 12mm with the dia at top
- 2 bars of 12mm with the dia at bottom
- It has been made on the 200mm c/c
- Area of steel = (πd^2)/4 where d is 12 and area of steel is 113
- We are having 2 bars hence 113x2 = 226

  Percentage of steel = ptxbxd/100=100*226/150x161 =0.93%

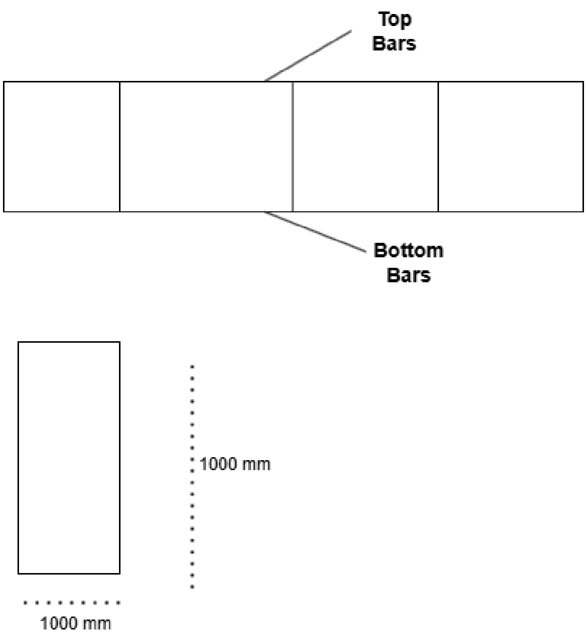

Figure 2: Design of beams

Finally the mixing propositions for final product are as follows,

Table 6: Final mix design

GGBS = 6Kg
FA = 22Kg
CA= 36 kg
Water = 5.5 litres
Sugarcane = 4Kg
Water and cement ratio is 0.55

Table 7: Specimen on tension reinforcement

Grade of cement	Percentage of tension reinforcement= (Area of steel$_s$/width*depth)*100
M20	(226/150*180)*100 = 0.838 %
Description	Dimensions in mm
Effective depth (d)	Beam width = 150 Beam depth (D) = 200 m i.e. height
Area of steel reinforcement	113
Number of bars = Area of steel / area of one bar	235/131.1 = 2.08 (round to 2 bars)
Shear force capacity	47.03 kN
Spacing of stirrups	50 mm

5. RESULTS AND DISCUSSION

The study analyzes the experimental results of a geopolymer concrete mix, focusing on its workability, strength, and durability. The mix design aims to find the optimal combination of aggregates, binder, and alkaline solutions. The study considers factors like aggregate suitability, water-to-geopolymer solids ratio, and polymerization efficacy. The experimental findings will be compared to theoretical values to determine if the concrete meets geopolymer concrete standards. The mix's preparation process involves manufacturing sugarcane bagasse ash and ground granulated blast-furnace slag, ensuring a uniform mixture for concrete construction.

Figure 3: Materials mixing

Prepared material mixture is pored on the beam design showed in Fig.5

Figure 4: Designed beam

After concrete pored on the beam design end specimen is as shown in the below figure,

Figure 5: Prepared specimen

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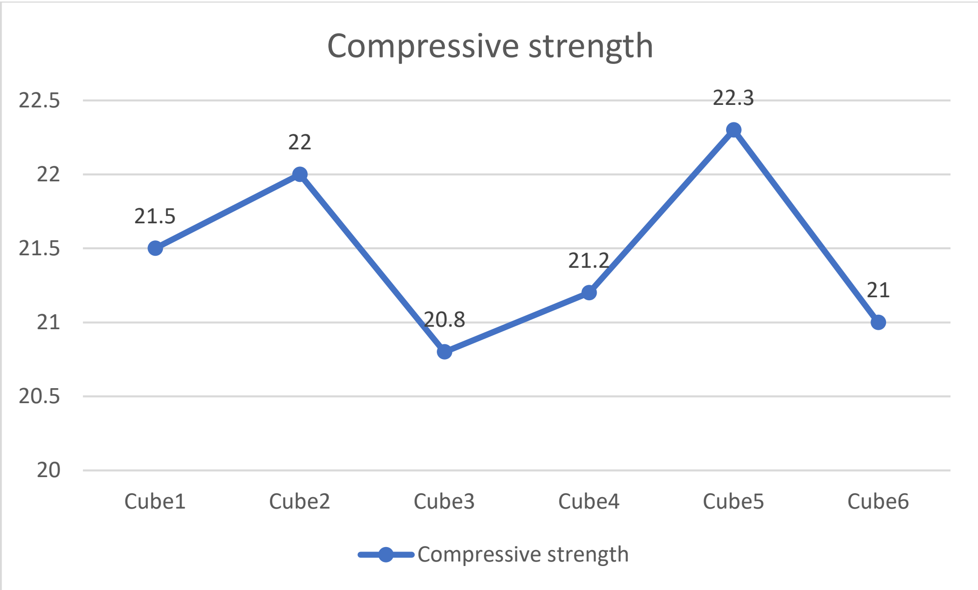
Curing is performed for 28 days on the prepared specimen for durability and setting of concrete. Is as shown in Fig.7.

Figure 6: Curing to prepared specimen

Compressive strength of the specimen is as shown in graph



Dimensions of the prepared specimen is as shown in Fig.8.

Table 8: Specimen dimensions

Details of specimen	Dimensions (in mm)
length	1000
Width	150
Height	200
Type	BEAM
Type of test conducting	Double point load

5.1 Testing load using double point load

Double point load testing is a method used to examine the behavior of concrete beams and girders under real-world loading conditions. This involves applying two focused loads at regular intervals throughout the beam's length, often in a symmetrical fashion around its centerline. The load is applied by a hydraulic or mechanical actuator, with the force distributed equally between the two locations. Instruments like strain gauges, displacement transducers, and load cells are used to measure the beam's reaction to stress. Double point load testing is crucial for understanding concrete beam behavior in real-world constructions, providing crucial information about safety and structural integrity, and enabling comparison of concrete mixes, reinforcement tactics, and building approaches.

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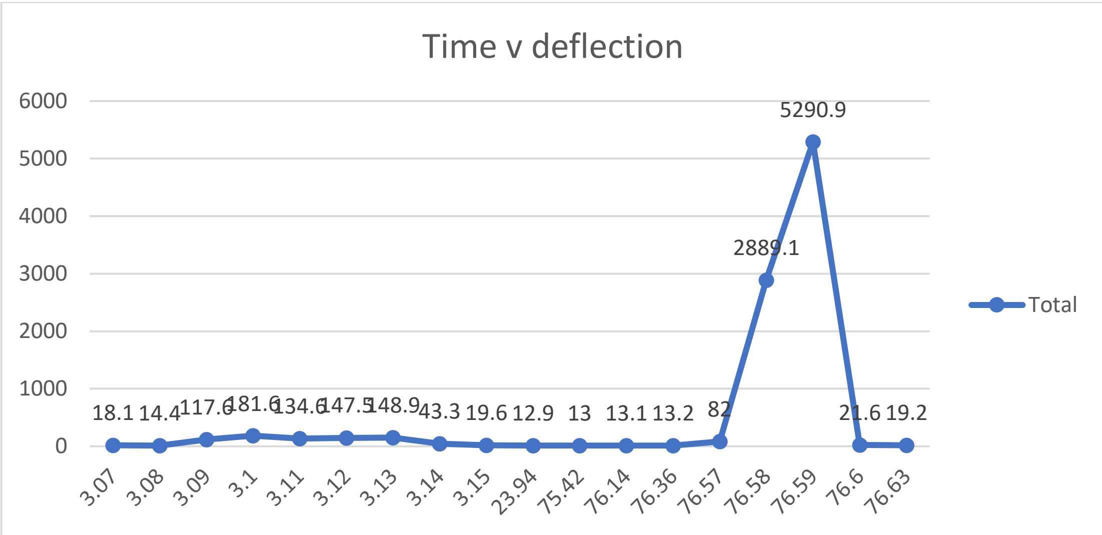
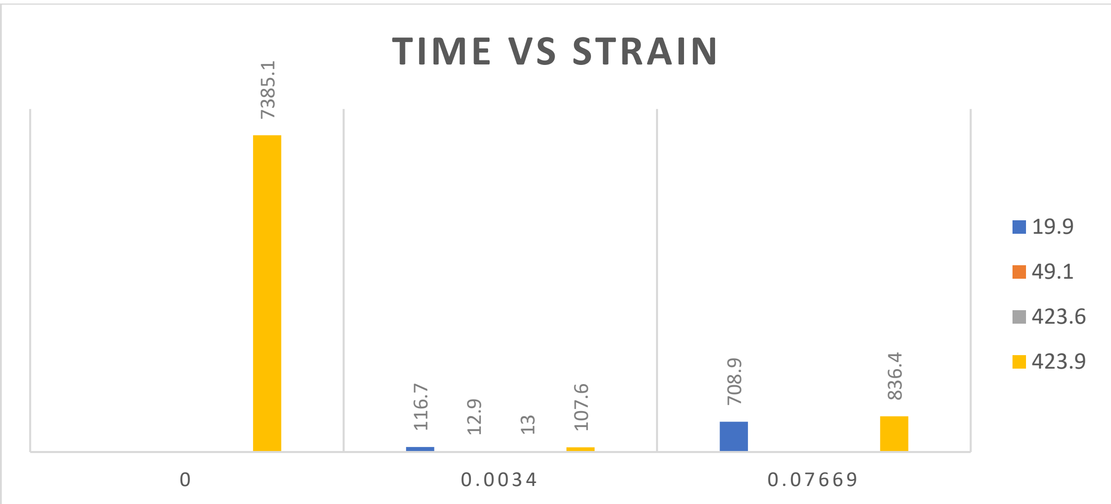
Figure 7: Testing of load framing using double point load.

The facility evaluated a specimen manufactured in Chitradurga and examined at Ballari RYMEC College. A graph was created to display the characteristics of a concrete beam subjected to stress test.

5.2 Time vs deflection

- X-Axis (Time in Seconds): The variable shown on the bottom of the figure is the time in seconds into the loading test.
- Y-Axis (Deflection in mm): A deflection of the beam or section of the structure in millimeters is along the vertical axis.



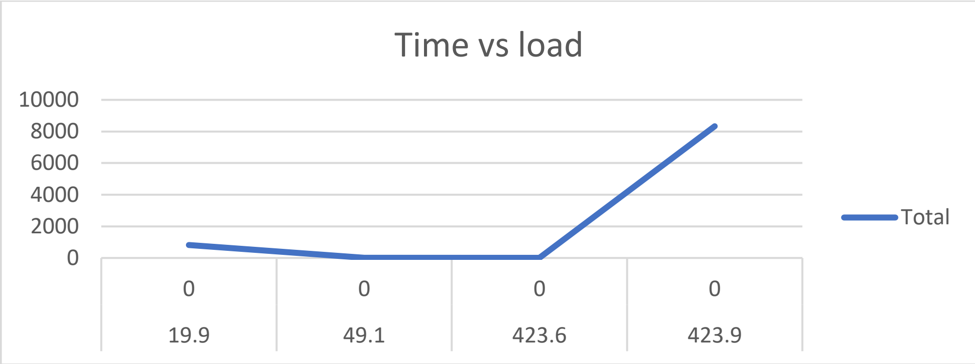


5.3 Time vs strain

The beam experiences progressive deflection due to applied force, proportional to the load. As weight increases, deflection becomes more pronounced, potentially leading to beam breakage.

5.4 Time vs load

The graph shows a X-Axis representing time in seconds and a Y-Axis representing load in KN. The load increases as time progresses, starting with a light load and ramping up until the maximum load is placed in the center.



5.5 Data acquisition system

Data collected is imposed to the system to determine the above stated graphs such as time versus load, strain and deflection. Frond end of the data acquisition system is as shown in the Fig.9.

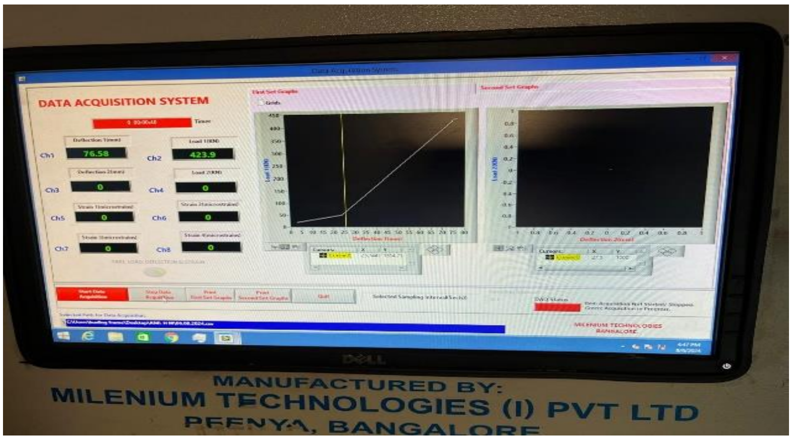


Figure 8: Data Acquisition system.

6. CONCLUSION

A 150 mm x 200 mm x 1000 mm beam was tested using 375 liters of concrete mixed with M20 grade concrete in a 1:1 proportion. The mix included sugarcane bagasse ash, fine aggregate, coarse aggregate, water-reducing admixture, and water. The goal was to find the optimal blend for sustainable building. The mix's suitability for structural applications will be confirmed through strength tests under stress.

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