Residue of Incinerated Sugarcane Bagasse as a Partial Substitute of Cement in Concrete

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ABSTRACT

Residue of incinerated sugarcane bagasse is an agro-based industrial waste material which is rich in silica. It has been studied that it is contributary in enhancing the mechanical property, thermal characteristics and durability aspects of concrete. This study attempted to see the range of application of this material in a concrete beginning from the early age of the concrete without altering or modifying the physico-chemical property of ash. A systematic volume-based replacement of cement by the residue of incinerated sugarcane bagasse was made with an amount of 10%, 20% and 30%. Mechanical and thermal assessments were made beginning from the early age of the concrete so as to see the influence of this material on early age distresses such as cracking due to heat that is generated from hydration reaction. The mechanical properties in compression and flexure based tensile strength were investigated from early age up to 56days. The heat of hydration characteristics at early age was also monitored using embedded thermocouples. Water penetration depth for each set of experiment was checked as an indicator for durability. The durability and thermal assessments had shown a better performance as the amount of residue of incinerated sugarcane bagasse in the mix increases. In the experiment made to study the effect of this material in the mechanical properties of a concrete, a relatively better enhancement was observed upto a replacement of 20%.

Keywords: Residue of Incinerated Sugarcane Bagasse, Concrete, Early Age Mechanical Property, Early Age Thermal Property, Durability

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1 INTRODUCTION

Portland cement is one of the major construction material that is extensively used in the world. The cement industry is responsible for the production of 5% of global anthropogenic CO_2 released into the atmosphere and there is an emission of around one ton of CO_2 per ton of clinker production (Ganesan K. et al., 2007). Researchers were and are in an endeavor of investigating alternative cementitious materials that can potentially substitute cement partially or fully and can also contribute to the reduction of negative environmental impacts that comes along with the manufacturing process of cement. Industrial or agricultural wastes with pozzolanic property are among the candidate materials that can technically be suitable for this purpose.

Residue of incinerated sugarcane bagasse (RISB) is an industrial waste material that is obtained from the sugar industry. The extraction of cane from sugarcane leaves a straw like material – bagasse - and this bagasse in return will be used as a fuel by most sugar factories for boilers and through this process the burning of the bagasse leaves a residue in the form of an ash. RISB has been extensively studied as a pozzolanic material and its effect in the enhancement of mechanical, thermo-hygro and durability property of concrete has been widely discussed. The effectiveness of RISB as a pozzolanic material is strongly related to its silica content. Amorphous or partially crystalline silica, and eventually amorphous alumina, are essential for the development of pozzolanic reactions with portlandite (Greenberg, 1958).

The presence of bagasse ash in a cement paste, mortar and concrete had improved certain properties such as compressive strength and water tightness with a certain percentage of replacement (Malyadri, 2015) (Muhammad NasirAmin, 2022). The development of a relatively better early age strength, degree of impermeability, and appreciable resistance to chloride permeation and diffusion are the specific advantages that can be gained in replacing cement with this material in a concrete (Amin, 2011) (Tolmatti Vamshi Krishna, 2018). A cement blended with RISB had showed a better resistance in an aggressive environment (Islane Santos, 2017).

Based up on the findings of researches made on RISB, this study tries to address the early age response of concrete with RISB. Most research findings focus on the matured property of concrete and assess the incorporation of various supplementary cementitious materials (SCMs) at the matured age of concrete – mostly from the age of 7days and beyond (Tiago Assunção Santos, 2018), (Sivakumar Ramanathan, 2019), (Siddique, 2014), (J.C. Arenas-Piedrahita, 2016). However, there are situations where early age property of concrete is very critical like that of the matured property. In areas where the average surrounding temperature is high or during hot weather concreting, the heat that will be generated from the concrete due to hydration reaction and the rate at which this heat be produced has a significant impact in the short- and long-term performance of the concrete. As the magnitude and rate of heat produced is high, the likelihood for the occurrence of early age thermal cracking is very high.

Some research findings made in industrial ashes showed that the pozzolanic nature of these materials has an effect in reducing the rate of heat production and the magnitude of heat that will be produced at the early age of the concrete. Cement hydration is an exothermic reaction (Koichi, Tetsuya, & Toshiharu, 2009). Consequently, the surrounding temperature has no effect in the magnitude of heat produced rather affects the rate of heat production. Therefore, in circumstances where the surrounding temperature is high, the rate of heat production will be high. Moreover, the higher the magnitude of heat produced due to the intrinsic nature of the binder, the higher will be the risk of early age thermal cracking (Koichi, Tetsuya, & Toshiharu, 2009). This study tried to address the early age response of the

concrete with RISB. In addition, as most studies exhaustively tried to study the effect of such materials at the matured age of the concrete, there also need to study their effect during the early age as well. By that, we build a comprehensive knowledge on the effect of the introduction of this material under various circumstances and scenarios respective of mechanical, thermal and durability parameters.

2. MATERIALS AND METHODS

The RISB used in this research was collected from Wonji Shoa sugar factory. It was collected when it was discharged from an ash discharging funnel of the furnace. It was transported into the laboratory and sieved with 300μm sieve. Its density was checked and a result of 2.131g/cc was obtained. And the chemical composition of the ash was showing constituent compounds as shown in table 1.

Table 1. Chemical composition of RISB and OPC

Investigated Constituents	ISB (%)	OPC (%)
Silicon Dioxide (SiO_2)	66.92	20.82
Aluminum Oxide (Al_2O_3)	7.06	5.41
Ferrite (Fe_2O_3)	6.12	3.37
Calcium Oxide (CaO)	3.6	66.32
Magnesium Oxide (MgO)	1.96	1.46
Sodium Oxide (Na_2O)	4.28	-
Potassium Oxide (K_2O)	4.92	-
Manganese Oxide (MnO)	0.2	-
Loss In Ignition (LOI)	3.65	-
Sulfate (SO_3)	0.25	2.16
Phosporous pentaoxide	0.19	-
Titanium oxide	0.16	-
Water	0.01	

Relative to other similar SCMs that are widely used for this purpose, RISB is found to be the richest in its silica content. The ternary diagram below is depicted to show this scenario.

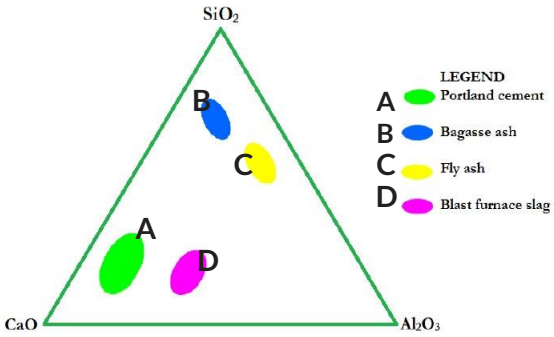


Figure 1 Ternary diagram of RISB relative to other supplementary cementitious materials.

As can be inferred from the above composition in table 1, more than half of the constituent compound is SiO_2. The desired form of silica for an effective pozzolanic reaction is the amorphous type of silica (Chidanand Patila, 2018). In order to see the crystallinity of the silica in the ash, we used X-ray diffraction (XRD).

Cristobalite and quartz phases are identified in the above XRD diagram. Moreover, the large bump shown in the left section of the graph shows the amorphous nature of sample RISB. The RISB examined in the XRD is a sample of RISB prepared by sieving it with 300μm sieve. This same RISB prepared in the above-mentioned manner is scanned using JSM-IT300LV scanning electron microscope (SEM). The images below show RISB samples examined under different magnification.

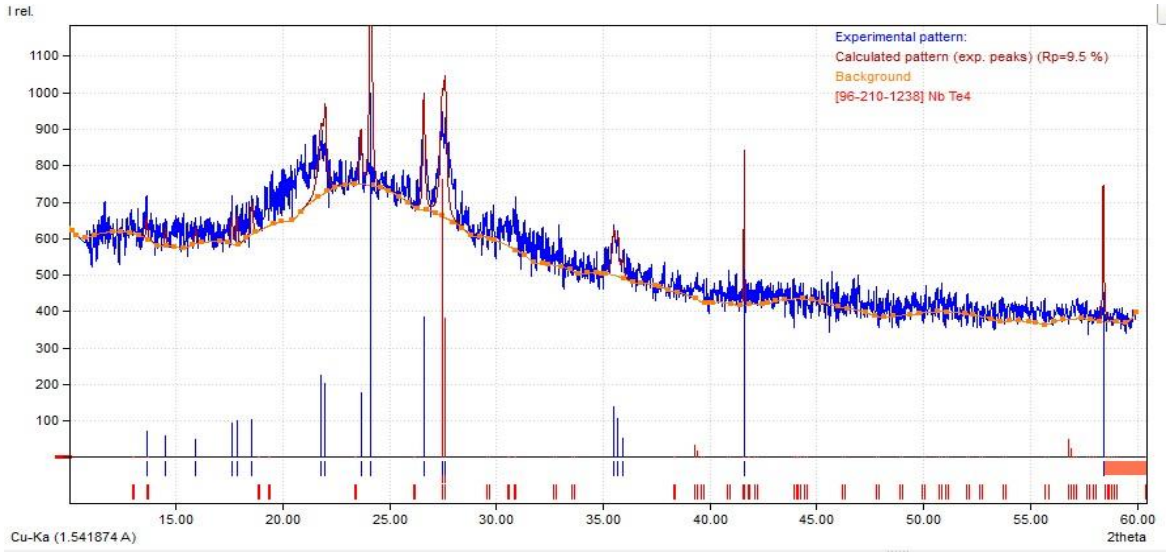


Figure 2 Cristobalite and amorphous structures in RISB at angle 10^0 to 60^0 of RISB

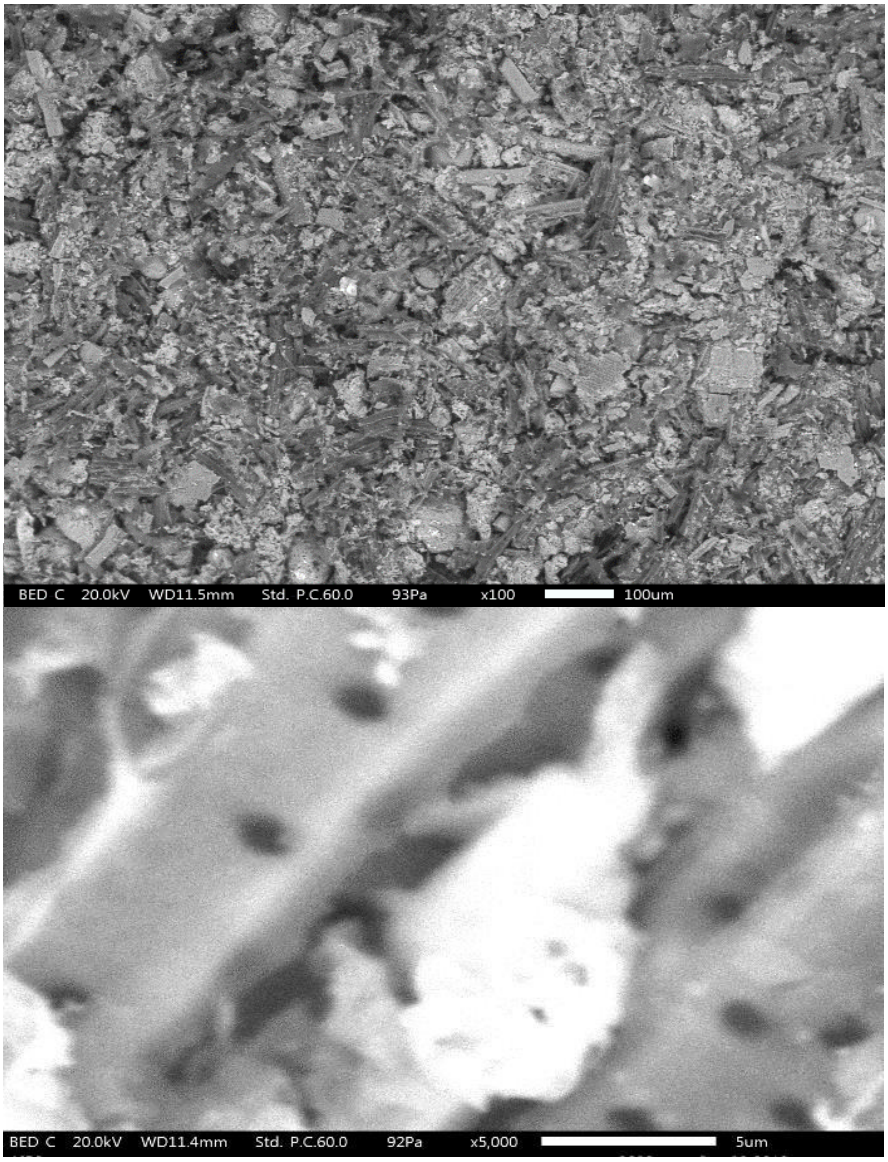


Figure 3 SEM images of RISB with various magnifications

The above images show the porous nature of RISB when it is examined under higher magnification. In addition, rounded and slender shaped structures are identified in the image. The porous nature of RISB has an advantage in allowing effective hydration as the water will have the chance to percolate through each particle. Moreover, the specific surface area of RISB particles will be high which in turn facilitates effective hydration.

The physical property of fine and coarse aggregate used for this study was checked using ASTM C128 and ASTM C127 respectively. The values in the table below show the unit weight and specific gravity of coarse and fine aggregate. In addition, fineness modulus and nominal aggregate size were determined for fine and coarse aggregate respectively.

Table 2. Physical property of fine and coarse aggreagte

Coarse aggregate	
Description	Result
Specific gravity (SSD)	2.785
Unit weight (gm/cm^3)	1.475
Nominal aggregate size (mm)	19
Fine aggregate	
Fineness modulus	2.76
Specific gravity (SSD)	2.483
Unit weight (gm/cm^3)	1.86

2.1 Experimental program

The mix design for each type of experiment was prepared based on a binary mix design. A sand to aggregate ratio of 0.392 was defined after passing a certain trials of checking an assumed sand to aggregate ratios. Later, a water to cement ratio of 0.47 was chosen based on literature and authors' interest of investigation. Accordingly, proportioning was made and values are defined as shown in table 3.

And replacement of the RISB was made by volume. Replacement by weight was another possibility to investigate the effect of partial replacement of RISB on the mechanical and hydration properties. Replacement by weight ensures a constant water to cement weight ratio. However, in the current study, the authors chose the volume-based replacement ratio to ensure a constant volume of cementitious material per unit volume of binary mix. Therefore, being calculated, replacing of 1% volume of cement by equal volume of RISB was found to be equivalent to replacing 0.6787% weight of cement with RISB. A water to binder ratio of 0.4 and superplasticizer of 0.5% of the binder by weight was used throughout the entire experiment. Accordingly, the mix proportioning was summarized and tabulated in the table below.

Table 3 Mix Proportioning

Percentage of replacement	**Water (Kg/m^3)**	**Cement (Kg/m^3)**	**RISB (Kg/m^3)**	**Coarse Aggregate (Kg/m^3)**	**Fine Aggregate (Kg/m^3)**	**Admixture – super plasticizer (Kg/m^3)**
0%	190	404	0	1069	690	2.02
10%	190	364	28	1069	690	1.95
20%	190	324	54	1069	690	1.89
30%	190	287	78	1069	690	1.83

Note: Air is considered as one of the constituents with a value of 2%.

With this mix proportioning, mechanical property in terms of compressive and flexure based tensile strength was investigated. The compressive and tensile strength of concrete with various dosages of RISB was studied beginning from the concrete's early age.

In addition, the thermal response of concrete with RISB was studied. A concrete sample without and with various percentages of RISB was checked using differential calorimeter. This was made to assess the hydration kinetics of the concrete specimen with and without RISB. A cement paste with 10%, 20% and 30% of RISB was used to make this experiment.

Furthermore, water penetration depth of concrete specimen subjected to pressurized water for 72 hours was checked as an indicator for permeability.

3. RESULTS AND DISCUSSION

3.1. Compressive and flexural strength

The compressive strength of the concrete made with various dosages of RISB has shown a result as depicted in the graph below. The compressive strength of concrete with 5% RISB has exhibited 25% increment at the age of 1day and 5% increment at the age of 28day relative to the strength of the control mix. And the mix with 10% replacements has shown similar values (with an increment that ranges from 1-3%) like that of the strength of the control mix. Similar finding was referred from a study made in an attempt to partially substitute cement by sugarcane bagasse ash (Biruk H, 2012) This strength enhancement was seen at all ages of the concrete which is in concern of investigation. Unlike the common phenomena – introduction of pozzolan delays strength development – the results obtained from these set of experiments were showing a different scenario by exhibiting a strength enhancement beginning from the early age of the concrete.

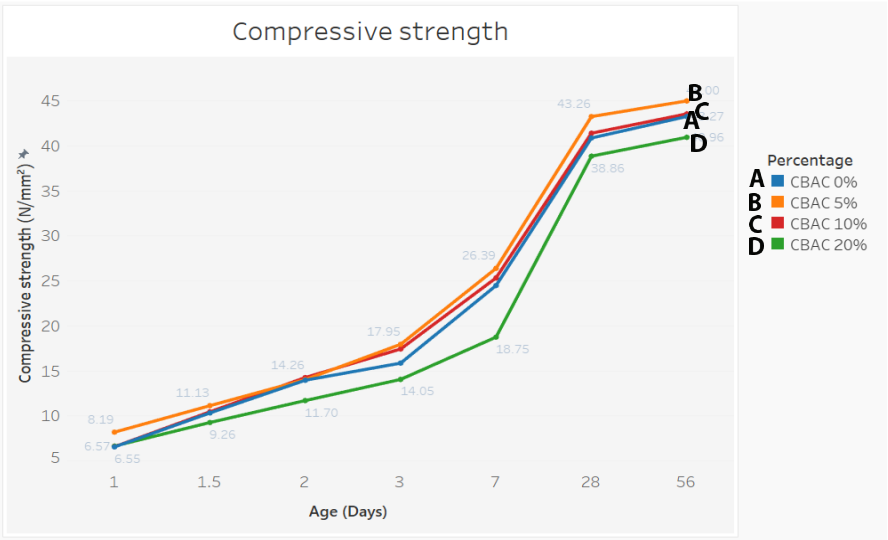


Figure 4 Compressive strength of concrete with various dosages of RISB

Similarly, the flexural strength of concrete specimen molded with a cross-sectional area of 10cm*10cm and a length of 50cm has shown a similar trend of strength development like that of the compressive strength. The flexural strength of concrete with 10% RISB has exhibited 30% increment at the age of 1day and 9% increment at the age of 28day relative to the strength of the control mix. Flexural strength development is depending not only on hydration reaction but also on the strength of the interfacial transitional zone (ITZ) - the micro space/distance between the aggregate and cement paste in a hardened concrete matrix which is dense in Portlandite ($Ca(OH)_2$) accumulation (Koichi, Tetsuya, & Toshiharu, 2009). The presence of the pozzolans consume the $Ca(OH)_2$ in order to undergo for secondary

hydration reaction and produce calcium silicate hydrate (C-S-H) – the main hydrated product during cement hydration (Kurdowski, 2014). The authors of this paper believed that the higher strength development seen in these experiments are due to the above factor which may potentially be attributed by the presence of the ash which is rich in silica and possibly undergo secondary hydration reaction.

Like that of the compressive strength, the flexural strength enhancement was seen from the early age of the concrete. The experiment was conducted using a two-point loading system.

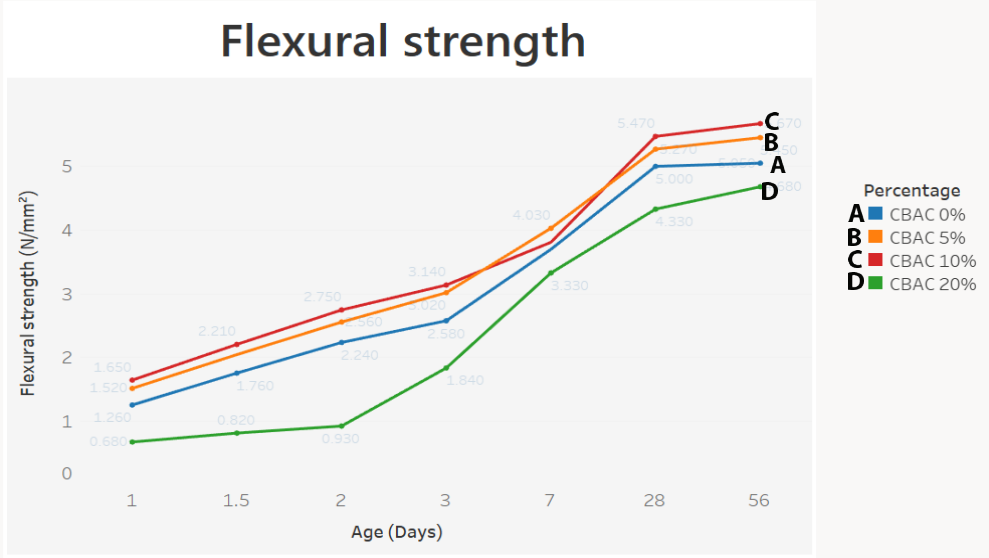


Figure 5 Flexural strength of concrete with various dosages of RISB

In both the flexural and compressive strength development, the value with 20% RISB was showing a lesser value as compared to all candidate mixes.

3.2. Thermal characteristics

The recording of heat evolution rate and cumulative heat in the adiabatic condition was made continuously for a total of 73 hours. The evolution of heat rate for the four set of cement paste samples and the accumulated heat are depicted in Figure 6. The data indicates a decreasing trend in heat evolution rate as the amount of RISB increases in the cement paste. A 20% decrease in heat evolution was observed by the cement paste sample with 30% of RISB relative to the paste without RISB. These results clearly indicate that the early-age heat generation of cement paste with partial RISB replacement is lower - shows a promising potential for reduced risk of early-age thermal cracking in concrete. Similar findings were referred from studies conducted in this area (Miheret G., 2022).

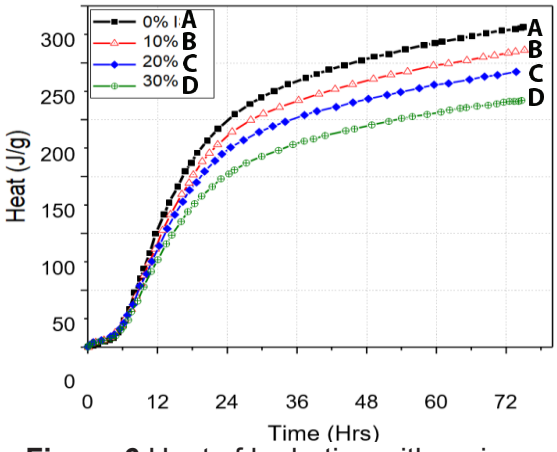


Figure 6 Heat of hydration with various dosages of RISB

3.3 Durability

Water penetration depth assessment was used as indicator for durability concern. The denser the concrete matrix, the less permeable will the harden concrete be. The value obtained from this experiment is

depicted in Figure 7. The specimen with 20% of RISB was showing a maximum water penetration depth which is less than by 0.9, 0.2 and 0.1mm from the maximum water penetration depth of the control mix at the age of 28, 56 and 90days respectively. This experiment was conducted using a total of 36 cylindrical shaped concrete specimen with a diameter of 10cm and a height of 20cm. The maximum water penetration depth was read from each set of specimens and an average value was taken for each set of data. Three specimens were used for one set of data or as a representative of a certain dosage of replacement. Accordingly, the result showed a better resistance to permeability as the dosage of RISB within the mix increases. As the concrete is less permeable, the ingress of undesirable materials to its inner core will decrease. The ingress of undesirable material in the inner of the concrete affects its long-term performance by corroding the reinforcement (if any) or by accelerating ASR (alkali silica reaction). The inclusion of RISB tends to reduce and inhibit the percolation of fluid into the concrete mass.

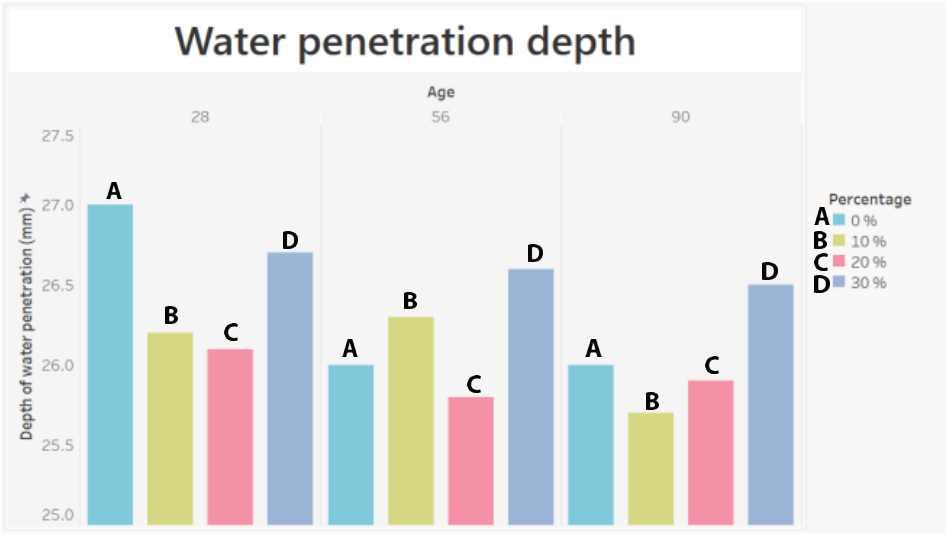


Figure 7 Maximum water penetration depth of concrete specimen with various dosages of RISB

4. CONCLUSION

Based on the experiments conducted under this study – mainly of parametrical assessment as an indicator for mechanical property, thermal characteristics and durability, the following conclusions are drawn.

- The compressive strength of concrete with 5% RISB has exhibited 25% increment at the age of 1day and 5% increment at the age of 28day relative to the strength of the control mix. And the mix with 10% replacements has shown similar values (with an increment that ranges from 1-3%) like that of the strength of the control mix.
- The flexural strength of concrete with 10% RISB has exhibited 30% increment at the age of 1day and 9% increment at the age of 28day relative to the strength of the control mix.
- This strength enhancement was observed beginning from the early age of the concrete for majority of the specimen.
- A 20% decrease in heat evolution was observed by the cement paste sample with 30% of RISB relative to the paste without RISB.
- The specimen with 20% of RISB was showing a maximum water penetration depth which is less

than by 0.9, 0.2 and 0.1mm from the maximum water penetration depth of the control mix at the age of 28, 56 and 90days respectively.

5. RECOMMENDATION

This study was made using RISB which did not pass through any sort of physico-chemical or morphological modification. It was the one that was passing through 300µm sieve after being collected from the production site. With this, if we are able to obtain such a result using RISB that did not pass through any modification or characteristics enhancement, a full-scale characterization and building of a comprehensive set of data about its property and characteristics, will going to give us a better result. And this strengthens the possibility of its applicability in the industry by contributing to the environment and technical parameters of concrete.

REFERENCES

Amin, N. (2011). Use of Bagasse Ash in Concrete and Its Impact on the Strength and Chloride Resistivity. *Journal of materials in civil engineering,* , Vol. 23, No. 5, pp. 717–720.

Biruk H, A. D. (2012). Bagasse ash as a cement replacing material. *Zede*.

Chidanand Patila, P. M. (2018). An Investigation on the Micro Structural and Elemental Composition of Sugarcane Bagasse Ash Blended Concrete using SEM and EDS Technique.

Ganesan K. et al. (2007). Evaluation of bagasse ash as a supplementary cementitious material. *Cement and Concrete Composites*, pp. 29: 515-524.

Greenberg, S. (1958). *Kinetics of hydrothermal reactions, I: reaction between silica and calcium hydroxide.* Bull. Geol. Soc. Am. .

Islane Santos, J. P. (2017). Effect of the chemical attack on the properties of cementititous composites with partial substitution of ash from sugarcane bagasse. *Revistamateria*.

J.C. Arenas-Piedrahita, P. M.-G.-R. (2016). Mechanical and durability properties of mortars prepared with untreated sugarcane bagasse ash and untreated fly ash. *Construction and Building Materials*, 69-81.

Koichi, M., Tetsuya, I., & Toshiharu, K. (2009). *Multiscale modeling of structural concrete.* Taylor and Francis.

Kurdowski, W. (2014). *Cement and Concrete Chemistry.* Springer.

Malyadri, T. a. (2015). Experimental Study on Bagasse Ash in Concrete by Partially Replacement with Cement. *International Journal of Computer Engineering in Research Trends*, 995-1001.

Miheret G., E. G. (2022). Effect of Incinerated Sugracane Bagasse in Reducing Heat of Hydration in Concrete. *International Society of Engineering Community*.

Muhammad NasirAmin, A. A. (2022). Mechanical and microstructural performance of concrete containing high-volume of bagasse ash and silica fume. *Springer nature, scientific report*.

Siddique, R. (2014). Utilization of industrial by-products in concrete. *2nd International Conference on Sustainable Civil Engineering Structures and Construction*, (pp. 335 – 347). Punjab,.

Sivakumar Ramanathan, P. S. (2019). Combining reactivity test, isothermal calorimetry, and compressive strength measurements to study conventional and alternative supplementary cementitious materials.

Tiago Assunção Santos, J. d. (2018). Influence of Physico-chemical Properties of Sugarcane Bagasse Ash in Portland Cement Hydration. ISSN: 1662-9795, Vol. 765, pp 324-328.

Tolmatti Vamshi Krishna, M. K. (2018). Partial Replacement of Cement Concrete with Biological Green Waste. *International Journal of Engineering & Technology*.