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Sugarcane Bagasse Ash as Partial Cement Replacement in Concrete: A Research Paper and Proposed Experimental Programme

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Abstract: ***Sugarcane bagasse ash (SCBA) is an agro-industrial residue with a high silica content that has been studied as a partial replacement for cement. This paper evaluates published evidence on SCBA as a cement replacement and proposes a controlled concrete testing programme. One published M30 dataset is reproduced as new graphs with its replacement basis preserved. In that dataset, 28 day compressive strength was 38.95 MPa for the control and 37.48 MPa at 10% replacement (a 3.77% reduction), falling to 25.36 MPa at 20%. Splitting tensile strength changed from 3.32 to 3.34 MPa and flexural strength from 3.82 to 3.89 MPa at 10%, differences too small to separate from specimen scatter. A 7 day compressive strength gain of 21.24% at 10% did not persist to 28 days. Other studies report best replacement levels of 5%, 10% or 15%, and one reports strength loss at 20% and 40%. These contrasting observations show that ash preparation, fineness and mix design govern the outcome, so a universal benefit cannot be assumed. The proposed programme compares as received sieved ash with calcined and ground ash at three replacement levels against plain concrete, using independent batches with mechanical and durability measurements. No original specimens were prepared for this manuscript and no original experimental results are claimed.***
Keywords Sugarcane bagasse ash; cement replacement; pozzolanic activity; compressive strength; water absorption; sustainable concrete.

I. INTRODUCTION

Concrete is the most widely used construction material, and cement is the component with the largest environmental burden. Replacing part of the cement with a reactive by-product is one route to lower cement demand without changing the form of construction. Agricultural ashes are attractive for this purpose because they are produced in large quantities near their point of use and are often rich in silica [8].

Sugarcane bagasse is the fibrous residue left after juice extraction, and bagasse burnt as boiler fuel leaves SCBA as the final waste of the sugar chain [8]. Figures quoted in [7] are 270 to 290 kg of bagasse per tonne of processed cane and 23.8 kg of ash per tonne of bagasse, which gives roughly 6 to 7 kg of ash per tonne of cane by simple multiplication. India is among the largest sugarcane producers in the world [1], so the ash is available in quantity in sugar producing regions.

Three material routes must be distinguished. SCBA may replace part of the cement, may replace part of the fine aggregate, or may be added on top of the full cement content. The study in [9] examines the fine aggregate route and the study in [6] examines the additive route. Evidence from one route cannot be transferred to another. This paper concentrates on replacement of cement by mass, with total binder content held constant in the proposed study. The engineering question is whether ash prepared from bagasse can replace a useful fraction of cement without unacceptable losses in workability, strength or durability.

II. RESEARCH QUESTION AND OBJECTIVES

The primary research question is whether SCBA can replace a measurable fraction of cement while retaining acceptable 28 and 56 day compressive strength, tensile and flexural behaviour and fresh concrete workability. A second question is whether controlled processing of the ash (calcination and grinding) gives a net benefit over using the ash as received.

The objectives are to document published strength and absorption trends; define the replacement basis unambiguously; compare as received and processed ash under a common mixture design; measure workability, mechanical performance and moisture related behaviour; and select a candidate replacement level using predefined performance criteria rather than the largest isolated strength value.

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III. PROPOSED RESEARCH CONTRIBUTION

The proposed contribution is a locally repeatable comparison using one ash source, a documented processing route, fixed mixture proportions and independent concrete batches. It is not a claim that SCBA concrete is new. Replacement levels, calcination temperatures and strength outcomes have already been reported in many studies [1 to 8]. Novelty must therefore be narrowed to a verified experimental question, namely whether processing changes the result for the same ash and the same mix design, and it must be supported by completed results.

The working hypotheses are that replacement level and ash processing influence strength and that high replacement dilutes the cement without a matching pozzolanic gain. These are hypotheses for testing. They do not predetermine a positive outcome.

IV. LITERATURE REVIEW AND SOURCE ASSESSMENT

Table 1: Literature review and source assessment of SCBA concrete studies.

Sr. No.	Source	System and useful evidence	Interpretation limit
[1]	Khatun and colleagues, E3S Web of Conferences, 2024	M30 concrete, OPC 43 grade; 0, 2.5, 5, 7.5, 10, 12.5, 15 and 20% replacement; 7 and 28 day data; water absorption	Conference paper; text and tables disagree in places (Section 6); ash burnt at 1200 °C
[2]	Addis Ababa University thesis (Wonji ash)	5 to 20% by cement mass, w/c 0.45; 5% best, about 8% (21 day) and 6% (28 day) gain	Abstract only; absolute strengths not accessed
[3]	Busitema University record (Uganda)	M25, w/c 0.5; 5 to 25% ash with 0.2 to 1.0% sugar; up to 15% possible; 8.9% gain at 15% ash with 0.2% sugar	Sugar addition is a second variable; abstract only
[4]	Kabale University record (Uganda)	5 to 20% by cement mass, 1:2:3 mix; usable up to 15%; 20% fell below C25	Nominal mix; abstract only
[5]	UCV HACER, 2018 (Peru)	210 kg/cm² concrete; 20 and 40% replacement; strength fell as ash increased; structural use not recommended	Authors and ash preparation need confirmation; abstract only
[6]	UPLB undergraduate thesis, 2015	Ash added as additive (0 to 20% of cement mass), w/b 0.5; optimum 10% at 28 and 56 days; slump decreased with ash	Additive route, not replacement; thesis source
[7]	Mansaneira and colleagues, Dyna, 2017	Ash calcined at 600 °C for 6 h then ground for 1 or 2 h; 10, 20 and 30% in mortar; activity only after calcination and grinding	Mortar, not concrete
[8]	Xu and colleagues, Materials, 2019	Review of SCBA characteristics; calcination, fineness, loss on ignition and crystalline silica govern activity	Review; used for mechanisms, not for graphed data
[9]	KSCST sponsored project report (VTU)	Ash replacing river sand 0 to 25% in M30 concrete	Fine aggregate route; abstract only

The strongest numerical evidence accessed is the dataset in [1], which is therefore reproduced in Section 5. The remaining records are used for trends and for the range of replacement levels, not for numerical pooling, because their dosage bases, water to binder ratios and ash preparations differ. Several optimum levels appear across [1 to 6]: 5% in [2], 10% in [1] and [6], and up to 15% in [3] and [4]. This spread is the central observation of the literature and is the reason a single local comparison is needed.

The review in [8] explains why such a spread is plausible. Ash properties depend on cane variety, combustion temperature and duration, boiler type, collection point and fineness, and long or hot burning produces crystalline silica that lowers pozzolanic activity. The mortar study in [7] found that only calcined and ground ash showed pozzolanic activity, and the ash in [1] was heated at 1200 °C. That temperature is well above the 600 °C used in [7], so the ash in [1] may have been less reactive than carefully calcined ash; this is an interpretation to test, not a conclusion.

V. PUBLISHED STRENGTH DATA

The dataset in [1] is reproduced here with the original replacement basis (percentage of cement mass) and curing ages preserved. The paper labels its mixes a to h; they are mapped to replacement levels here using the stated cement and ash contents in its mixture table (for example, 423 kg/m³ of cement in the control and 338.8 kg/m³ at the highest level, equal to 20% replacement). The 7 day values were read from the data labels of the source figures.

Table 2: Compressive, splitting tensile and flexural strength of M30 concrete with SCBA replacing cement (reported values from [1]).

SCBA % of cement	Source mix	7 day compressive MPa	28 day compressive MPa	28 day splitting tensile MPa	28 day flexural MPa	7 day split / flexural MPa
0	a	14.31	38.95	3.32	3.82	1.98 / 2.23
2.5	b	13.22	31.76	3.31	3.65	1.83 / 2.18
5.0	c	14.37	32.64	3.20	3.72	1.85 / 2.19
7.5	d	15.23	34.56	3.25	3.71	1.89 / 2.21
10.0	e	17.35	37.48	3.34	3.89	1.99 / 2.24
12.5	f	14.32	32.52	3.14	3.68	1.82 / 1.98
15.0	g	13.67	29.65	2.90	3.34	1.79 / 1.86
20.0	h	10.91	25.36	2.76	2.96	1.75 / 1.65

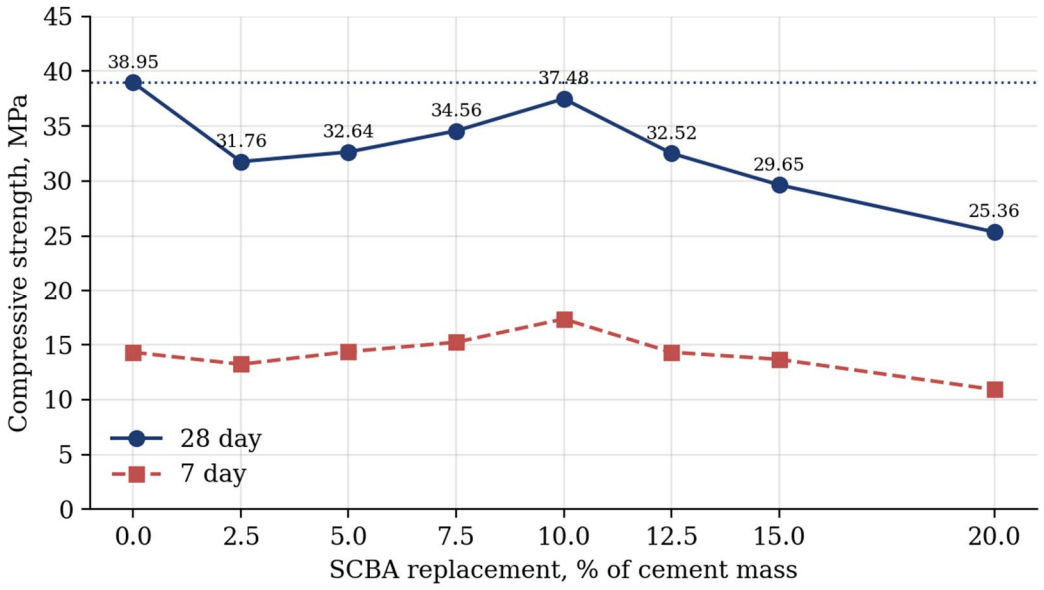


Figure 1 - Published compressive strength from [1]. Lines connect reported means only; the dotted line marks the 28 day control. Variability was not reported, so no error bars are shown.

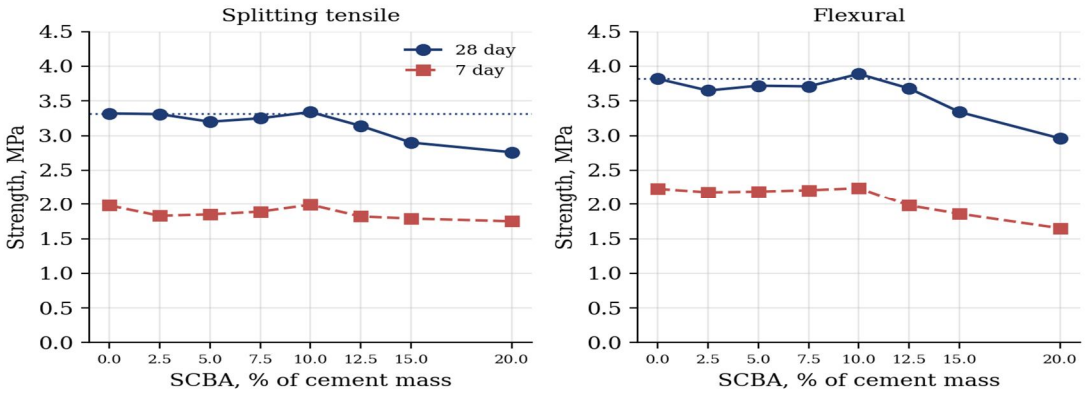


Figure 2 - Published splitting tensile strength (left) and flexural strength (right) from [1]. Dotted lines mark the 28 day control values.

VI. WATER ABSORPTION, DISCUSSION AND COMPARABILITY

Table 3: Change in 28 day strength from the control mixture and reported water absorption, calculated from [1].

SCBA % of cement	Compressive change %	Splitting tensile change %	Flexural change %	Water absorption % (reported)
0	0.00	0.00	0.00	11.60
2.5	−18.46	−0.30	−4.45	9.34
5.0	−16.20	−3.61	−2.62	5.95
7.5	−11.27	−2.11	−2.88	5.70
10.0	−3.77	+0.60	+1.83	5.68
12.5	−16.51	−5.42	−3.66	8.68
15.0	−23.88	−12.65	−12.57	9.50
20.0	−34.89	−16.87	−22.51	14.00

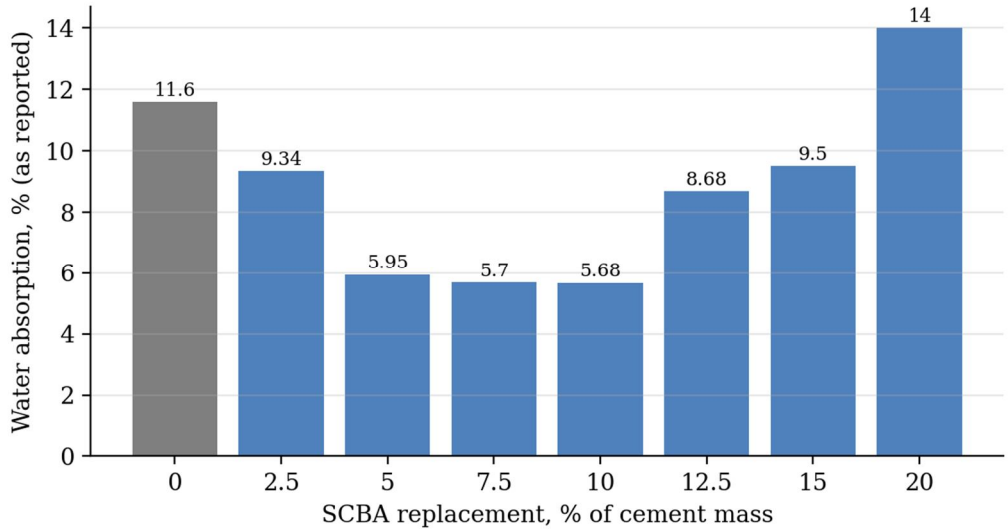


Figure 3 - Reported water absorption from [1]. Absorption fell to a minimum near 10% replacement and rose again at 15 and 20%.

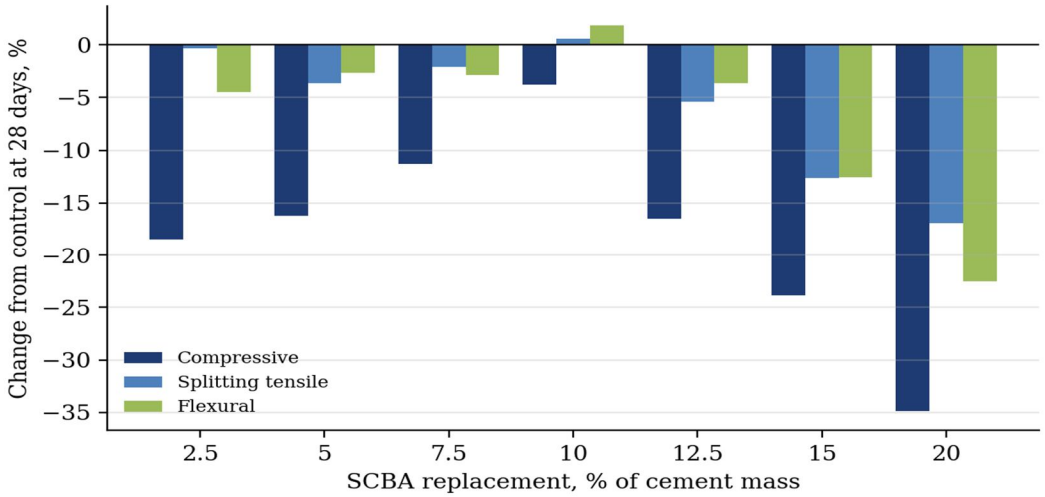


Figure 4 - Change in 28 day strength relative to the control, calculated from Table 2 as 100 × (SCBA mixture − control) / control.

The percentage changes were calculated as 100 × (SCBA mixture strength − control strength) / control strength. Three observations follow. First, 10% replacement is the best performing level in every strength series, but its 28 day compressive strength is still 3.77% below the control. Second, the splitting tensile (+0.60%) and flexural (+1.83%) differences at 10% are small enough that, without replicate data, they cannot be called real gains. Third, strength and absorption both deteriorate at 15 and 20% replacement, which supports an upper practical limit near 10% for this ash and this mix.

The source paper concludes that strength improves up to 10% replacement. Its own 28 day table does not show an improvement over the control; the improvement is visible only in the 7 day compressive values (14.31 to 17.35 MPa, +21.24%). Other details also need checking against the full study: the 2.5% mixture is reported to lose 18.46% of compressive strength while losing under 1% of splitting tensile strength, which is an unusual pattern; the quoted absorption limit of 4 to 6% is attributed to IS 1124, which should be verified because that standard is understood to address natural stone; and the control concrete absorbs 11.6%, which is high for M30 concrete. These points do not invalidate the dataset, but they argue against copying its conclusions without replication.

A. Mechanistic Interpretation

A plausible explanation for the pattern is a balance between three effects. Fine reactive ash can fill pores and react with calcium hydroxide, which helps strength and lowers absorption; unreactive or carbon rich ash dilutes the cement and adds water demand; and removing cement lowers early hydration product formation. The early gain at 10% followed by a 28 day deficit may indicate filler action before the pozzolanic reaction contributes, but the data alone do not prove this. The mechanisms should be investigated with workability, density, X-ray diffraction of the ash and, if available, microscopy of the hardened paste.

B. Comparability

Figures 1 to 4 belong to one study with one ash, one cement and one water content, and must not be presented as outcomes of the proposed experiment. The 5% optimum in [2], the 15% limit in [3] and [4] and the strength loss in [5] cannot be placed on the same axes because their mix designs, water to binder ratios and ash preparations differ. No numerical relationship between strength and replacement level is inferred across studies.

VII. PROPOSED MATERIALS AND EXPERIMENTAL DESIGN

The following protocol is proposed by the present author and requires laboratory and supervisor approval. Use a natural aggregate control mixture targeting M30 concrete, developed through an approved mix design rather than a nominal volumetric ratio. Select one cement source, potable mixing water and locally characterised aggregates. Keep total binder content, aggregate grading and the water to binder ratio constant across mixtures, and use a superplasticiser only to hold slump within a stated target, recording the dosage for every batch.

A. *Ash collection, processing and characterisation*

Record the sugar mill, boiler type, collection point, collection date and storage condition. Dry the ash, sieve out coarse and unburnt material and measure loss on ignition. Two ash conditions are prepared from the same lot. As received ash is dried and passed through a fixed sieve only. Processed ash is calcined under a documented temperature and duration chosen in a small supervised screening trial within the 500 to 700 °C range suggested by [7] and [8], then ground for a fixed time to a measured fineness. Do not assume that a higher temperature improves performance.

Characterise both ashes by oxide composition (X-ray fluorescence), mineral form (X-ray diffraction, to compare amorphous content and quartz), loss on ignition, specific gravity and particle fineness. If possible, determine the strength activity index of each ash in standard mortar using the current procedure in ASTM C311 with classification reference to ASTM C618, and verify the corresponding BIS provisions. Report all values; do not use generic literature composition in place of measured values.

Table 4: Proposed mixture identification, ash condition and replacement level for the first experimental phase.

Mix ID	Ash condition	Replacement % of total binder mass
C0	No ash (control)	0
A05	As received, sieved	5
A10	As received, sieved	10
A15	As received, sieved	15
P05	Calcined and ground	5
P10	Calcined and ground	10
P15	Calcined and ground	15

The 5 to 15% range is a proposed screening range based on the spread of optima in [1 to 4], not a literature established optimum. A separate exploratory 20% arm could be added if resources permit, because it is the level at which [1] and [4] report clear losses. Keep any such arm distinct in the design and specimen count.

B. *Replacement and moisture control*

Define $R = 100\ m_s / (m_s + m^c)$, where m_s is the dry ash mass and m^c is the cement mass. For an illustrative total binder content of 423 kg/m³, taken from the control mixture reported in [1], the proposed replacements require 21.15, 42.30 and 63.45 kg/m³ of ash, leaving 401.85, 380.70 and 359.55 kg/m³ of cement. These are batching calculations, not an approved mix design. Correct aggregate moisture for every batch and record ash moisture so that it does not silently change the effective water.

VIII. PROPOSED TESTING AND ANALYSIS

Produce three independently mixed batches for each of the seven mixtures. Randomise casting order and specimen test order. From each batch cast one compression specimen for each of 7, 28 and 56 days, one 28 day splitting specimen and one 28 day flexural specimen. This gives 15 primary strength specimens per mixture and 105 overall. Three specimens from a single batch do not substitute for independent batch replication. Increase replication after a variability or power assessment if resources allow.

Table 5: Proposed measurements, timing, reporting requirements and purpose.

Measurement	Timing and reporting	Purpose
Slump and fresh density	Every batch; record admixture dosage and mixing sequence	Identify water demand and dispersion effects
Compressive strength	7, 28 and 56 days; report specimen geometry	Check strength retention and late pozzolanic gain
Splitting tensile strength	28 days; report individual values	Evaluate tensile response

Measurement	Timing and reporting	Purpose
Flexural strength	28 days; loading setup and span recorded	Measure bending response
Water absorption and sorptivity	Separate specimens at agreed ages	Evaluate moisture transport
Acid or sulphate exposure	Extended programme; mass and strength loss	Evaluate chemical resistance
Chloride penetration	Extended programme at an agreed age	Evaluate transport properties

Use laboratory approved current test standards and record their exact editions, specimen dimensions, curing regime, loading rate and machine calibration. Consult the current BIS catalogue for IS 10262 mix design guidance and the relevant IS 516 test parts and the splitting tensile method, and consult ASTM C1585 (sorptivity), ASTM C642 (absorption) and ASTM C1202 (chloride penetration) for the durability tests. These are standards families to verify, not a claim that the proposed procedure already conforms to a specific edition. Durability specimens are excluded from the 105 specimen count and must be budgeted separately.

A. Calculations and statistical plan

Compressive strength is P/A, with load P in N and loaded area A in mm² giving MPa. Splitting tensile strength is $2P/(\pi LD)$, with specimen length L and diameter D in mm. For third point beam loading with fracture in the valid middle region, modulus of rupture is $PL/(bd^2)$, using total applied load P, support span L, width b and depth d. Other fracture locations or loading arrangements require the governing standard equation.

Report individual batch observations, means, standard deviations, coefficients of variation and uncertainty. Compare the seven groups using a planned model with control contrasts, and analyse the six ash groups additionally as replacement level by ash condition. Check assumptions and report effect sizes and confidence intervals. Batch is the replication unit. Repeated ages from the same batches need appropriate blocking or correlation handling. Do not discard weak specimens without documented technical reasons.

Before testing, agree on a screening rule with the supervisor, such as retaining at least 95% of control compressive strength at 56 days while keeping water absorption no higher than the control and meeting the slump target. This is a proposed project criterion, not a code acceptance rule. Select a candidate using the whole response set and confirm it in fresh batches.

IX. DURABILITY, SUSTAINABILITY AND LIMITATIONS

Short term strength is insufficient to establish service suitability. The selected mixture should be extended to acid or sulphate exposure, chloride transport and later age strength retention, with replication sufficient to compare against the control. Absorption results from [1] suggest a possible durability benefit near 10% replacement, but they come from a single study and a single test, so they are treated as a lead to verify and not as a durability claim. Use in reinforced elements also requires separate evaluation of the effect of the ash on reinforcement protection. For environmental assessment, define a functional unit such as one cubic metre of concrete meeting the same performance and intended life. At constant binder content each 10% replacement removes 10% of the cement mass per cubic metre, but processing the ash (drying, calcination, grinding) and transporting it consume energy, and rejected material and any extra admixture must be counted. Any comparison should state boundaries, input quantities and local emission factors. No carbon reduction percentage is claimed here. Ash variability, uncertain processing effects, differences in moisture condition and small sample sizes may limit transferability. The accessible literature contains inconsistencies between text and tables and incomplete uncertainty reporting, and the present review cannot resolve them. The proposed study uses a single ash lot and a single calcination condition, so it cannot identify a global optimum or the best processing route. It also excludes full scale elements, bond to reinforcing bars, fire response and long term field performance.

X. CONCLUSIONS

Published studies support investigating SCBA as a partial cement replacement, but they do not justify a universal strength improvement claim. The dataset reproduced here shows the best result at 10% replacement, with a small 28 day compressive deficit, tensile and flexural values close to the control, an early age compressive gain and the lowest water absorption, followed by clear losses at 15 and 20%. Other studies place the best level anywhere from 5 to 15%, and one reports strength loss at 20 and 40%. Preserving each study's conditions and replacement basis is essential to interpreting these results.

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The next defensible step is a controlled seven mixture experiment using characterised ash, as received and calcined and ground, explicit moisture and workability control, independent batches and both mechanical and durability indicators. A candidate replacement level should be selected only after measured trade offs are evaluated. On present evidence, replacement of roughly 5 to 10% of cement by well processed SCBA is the range most worth testing, and higher levels should be treated as unproven.

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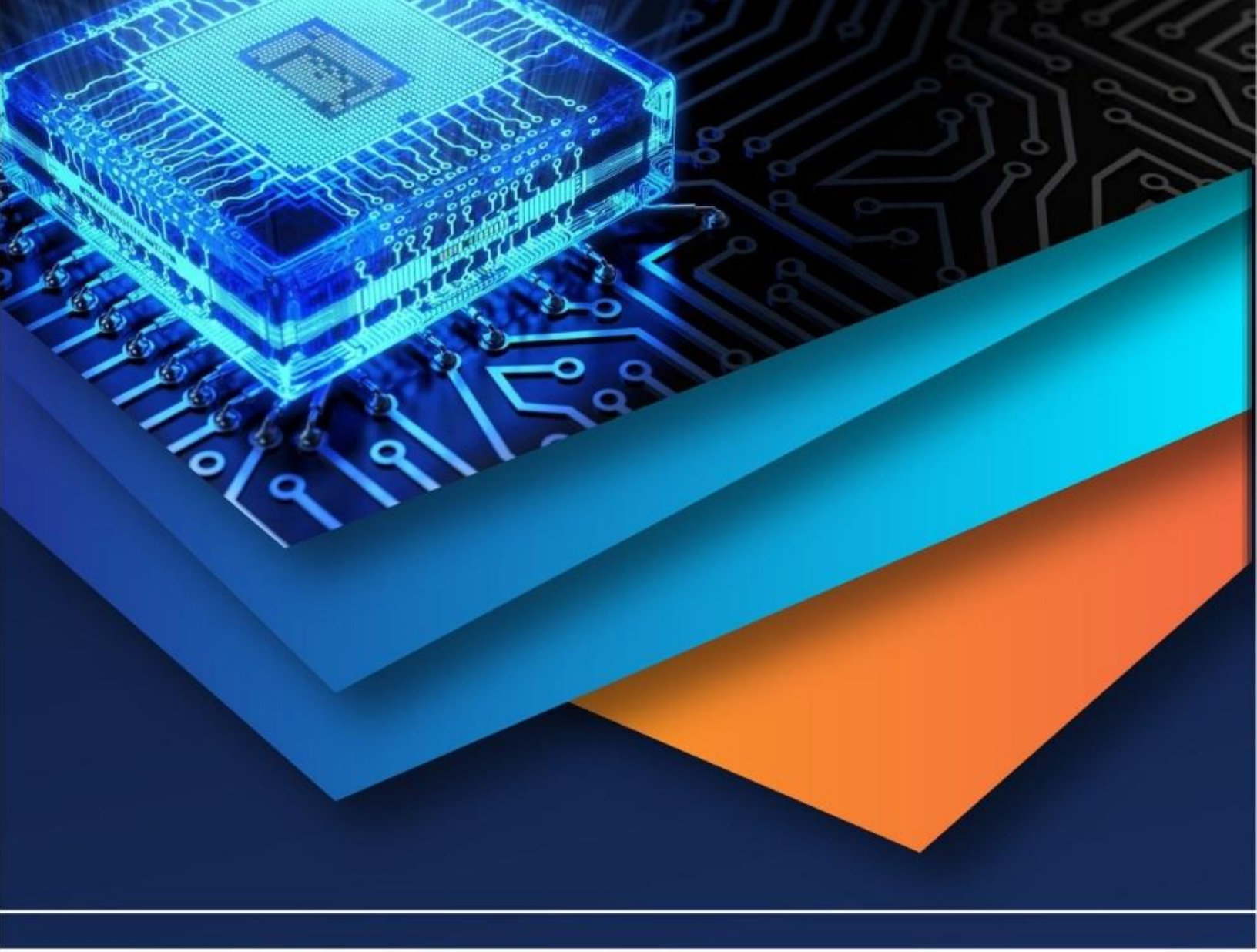
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