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Analytical Modeling of Eco-Friendly Concrete Blocks from Construction and Demolition Waste using ANSYS

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ABSTRACT

This research underscores the feasibility of repurposing C&D waste, particularly old concrete, for both new construction endeavors and revamping existing projects. This approach offers a dual advantage: preserving precious landfill space while curbing the extraction of raw materials for fresh construction initiatives. Focusing on the utilization of demolished waste as partial replacements for coarse aggregates sourced from C&D Waste Traders in Sirjala, Bengaluru, 10 mm sized recycled aggregates are employed.

Recognizing the porous nature of crushed aggregates owing to residual slurry, a meticulous treatment process is adopted. This includes two-stage treatment involving abrasion to eliminate residual loose slurry, followed by immersion in a fly ash solution with a concentration ratio of 1:6. Subsequently, these treated aggregates, after the curing process, are amalgamated with a robust geopolymer precursor in a mix ratio of 1:3:6 to fabricate 400X200X150 mm blocks.

To gauge the masonry behavior of these innovative concrete blocks, a battery of tests conforming to ASTM codes is meticulously conducted. These evaluations serve as a robust assessment of the structural integrity, durability, and performance characteristics of the blocks, providing critical insights into their potential for widespread adoption in construction practices. This comprehensive analysis contributes to the growing body of knowledge on sustainable construction materials and practices, advocating for a paradigm shift towards eco-friendly construction methodologies amidst the burgeoning challenges of waste management and resource scarcity.

Keywords-- Geopolymer Concrete, Masonry Behavior, Demolished Waste Utilization, ASTM Testing, Waste Management Strategies

I. INTRODUCTION

1. General

The utilization of waste materials in construction, such as construction and demolition (C&D) waste, has been a focus of recent research. Mahesh (2018) and Arulrajah (2014) both highlight the potential of these materials to improve the strength and durability of concrete, with Mahesh specifically noting the use of waste products as an alternative material. Ling (2012) further supports this, demonstrating the potential of agricultural and industrial waste in the production of lightweight concrete bricks. However, Hadavand (2019) cautions that while C&D waste can be used as a substitute for virgin aggregates in concrete, it may negatively impact workability and certain mechanical properties.

A range of studies have explored the use of construction and demolition waste (C&D waste) in the production of eco-friendly concrete blocks. Wang (2019) and Dakwale (2014) both found that C&D waste can be effectively used as a replacement for cement and aggregate in ultra-high performance concrete and sustainable construction materials, respectively. Rosman (2014) further demonstrated that the addition of concrete waste to concrete blocks can optimize their thermal and mechanical properties. Finally, Rodriguez (2017) showed that recycled aggregates from C&D waste can be successfully used in the production of precast non-structural concretes, meeting industry standards. These studies collectively highlight the potential for ANSYS to be used in the analytical modeling of eco-friendly concrete blocks from C&D waste, to further optimize their properties and performance.

Simultaneously, the construction and demolition processes generate substantial waste materials that are often relegated to landfills. Finding adequate land for these sites is increasingly challenging, emphasizing the critical need for effective construction waste management. Recycling and reusing demolished concrete as aggregates in new construction emerges as a practical solution to address these challenges. Not only does this approach promote sustainability in construction practices, but it also alleviates environmental concerns associated with the depletion of natural aggregates.

Globally, an estimated 2-3 billion tons of concrete go to waste, yet the recycling of crushed concrete can salvage and reuse up to 20% of the typical discarded amount. According to the Building Material Promotion Council (BMPTC) survey in New Delhi, India, the annual output of construction and demolition (C&D) waste is projected to escalate to 150 million tons by 2025, underscoring the urgency of effective waste management strategies.

Concrete block work has been a longstanding material utilized across various construction scales. Despite its prevalence, many existing unreinforced masonry (URM) structures struggle to withstand seismic forces and require retrofitting. The primary structural elements resisting seismic events in these structures are the old URM walls, originally designed primarily for gravity loads.

1.1 Geopolymers

Concrete, a fundamental construction material, heavily relies on Portland cement. As its demand surges, the reliance on Portland cement escalates, exacerbating resource depletion and environmental impact.

India, in particular, heavily depends on coal-based thermal power stations, generating approximately 110 million tons of fly ash annually. Regrettably, only around 30% of this fly ash finds utilization in various applications, such as landfills, embankments, and pavement bases. The rest remains underutilized.

The groundwork laid by Prof. Joseph Davidovits in 1989 introduced geopolymer technology as a promising alternative binder to Portland cement in the concrete industry. This technology presents an innovative and eco-friendly solution, potentially mitigating the reliance on Portland cement while effectively utilizing fly ash, thus addressing both resource depletion and waste management concerns.

II. MATERIALS AND METHODOLOGY

1. **Alkaline Liquid:** A blend of sodium hydroxide solution and sodium silicate is prepared at room temperature. The reaction between these solutions initiates upon mixing and is recommended for use within 36 hours.
2. **Fly Ash (Low-Calcium):** The mineralogical and chemical composition of fly ash depends largely on the composition of the coal used. It exhibits consistent physical properties and chemical compositions.
3. **Sodium Silicate:** This material offers advantages such as expandability and contact-making ability. It allows for controlled index adjustment over broad ranges and forms a rigid layer that acts as a strong, long-lasting seal, resistant to tearing, pests, and moderately resistant to heat and water. Commonly used in applications involving paper, wood, metal, sheet metal, and other materials except plastic.
4. **Sodium Hydroxide:** The sodium hydroxide used is in flake form.
5. **Water:** The water used complies with IS: 456-2000 standards, ensuring it is devoid of salts and other organic contaminants. In geopolymer concrete, the total water content includes the water present in the alkali solution.
6. **Recycled Aggregate:** Coarse aggregates for partial replacement specifically include crushed concrete aggregates with a maximum nominal size of 10 mm. These aggregates are sourced from Sirjala in Bangalore, obtained from various vendors dealing with construction and demolition waste.

2.1 Preparation of Geopolymer Concrete Blocks

Aggregate Extraction: 10mm sized aggregates are obtained from deconstructed concrete waste in the construction and demolition domain.

1. **Soaking Period:** Recycled aggregates soaked in fly ash solution of water: fly ash concentration of 1:0.75 for 3 days and dried for 4 days in air and oven for 24 hours at 105 – 110^{0}C.
2. **Mixture Preparation:** The concrete block's mixture ratio is set at 1:3:6, incorporating both fine and coarse aggregates. Notably, there's a 50% substitution of the typical coarse aggregate with recycled aggregate derived from the deconstructed concrete waste.
3. **Tests:** Modulus of elasticity of prepared concrete blocks and mortar of 1:8 ratio (cement: sand) has been found. Also performed a diagonal test on masonry and simulating it using ANSYS.

III. Results and Discussion:

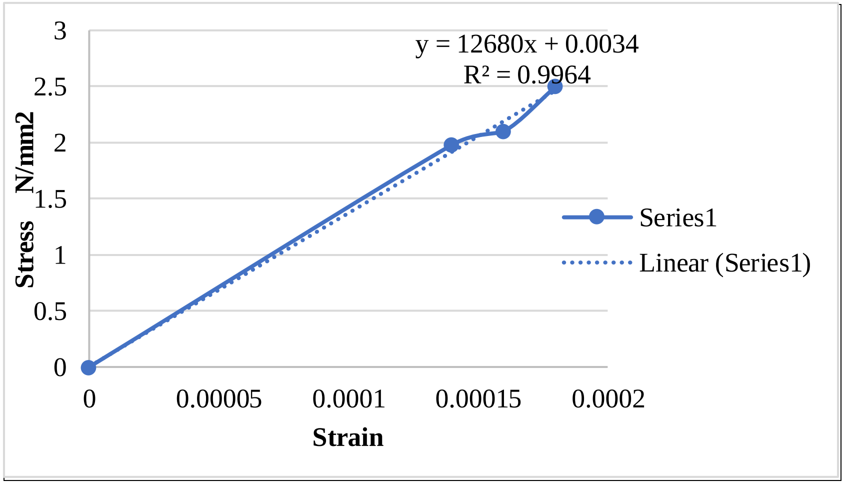
3.1 Physical Properties of Aggregates

Sl No.	Particulars	Values Natural Aggregate	Recycled Coarse Aggregate	Is Codes	Is Limits
1	Specific Gravity	2.72	2.84	IS 2386-3 (1963)	2.5-3
2	Water Absorption	2.76%	2.92%	BS 812-2	Should not exceed 3%
3	Crushing Values	29.6%	38.3%	IS2386-4 (1963)	Should not exceed 45%
4	Impact Values	25.56%	28.2%	IS 2386-4 (1963)	Should not exceed 30%

Table 1: Comparison of Physical properties of natural aggregate and Recycled Aggregate

3.2 Modulus of Elasticity on Concrete Blocks

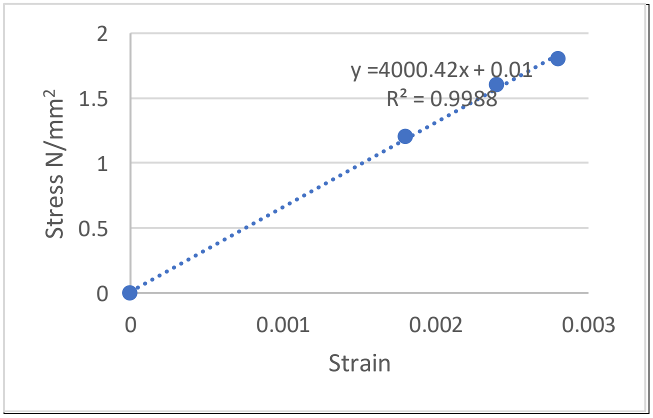
The initial tangent modulus was ascertained from the resulting graph.



Graph 1: Average stress-stain Curve for concrete blocks

3.3 Modulus of Elasticity of Mortar 1:8 Ratio

The modulus of elasticity of mortar was obtained by testing a mortar cube of 70 mm x 70 mm x 70 mm. The specimen was placed in UTM and load was gradually applied on the specimen until the specimen failed. The initial tangent modulus was thus found to be 4800.



Graph 2: Average stress-stain Curve for mortar (1:8)

3.4 Diagonal Compression Test (ASTM E519)

This testing procedure encompasses the assessment of the diagonal tensile or shear resistance of masonry assemblies by subjecting them to compression along a single diagonal, thereby inducing a diagonal tension failure wherein the specimen splits along the load direction.

Figure 1: Crack pattern of diagonal compressive strength

Specimen No.	Days	Load at failure kN	Stress MPa
1	28	145.46	3.58
2	28	148.24	3.64
3	28	147.56	3.63
Mean Diagonal Compressive Strength MPa		3.61	

Table 2: Diagonal Compression Strength of Masonry

3.5 Numerical Simulation of Masonry Diagonal Compression Strength using ANSYS

The masonry was modeled using the software ANSYS WORKBENCH.

Solid 65	**Linear isotropic**			
			Solid concrete block	**Mortar**
	EX	Youngs Modulus	12680	4000
	PRXY	Poisson’s ratio	0.165	0.209

Table 3: Linear Isotropic Material Properties of diagonal compression of masonry

Solid 65	Multilinear isotropic				
	Sl.no	Solid concrete block		Mortar	
		Strain	Stress	Strain	Stress
	1	0.00012	1.28	0.00010	0.54
	2	0.00016	1.42	0.00025	0.86
	3	0.00020	2.12	0.00140	0.98
	4	0.00030	2.42	0.00260	1.45
	5	0.00040	2.80	0.00350	2.10
	6	0.00060	2.95	0.00450	2.28
	7	0.00080	3.23	0.00550	2.68
	8	0.00120	3.45	0.00740	2.95
	9	0.00140	3.72	0.00840	3.42

Table 4: Multi Linear Isotropic Material Properties of diagonal compression of masonry

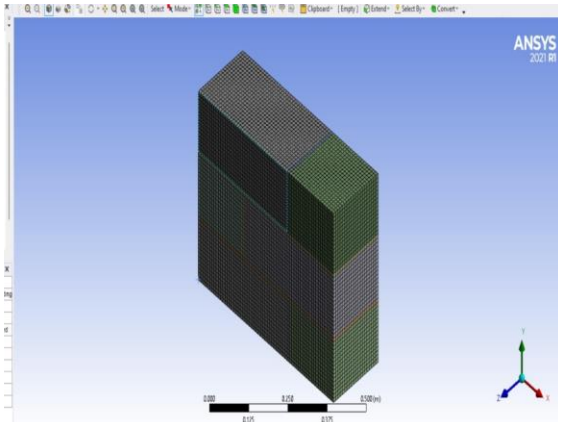


Figure 2: Meshing

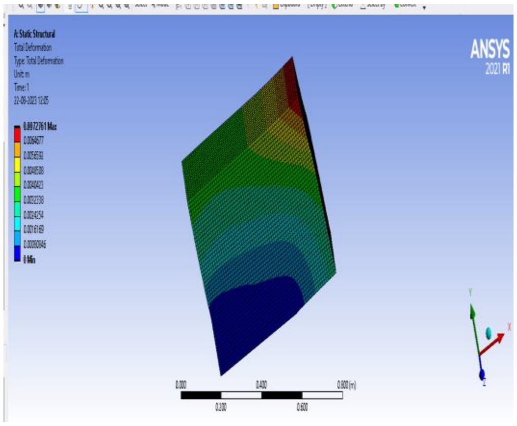


Figure 3: Total deformation

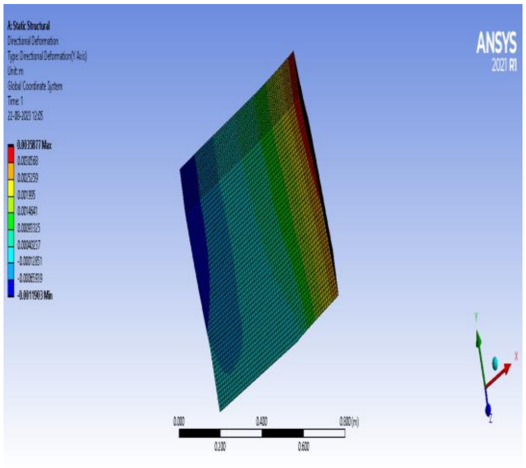


Figure 4: Directional deformation

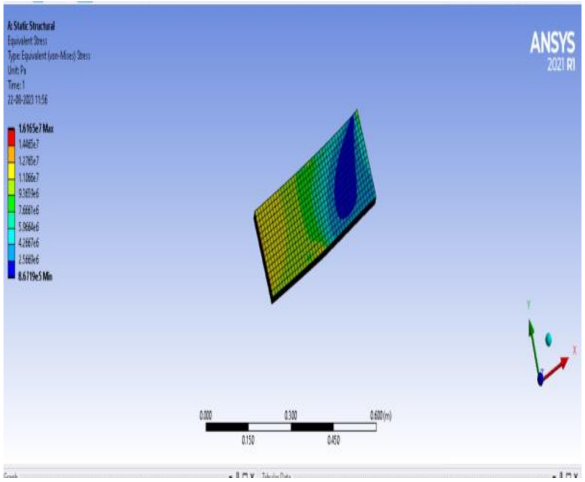


Figure 5: Equivalent stress in concrete block

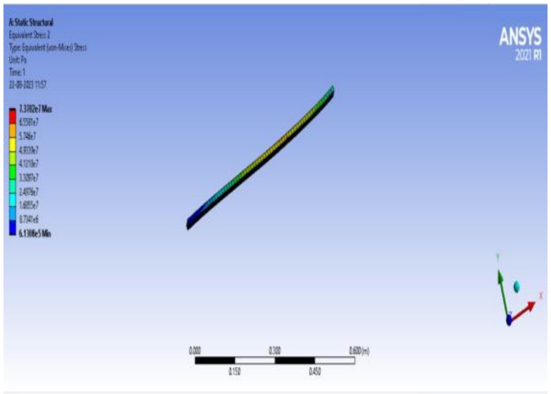


Figure 6: Equivalent stress in mortar

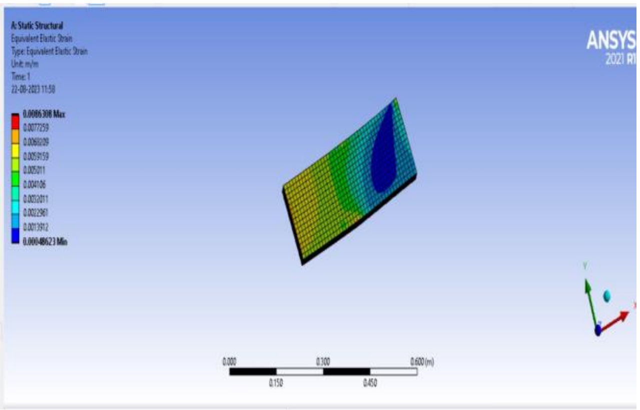


Figure 7: Equivalent strain in mortar

IV. CONCLUSIONS

In conclusion, the study has demonstrated several key findings that contribute to the viability and sustainability of using recycled aggregates in geopolymer concrete blocks:

1. **Compliance with IS Code Standards:** The recycled aggregates utilized in the concrete blocks meet all conventional criteria outlined by the IS code IS2386-(1963) for aggregates employed in concrete. This compliance assures the quality and suitability of recycled aggregates in concrete block construction.
2. **Rapid Strength Attainment in Geopolymer Concrete:** Geopolymer concrete exhibits a remarkable ability to achieve significant strength within a short period, specifically within 24 hours during ambient curing. This eliminates the need for conventional water curing methods, thereby streamlining the construction process. Additionally, the inclusion of fly ash in geopolymer concrete eliminates the requirement for heat curing, contributing to both time and energy efficiency.
3. **Crack Patterns Consistency:** The crack patterns observed during the masonry diagonal test in the experimental phase closely align with those predicted by ANSYS simulation. This convergence between experimental and simulated results signifies the accuracy and reliability of the numerical modeling approach, providing valuable insights into the structural behavior and failure modes of the geopolymer concrete blocks under diagonal loading conditions.

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