

Research Article

Experimental Investigation on Partial Replacement of River Sand with Waste Brick and Laterite Soil in Concrete Production

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Abstract

Concrete stands as the most widely used building material in the world due to its affordability, accessibility, and durability as well as its adaptability and diversity. Due to these developing countries, like Ethiopia, are facing a scarcity of river sand in quality and quantity that satisfies the demand for rapid infrastructure growth. The balance between material availability and demand will be disrupted by this rise in demand. Therefore, in order to handle the circumstance, an alternate substance is needed. This study's primary objective was to examine the workability, durability, strength, and cost of partially replacing sand for normal strength concrete with waste brick and laterite soil. The purpose of this experimental study was to examine the physical and mechanical characteristics of concrete that contained laterite soil and waste brick. And this study contains 13 distinct set of mixes, including the control mix utilized in the investigations were available. For concrete with a compressive strength of 25 MPa without additives, mixes with a consistent water-to-cement ratio of 0.49 and slump ranging from 75 to 100 mm were used in this study. And right after mixing, each fresh concrete mix's workability was assessed. After three, seven, and twenty-eight days, the compressive strengths of 117 concrete cubes measuring 150 mm by 150 mm by 150 mm were evaluated. In comparison to conventional concrete, concrete containing waste brick and laterite soil as a natural substitute for sand shows superior compressive strength and lower proportion of water absorption which is an indication of better durability. However, as the percentage of waste brick and laterite soil replacement increased, workability decline. Concrete having 45% waste brick and 22% laterite soil was the optimum replacement rate, which has 4.43% water absorption capacity and can reduce concrete costs by up to 4.58%.

Keywords

Compressive Strength, Concrete, Fine Aggregate, Laterite Soil, Waste Brick

1. Introduction

Around 4.4 billion tons of concrete are produced year worldwide, but by 2050, that amount is predicted to increase to almost 5.5 billion tons. This places it among the world's

biggest consumers of natural resources [9].

Currently, Riverbeds are the primary natural supplies of sand, and these natural resources are rapidly running out. Due to

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these shortages are mostly caused by land-use conflicts, transportation, growing building, and environmental issues brought on by fast urbanization. Additionally, when resources are depleted, low-quality sand is produced and supplied, which results in defects in applications used to produce concrete [6]. Therefore, rather than making aggregates and minerals from virgin sources, it is important to discover a locally abundant supply of natural material, industrial and building wastes, or demolish work as an alternative. However, when construction increases, a large amount of garbage is produced, which has both direct and indirect effects on the environment [1]. Concern about the planet's future led to the introduction of sustainable construction since the building sector is known to use a lot of natural resources and generate a lot of waste [5].

Brick is one of the most widely used conventional construction materials throughout the world [2]. The masonry of ancient time's in Gondarian time involved two major materials one of them is brick manufactured from sun-dried mud or burned clay and shale [8].

One of the most popular traditional building materials in the world is brick [2]. Bricks made from sun-dried mud or burned clay and shale were one of the two main materials used in Gondarian time as building masonry product [8]. But during and after the Italian invasion bricks application becomes widely spread as masonry construction for different functional buildings in Gondar [14]. And 1.5 trillion bricks are produced globally each year (CCAC, 2015). Annually above 497,000 tons of brick/brick rubble is generated [13]. Clay brick wastes typically come in a variety of forms. It could have been caused by errors made during production, the use of improper materials, transportation, or the most frequent source, which is a significant amount of demolished material. Sometimes, it could cost more to remove this material from the cart [12]. This waste may be utilized as a replacement for sand in concrete production.

Tropical Laterite soil, which can vary in color, is found in portions of Africa, Asia, and America. In addition to the potential advantages of using laterite in concrete, such as better

residual concrete structure, lower construction costs, increased resistance to cracking and spalling, and better post-yielding and post-cracking behavior, its neglect as an engineering material is associated with uncertainty regarding its strength and other structural characteristics like creep, shrinkage, and long-term durability [4]. These accessible materials haven't been put to the test or given the go-ahead to be widely used in Ethiopian building, though.

Nowadays there is a scarcity of sand and it becomes a very difficult process to get sand easily in an economical way [6]. Overcoming this problem is very essential by finding alternative materials. Hence, the general objective of the study is to determine whether using of waste brick and laterite soil in as ideal replacement of riverbed sand in an experimental setup.

2. Materials and Methods

Following the EBCS2:1995 standard, 117 concrete cubes measuring 150 mm by 150 mm by 150 mm were prepared and tested [7]. Waste brick: laterite soil ratios of 2:1, 1:1, and 1:2 were employed, and the combined level of both waste brick and laterite soil increased from the percentage value 33 to 50 to 67 to 100 in order to replace natural sand. This setup yields 13 different sets of a mix including the control concrete. Each concrete cubes was prepared by applying a compressive strength of 25 Mpa (C-25). The cement content for all mixes will be 394 kg/m³. And right after mixing, each fresh concrete mix's workability was evaluated. Water absorption was carried out at the ages of concrete 28 days to check the durability of the concrete according to ASTM C642. The parent 100 × 200 mm dry hard cylinder concrete required to be cut into three little cylinders, each measuring 100 mm in diameter and 50 mm in height. To remove the end effects, thin portions from both ends have to be thrown away during the cutting process. No admixture was used for this research.

Table 1. Shows the proportioning and test specimens.

w/c	Sand (%)	Waste brick (%)	Laterite soil (%)	Number of cubes			Total
				3 day	7 day	28 day	
Constant	100	0	0	3	3	3	9
	67	11	22	3	3	3	9
	67	16.5	16.5	3	3	3	9
	67	22	11	3	3	3	9
	50	17	33	3	3	3	9
	50	25	25	3	3	3	9
	50	33	17	3	3	3	9

w/c	Sand (%)	Waste brick (%)	Laterite soil (%)	Number of cubes			Total
				3 day	7 day	28 day	
	33	22	45	3	3	3	9
	33	33.5	33.5	3	3	3	9
	33	45	22	3	3	3	9
	0	33	67	3	3	3	9
	0	50	50	3	3	3	9
	0	67	33	3	3	3	9
Total							117

2.1. Physical and Material Properties

2.1.1. Cement

Throughout the trial, Dangote Cement PLC's Ordinary Portland Cement (OPC) of grade 42.5R was utilized. Ordinary Portland cement (OPC) was conducted on the cement to confirm the Ethiopian standard.

Table 2. Cement test.

Item no.	Description	Test Result
1	Consistency Test of Cement	Water -Cement ratio (%)
		30%
		Water (gram)
2	Setting Time of Cement	150
		Penetration of needle (mm)
		11
2	Setting Time of Cement	Initial setting time of the paste (min)
		60 min
		Final setting time of the paste (min)
		510 (8 hr. 30 min)

2.1.2. Properties of River Sand, Laterite Soil and Waste Brick, and Course Aggregate

Aggregates underwent a number of experiments in order to design and create a concrete mix. Sieve analysis, bulk and dry density, moisture content, absorption capacity, unit weight, and other tests are conducted. All aggregates tests were done to conform to ASTM and Ethiopian standards requirements.

Table 3. The physical properties of Aggregates.

Item no.	Description	Sand	Laterite soil	Waste brick	Course aggregate
1	Fines modules	2.75		2.9	-
2	Nominal maximum aggregate size	-	-	-	25 mm
3	Silt content	3.45%	3.45%	5.26%	-
4	Moisture content	2.88%	14.68%	0.41%	0.25%
5	Dry unit weight	1814.78 kg/m ³	1303.62 kg/m ³	1055.7 kg/m ³	1747.03 kg/m ³
6	Absorption capacity	3.88%	16.62%	15.2%	0.55%
7	Specific gravity Bulk	2.64	1.93	1.9	2.9
	Bulk (SSD)	2.74	2.25	2.2	2.92

Item no.	Description	Sand	Laterite soil	Waste brick	Course aggregate
	Apparent	2.94	2.83	3.08	2.95

2.2. Properties of Fresh Concrete

With varied amounts of alternate sand replacement, thirteen distinct concrete mixes were created.

Table 4. Workability of mixes.

Mix-no.	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9	Mix 10	Mix 11	Mix 12	Mix 13
Slump (mm)	75 mm	60 mm	65 mm	60 mm	70 mm	85 mm	95 mm	70 mm	75 mm	90 mm	70 mm	75 mm	100 mm

According to the test results, the slump test results for all but Mix 7, Mix 10, and Mix 13 are higher than or equivalent to the control mix. This indicates that the workability of the concrete mix using this alternative sand is comparatively lower than that of the control mixes. This is mainly because both waste brick and laterite soil have a larger absorption, in turn, they need more water.

2.3. Hardened Concrete Properties

2.3.1. Compressive Strength

Testing concrete cubes measuring 150 mm in accordance with EBCS2:1995 allowed for the determination of the specimens' compressive strength [7]. Weighing and measuring each specimen allowed us to calculate the concrete's density and cube area. At three, seven, and twenty-eight days, the

concrete's hardened characteristics were determined.

2.3.2. Concrete Water Absorption

Concrete absorption characteristics are one way to evaluate the material's durability. It is evident from Table 6 that waste brick and laterite soil concrete have higher water absorption than the reference concrete when compared to all other mixes at their 28-day age. And as waste brick and laterite sand percentage increase 0 to 33% to 50% to 67% to 100% (Mix 1 to Mix 13), the water absorption percentage also increases. According to Neville (2008), the majority of high-quality concretes have absorption rates of less than 10% [11]. Since all concretes contain waste brick and laterite soil where their water absorptions capacity was below 10%, satisfy the requirement for high quality concrete.

Table 5. Compressive strength of concrete mixes.

Mix-no.	Con-crete Mix 1	Con-crete Mix 2	Con-crete Mix 3	Con-crete Mix 4	Con-crete Mix 5	Con-crete Mix 6	Con-crete Mix 7	Con-crete Mix 8	Con-crete Mix 9	Con-crete Mix 10	Con-crete Mix 11	Con-crete Mix 12	Con-crete Mix 13
3 day	18.9	19.2	16.87	24.57	17.1	18.67	17.87	16.8	18.87	18.7	15.63	14.1	15.47
7 day	22.6	25.27	25.03	29.7	22.2	24.8	24.6	19.8	21.6	21.4	17.7	17.5	20
28 day	35.6	39.23	41.2	42.9	35.87	38.77	39.7	30.13	35.3	39.4	30.1	30.07	33.43

Table 6. Concrete absorption of Water.

Mix-no.	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9	Mix 10	Mix 11	Mix 12	Mix 13
S1	5.29	5.34	4.94	4.82	5.4	5.3	5.4	6.39	7.17	3.8	6.74	7.02	5.89
S2	4.68	4.62	4.15	3.9	4.35	4.25	4	5.54	3.16	4.39	5.53	5.52	4.84

Mix-no.	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9	Mix 10	Mix 11	Mix 12	Mix 13
S3	4.23	3.55	3.64	3.42	4.25	3.9	3.99	4.85	4.94	5.11	4.79	5.02	4.3
Average	4.73	4.5	4.24	4.05	4.67	4.48	4.46	5.59	5.23	4.43	5.69	5.85	5.01

2.4. Univariate Factorial Analysis of Variance for Compressive Strength of Concrete

The factors influencing the compressive strength of concrete are examined using a univariate factorial ANOVA with a 95% confidence interval and a significant level of $\alpha = 0.05$.

According to the decision rule for the F-test that was performed on SPSS for the main effect, the variable is regarded as a significant factor that influences the compressive strength of concrete if the P-value is less than 0.05, in which case the null hypothesis is rejected; if the P-value is greater than 0.05, the variable is reflected as non-significant, and the null hypothesis is not rejected.

Table 7. Main effect and interaction effects of SPSS test results.

Source	Sum of Squares	Degree of freedom	Mean Square	F Statistic	Significant.	Partial Eta Squared
Corrected Model	2961.410a	38	77.932	67.929	.000	.975
Intercept	25001.353	1	244469.724	8056.31	.000	.997
Age	2523.919	2	1261.96	415.483	.000	.972
Brick	56.024	2	28.012	9.223	.001	.435
Laterite	98.743	2	49.371	16.255	.000	.575
Age * Brick	54.849	20	2.742	.608	.798	.752
Age * Laterite	2893.317	32	90.416	7.967	.08	.977
Brick * Laterite	364.594	12	30.383	.304	.983	.123
Error	.000	0	0	Error		
Total	28550.154	39	732.06	Total		
Corrected Total	2961.410	38	77.93	Corrected Total		

Dependent Variable: compressive strength of test result

The null hypotheses μ_{01} , μ_{02} , and μ_{03} are rejected since Table 7 shows that the major effects of brick, laterite soil, and age have a substantial impact on the compressive strength of concrete, with a p-value of less than 0.05 for the 95% confidence range. Considering that the p-value is higher than 0.05, the null hypotheses μ_{04} , μ_{05} , and μ_{06} are not rejected because the interaction effect is not major.

2.5. Modeling

A variety of natural constants in the form of coefficients (β) and constants (α) can be produced when waste brick and laterite soil interact with one another in different ways at equal rates for different combined or partially combined rates. So based on SPSS v20 for three mix designs setting up mathe-

matical modeling formulations was developed. The independent variable in this context is the replacement rate, which refers to the percentage of substitute sand materials. The dependent variable is the compressive strength.

To model this relationship, a formula for linear regression is employed; the formula will be look like [10].

$$Y = \alpha + \beta X$$

Where X is replacement percentage; Y is the compressive strength; β is the slope of the line and α is the Y intercept

a. Dependent Variable: compressive strength

For all combined rate of laterite soil twice the waste brick or 2:1 ratio, based on regression analysis for 2:1, having coefficient (β) = -0.077 and constant (α) = 38.038. So our equation would be $y = 38.038 - 0.077x$. Where x is the percent

of replacement and y is compressive strength.

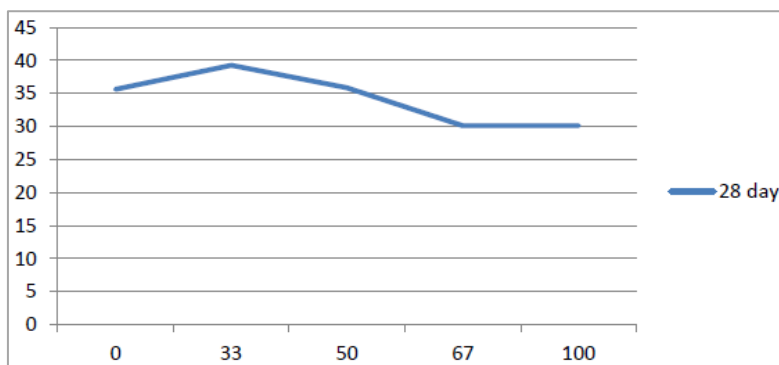


Figure 1. Compressive strength graph for laterite soil to waste brick 2:1 ratio.

So based on the regression analysis result for 1:1 or an equal ratio of waste brick and laterite soil replacement rate, having coefficient (β) = -0.062 and constant (α) = 39.409. So the equation would be $y = 39.409 - 0.062x$. Where x is the percent of replacement and y is compressive strength.

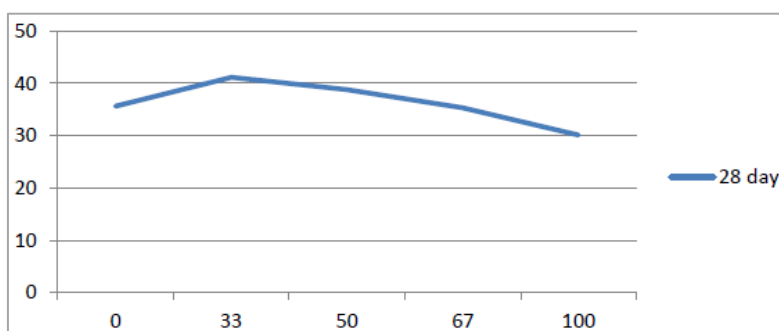


Figure 2. Compressive strength graph for laterite soil to waste brick 1:1 ratio.

The last model is prepared for the concrete mix with waste brick twice that of laterite soil using spss v-20.

Based on regression analysis for waste brick twice laterite soil contains or 1:2 replacement rate coefficient (β) = -0.03 and constant (α) = 39.712. So the equation would be $y = 39.712 - 0.03x$. Where x is the percent of replacement and y is compressive strength.

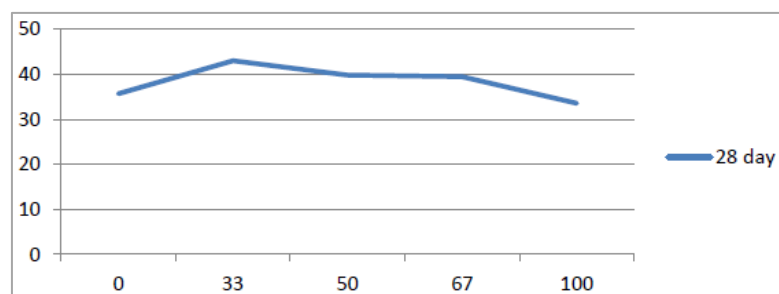


Figure 3. Compressive strength graph for laterite soil to waste brick 1:2 ratio.

Generally, from these three graphs at a replacement rate of waste brick twice laterite soil improved concrete compressive strength more than the rest ratios when compared with control concrete.

2.6. Economic Analysis

Partial replacement of sand at 67% by waste brick and laterite soil having waste brick twice laterite sand can save 4.16% cost than the control mix. Waste brick and laterite sand with 50% replacement of the control mix is around 3.13% aver-

agely cheaper than the control mix. Even this alternative material with a 33% partial replacement is also cheaper than the control mix by 2.02% averagely. Generally, partial replacement of sand by waste brick and laterite soil is pretty much cheaper than the control mix and it can be a potential solution for an increasing cost of virgin aggregate.

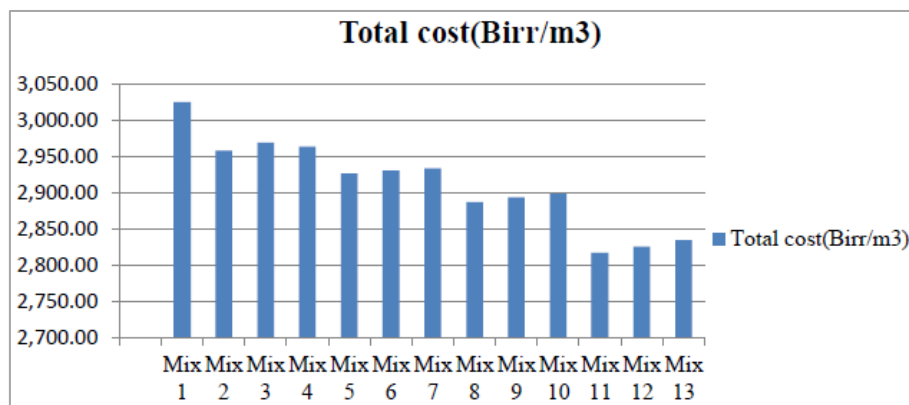


Figure 4. Cost comparison indifferent mix with conventional concrete.

2.7. Efficient Substitution of Sand with Waste Brick and Laterite Soil

Optimization of the concrete mix design is a process of a search for a mix having the sum of the costs of the ingredients

is lowest, but fulfills the required strength, workability, and durability. Figure 5 shows the percentage gain or decrease in strength, cost, and workability with the control mix to determine the best or most efficient replacement of concrete with waste brick and laterite soil.

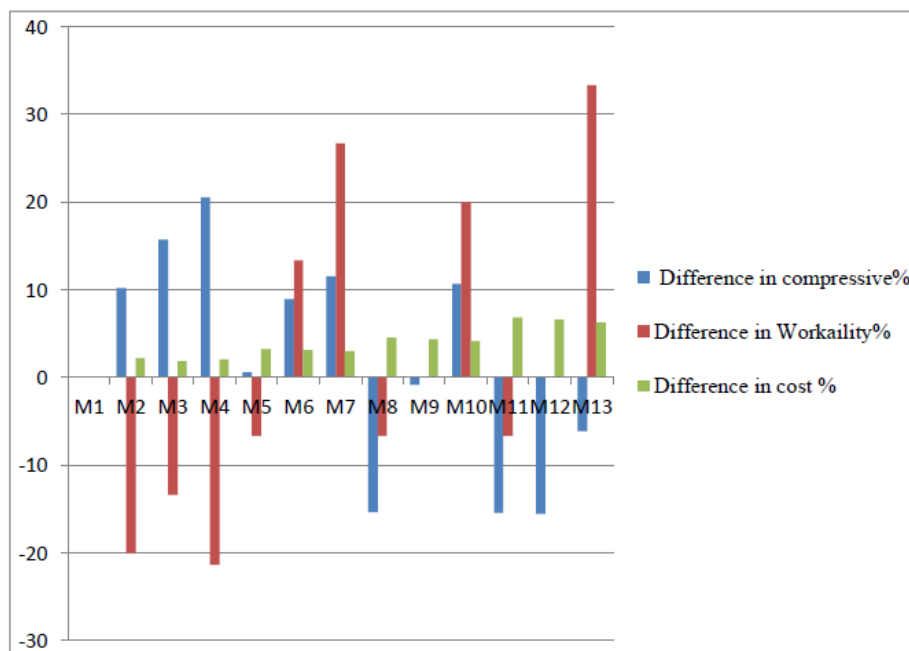


Figure 5. Percentage difference in compressive strength, workability, and cost.

3. Conclusion

The following conclusions are derived from the experimental investigation's findings by partial replacing sand with waste brick and laterite soil in concrete production.

1. When sand is partially replaced with waste brick and laterite soil up to 67%, concrete's compressive strength can be increased by 10.67% with a water absorption of 4.43%; however, when waste brick and laterite soil replacement rates are increased further, the concrete's compressive strength decreases, while the workability and water absorption of the concrete are increased.
2. Based on the cost estimation, it was clearly established that concrete contains this alternative material made of waste brick and laterite soil can save 4.58% of the total cost than using ordinary concrete production.
3. For C-25, using a water to cement ratio of 0.49, the combined replacement rate of 67% waste brick and laterite soil, or 45% waste brick and 22% laterite soil, will provide an efficient and ideal natural sand substitution rate from the perspectives of strength, durability, workability, and cost.

4. Recommendations

In light of the conclusion above the following recommendations are stipulated.

1. Further studies and standardization should be done on laterite sand as fine aggregate and coarse aggregate replacement due to its abundance in Ethiopia.
2. Waste brick has pozzolanic properties so, blending it with laterite sand will give a higher compressive strength than the regular concrete, beside of having green, good quality and environmentally friendly concrete, so the regulatory body should encourage the use of waste brick and laterite sand in concrete production.
3. Further study should be conducted for different compressive strength containing waste brick and laterite sand.

This study emphasizes workability, durability and compressive strength properties of concrete containing waste brick and laterite sand as partial replacement of sand. However, further studies are suggested in the following areas:

1. It is important to investigate the impact of partially substituting waste brick for cement and laterite sand for sand.
2. Production of high strength concrete using laterite sand and waste brick as sand and coarse aggregate replacement respectively.
3. The impact of using admixture to partially replace sand with waste brick and laterite sand should be investigated.

Abbreviations

ACI	American Concrete Institute
ASTM	American Society for Testing Materials
ERA	Ethiopian Road Authority
FM	Fineness Modulus
HCB	Hollow Concrete Block
OPC	Ordinary Portland Cement
PPC	Portland Pozzolana Cement
W/C	Water to Cement Ratio
ETB	Ethiopian Birr
IS	Indian Standard
RS	River Sand
EBCS	Ethiopian Building Code Standard

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Author Contributions

Wondirad Worku Mekonen: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing – original draft

Bahiru Bewket Mitkie: Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing

Efrata Maru Lakew: Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing

Data Availability Statement

Upon reasonable request, the corresponding author will provide the data supporting the study's conclusions. The data include references to relevant literature and materials used in the research, as detailed in the manuscript's references section. For access to supplementary materials or additional information related to the study, please contact the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

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