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Effect of Polyethylene Terephthalate Plastic Waste on the Physico-Mechanical and Thermal Characteristics of Stabilized Laterite Bricks

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Abstract

The present work investigated the effect of polyethylene terephthalate (PET) plastic waste on the physico-mechanical and thermal properties of cement-stabilized laterite bricks to see the durability of the modified bricks (CSLB). Samples were formulated by mixing laterite, cement, and different percentages of PET (0%, 3%, 5%, and 7%) by volume. The bricks were produced using the M7MI Hydraform standard interlocking block and kept in the shade for a curing period of 28 days. The addition of 3% to 5% PET to the laterite stabilized with 10% cement results in a decrease in both dry and wet compressive strength, which is determined using the Controlab compression machine. However, the obtained results are in concordance with the standards. The thermal conductivity of CSLB, determined using the box method with the EI700 measurement cell, decreases as the PET content of the mixture increases. A decrease in bulk density from 1.67 to 1.58 g/cm^3 was observed.

Keywords

Plastic Waste, Polyethylene Terephthalate, Laterite Bricks, Cement Stabilization, Thermal Conductivity

1. Introduction

To provide sustainable houses, most residents in developing countries prefer to build low-cost homes using locally available materials, such as laterite, sand and clay [1]. Laterite is the result of a weathering process of parent rock that becomes depleted in silica and enriched in iron and aluminum in the form of oxides Fe_2O_3 and Al_2O_3 [2]. To enhance the dry and wet mechanical strengths of these bricks, a stabilizing product can be added to the soil, resulting in stabilized compressed earth bricks (CEBs). Soil stabilization consists to modify the properties of a soil-water-air system to achieve permanent properties suitable for a particular application. Common stabilizing agents used in the production of CEBs include hydraulic binders (cement, lime…) and organic binders (cow dung, plant fibers…) [3]. Cement-stabilized laterite bricks are composed of laterite and cement in well-defined proportions. Due to their self-locking shape, the construction of a cement-stabilized laterite brick wall is simple [4]. The use of cement-stabilized laterite bricks as a masonry material offers advantages in terms of environmental protection, thermal comfort, cost savings, and easy production [5]. In the construction sector, elevated temperatures inside buildings and structural degradation, such as wall cracks, are often observed. It is necessary to find solutions to address these issues [6]. Adding plastic waste to construction materials can help to reduce indoor temperatures. Several researchers have used plastic waste such as polyethylene terephthalate (PET) [7] [8], polyvinyl chloride (PVC) [9], high-density polyethylene (HDPE) [10], and polyethylene as aggregates, fillers, or fibers in mortar bricks preparation [11]. Nowadays, several research projects focus on the incorporation of PET plastic waste into cement-stabilized laterite bricks for construction purposes. J. O. Akinyele *et al.* mixed percentages of 0%, 5%, 10%, and 15% PET granules with compressed stabilized earth bricks containing 0%, 2.5%, 5%, 7.5%, and 10% cement. The compressive strength of samples without granules ranged from 0.86 to 5.71 MPa, while samples containing granules ranged from 0.8 to 3.8 MPa at 28 days. Flexural strength started to decrease with more than 5% addition of PET granules. Tulane Rodrigues da Silva *et al.* proposed an environmentally friendly solution by adding PET waste to soil-cement bricks. Standard tests showed an increase in compressive strength, from 0.83 MPa for plain soil-cement bricks to 1.80 MPa for bricks containing 20% PET waste [12]. Regarding water absorption, all bricks had values between 15% and 16%, corresponding to the standards and being suitable for non-structural applications such as wall closures in building construction [13]. The work of Akinyele, J.O. *et al.* concluded that cement-stabilized earth bricks can be mixed with 5% PET granules [14]. Salifu T. Azeko *et al.* demonstrated that the composite containing 20% PET granules by volume exhibited the best performance in terms of flexural strength, compressive strength, and toughness after water curing. Moreover, this composite also showed improved resistance to erosion compared to composites containing 10% and 30% PET by volume [15]. Houssame Limami *et al.* have developed an innovative method to improve the performance of raw earth bricks by using polymer additives, such as HDPE and PET. The results showed that the use of smaller-sized additives ($\delta \leq 1$ mm) resulted in lighter bricks, with a density lower than 1.75 g/cm^3, as well as a 17% improvement in capillary water absorption coefficient and a 28% increase in compressive strength compared to larger-sized additives (3 mm < $\delta \le$ 6 mm) [16]. The improvement of physico-mechanical and thermal properties of the modified materials with polymers would depend on the nature of the materials and the composition of the mixture. This study aims to evaluate the effect of polyethylene terephthalate (PET) plastic waste on the physico-mechanical and thermal properties of CEBs (raw earth bricks).

2. Materials and Methods

2.1. Materials

The materials used are:

A CONTROLAB M7M1 Interlocking Block Production Machine with a manual Footmeter compression press of 3000 kN for brick compression tests.

A Niton XL3T Gold mobile test stands X-ray fluorescence spectrometer for determining the chemical and mineralogical composition of cement and laterite.

A series of CONTROLAB ISO 3310 standard control sieves, properly nested with mesh sizes ranging from 0.08 to 125 mm, supplemented with a bottom pan and lid for particle size analysis of natural aggregates (sand, laterite).

The river sand from Kalaban-Coro; the laterite used is sourced from the Titibouou-Bamako quarry (Republic of Mali); CM II 32.5 R Portland cement and PET plastic waste obtained from the market, previously sorted, washed, dried, and cut.

2.2. Methods

The local materials used were initially characterized for sample preparation. The degree of sand cleanliness, measured by the sight sand equivalent test (96.54%) and piston sand equivalent test (94.56%), is in concordance with the NF P18-598 standard. The bulk and specific densities of the sand are 1.55 and 2.57 g/cm^3, respectively. Those of the laterite are 1.67 and 2.46 g/cm^3, respectively. The fineness modulus obtained through particle size analysis is 2.49, indicating that the sand has satisfactory workability and good strength with limited risks of segregation according to the XP P 18-540 standard. The particle size distribution of the Titibougou laterite falls within the soil texture diagram range according to the NF XP P13-901 standard. Its plasticity index, which is 14.99, shows that the Titibougou laterite has low plasticity. The methylene blue value of 2.44%, combined with the values obtained from the particle size analysis and plasticity tests in accordance with the NF P 18-592 standard, gives a class A2: acceptable material with too many fines according to the NF XP P13-901 standard [17]. The standard Proctor compaction test on the laterite yielded a moisture content of 20.60% and a maximum dry density of 1.68 t/m^3. The Titibougou laterite is fine and can only be used for earth bricks or dikes. According to the ECOSTAND 069-01 standard, the values obtained from mineralogical and chemical analysis confirmed that the CEMII/B-M 32.5R cement can be safely used with reinforcements without risk of corrosion. The materials were mixed, and water was added to achieve homogeneous consistencies. The proportions of materials used for the formulation of BLSC with 0%, 6%, 8%, and 10% laterite are illustrated in Table 1.

With the optimum blend of 10% cement replacing laterite by weight chosen for economic reasons and normal water absorption, laterite was then replaced in volume by PET at 3%, 5%, and 7% as illustrated in Table 2.

The bricks were molded using the 24 cm long, 22 cm wide, and 11 cm thick Hydraform machine. The bricks were kept in the shade under plastic bags at a temperature of approximately 35˚C until they cured, as shown in Figure 1.

2.2.1. Compression Test

The test was conducted under two conditions: a dry compression test (on the 7th and 28th days) and a wet compression test on the 28th day. The Controlab brand universal compression machine was used for these tests.

Table 1. The proportion of the stabilized laterite brick mixture with cement.

% cement on the laterite	Laterite (g)	Cement (g)	Water (mL)	W/C	Number of Bricks
0%	29,199	-	6015	-	3
6%	27,447	1752	6015	3.43	3
8%	26,863	2336	6015	2.57	3
10%	26,279	2920	6015	2.05	3

Table 2. The proportion of Stabilized Laterite Brick Mixtures with Various Percentages of PET.

% of substitution	PET (g)	Laterite (g)	Cement (g)	Water (mL)	W/C	Number of brick
3%PET	788	25,492	2920	6015	2.06	3
5%PET	1314	24,965	2920	6015	2.06	3
7%PET	1814	24,465	2920	6015	2.06	3

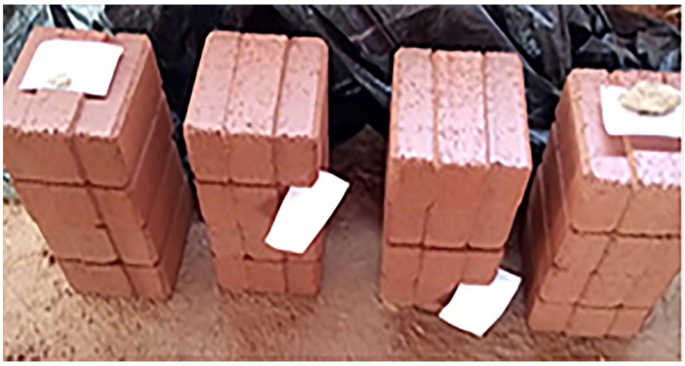

Figure 1. Conservation of bricks in the shade.

2.2.2. Determination of Brick Density

The masses of the blocks were determined at 7 and 28 days. All bricks had the same volume (5808 cm^3). The density was obtained by dividing the mass of the considered sample by its volume.

Water absorption test

The water absorption test by immersion is used to determine the behavior of bricks about moisture conditions. It involves drying a brick sample until a constant mass of 1 is obtained, then fully immersing it in water for 24 hours and subsequently weighing it. Let m^2 be the mass of the wet brick sample removed from the water.

2.2.3. Thermal Conductivity Test

Thermal conduction is a mode of heat transfer caused by a temperature difference between two regions of the same medium or between two contacting media, occurring without any overall movement of matter at the macroscopic scale. It was determined using the steady-state box method according to the NF ENISO10456 standard and is denoted as λ in W/m·˚K. The proportions for the preparation of cement-stabilized laterite bricks for thermal conductivity (**Figure 2**) testing are recorded in **Table 3**.

3. Results and Discussions

3.1. Properties of Cement-Stabilized Laterite Bricks without PET

3.1.1. Compressive Strength of Cement-Stabilized Laterite Bricks

The dry and wet compressive strength of the CSLB is shown in **Figure 3**. On the 7th day, the compressive strength of CSLB is 2.3, 2 and 3.5 MPa, and on the 28th day, it is 2.5, 5 and 5.2 MPa respectively, at 6%, 8%, and 10% cement content by weight, replacing laterite. An increase in dry compressive strength with increasing cement content in CSLB was observed, and this compressive strength increases as the amount of cement decreases. This strong strength observed with increasing cement content indicates that at higher content, the grains are closer together, and the consolidation between the grains becomes stronger. The dry strength of cement-stabilized laterite bricks at 8% and 10% cement content exceeds 4 MPa on the 28th day. The wet compressive strength on the 28th day of CSLB is 1.5, 2 and 3.95 MPa respectively, at 6%, 8%, and 10% cement content by weight, replacing laterite.

An increase in wet compressive strength with the increase of cement content in CSLB was observed. These results reveal that as the cement content increases, the wet compressive strength of cement-stabilized laterite bricks also increases.

Table 3. Proportions of cement-stabilized laterite bricks for thermal conductivity testing.

% PET	Laterite (g)	PET (g)	Cement (g)	Water (mL)	W/C	Number of brick
0% PET	3637.8	-	404.2	833	2.06	1
5% PET	3435.8	202	404.2	833	2.06	1

Figure 2. Sample brick for thermal conductivity testing.

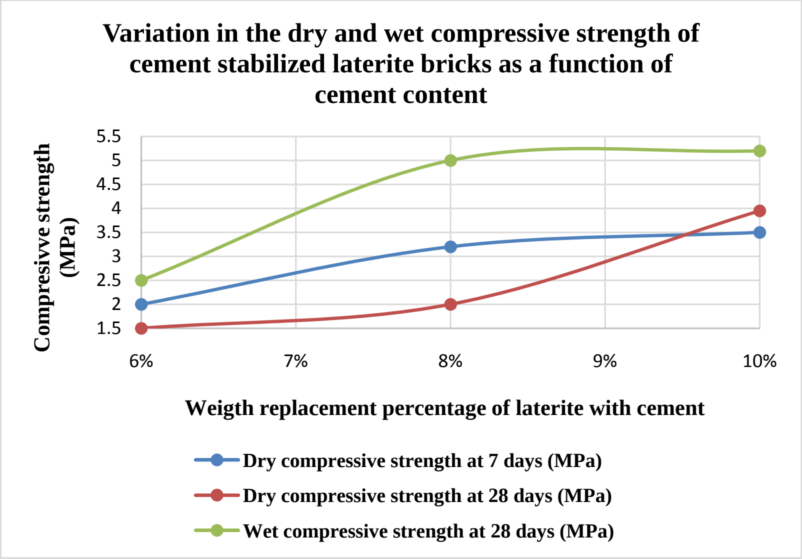

Figure 3. Variation of dry compressive strength (at 7 and 28 days of age) and wet compressive strength at 28 days of cement-stabilized laterite bricks as a function of cement content.

3.1.2. Density of Cement-Stabilized Laterite Bricks

The density decreases with the increase in the percentage of cement replacement for laterite (Figure 4). This is due to the lower density of cement (1 g/cm^3) compared to that of laterite (1.68 g/cm^3).

3.1.3. Water Absorption of Cement-Stabilized Laterite Bricks

The water absorption coefficient of CSLB (cement-stabilized laterite bricks) shown in Figure 5 is 28%, 24.94%, and 9.77% respectively at 6%, 8%, and 10% cement content replacing the laterite. The water absorption coefficient decreases as the cement replacement percentages increase according to standard XP P13-901. The 10% cement content for CSLB falls within the recommended range of 9% - 20% [18]. This high water permeability would result in the presence of water in the brick pores, which tend to cyclically expand and contract, creating stresses in the material and causing the bricks to become brittle.

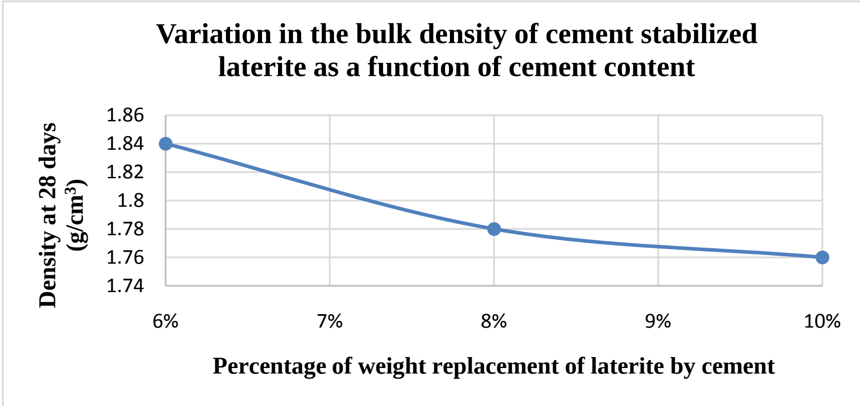

Figure 4. Variation of the bulk density of cement-stabilized laterite bricks.

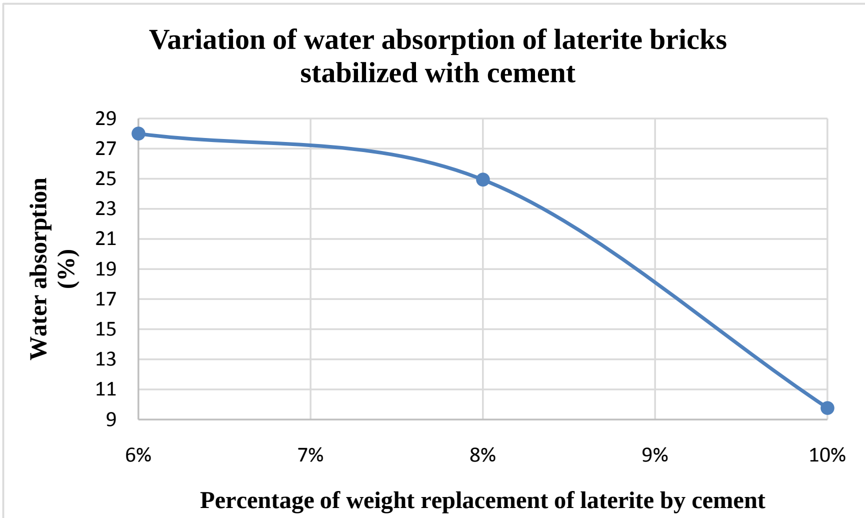

Figure 5. Water absorption of cement-stabilized laterite bricks as a function of cement content at 28 days.

Based on these results obtained at the 28th day, a significant improvement in the physical and mechanical properties of cement-stabilized laterite bricks with 10% cement replacement of laterite was observed, and this replacement percentage was considered optimal.

3.2. Properties of Cement-Stabilized Laterite Bricks with Different Percentages of PET

3.2.1. Compressive Strengths of Cement-Stabilized Laterite Bricks with Different Percentages of PET

The dry and wet compressive strengths of 10% cement-based laterite bricks with the incorporation of 3%, 5%, and 7% PET by volume as a replacement for laterite are illustrated in Figure 6. At the 7th day, the dry compressive strength of 10% cement-based laterite bricks is 3.5 MPa, 3.2 MPa, and 2 MPa, and at the 28th day, it is 4.8 MPa, 4 MPa, and 3.5 MPa, respectively, for 3%, 5%, and 7% PET, according to the standard XP P 13-901. A decrease in the strength of these bricks was observed as the content of PET waste polymers increased. The 3% and 5% PET-based laterite bricks showed better dry strength exceeding the minimum dry strength of 4 ona at the 28th day. The wet compressive strength at the 28th day of 10% cement-based laterite bricks was 2.7 MPa, 2.3 MPa, and 2 MPa, respectively, for 3%, 5%, and 7% PET.

A decrease in wet compressive strength was observed with increasing PET polymer content. A decrease in dry compressive strength was observed after immersion of the bricks compared to the dry strengths at 28 days, ranging between 32% and 53% decrease.

3.2.2. Bulk Density of Cement-Stabilized Laterite Bricks with Different Percentages of PET

A decrease in the bulk density of CLSB was observed with an increase in the percentage of PET waste replacing laterite (**Figure 7**). This is attributed to the lightweight nature of PET polymers used and the weak adhesion between PET polymers and the mix of different materials. Therefore, the incorporation of PET results in a decrease in the bulk density of the different bricks.

3.2.3. Water Absorption of Cement-Stabilized Laterite Bricks with Different Percentages of PET

The water absorption coefficient of cement-stabilized laterite bricks with 10% cement content is 16.78%, 16.92%, and 19.85% respectively at 3%, 5%, and 7% PET content (**Figure 8**). The cement-stabilized laterite bricks with the incorporation of 3%, 5%, and 7% PET are within the recommended water absorption range of 9% - 20% [18].

3.2.4. Thermal Conductivity of Cement-Stabilized Laterite Bricks

The thermal conductivity of CSLB is 0.82 and 0.53 W/m˚K at 0% and 5% PET content, respectively. According to the NF EN ISO 10456 standard, the thermal

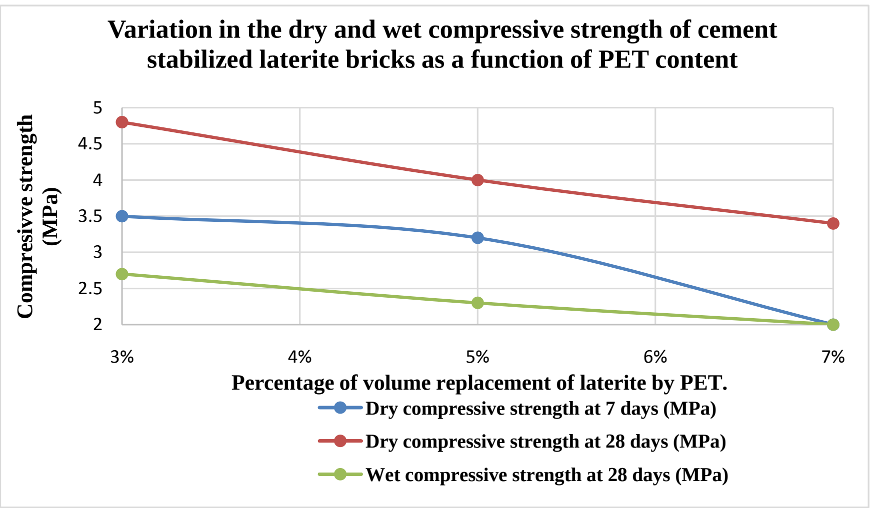

Figure 6. Variation of the dry and wet compressive strength of cement-stabilized laterite bricks as a function of PET content.

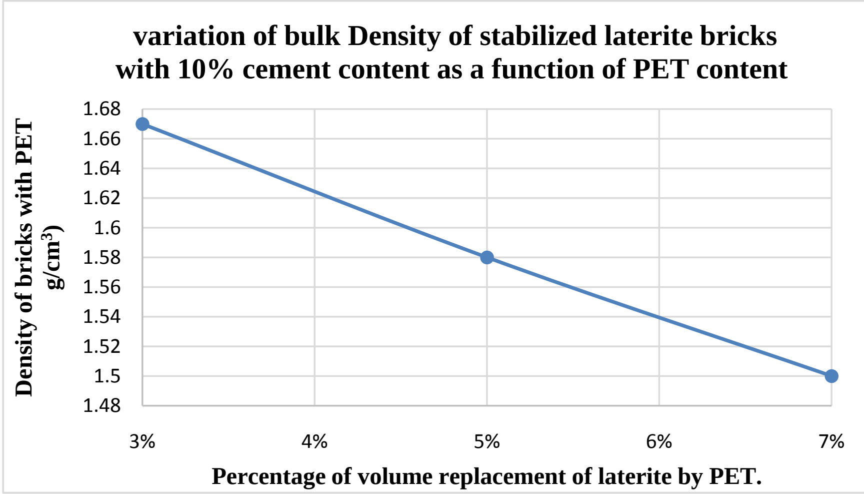

Figure 7. Variation of the bulk density of cement-stabilized laterite bricks with different percentages of PET.

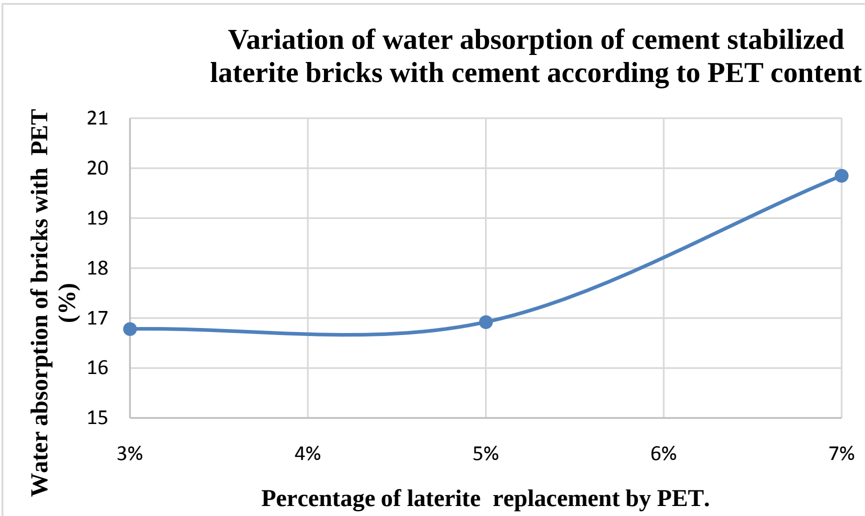

Figure 8. Variation of water absorption of cement-stabilized laterite bricks with 10% cement content as a function of PET content at 28 days.

conductivity decreases with the incorporation of 5% PET. The thermal conductivity of the formulated CSLB is lower than the upper limit of BTS, which is 1.04 W/m˚K according to the standard. The incorporation of 5% PET leads to a significant weakening of brick cohesion and a decrease in thermal conductivity due to increased pore diameter caused by poor distribution of the PET polymer. These results indicate good thermal insulation properties for these materials.

4. Conclusion

The physico-mechanical properties of cement-stabilized laterite bricks, such as dry and wet compressive strengths, bulk density, and water absorption, show that 10% cement replacement by weight of laterite and 5% PET polymer replacement by volume of later were used as the optimum proportions. These results allow us to conclude that there is a decrease in the thermal conductivity of CSLB with 10% cement and 5% PET plastic waste modification. The 10% cement-stabilized earth bricks modified with 5% PET polymer exhibit good physico-mechanical and thermal properties and can be used as a building material.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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