Concrete with Coconut Fibre Treated with Sodium Hypochlorite – Compressive and Flexural Strength

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ABSTRACT

Concrete needs to be reinforced to improve its engineering qualities. Coconut fibres were employed for this study since they are widely accessible and come in big numbers. The study compares the qualities of plain concrete and concrete reinforced with coconut fibre based on a laboratory experiment. Better management of these waste fibres will result from using coconut fibres. Two types of coconut fibre treatment were employed – treatment with tap water and treatment with sodium hypochlorite. It is found in this study that adding 1% of coconut fibre does not increase the concrete strength after 7 and 14 days of curing. However, it was discovered that using 1% coconut fibres treated using tap water increased the compressive and flexural strength of the concrete after 28 days of curing by roughly 4% and 3%, respectively. Compressive and flexural strength development agrees very well with each other. Hence, it is concluded that 1% was the ideal fibre concentration (by weight of cement) to obtain a better 28th day of compressive and flexural strength, although not for 7 and 14 days. However, concrete with the highest strengths demonstrated a very low slump value, only 20 mm. A smaller or bigger slump value showed smaller concrete strengths.

Keywords: *Concrete; Coconut Fibre; Treatment; Compressive Strength*

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Introduction

Concrete is an essential material in the construction industry. The performance of concrete is evaluated on mechanical properties, which include compressive strength, tensile strength, and flexural strength. However, the use of cement in the current concrete has produced many environmental issues. Sustainable development can be attained by using coconut fibre reinforced concrete (CFRC) in the construction industry by declining CO_2 emissions and saving natural sources [1]. Therefore, much research has been carried out to replace cement with other materials. One of the most potential materials to replace cement is coir fibre.

Coconut fibre, also known as coir fibre, is a natural fibre that falls under fruit and comes from plants. Raja et al. [2] mentioned that CFRC is advantageous for commercial applications since it is lighter in weight, has a lower density, costs less money, and has less solidity than regular concrete. According to Ali et al. [3], coconut fibres have the highest toughness among natural fibres. The inclusion of coconut fibres effectively increased the splitting tensile strength and compressive strength of CFRC exposed to room temperature regimes for 7 and 28 days [4]. Findings in these studies [3]-[4] show that coconut fibre can be used as reinforcement in low-cost concrete structures.

Besides fibre length and content, the properties of CFRC can increase or decrease depending on fibre treatment [1]. For example, moisture in the coconut fibre contributes to the concrete's water volume if the fibre is not dried before mixing. In addition, the coconut fibre's density may affect the concrete's density. Therefore, the type of treatment used for the coconut fibre plays a vital role in determining the strength of the CFRC. According to Bhowmick et al. [5], the main drawback of natural fibres' use in composites lies in their hydrophilic nature, which can be improved by surface modification or matrix adjustments. Furthermore, selecting the correct content of coconut fibre in the mix design is very important because too much coconut fibre may decrease concrete performance [1]-[5].

Hence all properties such as mechanical, physical, method of fibre treatment and mix design must be considered in the study of the CFRC. Therefore, this study investigates the effect of treated coconut fibres on concrete density, compressive strength, and flexural strength. Thus, laboratory experiments were conducted to obtain the following:

1. The density of regular concrete and CFRC
2. The workability of regular concrete and CFRC
3. The compressive strength of regular concrete and CFRC
4. The flexural strength of regular concrete and CFRC

Treatment of Coir Fibres

A cementitious microstructure of high-performance concrete may give higher mechanical qualities with coir by improving its roughness through alkali treatment of the coir and protecting it with latex and pozzolana [6]. Brígida [7] reported three types of chemical treatment for coconut fibre; treatment with H_2O_2, treatment with NaOCl, and treatment with NaOCl and NaOH. However, green coconut fibres were washed with distilled water before being treated and dried at 60 ºC for 24 hours. For treatment with H_2O_2, 2 g of coconut fibres were submitted to oxidation using 40 mL of a H_2O_2 solution in basic medium (0.05 g NaOH and 18 mL of H_2O_2 30%, v/v, for 100 mL of solution) at 85 ºC for 2 hours. Meanwhile, for treatment with NaOCl, 5 g of fibres were soaked in 100 mL of 0.4% NaOCl (v/v, in glacial acetic acid) for about 2 hours at 85 ºC. For treatment with NaOCl and NaOH, 5 g of fibres were soaked in 100 mL of NaOCl 4–6% (v/v): H2O (1:1) for 2 hours at 30 ºC. Finally, the fibres were washed with water and soaked in 100 mL of 10% NaOH for one hour at 30 ºC to complete the treatment. After being treated, fibres were thoroughly rinsed with distilled water and dried under a vacuum for two hours.

Natrium Hydroxide (NaOH) was also used by Naveen [8]. This paper described how the coir fibres were processed before using them as replacement material. First, the coir fibres were immersed in a 5% Natrium Hydroxide (NaOH) solution for 24 hours to remove the unwanted layer of coconut coir fibres. The fibres were then washed abundantly with water to remove the NaOH before drying them in a furnace at 70 ºC to 80 ºC for 24 hours. Afterwards, the coir fibres were soaked in 5% silane and 95% methanol solution for 4 hours and dried at 70 ºC for 24 hours. After the drying process finished, the coconut fibres were inserted into the cutting machine to cut into smaller pieces which lengths of less than 10 mm and this form is called whickers.

Other than concrete, coconut fibre was also tested as ropes. In this study [9], coconut fibre ropes were soaked in tap water for four hours to remove coir dust and dried in the open air afterwards. Ali and Chouw [9] conducted two types of treatment on the soaked ropes: treatment with boiling water and washing and treatment with chemicals. The soaked ropes were put in boiling water for two hours for treatment with boiling water. They were then washed with tap water until the colour of the water became clear. The ropes were finally dried in the same manner as soaked ropes. For chemical treatment, the soaked ropes were dipped in 0.25% Sodium Alginate ($NaC_6H_7O_6$) solution prepared with distilled water for 30 minutes. Next, these ropes were removed from the solution and soaked in 1% calcium chloride ($CaCl_2$) solution for 90 minutes. The ropes were finally dried.

Design Mix and Properties of CFRC

Ali [10] presents several researchers' results on the physical and mechanical properties of coconut fibres. Concerning this paper, the density of coconut fibre differs from 145 to 1370 kg/m^3, while tensile strength varies from 15 to 500 MPa. The highest tensile strength presented in this paper comes from coconut fibre, with a density of 1150 kg/m^3. The percentage of moisture present on a weight basis at the standard atmospheric condition for this coconut fibre is 11.4%. Ali [10] also reviewed the effect of fibre content, the impact of fibre pre-treatment and the development of fibre volume-fraction on the mechanical properties of mortar or concrete.

On the effect of fibre content, Ali [10] cited Slate [11] which used two types of design mix using cement sand ratio by weight. The first design mix was 1:2.75 with a water cement ratio of 0.54 and the second design mix was 1:4 with a water-cement ratio of 0.82. The fibre content was 0.08, 0.16 and 0.32% by total cement, sand, and water weight. Ali [10] found that the strengths of fibre-reinforced mortar increased for all designs with fibre contents. However, a drop in mortar strength was also noted when the fibre percentage rose.

On the effect of fibre pre-treatment, Ali [10] cited Li et al. [12], which studied untreated and alkalized coconut fibres with two different lengths, 20 and 40 mm, in cementitious composites as reinforcement materials. This study used a design mix with cement: sand: water: superplasticizer ratio of 1: 3: 0.43: 0.01 by weight. The mortar with treated fibre has better flexural strength, higher energy absorbing ability and ductility and is lighter than the conventional mortar. In addition, a low amount of chemical agent and coconut fibres added to the cementitious matrix produced positive results.

On the effect of fibre volume, Ali [10] cited Baruah and Talukdar [13], which utilized a mixed design of cement: sand: aggregates as 1:1.67: 3.64 with a water cement ratio of 0.535 for ordinary concrete. Cement weighed 350 kg, fine aggregates weighed 568.40 kg, coarse aggregates weighed 1239.40 kg, and water weighed 182 kg per cubic meter of concrete mix. The maximum size of aggregates is 20 mm. For CFRC, Baruah and Talukdar [13] added 4 cm long by 0.4 mm wide coir fibres with volume fractions of 0.5, 1, 1.5, and 2%. They [13] found that the highest increment in all types of tested strength was obtained from a mixed design with 2% fibres. The compressive strength, splitting tensile strength, modulus of rupture and shear strength were increased up to 13.7, 22.9, 28.0 and 32.7%, respectively, compared to plain concrete. The strength of CFRC with other volume fractions also increased but in a smaller percentage. Meanwhile, Ali et al. [6] concluded in their review that most studies suggested that maximum gain in compressive strength of normal strength concrete is achieved at 0.5-1.5% incorporation of coir by the weight of cement.

Nadgouda [14] from Mumbai used local coconut fibre in his study of CFRC. The study used 3%, 5%, and 7% (by the weight of cement) of coconut fibre in the concrete mix. The nominal mix design was 1:1.5:3. Nadgouda [14] used cubes for compressive strength, beams for flexural strength and cylinders for tensile strength tests. Tests were conducted on 3, 7 and 28 days. Nadgouda [14] found that an increase in the fibre content decreases all the strength (compressive, flexural, and tensile) on the 28th day. Interestingly, the strength of the concrete specimen on day 7 dropped to a smaller value than that of the concrete specimen on day 3. This condition is valid for all the strengths for CFRC containing 7% fibre.

Raja et al. [2] present the properties of coir fibre as follows. The density, tensile strength, Young's modulus and failure strain of coir fibre is 1.2 g/cm^2, 150-180 MPa, 4-6 GPa and 20-40%, respectively. According to them, factors affecting the mechanical performance of natural fibre composite include fibre selection, matrix selection, interface strength, fibre dispersion, fibre orientation, manufacturing method, and porosity. Furthermore, chemical treatment can further improve the physical and mechanical properties of coir fibre. Meanwhile, surface modification of coir fibre can reduce moisture adsorption. Hence, it is essential to consider all these factors before using coir fibre as a replacement material.

Bamigboye et al. [15] investigated cement replacement with coconut fibre. The replacement percentages were 0.25, 0.5, 0.75 and 1% by weight of cement in a design mix of 1:3:4. Types of fibre treatment were untreated, soaked in water, and soaked in 1% NaOH. The fibres were washed in water three times and oven dried at 110 ºC. Concrete cubes were moulded and cured for 7, 14, 24 and 28 days. These concrete cubes were subjected to 250 ºC and 150 ºC for two hours. The compressive strength of the concrete increased when using 0.25 and 0.5% of cement replacement but reduced for more than 0.5% replacement. Concrete with 0.5% cement replacement and treated with water exhibited the highest 28th days compressive strength, 28.71 N/mm^2, 3.88% more significant than the control specimens. Hence, Bamigboye et al. [15] concluded that coconut fibres are an excellent material for improving the strength of concrete, even after it was exposed to a certain degree of elevated temperature. However, research by Avubothu [4] found that compressive strength and split tensile strength of CFRC only increased very little when subjected to 200 ºC.

Syed [16] conducted a study to obtain a good compressive strength of CFRC, in which he concluded that the ideal water-cement ratio is 0.40 while the optimal fibre content ratio is 0.6% and 1.2%. In the same year, Hettiarachchi [17] used a mix design ratio by unit weight per metre cube (kg/m^3) of 1:0.55:1.72:3.2 for cement:water:sand:gravel, respectively to study CFRC. The coir fraction was 0.5, 1.0, 1.5 and 2.5%. The fibres used were washed with potable water three times to remove impurities, naturally dried for 24 hours, and immersed in a 5% NaOH solution for 30 minutes. After immersing the fibres in alkaline solutions, they were washed with water several times to allow the absorbed alkali to leach from the fibres and dried again naturally for over 24 hours before mixing with concrete. This study used two types of fibre coatings: epoxy paint and varnish coating.

Hettiarachchi and Thamarajah [17] found that an increase in coir fibre content reduced the workability of the coir-concrete mix. CFRC specimens with alkali-treated coir fibres and fibres coated with epoxy and varnish exhibited an apparent increase in workability. Epoxy and varnish indicated slightly higher workability compared to sodium hydroxide. The fibre content of around 1% (by cement mass) in CFRC gave the best compressive strength, flexural strength and split tensile strength. At a fibre content of 1%, the compressive strength and flexural strength increased by 5.59% and 12.96%, respectively. For split tensile strength, the results vary from 2.99 to 3.25 MPa.

The previous studies show two tests essential for normal concrete strength: compressive and flexural strength tests. Also, two kinds of fibre treatment were selected, treatment with tap water and treatment with NaOCl. One percent of fibre [17] was chosen as additional material to the original concrete mix.

Materials and Methodology

This study used two treatments: treatment using tap water and treatment using NaOCL solution. First, the coconut fibres were oven-dried for two hours at 30 $^{\circ}$C. Then, the dried fibres were soaked in tap water for 30 minutes and washed. These steps were repeated three times to remove dust in the coconut fibres that may cause degradation. Once completed, these soaked coconut fibres were sun-dried to remove any moisture and cut into 50 mm [18] in length. These coconut fibres are tap water-treated coconut fibre (TWF).

For bleach treatment, a solution consisting of 4 litres of bleach (4-6% of NaOCl) and 4 litres of tap water was used. TWF was immersed in the sodium hypochlorite solution for 24 hours at room temperature. After being immersed, the TWF was exposed to the sun again for drying. These coconut fibres are known as NaOCL-treated coconut fibres (NaF). Figure 1 shows the coconut fibre in several conditions. Figure 1a shows the coconut fibre's condition before being treated, while Figure 1b shows the condition of the coconut fibre after being treated with tap water. Figure 1c illustrates the coconut fibres being soaked in NaOCL, and Figure 1d portrays the coconut fibres after being treated with tap water.

All concrete batches were designed as plain concrete (without fibre) with a 28th day compressive strength of 30 MPa. The concrete mix design followed Othman [19] with the mix design ratio by unit weight per meter cube (kg/m^3) of 1:0.53:1.74:2.13 for cement: water: sand: gravel, respectively. The maximum size of aggregate used is 10 mm. The concrete was mixed in a concrete mixing machine. All the materials were carefully added to the drum while mixing. Mixing was stopped once all the materials had been thoroughly mixed. The number of specimens for each concrete batch is shown in Table 1. The cube size is 100 x100 x 100 mm, while the prism size is 100 x 100 x 500 mm. Due to a lack of power and material, only one prism was moulded for each flexural strength test. Before pouring the concrete into the cube mould, the density and the workability of the concrete were tested. Figure 2 shows the slump test being conducted, while Figure 3 shows the container used to measure density.

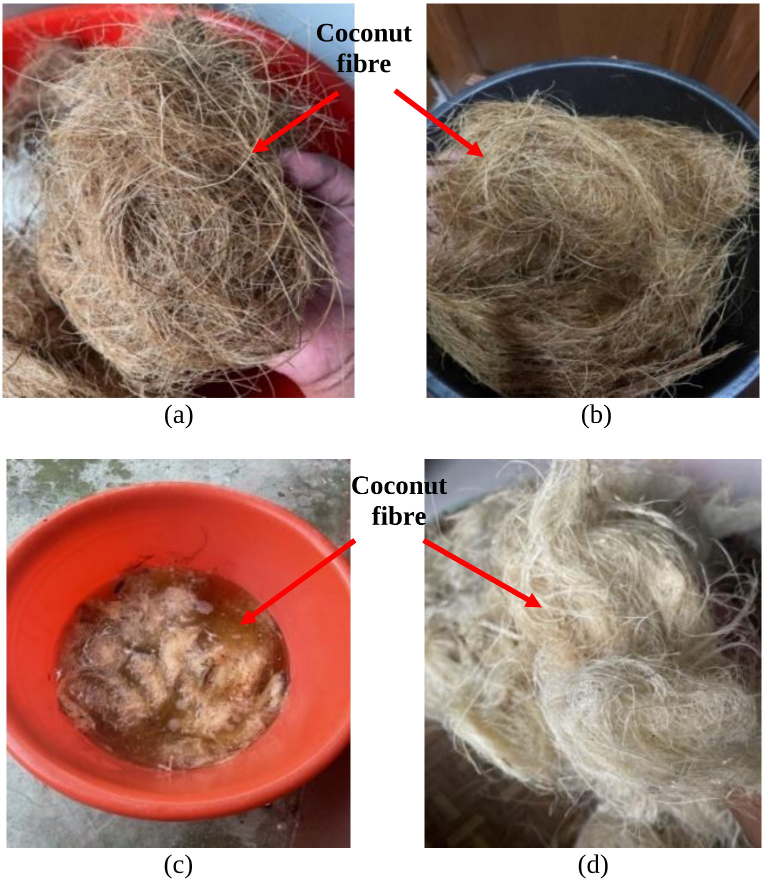

Figure 1: (a) Coconut fibre before treatment, (b) coconut fibre after being treated with tap water, (c) coconut fibre being soaked in NaOCL, and (d) coconut fibre after being treated with NaOCL

Table 1: Number of specimens for each concrete batch

			Compressive strength			Flexural strength
	Coconut fibre (%)	Sample names	7 days	14 days	28 days	28 days
Plain concrete	0.0	PC	3	3	3	1
Concrete with TWF	1.0	1.0TWF	3	3	3	1
Concrete with NaF	1.0	1.0NaF	3	3	3	1

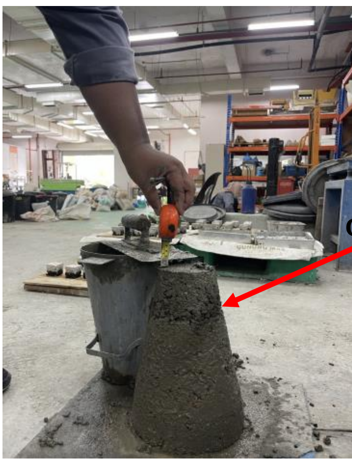

Figure 2: Slump test being conducted

Figure 3: Container for density measurement

Results and Discussion

Table 2 shows that plain concrete exhibits the most considerable density. Meanwhile, adding concrete with 1% fibre treated with either tap water or sodium hypochlorite solution reduced the density of the concrete by 3.58 and 4.67%, respectively. Similar findings were obtained by Hwang et al. [20] and Ahmad et al. [21]. This reduction in density can be attributed to the relatively low density of the coconut fibres, which is from 145 to 1200 kg/m^3 [10].

Table 2: Density of the concrete

Concrete	PC	1.0TWF	1.0NaF
Density (kg/m^3)	2494.04	2404.67	2378.87
Increase (%)	0.00	-3.58	-4.67

Table 3 shows the slump test result of the fresh concrete. The plain concrete shows a slump value of 37 mm, considered low workability [15]. Adding 1% coconut fibre even reduced the workability of the fresh concrete. Similar findings were observed by Hettiarachchi and Thamarajah [17], Bamigboye et al. [15], and Hwang et al. [20]. Adding 1% of non-treated coir fibre reduced the slump from 114 mm to 82 mm but increased to 88 mm for coir fibre treated with sodium hydroxide [17]. The finding from the current study is also supported by Ali [6], which concluded that coir as a fibre reinforcement is harmful to the workability of normal strength concretes. The increase in fibre content beyond 0.5% decreased the workability [15] due to the hydrophilic character of coir, where moisture absorption is very high, leading to poor interfacial adhesion with the hydrophobic cement matrix [17]. Water absorption of specimens made with 1% volume fractions of coconut fibre was 7.1% [20]. Hence, Ali [6] recommended the application of superplasticizers in coir-reinforced mixes to avoid workability issues. The optimum range suggested is 1.0% by weight of cement. Coconut fibre treated with sodium hypochlorite solution has the lowest slump value.

Table 3: Workability of the concrete

Concrete	PC	1.0TWF	1.0NaF
Slump (mm)	37	20	11
Increase (%)	0.00	-45.95	-70.27

The compressive strength result is displayed in Table 4. After seven days of curing, plain concrete has the highest compressive strength (34.19 MPa) compared to concrete added with 1% concrete fibre and the same after 14 days of curing. However, concrete fibre with water-treated coconut fibre shows the highest 28th-day compressive strength with 44.30 MPa, followed by plain concrete with 42.55 MPa. The lowest 35.59 MPa is demonstrated by concrete with coconut fibre treated with sodium hypochlorite. These results indicate that adding 1% of coconut fibre treated with sodium hypochlorite solution without any superplasticizer decrease the compressive strength of the concrete. Concrete with coconut fibre treated with tap water also reduced the compressive strength at 7 and 14 days. This finding agrees very well with Hwang [20]. However, the strength of CFRC using coir treated with tap water increased when tested at the age of 28 days. This increase shows a good sign of significant improvement from 14 to 28 days. Although Ali [6] suggested that coir fibre is helpful for normal-strength concrete, this study indicates that this suggestion is valid for concrete mixed with coir treated with tap water at 28 days.

Table 4: Average compressive strength (CS) of the concrete

Type of concrete	PC	1.0TWF		1.0NaF	
Concrete age (day)	CS (MPa)	CS (MPa)	Increase (%)	CS (MPa)	Increase (%)
7	34.19	32.70	-4.36	28.67	-16.14
14	39.19	38.25	-2.40	32.13	-18.01
28	42.55	44.30	4.11	35.59	-16.36

Flexural strength tests were conducted after 28 days of curing. Results are shown in Table 5. Concrete with 1% coconut fibre treated with tap water showed higher strength than the other two. This result is parallel with the results obtained from the compressive strength test.

Table 5: Flexural strength (FS) on 28th days

Type of concrete	PC	1.0TWF		1.0NaF	
Concrete age (day)	FS (MPa)	FS (MPa)	Increase (%)	FS (MPa)	Increase (%)
28	24.77	26.73	3.19	22	-17.70

According to Ahmad et al. [21], the most crucial factor for better concrete performance is the coconut fibre dosage, as a higher dose causes more voids in hardened concrete due to a lack of workability, which lowers the concrete's mechanical and durability performance. Ahmad et al. [21] further explained that different concrete doses are appropriate depending on the fibre length, diameter, and aspect ratio. Therefore, Figure 4 illustrates the relationship of slump value on the compressive strength and flexural strength of the CFRC at 28 days. It is observed from the graph that the development of compressive strength agrees very well with the progress of flexural strength. This finding demonstrates that the highest compressive and flexural strength on the 28th day is obtained from CFRC with a slump value of 20 mm, which comes from concrete added with coir fibre treated with tap water.

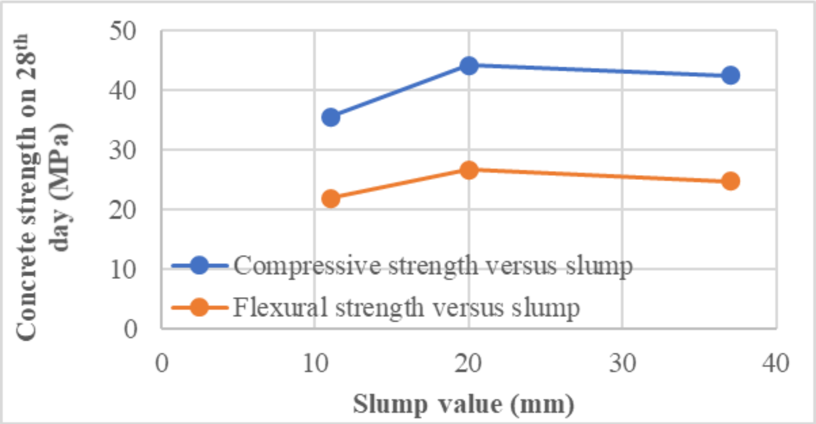

Figure 4: Concrete strength on 28th day versus slump value

Conclusion

The study discovered that adding coconut fibre treated with tap water into the concrete mix increased the compressive and flexural strength of the concrete after 28 days of curing. This strength increase shows that coconut fibres treated with water gave higher concrete strength due to reduced hydrophobic surface impurities such as hemicellulose, pectin and waxes, which makes the fibre more hydrophilic [22], hence increasing the bond between the fibre and cement matrix [23]. However, when coconut fibre treated with sodium hypochlorite was added to concrete, it resulted in lower compressive strength than tap water treated fibre and plain concrete. This is because, treatment with sodium hypochlorite removes the hemicelluloses and surface lignin of the coconut fibre. Removal of hemicellulose increases moisture adsorption, and lignin removal increases the water retention ability. Hence the concrete becomes weaker. In addition, water penetrating the fibre breaks the bond between the fibre and cement matrix, resulting in more void and increased water permeability [24].

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflicts of interest

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