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Potential Use of Recycled Brick and Demolition Concrete Aggregates in the Self-Compacting Concrete

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Abstract: This work aim to investigate the possibility of recycling waste materials, specifically brick aggregates (BA) and demolition concrete aggregates (DCA) in the formulation of self-compacting concrete (SCC), for this an experimental study was carried out to evaluates the fresh and hardened properties. A reference mixture composed entirely of natural aggregates (NASCC) was compared to six mixtures incorporating recycled brick aggregates (BASCC), recycled demolition concrete aggregate (DCASCC) and a combination of recycled brick and demolition concrete aggregates (BDASCC), as partial replacement of natural aggregates have been prepared. The fresh properties were assessed through slump flow, L-box, and sieve stability tests. Compressive and flexural strengths tests were conducted to evaluate the hardened properties. The results are very interesting, suggesting a possible use of brick aggregate and demolition concrete aggregate in formulation of SCC, and can lead to new concrete with satisfactory physical mechanical properties satisfying the criteria of self-compacting concrete.

Keywords: Recycled, Waste, Aggregate, Brick, Demolition, Self-compacting concrete

Introduction

Concrete is a heterogeneous material which is made with cement, aggregate and water. The strength of the concrete produced is dependent on the properties of aggregates used; it covers 70% to 80% of the total for any concrete mix. However, the construction industry is increasingly making higher demands of this materials which are not available in plenty and some of them are energy intensive is feared to accommodate the many requests. For these reasons their use must be economized. Hence need for an alternative aggregate arises.

One of the major environmental challenges today is the recycling of construction and demolition waste materials. Brick aggregates (BA) and demolition concrete aggregates (DCA) generate millions of tons of waste annually. These materials, which offer both economic and technical benefits, have the potential to replace natural aggregates (NA) in the production of self-compacting concrete (SCC). The use of recycled aggregates (RA), including BA and DCA, as partial or full substitutes for NA in concrete mixtures and their impact on fresh and hardened properties such as workability, strength, and durability has been widely investigated by several researchers (Duan & Poon, 2014; Yang et al, 2011; Debieb et al, 2010; Chen et al, 2003; Mansur et al, 1999; Khatib, 2005; Khalaf, 2006; Ghernouti et al, 2016; Ghernouti et al, 2024).

Many authors from different countries study the use of recycled aggregates in concrete: (Levy & Helene, 2004), and (Poon et al, 2007) in their research papers show that the aggregates which are got from demolished masonry and concrete structures are potentially good for use in new concrete. (Cachim, 2009) reported that crushed bricks could be used as a partial replacement of natural coarse aggregate without reduction in concrete properties for 15% replacement and with reductions up to 20% for 30% replacement. (Khaloo, 1994) found a decrease by 7% in concrete compressive strength by using crushed clinker bricks as coarse aggregate compared to natural aggregate concrete. (Poon & Chan, 2007) found that the incorporation of 20% fine crushed brick aggregate decreased the compressive strength and the modulus of elasticity of the concrete by 18% and 13%, respectively. (Mansour & Ghernouti, 2021) demonstrated that replacing 50% of aggregates or 10% of cement with natural rock perlite improves the workability and mechanical properties of self-compacting concrete, while also contributing to resource conservation, cost savings, and reduced CO_2 emissions.

In the work of (Kou & Poon, 2009), the recycled glass (RG) cullet was used to replace river sand (in proportions of 10%, 20% and 30%), and 10 mm granite (5%, 10% and 15%) in making the SCC concrete mixes. their experimental results showed that the fresh properties of the RG–SCC mixes increased and the hardened properties decreased with increasing recycled glass content. Moreover, the resistance to chloride ion penetration increased and the drying shrinkage of the RG–SCC mixes decreased when the recycled glass content increased. The results showed that it is feasible to produce SCC with recycled glass cullet.

The present study focused on the use of brick aggregate (BA) and demolition concrete aggregate (DCA) resulting from recycling waste materials such as, brick industries and demolition concrete and to find new ways of valorization in the self-compacting concrete (SCC). We will present, therefore, the fresh and hardened states properties of the concrete.

Experimental program

Materials

The reference self-compacting concrete (SCC) mixture investigated in this work was prepared with Ordinary Portland cement (OPC) CEMII/A42.5.

Limestone filler were used as addition materials in the mix proportions, they are rich in lime (CaO) above 55% and their specific surface area is about 3400cm^2/g.

The aggregates used are natural sand (NS), with a maximum particle size of 4 mm and two natural crushed limestone gravel with particle size between 3/8 and 8/15 (fig 1).

The recycled waste aggregates used in this investigation are brick aggregate (BA) and demolition concrete aggregate (DCA) from local sources resulting from crushing waste materials such as, brick industries and demolition concrete (see figure 2). The physical properties of all aggregates used in this work are listed in Table 1 and 2, the granular size analysis are presented in Fig.3, 4 and 5.

A polycarboxylate-based superplasticizer named Sika viscocrete Tempo 12 was used to achieve the appropriate workability of the self-compacting concrete (SCC) mixes.

Table 1. Physical properties of fines aggregates

	Natural sand (NS)	Recycled brick waste sand (BA)	Recycled demolition concrete sand (DCA)
Apparent density, (g/cm^3)	1.56	1.26	1.24
Specific gravity, (g/cm^3)	2.64	2.22	2.3
Visual sand equivalent, VES (%)	81	79	77
Fineness modulus	2.86	3.8	3.4
Water absorption (%)	3	19	8

Table 2. Physical properties of coarse aggregates

	Natural coarse aggregates (3/8 and 8/15)	Recycled brick coarse aggregates (3/8 and 8/15)	Recycled demolition concrete coarse aggregates (3/8 and 8/15)
Apparent density, (g/cm^3)	1.20	1.2	1.24
Specific gravity, (g/cm^3)	2.38	2.4	2.3
Los Angeles (%)	25	28.5	77
Micro-Deval (%)	26	27.2	3.4

Figure 1. Natural aggregates

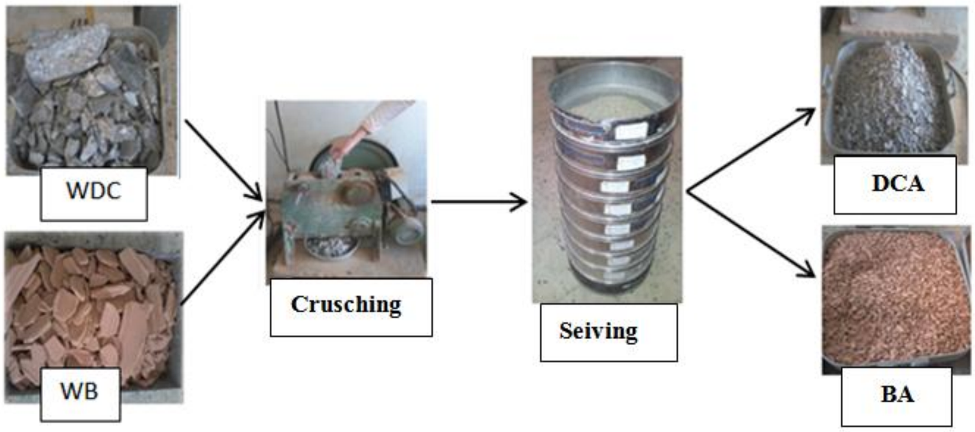

Figure 2. Preparation of recycled aggregates

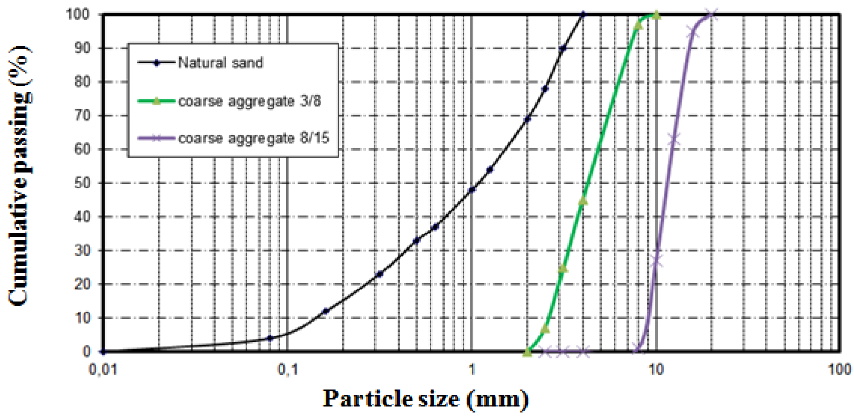

Figure 3. Particle size distribution of natural aggregates

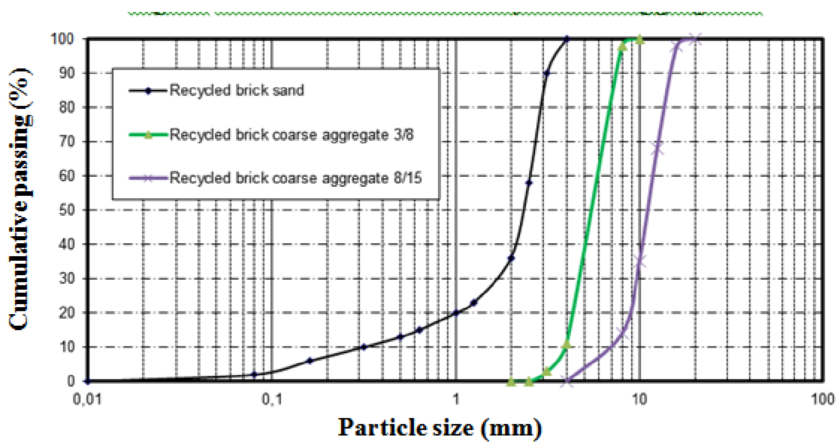

Figure 4. Particle size distribution of Recycled brick waste aggregates

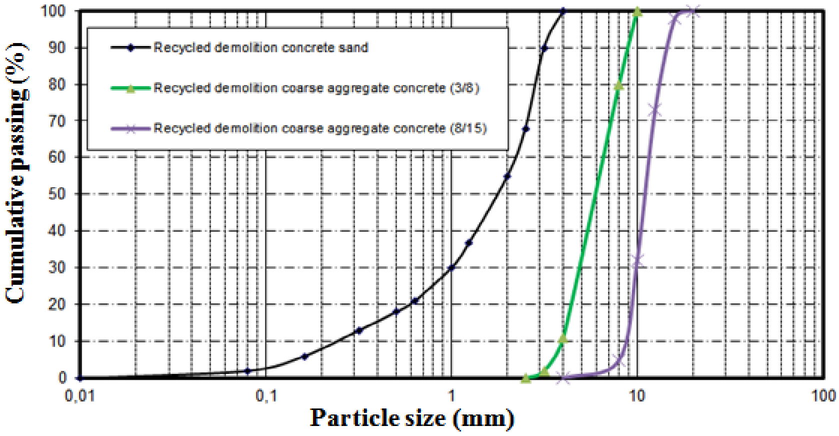

Figure 5. Particle size distribution of recycled demolition concrete aggregates

Mixture Proportions

Based on self-compacting concrete mix design Japanese method (Okamura H & Ozawa K, 1995), seven mixes were produced: A reference mixture based on natural aggregates (NASCC) with the total amounts of cement, fillers, coarse aggregates, sand, water and superplasticizer were all kept constant (430, 43, 844, 903, 174 and 7.6 kg/m^3, respectively), Two mixtures incorporating recycled brick aggregate (BSCC) with 25 and 50% replacement, Two mixtures incorporating recycled demolition concrete aggregates (DSCC) with 25 and 50% replacement and two mixtures incorporating combination of recycled brick and demolition concrete aggregates (BDSCC), as replacement of 50 and 100% natural aggregates.

Preparation and Casting of Test Specimens

The mixing procedure and time are very important, thus the mixing process was kept constant for all concrete mixtures. All the ingredients were first mixed under dry condition in the concrete mixer for one minute. Then 70% of calculating amount of water was added to the dry mix and mixed thoroughly for one minute. The remaining amount of water was mixed with the superplasticizer and was poured into the mixer and mixed for five minutes. After this sequence of preparation, flowability, passing ability and resistance to segregation of prepared mixtures are measured. For each concrete mixture three prisms of (7x7x28) cm and three cylinders (11x22) cm specimens were cast. Therefore, the total number of specimens considered in this experimental investigation was twenty one cylinders and twenty one beams. The specimens were demolded after one day and then placed in a curing room with a humidity of 90% and a temperature of 20 ± 2°C until the testing days (See Figure 6).

a) Mixer b) Specimens c) Curing of specimens

Figure 6. Preparation and casting of test specimens

Results and Discussions

Fresh Concrete Properties

The objective is to know the influence of the plastic brick aggregate (BA) and demolition aggregate concrete (DAC) on the workability of concrete. The flowability was evaluated by slump flow diameter, the passing ability was measured by L-box and the resistance to segregation was measured by sieve stability test, according to the specification and guidelines for SCC prepared by the European project group (EFNARC, 2005), (Figure 7). The obtained results of the slump flow diameter, L-box and sieve stability test of different mixtures are given in Table 3.

a) Slump flow test b) L-box test c) Sieve stability test
Figure 7. Tests on fresh concretes

The slump flow test is most used to measure the ability of self-compacting concrete to flow in the absence of obstructions. The test method is very similar to that for determining the slump of concrete. The difference is that, instead of the loss in height, the diameter of the spread concrete is measured in two perpendicular directions and recorded as slump flow. The obtained results show that the increasing of recycled aggregates brick or the demolition aggregates concrete as replacement of natural aggregates in formulation of SCC reduces the spread of concrete, we can note that all SCC mixtures meet the spreading criteria (60mm). The slump flow diameter was between 580 and 700mm, the time measured to reach a diameter wafer of 500 mm (t50) is close to the values recommended (3 seconds). However the SCC mixtures containing recycled aggregates of demolition concrete has a slightly greater spreading comparatively to SCC mixtures based on recycled brick aggregates, this is due to the shape and nature of the recycled aggregates, indeed these aggregates being more porous than the natural aggregates, led the mixture to a strong water absorption, increasing in viscosity, leads to a decrease in workability of SCC.

The demolition concrete aggregates contain in its compositions the natural aggregates which can lead to a good fluidity even with 50% replacement of natural aggregates. For the SCC mixture with 25% recycled brick aggregates and 25% recycled demolition concrete aggregates, therefore 50% of combined recycled aggregates, noted 50BDSCC, was obtained acceptable workability. The better workability was recorded for mixture containing 25% of recycled demolition concrete aggregates with 630mm in diameter of the spread concrete.

Concerning the L-box test is also performed to assess the passing ability of SCC in confined environment, the concrete flows through the frames properly and no blocking has been observed for SCC mixes containing 25% replacement aggregates regardless the type of recycled aggregates (brick or demolition concrete), the L-box ratio is higher than 0.80 (see table 5). However, the increase of brick aggregates until 50% causes immobility of concrete in confined environment, this is due to the shape and nature of the BA, indeed these aggregates being more porous than the natural aggregates, led the mixture to a strong water absorption, increasing in viscosity, leads to a decrease in workability and mobility of SCC. The results show that the replacement of natural aggregates by demolition concrete aggregates, until 50% has not caused immobility of SCC mixes in the confined environment (L-box ratio is 0.80). This may be attributed to the fact that DCA contains in its compositions the natural aggregates which can leads to a good fluidity. The mixture with 50% of combined recycled aggregates, noted 50BDSCC give a satisfactory result concerning the passing ability of SCC in confined environment, (L-box ratio of 0.79).

The sieve stability test is used to calculate a rate of segregation and to deduce whether the tested concrete has satisfactory or not stability, its values must be in the range of 0–15%. The results of sieve stability test used to measure the ability of self-compacting concrete to withstand the segregation, show acceptable values. For all

SSC mixtures with natural aggregates or waste aggregates have a segregation rate below 15%, synonymous with proper stability.

Based on the results of the three tests on fresh concrete (slump flow diameter, L-box, and sieve stability), it can be concluded that the SCC mixtures containing 25% recycled brick aggregates (25BSCC) or 50% recycled demolition concrete aggregates (50DSCC) as replacements for natural aggregates offer the best performance in meeting self-compacting concrete criteria.

Table 3. Fresh properties of all SCC mixtures.

Mix ID	Slump flow (mm)	L-box ratio (%)	Sieve stability (%)
NSCC	700	0.85	8.80
25BSCC	600	0.80	7.34
50BSCC	580	0.77	6.44
25DSCC	630	0.82	7.30
50DSCC	600	0.80	7.10
50BDSCC	580	0.79	6.20
100BDSCC	560	0.75	5.4

Hardened Concrete Properties

Compressive strength has been determined at 28 days in accordance with NF EN 12390-3 standard and the flexural strength test was carried out using a three-point loading method at 28 days of curing age, conforming to NF EN 12390-5 standard (Figure 8). Figures 9 and 10, presents the results of compressive and flexural strength at 28 days for all SCC mixtures.

a) Compressive strength test b) Flexural strength test

Figure 8. Tests on hardened concretes

By examining the Figure 9, it can be found that the compressive strength at 28 days is a decreasing function with the increase amount of recycled waste aggregates, whatever the types of these aggregates, brick or demolition concrete aggregates, this decrease is proportional to the amounts of recycled aggregates substitute the natural aggregates, it reaches 50% in the case of concretes containing 100% of recycled combined aggregates. For the flexural strength (figure 10), we noticed the same trend. Indeed, increasing the recycled aggregates rate decreases the flexural strength of SCC mixture of 33% for a substitution rate of 100% (table 4). This reduction in resistance can be explained by the decrease of the compactness of the granular mixture as well as the hardness of the waste which is lower compared to sand-lime granules, which causes an increase in porosity and decrease in strength. Nevertheless, we can notice that for SCC mixtures containing 25% of recycled aggregates, the compressive strengths loss about 13% and 15% for recycled brick and demolition concrete aggregates, respectively. All SCC mixtures with combined recycled aggregates have strengths lower than SCC mixtures with natural aggregates. The mixtures with 50% and 100% of both recycled aggregates waste, noted by 50BDSCC and 100BDSCC have given a reduction in compressive and flexural strength about 25 to 50% and 28% to 33% respectively, however, the SCC mixture containing 50% combined recycled aggregates waste, allowed us to gain in strength relative to the composition with 50% of brick waste or 50% of demolition concrete waste, or the decrease is less important with respect to these two compositions.

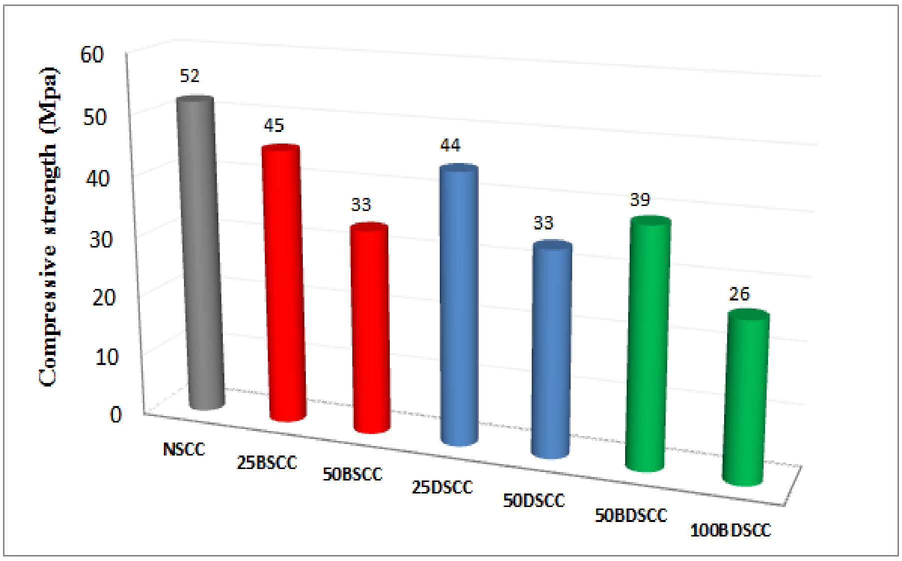

Figure 9. Compressive strength of all SCC mixtures

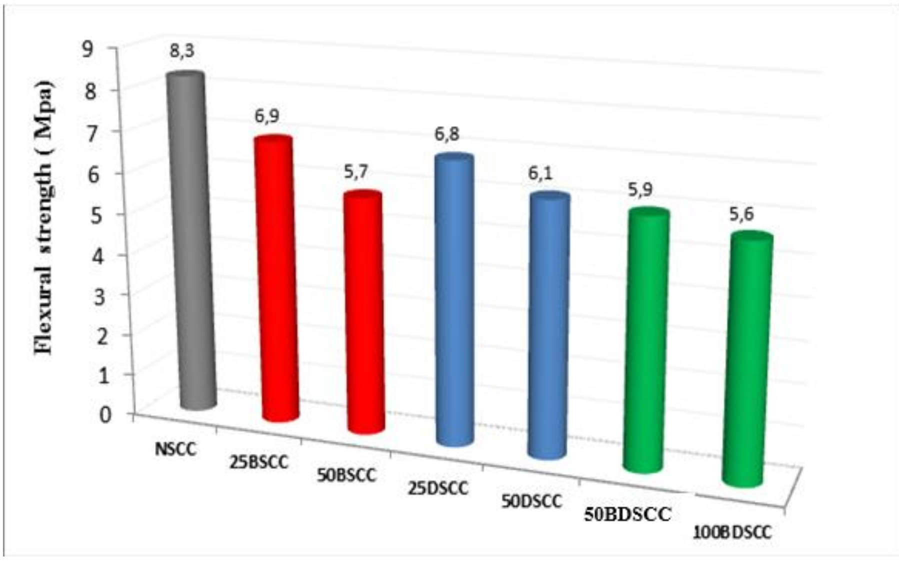

Figure 10. Flexural strength of all SCC mixtures

The SCC mixtures with 25% of any recycled aggregates or 50% of combined recycled aggregates give satisfactory mechanical resistance; the decrease in the compressive strength is about 13% to 15% and 25% respectively. These formulations can be used for constructions that do not require great strength, and whose environmental and ecological interest allows the use of recycled waste brick or demolition concrete.

Table 4. Compressive and flexural strengths losses

Mix ID	Compressive strength loss (%)	Flexural strength loss (%)
25BSCC	13	17
50BSCC	38	31
25DSCC	15	18
50DSCC	38	26
50BDSCC	25	28
100BDSCC	50	33

Conclusion

This experimental investigation aims the effect of recycling waste materials, brick aggregates and demolition concrete aggregates on fresh and hardened properties of self-compacting concrete. The ecological benefit of effectively utilizing this waste material is another motivation for this work. In the light of obtained results, the following conclusions can be drawn:

- The increasing brick and demolition concrete aggregates as replacement of natural aggregates in formulation of SCC reduces the spread of concrete. However, the SCC mixtures containing recycled demolition concrete aggregates has a slightly greater spreading comparatively to SCC mixtures based on recycled brick aggregates.
- The concrete flows through the frames properly and no blocking has been observed for SCC mixes containing 25% replacement natural aggregates regardless of the type of recycled aggregates. However, the increase of brick aggregates until 50% causes immobility of concrete in confined environment, on the other hand the increase of demolition concrete aggregates until 50% has not caused immobility of SCC mixes.
- The mixture with 50% of combined recycled aggregates noted by 50BDSCC, has an acceptable workability and gives a satisfactory result concerning the passing ability of SCC in confined environment, (L-box ratio of 0.79).
- All SSC mixtures with natural aggregates or waste aggregates have a segregation rate below 15%, synonymous with proper stability
- The compressive and flexural strengths at 28 days, are a decreasing functions with the increase amount of recycled waste aggregates, whatever the types of these aggregates, this decrease is proportional to the amounts of recycled aggregates substitute the natural aggregates, it reaches 50% for compressive strength and 33% for flexural strength in the case of concretes containing 100% of recycled combined aggregates.
- The SCC mixtures containing 25% of recycled aggregates, have compressive strengths loss about 13% and 15% for recycled brick and demolition concrete aggregates, respectively.
- The SCC mixtures with 25% of any recycled aggregates or 50% of combined recycled aggregates give a satisfactory mechanical resistance; the decrease in the compressive strength is about 13% to 15% and 25% respectively.

Finally, we can be concluded from the fresh and hardened properties of concrete that the best formulations satisfying the criteria of self-compacting concrete are the SCC mixtures containing 25% of any recycled aggregates (25BSCC and 25DSCC) and 50% of combined recycled aggregates (50BDSCC) as replacement of natural aggregates, whose environmental and ecological interest allows the use of recycled waste brick or demolition concrete.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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