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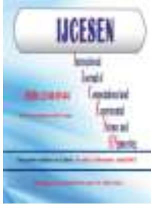

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Research Article

Development of Sawdust in Cement Particle Board Using Eco-Friendly Process

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Abstract:

Environmentally sustainable and effective methods of recycling industrial waste are needed due to its continuous rise. This study therefore looked at whether sawdust waste might be used to make cement-bonded particleboards and how to improve the sawdust's compatibility with cement through the use of physical pretreatment techniques, the addition of nano slag, and rapid carbonation curing. Each test was conducted using a separate set of manufacturing setups, including treated and untreated wood, CO_2 solidification, nano-slag addition, and sawdust/cement ratios of 20%, 30%, and 40%. The mechanical properties of the produced particleboards were experimentally evaluated, including density (D), water absorption (WA), thickness expansion (TS), and flexural strength (BS). The microstructure of the cement particleboards was analyzed using SEM or scanning electron microscopy. The results showed that employing the accelerated CO_2 curing procedure for sawdust particleboards improved the mechanical and microstructural properties of the sawdust-treated cement bonded particleboards. The SEM micrographs demonstrate that some of the carbonate crystals both protruded from sawdust surfaces and diffused into the cell walls and cavities.

1. Introduction

Human activities generate large amounts of wood waste each year, which can be used as industrial and agricultural residues. If water is excluded, wood-cement particleboard consists of 60-90% by weight of cementitious materials (20-55% by volume) and 10-40% by weight of wood (45-80% by volume) [1, 2]. Almost all studies on wood-cement composites support the hypothesis that wood hinders the setting and solidification of cement. Compounds that negatively affect cement hydration include sugars, tannins and starch [3]. The topic of sustainable development has become increasingly important since the beginning of the industrial revolution in the 19th century. The CO_2-accelerated curing process has revolutionized the production of wood-cement composites [4]. Carbonation has been accepted as an accelerated curing process in cement-based composites because it is a CO_2 sequestration technology that can improve product quality. CO_2 can be used to accelerate the curing of cementitious matrices to improve the long-term strength and durability of composites including sawdust particles, as the matrix's alkalinity is reduced and its hostility to wood particles is reduced [5]. The compatibility of wood and cement is a fundamental issue in wood-cement composites. Many types of wood cannot be used with cement because soluble carbohydrates and certain wood extractives prevent cement from setting and hardening [6]. In general, lignin appears to have little effect on cement hydration, while sugars, acids, hemicelluloses, etc. tend to greatly alter cement hydration [7]. The carbonization of wood cementitious materials offers great potential for developing good wood-cement compatibility. Since cement hardens very quickly, the inhibitory substances in the wood have little effect on cement hydration [8]. Another approach is to treat the wood with chemicals or hot water before mixing. In fact, this is currently the most widely used technique to reduce the deleterious effects of wood on cement hydration. [9]. The compatibility of wood and cement can be enhanced by adding silica fume or rice husk ash, which will increase the composites' strength. With the inclusion of fly ash, particleboards have improved mechanical and physical properties [10,11]. Composites composed of wood and cement combine the superior qualities of two essential building elements. It is well renowned for having good strength, stiffness, and resistance to water, fire, and decay attack. It is also easily machinable, making sawing, drilling, and nailing tasks simple. Excellent heat and sound insulation qualities as well as high impact resistance were tested. Although the items were safe for the environment, neither during processing nor during usage do they produce any dangerous pollutants. Moreover, inexpensive and light in weight [12]. Arenga Pinata fibers in smaller percentages (0.6–0.8) demonstrated a 120% increase in flexural toughness over those in larger volumes [13]. When the cement/wood ratio increases from 0.75 to 1.5, the flexural strength properties of the board improve [14]. In addition, when the cement/wood ratio increases above 2.0, the flexural stiffness of the wood particleboard decreases [15]. The aim of this study was to improve the mechanical properties of cement-bonded particleboard. The properties of cement-bonded particleboard were also examined with sawdust additives, nano-slag, and faster carbonization. In addition, the release of carbon dioxide gas into the atmosphere was studied.

2. Materials and methods

2.1 Properties of Materials

The main raw materials used were Type I cement, microsilica fume, natural fine aggregate, tap and distilled water, superplasticizer, nano slag and sawdust particles. The particleboard was made of ordinary Portland cement (I.Q.S. 5/1984 corresponding. Table 1 shows the chemical composition of nano slag and microsilica fume (manufactured by BASF). Microsilica pozzolanic additive was used with an accelerated pozzolanic strength activity index of 135%. The results showed that the microsilica fume and nano slag used in this study met the ASTM C-1240-05 and ASTM C-618 standards. The combination used Sika ViscoCrete 5930, third generation premium HRWR (SP), with a density of 1.095 g/cm^3. Type G is the classification specified by ASTM C494-03 for this superplasticizer. The sawdust particles were purchased from an Iraqi timber company. After further grinding, the sawdust was sieved to a mesh size of 4 mm in a lobster mill as shown in Figure 1. Table 2 lists the physical properties of sawdust particles. Physical particle preparation (keratinization) was performed to remove extractables that hinder cement reaction. Toxic extractables were eliminated by heating the sawdust in 20% $Ca(OH)_2$ saturated water for 60 min [16]. Table 3 shows the particle sizes of sand and sawdust used in this study. In this study, natural sand with I.Q.S. No. 45/84, zone 3, with a maximum size of 4.75 mm was used as fine aggregate.

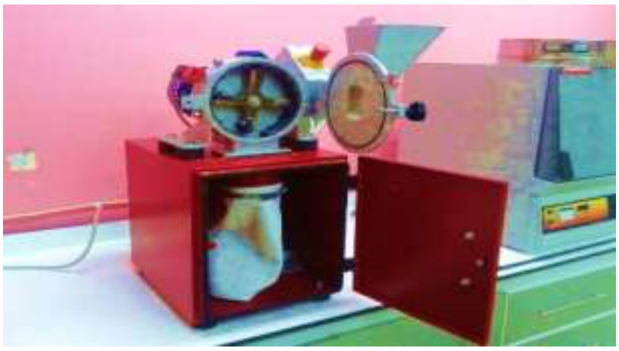

Figure 1. *The humming machine for producing sawdust.*

2.2 Experimental Setup

Equations 1 and 2 illustrate how the amounts of raw materials required to create the particleboard were calculated using the Japanese industrial standard for particleboards (JIS A 5908: 2003):

$$G = \frac{DV\delta}{(1+B+R)} \qquad (1)$$

$$P = GB(1+M) \qquad (2)$$

The variables in these equations are: G = mass of cementitious material used to make particleboard; P = mass of sawdust used to make particleboard; D = target board density (D = 1400 kg/m^3); V = target board volume (m^3); δ = raw material loss coefficient during production (δ = 1.1); B = sawdust-cement mass ratio (%); M = moisture content of sawdust particles (%); R = water-cement ratio (%).According to ASTM C1185-12 standard, cement-bonded particleboards made of treated and untreated sawdust particles with a density of 1400 kg/m^3 were used in this study and examined after

Table 1. *Micro silica and nano slag's chemical structure.*

Constituent	Micro Silica (%)	Nano Slag(%)	Limits ofASTM C-618/05
CaO	1.27	1.16	
SiO_2	89.36	67.95	≥ 70 %
Al_2O_3	0.81	20.75	
Fe_2O_3	0.52	3.50	
SO_3	1.04	0.01	≤ 5
NaOH+KOH	1.33	0.50	
Loss on Ignition	4.7	-	≤ 6 %
Fineness	≥ 15000 cm^2/gm	= 63 nm *	

28 days. Based on previous studies, the experimental factors were as follows: Sawdust/cement: 20%, 30%, 40%; treated and untreated wood; CO_2 hardening; addition of nano-slag with a constant water-cement ratio of 30%; addition of 1% SP by weight of cement; nano-slag added at 0.2% by weight of cement; and replacement of 20% of the weight of cement with microsilica. The 305 x 152 x 20 mm samples were all stored in the mold and covered with a moist burlap wrap for a whole day. The particleboard was then carefully removed from the mold, dried at 105 ± 2 °C for 30 minutes and cured using the prescribed method. This drying process ensured a clear path for CO_2 production. The samples in the curing chamber were soaked with 6.9 MPa (1000 psi) of CO_2 gas at 55°C for 2 hours as shown in Figure 2. Sample preparation for this and subsequent parts included applying a vacuum for 20 minutes before injecting CO_2 with a CO_2 flow rate of 10 L/min. Structural analysis of the fracture surfaces of all samples was performed using a SEM model: TESCAN-VEGA/USA, equipped with a tungsten source and a 20 mm detector to confirm whether accelerated carbonation occurred. Similarly, X-ray diffractometer (XRD) analysis was used to characterize the reaction products of concrete samples of different mixtures. XRD is an ideal analytical technique for concrete research due to its easy operation and fast test speed. The method is non-destructive and requires only a few grams of material to examine, making it an effective tool for studying crystal structures.

Table 2. *Sawdust particles' appearance.*

Features	**Values**
Specific gravity	0.65
Water absorption (%)	189
Moisture content (%)	62
Dry density (kg/m^3)	627

Table 3. *Grading of sawdust and sand particles.*

Type	Sieve size (mm)						
	10	4.75	2.36	1.18	0.60	0.30	0.15
Sawdust	100	79	38	13	5	4	1
Sand	100	92	80	54	42	13	5

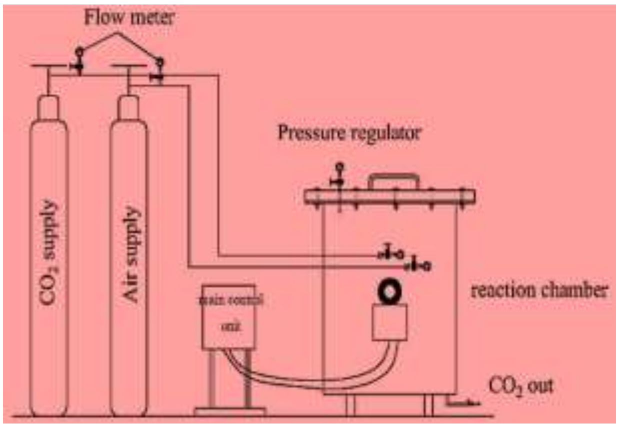

Figure 2. *Experimental setup for CO2-curing.*

3. Results and Discussion

3.1 SEM Micrographs Outcomes

Figure 3 shows sawdust particleboard with fractured surfaces captured in SEM micrographs before and after various acceleration effects. Five representative pictures were taken for each sample, and only one SEM micrograph was selected from the set. $Ca(OH)_2$ appears to be clearly coated on the surface of the sawdust particles (arrow 1/a). Moreover, it is clear that after sawdust pretreatment, there is a strong bond between the sawdust particles and the cement paste, which is why the cracks form far away from the ITZ (arrow 2/a). Therefore, the fracture cracks start when failure occurs within the ITZ and on the sawdust particles. At the same time, the cross-section of the sawdust particles used here consists of empty black holes (arrow 3/b). In the non-carbonized samples, these black holes are not filled; however, for the carbonized boards, they are completely filled with $CaCO_3$. After CO_2 curing, plate-like $CaCO_3$ can be seen on the particle surface and around the fiber pores (arrow 4/c). To this end, the carbonized cementitious matrix is denser than the control mixture, which can improve the interfacial transition zone between the particles and the cementitious matrix, undoubtedly increasing the flexural strength of the final composite. Also, from these micrographs, it can be seen that the addition of nano-slag to the cementitious matrix resulted in a denser and more compact cementitious matrix, as shown by (arrow 5/d). This improved contact between the sawdust and cementitious matrix can improve the adhesion between the two, reduce the ITZ thickness, and increase the panel density. This is due to the filling effect of carbonate crystals produced by carbonation and nano-slag. Figure 4 shows the results of X-ray diffraction spectra. Four representative mixtures - untreated test matrix, treated, carbonized, and including nano-slag - are represented by the data. For each of the

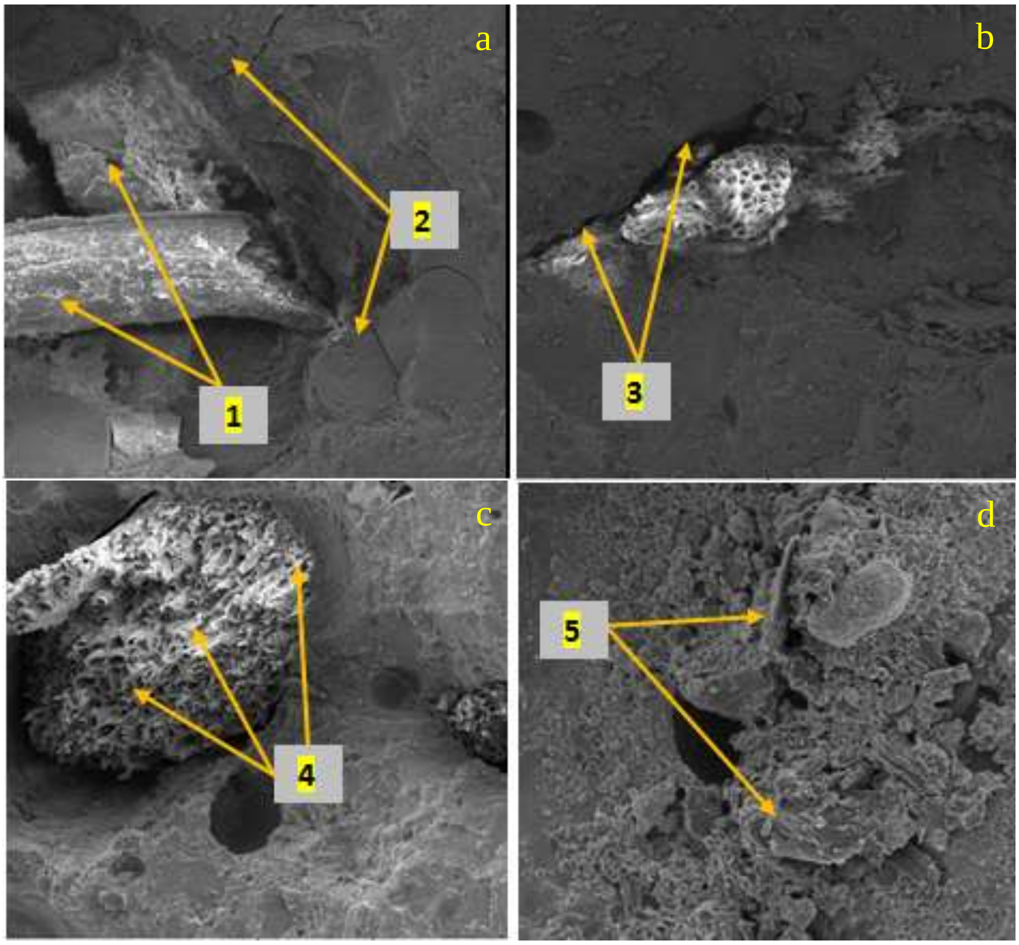

Figure 3. *SEM micrographs of the broken surfaces of the following: (a) treated, (b) untreated, (c) CO2 cured, and (d) added nano slag.*

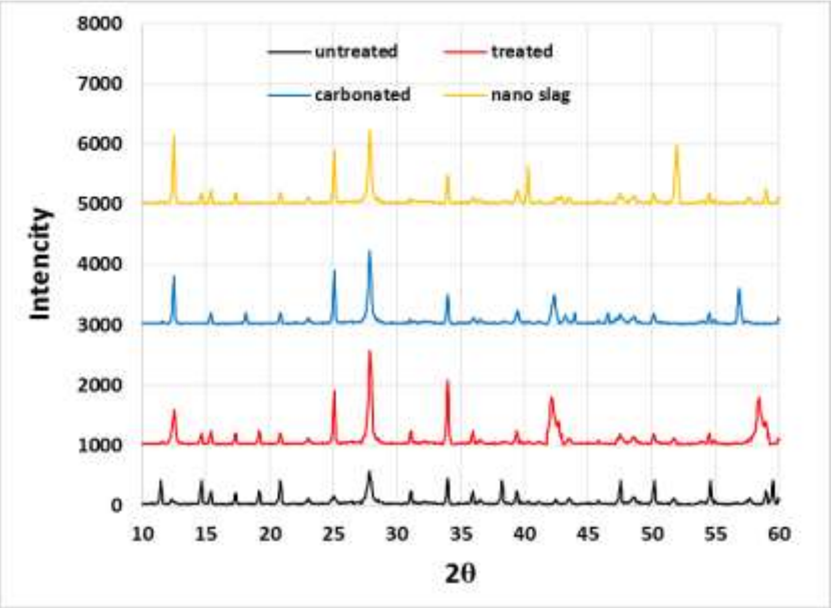

Figure 4. *X-ray diffraction results for the following conditions: (a) untreated; (b) treated; (c) carbonated; and (d) with nano slag.*

studied mixtures, large humps ($CaCO_3$ and CSH) were observed in the diffraction pattern between 13°, 25°, and 30° 2θ values. At the same time, small peaks in the diffraction pattern were observed between 34°, 43°, and 52° 2θ values ($Ca(OH)_2$ and quartz Qz). This could be due to the presence of amorphous glassy material due to increased cementitious activity (in the case of treated sawdust), carbonate hardening or the presence of carbonate crystals due to pozzolanic activity (related to the addition of nano-slag). It was found that the crystallinity of the untreated sawdust particleboard samples was lower than that of the treated carbonate and nano-slag samples. These humps indicate the formation of aluminosilicate hydrate gel C-A-S-H, which was identified as the main reaction product of the hydration process in the specific diffraction pattern.

3.2 Mechanical and Microstructural Features Outcomes

Analysis of the data collected using the previously described test procedures revealed some insightful information about the effects of various variables on the mechanical, microstructural, and physical properties of cementitious particleboards. The results of the study showed that there were significant differences between the treated and untreated sawdust particleboards. The flexural strength and density of the treated sawdust particleboards appeared to be higher than that of the untreated particles. In addition, all the treated particleboards made from sawdust had lower moisture absorption and thickness expansion compared to the treated wood. All CO_2-hardened boards had higher flexural strength and density compared to the non-CO_2-hardened particleboards, which was associated with lower moisture absorption and thickness expansion. In other words, the samples cured with CO_2 gas showed less rebound in the panels after the water immersion period, making them stronger after 28 days than the samples prepared using the conventional method. The relationship between sawdust-cement ratio, thickness expansion, and moisture absorption for the different treatment settings is shown in Figures 5 and 6. After 24 hours of immersion in water, it can be clearly seen that the thickness expansion, moisture absorption, and sawdust-cement ratio of all the panels increased up to 210% and 66%, respectively. This is because the boards have more permeable wood particles. Furthermore, sawdust treatment, carbonization, and nano-slag addition had a positive impact on reducing moisture absorption and thickness expansion by up to 20%, 43%, and 24%,

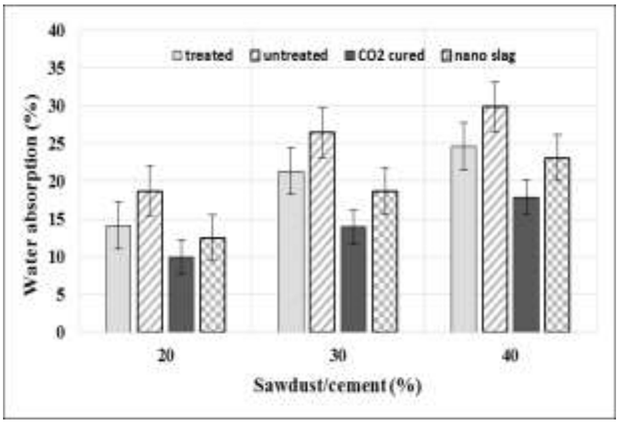

Figure 5. *Cement-bonded particleboard's water absorption.*

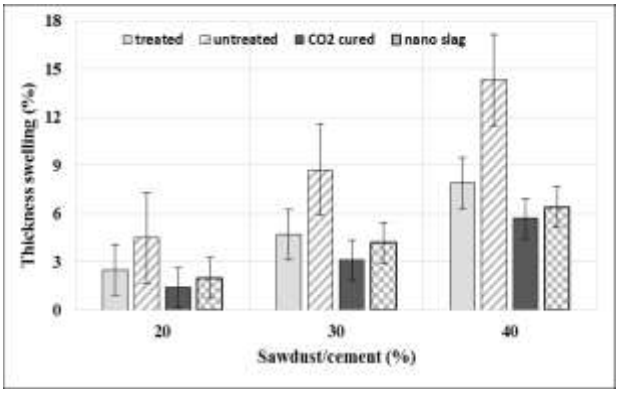

Figure 6. *Swelling of cement-bonded particleboard thickness.*

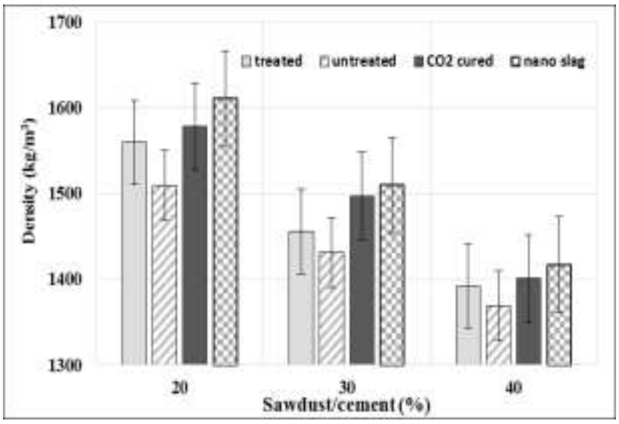

Figure 7. *Density of particleboard bound with cement.*

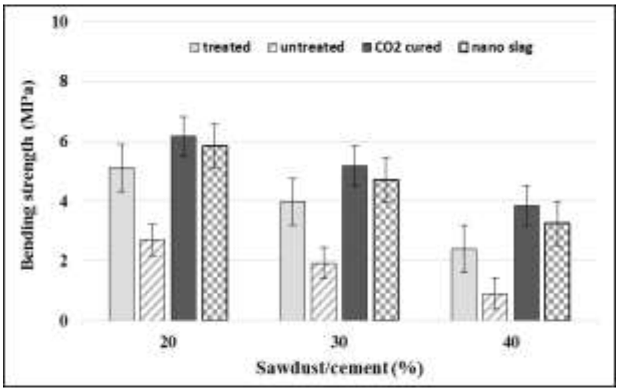

Figure 8. *The bending strength of particleboard bound with cement.*

respectively, compared to untreated sawdust particleboards. The elimination of extractable materials and the filling effect of nano-slag and its pozzolanic reaction could be the main reasons for these improvements. As can be seen in Figures 7 and 8, the denser particleboards did not result in higher flexural strength. This could be due to the petrification of sawdust particles due to carbonization solidification and improved interfacial transition zone, as shown in the subsequent SEM micrographs, and CO_2 solidification improved the bond between sawdust particles and the matrix. As a result, the bond between sawdust particles and the matrix increased, and the ITZ became thicker and stronger. Panels made from treated particles had higher density and flexural strength values compared to those made from untreated particles. Moreover, the density and flexural strength decreased the most (6%, 11%) and (17%, 48%), respectively, when the sawdust/cement ratio increased from 20% to 30% and 40%. However, after sawdust treatment, carbonization hardening and addition of nano-slag, the increase rates of density and flexural strength were 4%, 5% and 7%, 100%, 134% and 126%, respectively. In conclusion, these results all indicate that sawdust pretreatment, board carbonization and the addition of nano-slag help to improve the compatibility of sawdust particles with cement, thereby improving the strength of the final product.

4. Conclusions

Portland cement and treated sawdust are more compatible, as evidenced by the higher flexural strength, density, and lower water absorption and thickness expansion of the treated particleboard compared to the untreated particleboard. The particleboard and matrix appear to be improved due to carbonate hardening. It was found that some carbonate crystals protruded from the surface and were distributed in the cell walls and cavities of the sawdust. The densification of the interface transition zone and the petrification of the sawdust increased the ultimate strength. At the fracture surface, petrified sawdust with stronger bonding tended to break rather than separate. Petrified sawdust with higher bonding usually broke rather than separated at the fracture surface. Two types of peaks were seen in the X-ray diffraction spectrum: large peaks and small peaks. After sawdust treatment, the CSH peak in the X-ray diffraction spectrum became more obvious. After carbonate hardening, carbonate crystals appeared. After the addition of nano-slag, higher peaks appeared for stable CSH and CSH Qz.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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