2. Application of Power Ultrasound Treatment in the Preparation of Cement-Based Composites

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In order to enhance cementitious material hydration and increase the efficacy of substituting supplemental cementitious materials (SCMs) in terms of physicochemical and mechanical properties, a new approach such as the power ultrasound treatment (PUS) is presently being considered. The process by which PUS acts in cement-based composites is poorly understood, and a handful of studies have looked into this promising field. This is an up-to-date study that compiles all the information available for cement-based composites design and development, taking into account all PUS phenomena. Additionally, prior research on the mechanical and physicochemical effectiveness of PUS on cement pastes, mortars, and supplementary cementitious materials is reviewed and analyzed. This study also examines possible future directions, such as combining PUS with other physical processes like sonofragmenation to further improve treatment efficiency during PUS treatment. The conclusion of this study offers some remarks and future research perspectives that are required to obtain a fundamental understanding of this new field related to PUS treatment.

Keywords: power ultrasound treatment, early strength development, Portland cement, sonofragmentation, cement-based composites.

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Abbreviations

ASZ – amorphous synthetic zeolite,
DSF – densified silica fume,
GO – graphene oxide,
GBFS – granulated blast furnace slag,

MK – metakaolin,
NS – nano-silica,
PCS – polycarboxylate superplasticizer,
PC – Portland cement,
PUS – power ultrasound treatment,
SF – silica fume,
SP – superplasticizer,
SCMs – supplementary cementitious materials.

1. Introduction

The Portland cement's (PC) hydration process, which entails the conversion of anhydrous to hydrate phases, is generally acknowledged to be a complex dissolution-precipitation process [1]. Cement hydration products are characterized by a combination of interdependent microstructural and chemical phenomena and kinetic mechanisms of PC hydration, which are not fully understood. However, considerable effort has been invested in enhancing the perceived performance of PC in cement-based composites through an environmentally sustainable approach [1]. The idea of replacing PC with supplementary cementitious materials (SCMs) has recently generated a lot of scientific and environmental discussion to mitigate the use of natural resources and CO_2 emissions during cement production. The inferior early strength performance of low-CO_2 cement-based composites is the major reason impeding their use in practice [2, 3].

Improved consistency and fresh cement-based composite properties [4], reduced hydration heat evolution [5], enhanced mechanical/structural properties such as long-term strength development [6], increased durability [7–9], and decreased autogenous shrinkage [10] are some of the advantages that have been studied in cement-based materials that incorporate SCMs. Nevertheless, the application of SCMs frequently results in increased drying shrinkage [10, 12], decreased early strength development [6], prolonged setting times [11], reduced freeze-thaw resistance [13–15], decreased scaling resistance [13–15], and decreased slump flow and workability [13–15].

To maintain production cycles, high early strength is vital for the application of concrete technologies in modern construction. This issue can be resolved by using heat treatment, hardening accelerators, or cement clinker that contains more reactive strength-determining ingredients (like alite) [2, 3, 13–15]. Three primary approaches have been investigated to address the limitations and enhance the effectiveness of PC and SCMs in cementitious systems: thermal, mechanical, and chemical. There are two types of heat treatment, or thermal activation: calcination [16–18] and increased temperature curing [19]. Chemical activators [20, 21] can be used to chemically modify PC and SCMs, which can immediately disintegrate the structure, fracture the chemical bonds, and promote the formation of cement-based composites. The reactivity of the amorphous phases, the reduction of the specific surface area and soluble fraction, and the increase in the crystalline fraction have all been found to be limiting factors for the former. In cementitious materials that incorporate SCMs at later ages, the latter frequently results in reduced strength development [22, 23]. By grinding certain types of SCMs into ultrafine powders over an extended period, mechanical methods have been widely used to enhance their pozzolanic activity. This accelerates the pozzolanic reaction rate and, in turn, the strength development of cement-based composites containing SCMs by decreasing the particle size distribution and increasing the dissolution of pozzolans [13–15].

Recently, power ultrasound (PUS) treatment has been developed as an unconventional method to improve the mechanical and microstructural properties of cement-based composites. In materials science and engineering, PUS has been applied to a variety of processes, including particle dispersion, surface cleaning, degassing, and nanostructure production. While some of these applications have been thoroughly studied, others, like the use of PUS to improve the properties of SCMs containing composites and regulate the performance and properties of cementitious materials, have not yet been examined and provide interesting new opportunities. In order to provide an overall assessment of the mechanical strength, porosity, permeability, and durability of cementitious composites, a number of PUS techniques have been employed to characterize the hardening and setting processes of cement pastes, mortar, and concrete. The impact of PUS on the efficiency of cementitious matrices and composites' early age hydration reactions, including SCMs, has been investigated in a few studies [24, 25].

The literature on PUS's impact on SCMs and cement-based composite preparation is examined in this work, along with some of the underlying mechanisms in action. We compare the effects of various PUS power and time on compressive strength. Additionally, this work aims to help disperse SCMs and cement paste by using the PUS technology. The most advantageous ultrasonic parameters for cement-based material strength development are identified using this method. PUS's potential uses in cement-based materials will also be taken into account.

2. Basic principles of the role of PUS in the preparation of cement-based composites

Sound waves with a frequency higher than the human auditory limit (often $\geq$20 kHz) are referred to as ultrasound. Physical and chemical processes are involved in PUS. The mechanical impact of unstable cavitation prevails at low frequencies (20 kHz to 80 kHz), and the bubbles collapse more violently as the frequency gets closer to 20 kHz [24, 26]. The chemical impact is stronger at high frequencies (>100 kHz), when more bubbles develop and collapse with less force. Regarding the PUS's chemical impacts, the precise term 'sonochemistry' was specifically created to refer to a unique field of research where strong PUS either initiates chemical reactions or just takes part in some chemical processes as the potentially disruptive and unconventional technology. Sonochemistry's versatility across a wide range of domains can be attributed to its widespread application. Furthermore, the 'cavitation' effect – that is, the continuous rarefaction and compression cycles – occurs when an ultrasonic wave passes via a liquid medium, and is responsible for the most often seen effects of PUS treatment on solid surfaces and chemical reactions. Acoustic cavitation or implosion is the term used to describe this bubble formation, growth and an implosion process. Extreme temperatures (5000 K) and pressures (1000 bar) generated by cavitation bubbles (Fig. 1) have the potential to produce extremely high shear forces [24–26]. High-speed jets, reactive radicals, and shock waves all accompany this spectacular collapse at the same time. These extreme conditions are the main preconditions for the special physico-chemical processes that sonic cavitation in liquids causes. The heart of sonochemistry is the PUS irradiation of liquids, which locally creates pressure changes to support green chemistry's objectives by employing more environmentally friendly techniques to address the current environmental challenges. PUS treatment can solve problems with cement particle hydration, such as hydration rate control, packing density control, and aggregation/agglomeration, when preparing cement-based composites. The mechanical properties and durability of hardened cement materials are greatly influenced by pore structure, and hydration mechanisms during PUS treatment are intricate [24–27]. The early age and long-term strength properties of cement-based composites are largely controlled by the penetration/dissolution of anhydrous phases during hydration [24–27]. PUS does not affect the overall heat release, but it speeds up the heat release rate during the hydration acceleration phase [25] (Fig. 2). Rapid cement hydration is probably the cause of the increased strength growth in PUS treatment of cement suspensions that is seen for the first 16 h [25].

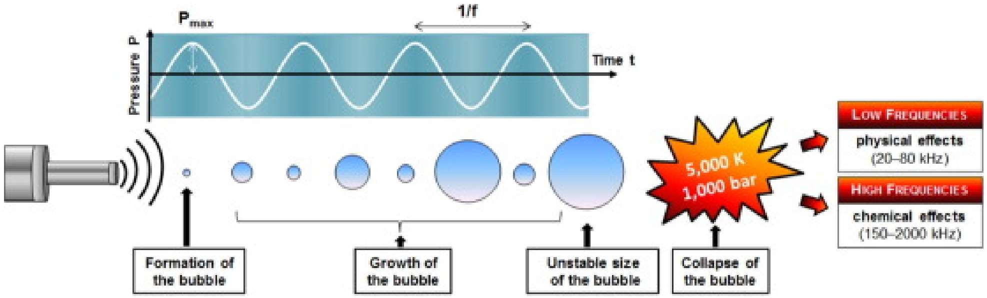

Fig. 1. PUS methodology (open access status) [25].

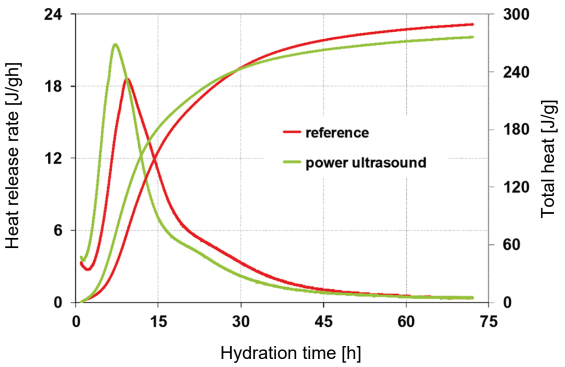

Fig. 2. PUS treatment's impact on cement hydration (open access status) [25].

It is noteworthy that PUS can achieve a high dispersion of particles uniformly dispersed into cement paste, increase the specific surface area, improve the pozzolanic reactivity of mineral additives, change the degree of de-agglomeration (particles become more stable and have a lower propensity to agglomerate), and alter the particle size distribution in favour of smaller particle sizes. Furthermore, during the cement hydration-acceleration phase, PUS can accelerate the heat release rate.

3. Supplementary cementitious materials treated by PUS

There are several methods for avoiding agglomerates, including mixing and grinding. Deagglomeration is physically limited by both of these techniques, and because the particles come into close contact with the mill, contaminants may be added. However, PUS treatment can offer many options for reducing agglomeration in liquid suspensions of particles (Table 1). Additionally, it has

Table 1. Supplementary cementitious materials treated by PUS.

Material subjected to sonication	Power of PUS [W]	Frequency of PUS [kHz]	Treatment time [min]	Ref.
Densified silica fume	600	20	2–20	[28]
Silica fume	215	35	5–35	[29]
	30	20	0.25–60	[30]
	750	20	10	[31]
Nano silica	400	24	10	[32]
	135	59	5	[33]
Metakaolin	720	20	60	[34]
Zeolite	60	28	15	[35]
Electric arc furnace slag	120	40	30	[36]

been used extensively to disperse mineral additives in aqueous solution based on acoustic cavitation caused by PUS treatment, such as silica fume [29, 37], clays [38], and glass fume [39].

PUS dispersion has the important advantage of producing silica fume (SF) particles that are usually 1 µm or smaller, which raises the reactivity of SF in concrete [40]. An ultrasonic dispersion device is installed in the water tank as part of the industrial concrete manufacturing process to incorporate ultrasonic dispersion. In order to create a suspension, the necessary quantity of SF is added first. The apparatus for dispersing ultrasonic waves is then turned on before the suspension is added to the concrete mix while it is being mixed [40]. According to Fraga *et al.* [31], sonication effectively disperses silica fume, increasing the amount of C-S-H phase and densifying cement pastes' microstructure that includes SF. When densified SF was subjected to a 25 min of PUS treatment, the particle size decreased from 22 µm to 4 µm [28]. Similar outcomes to those of Wang *et al.* [41] were obtained using the ultrasonic dispersion technique. After 12 min of PUS treatment, the low-grade silica fume's particle size was less than 10 µm, while the high-grade silica fume's was around 4 μm [41]. Additionally, the de-agglomeration of particle agglomeration by PUS treatment is a key step in the sonication process. Therefore, 12 min can serve as a useful reference point for analysing how the sonication dispersion duration affects the distribution of SF particles [41]. According to Ni *et al.* [42], the densified silica fume (DSF) particles clearly raise the cement's hydration heat release rate considerably following ultrasonic treatment. Martınez-Velandia *et al.* [28] investigated the sonication procedure of the DSF to deagglomerate the SF and reduce particle sizes. Sonication improved the pozzolanic properties of DSF and increased the pace of interaction with calcium hydroxide by producing a larger proportion of extremely small particles. Additionally, this behaviour makes it possible to increase the mechanical strength of mortars prepared with sonicated silica fume. Submicrometric particles might be produced in greater quantities by increasing the sonication power level and duration. According to Rodríguez *et al.* [43], densified silica fume's reactivity is increased by sonication through the deagglomeration process. When SF particles were evenly distributed throughout the cement paste, the C-S-H phase development was accelerated. Cement pastes prepared with the sonicated SF showed a significant reduction in calcium hydroxide concentration after 28 days of curing. In contrast to samples prepared with raw silica fume, Wang *et al.* [44] found that cement paste that had solidified and included sonication-treated SF had higher strength, indicating more efficient dispersion of sonication-treated SF in the cementitious materials. The pozzolanic activity of SF in cementitious materials was enhanced to generate calcium silicate hydrate, which improved the compressive strength. This was due to the silica fume's good particle size distribution and improved cementitious material dispersion [45].

The use of dispersion techniques prior to mixing and in conjunction with high-shear mixing, such as silica fume-slurry preparation using sonication treatment [46], can serve as an alternative method of preparation for paste samples. Agglomerates frequently undergo partial disintegration after PUS treatment, resulting in tiny fragmented agglomerates that are usually around 0.5 μm in size. However, the degree of partial fragmentation breakdown varies greatly throughout densified silica fumes. Relatively short ultrasonic treatments are typically used for dispersion treatments, which separate individual particles from one another [46]. The moderate PUS treatment can disperse DSF from some sources into tiny chains of spheres or clusters, whereas other sources resist this treatment and mostly stay as massive agglomerates. Large amounts of agglomerates are nearly always retained in concrete under standard mixing conditions. The undispersed agglomerates that remain in concrete following mixing frequently have sizes larger than the PC particles, which limits the potential advantages of the fine particle filler effect [47].

Concrete's microstructure can be strengthened and consolidated by adding nano-silica (NS), which introduces nucleation sites for the precipitation and growth of hydrate phases at the nanoscale. In addition to reducing concrete shrinkage through its seeding action, appropriately sonicated NS may have increased the effect of NS on concrete by delaying the agglomeration of particles [32]. The most important de-agglomeration technique was sonication, which increased the concrete's compressive strength by 23 % with just 1 % nano silica (NS) substituted for cement [33]. Because NS is more dispersed after sonication, concrete workability was also much increased. The results showed that adding a modest quantity of NS shortens the setting time and increases the compressive strength after 3 and 7 days. When it comes to properly dispersing nano-silica, PUS treatment of the combination with water is likely a better option than mechanical mixing [48]. Hydrothermal synthesis can potentially be substituted with the sonication process. A method for turning rice husk ash into belite cement is described by Rodrigues [49]. In contrast to earlier studies, sonication, which is as effective but far less costly, replaced the hydrothermal treatment [49].

The scalable and environmentally friendly ultrasonic method that Long *et al.* [34] devised for the efficient preparation of high-dispersity metakaolin (MK) also shows a notable increase in cement composites' compressive strength. These findings would allow MK to be used in cement composites more successfully by increasing their advantages and reducing their cost. Carbon nanotubes must be uniformly dispersed, and this is accomplished by using a sonication approach [50]. Sonicating PC and carbon nanotubes at the same time is another technique for dispersing carbon nanotubes [51, 52]. After 3 days of hardening, sonication of the cement paste, irrespective of the presence of amorphous synthetic zeolite, considerably improves the compressive strength [35]. The aragonite whiskers, which fill the cement paste's pores as nanomaterials, can be evenly distributed by PUS. Furthermore, the nucleation of C-S-H during hydration was aided by the exposed silica-rich surface [36]. According to Kawashima *et al.* [53], PC and fly ash–cement pastes were used to examine the effects of sonication and blending of the nano-$CaCO_3$ on the hydration rate, setting time, and early compressive strength growth. In these instances, sonication improved the nano-$CaCO_3$'s impact. Cement composites' mechanical properties have been effectively enhanced by the use of this technique [53].

4. Cement paste and mortars treated by PUS

Given the significant physicochemical impact of PUS, it has considerable promise as a new PUS-assisted mixing technique for making homogeneous cement paste (Table 2). PUS-induced hydration is the primary cause of the mechanical properties. It suggests that cement-based materials may have their mechanical strength increased by the PUS treatment. This could be because sonication improves the material's homogeneity and disrupts the flocculation structure of the cement particles [54, 55, 60].

Table 2. Cement paste under the influence of PUS.

Specimen subjected to sonication	w/c	Power of PUS [W]	Frequency of PUS [kHz]	Treatment time [min]	Ref.
Cement paste	0.50	30–300	20	1–5	[54]
	0.50	593, 541	26, 132	2–10	[56]
	0.35	250	24	10–60	[57]
	0.30 0.50	100, 450, 900	28	1–30	[58]
	0.30 1.00	912	28	3	[59]

PUS can accelerate the early hydration rate, increase the mechanical properties, reduce the cement paste's dynamic yield stress and apparent viscosity, and efficiently disperse flocculated particles, according to a recent study by Xu *et al.* [54]. Following the PUS treatment, the hardened cement paste's C_3S content is marginally lower, and its C_2S level is noticeably lower than that of the cement paste without PUS. A homogenous maximum temperature field can be achieved by using 900 W (28 kHz) PUS treatment for 10 min, according to Xiong *et al.* [58]. PUS increases the compressive strength, accelerates C_3S consumption, and promotes Portlandite formation. The optimal combination of ultrasonic power and irradiation duration is thought to be 900 W for 10 min, taking into account the practical ranges of temperature rise. The acceleration of C_3S hydration by PUS is more noticeable at lower calcium concentrations, according to Remus *et al.* [61]. This implies that cements containing a larger percentage of

SCMs benefit most from the PUS treatment. PUS enhanced the yield of portlandite, precipitated extremely early C-S-H phases and amorphous AH_3, and accelerated the dissolution of Ca^{2+}, Si^{4+} and Al^{3+}, according to recent research by Ehsani *et al.* [62]. Additionally, the effect of PUS treatment on the chemical shrinkage of cement pastes and the development of mortars' compressive and flexural strengths was examined by Ehsani *et al.* [56]. The results demonstrated that applying frequencies of 26 kHz and 132 kHz to the cement paste for 2 min shortly after mixing the rate of chemical shrinkage increased. After mortars were cured for 91 days, sonicating at a more intense acoustic power of 26 kHz led to a faster growth of the compressive and flexural strength. When aggregates were added to the pre-sonicated paste, the flexural strength of mortars increased by 17 % after 28 days, suggesting that the paste-aggregate interface may have changed. PUS-assisted PC mixing was investigated by Xiong *et al.* [63] and applied varying ultrasonic power levels to the cement paste. The results showed that the cement paste's compressive strength, porosity, and degree of hydration all improved. The impact on the paste mixes of a temperature increase brought on by the use of a high-power ultrasonic system was not discussed. Only cement pastes with a w/c ratio of 0.3 were examined.

The impact of the PUS treatment on the pore solution of fresh cement pastes with varying water-to-cement ratios was further investigated by Ehsani *et al.* [64]. Their findings showed that PUS treatment increases the amount of aluminate ions released into the pore solution, which in turn encourages the formation of amorphous aluminum hydroxide hydrate. The PUS treatment is more adaptable and energy-efficient than conventional acceleration methods, like steam curing at high temperatures in the manufacturing of precast concrete. Xiong *et al.* [59] investigated the hydration and dispersion of the cement paste prepared by the PUS-assisted mixing technology. The PUS enhanced strength in the early stages and late hydration ages. After 1 day and 28 days, the compressive strength was increased by 26.1 % and 18.3 %, respectively, compared to the reference specimens. According to these results, PUS-assisted mixing is beneficial for improving the sustainability of building material production.

By applying PUS to fresh PC (frequency: 20 kHz, amplitude: 43 µm, energy input: 75 J/ml), Peters [65] was able to decrease the induction period and increase the heat release during hydration. PUS treatment was shown to primarily accelerate alite hydration without changing the cement's overall reaction pathway. By exposing more unwrapped surfaces of C_3S grains and providing more nucleation sites for the C-S-H growth, the facilitator of mass transfer and the localised erosion effect near the clinker surface significantly increase the precipitation of the very early C-S-H phase, according to the author's theory. Only one PUS power density/frequency was used for the PUS treatment, and a probe-based setup was used for the ultrasonic delivery. In either the cement suspension or the mixed mortar, this resulted in a notable increase in temperature in the high-energy cavitation zone formed near the probe tip. The increased dissolution rate of cement phases may result from erosion and exfoliation of anhydrous grains brought on by the accelerated mass transfer linked to PUS cavitation [24]. Additionally, cavitation can result in degassing or deaeration [66], which removes trapped air and affects the mechanical properties of cement-based composites [24]. In particular, this is true for longer exposure times of PUS treatment.

As high-intensity PUS waves propagate through the cement paste, the most significant energy transfer mechanism is conversion of sound energy into thermal energy [54]. However, there are still several unanswered questions and limitations in the current research on the thermal effect of PUS in the cement paste. In the first place, transducer reactors of the ultrasonic bath or horn types are commonly employed for experimental purposes [67]. Due to the constraints of physical sizes and technical procedures, the sound fields of the two reactors were both heterogeneous, even in the diluted solution [68]. The cement paste's temperature increased significantly near the reactor tips after the PUS treatment with the horn type [65]. The distinctions between the tip position and other positions, however, were not explained in that study. Prior research has not focused on the temperature evolution in the cement paste caused by batch-type reactors. Secondly, it is yet unknown how far the heat effect in cement paste will actually work.

The effects of PUS-assisted preparation on the mechanical and physicochemical properties of cement-granulated blast furnace slag (GBFS) composite pastes are examined for the first time by Lisowski *et al.* [69]. Using PUS in a pulse mode in the vertical jacketed glass sonoreactor with closed-circuit cooling (Fig. 3), specimens with different particle size fractions were obtained. Comparing the best-performing cement-GBFS composite to traditional mixing methods revealed a significant improvement in Vickers hardness and modulus of elasticity (98 % and 74 %,

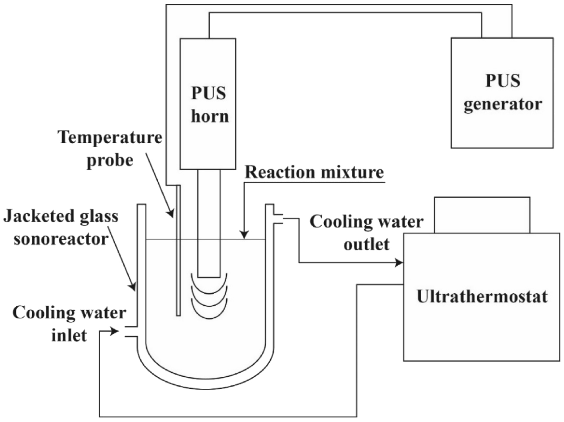

Fig. 3. System for the preparation of cement-GBFS composite under the impact of PUS (open access status) [69].

respectively), as well as compressive and flexural 2-day strengths (132 % and 58 %, respectively). In a similar vein, after 2 days, the BET surface area grew by about 111 %, the cumulative heat release increased by roughly 34 %, and the Portlandite content dropped by roughly 29 %.

The improved PUS treatment, combined with an effective cooling system to regulate the mixture temperatures, makes this study unique when compared to earlier research on PUS in cement systems. This enables progress in identifying the effects of PUS on the hydration and strength development of cement systems containing GBFS. The sonofragmentation (particle size refinement during the PUS treatment) of GBFS particles was tuned to maximize the effectiveness of the PUS treatment (Fig. 4).

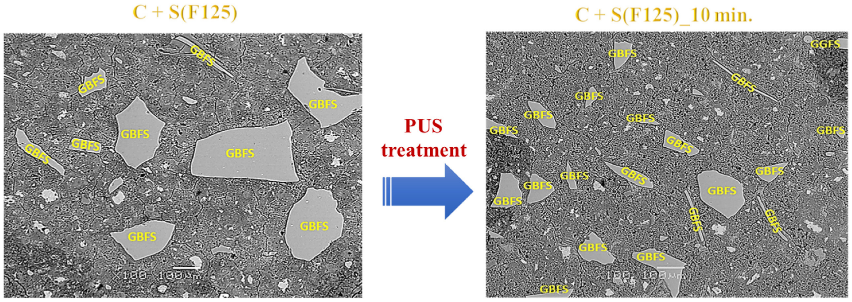

Fig. 4. SEM images of cement-GBFS composite without PUS and under the influence of PUS (open access status) [69].

Another interesting way to increase the early strength of concrete that contains SCMs is the PUS technique. Without sacrificing early strength performance, it is possible to substitute up to 30 % of the cement in concrete with SCMs by using the PUS treatment during the mixing phase [61, 70]. Furthermore, Serelis *et al.* [71] discovered that high-frequency PUS treatment can deagglomerate the SF and microfine cement powder particles. Xiong has also reported similar effects [63]. On the other hand, equally pre-dispersed graphene oxide (GO) was adsorbed on the surface of cement particles and quickly lost its redisperse ability when the cement paste was mixed with the GO aqueous solution [72]. Consequently, PUS is anticipated to enhance the matrix's mechanical properties and microstructure while preserving the graphene oxide's advantageous dispersion state throughout the mixing process. In addition to examining the dispersion and strengthening mechanism of the cement paste modified with GO, Xiong *et al.* [73] suggested the PUS-assisted mixing technique. The modified cement paste's GO particle size was significantly reduced as a result of the PUS-assisted mixing treatment. In cement composites, PUS-assisted mixing is expected to be a viable way to disperse GO and contribute to the realization of nanoengineering's wide-ranging applications.

When the hydrated cement pastes contain polycarboxylate superplasticizer (PCS), Wang *et al.* [57] examined the impact of the PUS treatment on cement hydration. The PUS treatment significantly reduces the setting time and increases the 1-day compressive strength of mortars containing PCS, according to the results, but it does not affect the reference mortar.

PUS's influence on hydration kinetics and deaeration performance by measurement of trapped air in concrete and mortar are two examples of how PUS works in cement-based composites, in spite of the fact that PUS has been used in industry for a variety of purposes [74, 75]. Additionally, bespoke PUS equipment that can perform sonication at different power and frequency levels is also needed. Vaitkevicius *et al.* [76] used a PUS (water-cooled transducer) to disseminate fresh 3D printed concrete and discovered that the cavitation effect of PUS greatly aided in the early growth of ettringite.

Furthermore, the mechanism of PUS's cavitation effect in the cement paste is not systematically discussed in the literature that is currently available; instead, it usually concentrates on the cement hydration acceleration from the perspective of PUS. Furthermore, more investigation is required to ascertain whether the PUS treatment causes temporary or permanent cavitation.

5. Concluding remarks and future trends

The possibilities of sonication to improve dispersion in cementitious systems and affect the properties of cement-based composites have been summarized in this work. Prior research found that PUS improved pozzolanic activity by facilitating the dispersion of natural pozzolans and mineral additives in cementitious systems. The amplitude and intensity of the sonication might be changed to provide stronger sonication effects on the early strength development of cement-based composites. Entrapped air spaces in hardened cement pastes and cement suspensions were eliminated by the PUS-induced degassing action, enhancing the mechanical characteristics that followed. The PUS technology is superior to some conventional procedures in a number of ways. Advantages include low energy usage (sustainable processing), easy scaling (viability), decreased or eliminated use of hazardous solvents (greener processing), and reduced or eliminated heat (non-thermal processing). Regarding the technology's scalability and commercialization, there are still a lot of obstacles to overcome. Despite being a 'green' technology with several possible field applications and multiple proven results from lab-scale operations, there aren't many viable PUS applications being implemented at the industrial scale. The lack of scale-up techniques for reactors to fulfil industrial demands is a significant barrier to the technology's further development. Without a thorough understanding of physical and chemical phenomena, it is impossible to manage the sensitivity and vulnerability of PUS systems to operating parameters. As a result, the current study also attempts to examine the primary parameters that should be taken into account when cavitational activity intensifies. Uniform distribution of cavitational activity inside the reactor, the precise term ‘Sonoreactor’ [77, 78], is one of the most significant issues in the PUS treatment scale-up design. Even though these reactors have higher operating costs than conventional ones, Lisowski *et al.* [69] proposed that a sonoreactor with closed-circuit cooling may be more cost-effective because of its unique ability to regulate mixture temperatures, which advances the understanding of PUS effects on cement-based composites’ hydration and strength development. The impact of sonotrode position and cycle (pulse control mode) on the cement paste treatment by PUS has not been investigated in any of the aforementioned studies. A sonoreactor’s design must include energy conversion, high volume operation, process efficiency, and rates that might result in higher treatment costs. Furthermore, because it is challenging to precisely replicate the Sonoreactor geometry and PUS environment that are comparable to laboratory-scale reactors, along with an even distribution of cavitational activity, it is crucial to make sure that the design of industrial-scale sonoreactors can achieve maximum efficiency. Since scaling up the process is still a significant difficulty, this approach is now far from being completely developed. The thorough investigation and understanding of a number of critical operating parameters, including temperature, ultrasonic frequency, sonication time, irradiation intensity, and sonoreactor design, are essential to bringing the lab-scale process to the level of industrialization. Designing and developing effective power ultrasonic systems (generators and sonoreactors) that can be tailored to each unique industrial process is also crucial. A description of the cavitational activity within the sonoreactor and the geometrical aspects of the employed sonoreactor should always be documented in terms of fundamental laboratory experiments. The comparability of various setups is sadly limited by the frequent absence of key elements in literature reviews, particularly those published in non-specialist publications. As it is being developed, the state-of-the-art for defining the entire spectrum of PUS’s chemical and physical impacts is still limited, even though this work compiles existing data and offers recommendations on how to employ analytical techniques to harness ultrasonic potential. A deeper understanding of the intricate physical-chemical processes that underlie PUS’s activities and how they impact its functional and technological qualities will also help reinforce the potential uses of PUS technologies in the cement and concrete industry in the future. In many industrial processes, the efficient application of high-intensity PUS will have a promising future.

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