Proceedings of the 10th World Congress on Civil, Structural, and Environmental Engineering (CSEE 2025)
Barcelona, Spain - April, 2025
Paper No. ICSECT 169
DOI: 10.11159/icsect25.169

Enhancing Cement Grinding Efficiency: Performance of Combined Polycarboxylate Ether and Triethanolamine Additives

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Abstract - Grinding is one of the most energy-intensive and costly processes in cement production, consuming nearly two-fifths of the total electrical energy. To enhance efficiency and mitigate environmental impacts, including greenhouse gas emissions and energy waste, grinding aids (GAs) are widely utilized, with amine- and glycol-based additives being the most common. While these additives enhance grinding efficiency and cement properties, they can negatively affect setting time and fluidity. Polycarboxylate ether-based water-reducing admixtures (PCEs) have emerged as promising alternatives due to their similar mechanisms of action. Studies indicate that PCEs can achieve comparable grinding efficiencies to conventional GAs, and their combination with triethanolamine (TEA) offers further performance benefits. This study investigated the time-dependent grinding efficiency of cement when TEA and PCE were used individually and in combination. A Bond ball mill was used for grinding experiments, with TEA, PCE, and a combined P-TEA additive (PCE and TEA in a 1:1 ratio) added at 0.05% of the total clinker and gypsum weight. Blaine fineness values (cm²/g) were measured after 2000, 4000, and 6000 grinding cycles. All GA types improved Blaine fineness compared to control cement, confirming their effectiveness. Among them, the P-TEA combination exhibited the highest performance, demonstrating a synergistic effect between PCE and TEA. These findings highlight the potential of combining PCE with traditional GAs to optimize grinding efficiency and cement performance. The superior results achieved with P-TEA suggest that tailored formulations integrating PCEs with conventional GAs could enhance both grinding efficiency and cementitious properties, contributing to more sustainable cement production.
Keywords**:** Grinding efficiency; grinding aids (GAs); polycarboxylate ether-based admixtures (PCE); triethanolamine (TEA); Blaine fineness

1. Introduction

The cement industry presents a major environmental challenge due to its high energy demand, depletion of raw materials, and significant carbon dioxide emissions [1,2]. Cement production is responsible for approximately 5-7% of global CO_2 emissions [3]. The manufacturing process requires around 1.2 metric tons of raw materials and 130 kilowatt-hours of energy per metric ton of cement, resulting in nearly one metric ton of CO_2 emissions [1,4]. Among the various stages, clinker grinding consumes approximately 60% of the total energy input, with substantial losses occurring as heat, noise, and vibration [5]. To improve energy efficiency and mitigate emissions, Grinding Aids (GAs) are incorporated during clinker grinding [6,7]. These additives adsorb onto clinker particle surfaces via highly polar functional groups (-OH, $-NH_2$, -COOR, $-SO_3$, etc.), neutralizing surface charges, and reducing particle agglomeration and adhesion to milling components [8].

Amine-based GAs, such as triethanolamine and triisopropanolamine, are commonly used in practice [2, 9-10]. While these additives effectively enhance grinding efficiency [8-11], they also exert a significant impact on the fresh and hardened properties of cementitious systems [2,12]. Besides, amine- and glycol-based GAs have been associated with drawbacks such as undesirable effects on setting time and fluidity [2,4,9]. As a result, polycarboxylate ether-based water-reducing admixtures (PCEs) have emerged as promising alternatives due to their similar mechanisms of action [1,11]. The incorporation of PCE-based admixtures as GAs can enhance the fresh-state properties of cementitious systems by improving the dispersion of cement particles, a phenomenon attributed to the adsorption behaviour of PCE [12].

Research has shown that PCEs can achieve grinding efficiencies comparable to conventional GAs [12-14]. Notably, studies indicate that incorporating PCEs with commonly used additives, such as triethanolamine (TEA), enhances performance compared to using PCEs alone [15-17].

This study investigated the time-dependent grinding efficiency of cement by combining TEA with PCE. Grinding experiments were performed using a Bond ball mill, where TEA, PCE, and a combined P-TEA additive (a 1:1 mixture of

PCE and TEA) were dosed at 0.05% of the total clinker and gypsum weight. Blaine fineness (cm^2/g) was measured after 2000, 4000, and 6000 cycles to assess grinding performance.

2. Material and Methods

Clinker grinding was conducted using a laboratory-scale ball mill under the ball conditions specified in Table 1. The control cement, produced in accordance with TS EN 197-, contained 96% clinker and 4% gypsum, without the addition of GAs. GAs was incorporated at a dosage of 0.05% of the total clinker and gypsum weight. Consequently, four different CEM I 42.5 R type cements were produced, including one with PCE, one with a PCE-TEA blend (P-TEA), and one with TEA, alongside the control cement containing no GA. The physical and chemical properties of the clinker and gypsum, as provided by the manufacturer, are summarized in Table 2.

Table 1: Ball mill conditions used in the grinding process

Ball diameter (mm)	**Ball Distribution (Bond-type) (pcs)**
37	43
30	67
25	10
20	71
15	97
Total surface area (mm^2)	551796
Total weight (g)	19922

Table 2: Chemical contents of clinker and gypsum

Chemical Component	**Chemical Content Value (%)**	
	Clinker	**Gypsum**
SiO_2	21.12	2.43
Al_2O_3	5.58	0.70
Fe_2O_3	3.26	0.37
CaO	66.71	31.78
MgO	1.11	0.56
SO_3	0.50	42.30
Na_2O	0.51	0.15
K_2O	0.68	0.10
Cl	0.02	
Loss on ignition	0.30	

Some chemical properties of triethanolamine (TEA) and PCE used as GAs are presented in Table 3. As stated in the introduction, P-TEA was prepared by blending TEA and PCE in a 1:1 ratio.

Table 3: Chemical content of GA used

Type of GA	Alkaline content (%) (Na_2O)	Density (g/cm^3)	Solid content (%)	Chloride content (%)	pH 25 ° C
PCE	<10	1.10	40.25	<0.1	3.82
TEA	<10	1.10	85.00	<0.1	10.00

In a Bond-type mill, clinker and gypsum (passing through a 3.35 mm sieve) were ground following Bond standards, both with and without GA (control cement), up to 2000, 4000, and 6000 cycles. After grinding, Blaine fineness values were measured to assess grinding performance.

3. Result and Discussion

The Blaine fineness values of all cements after 2000, 4000, and 6000 cycles are presented in Figure 1.

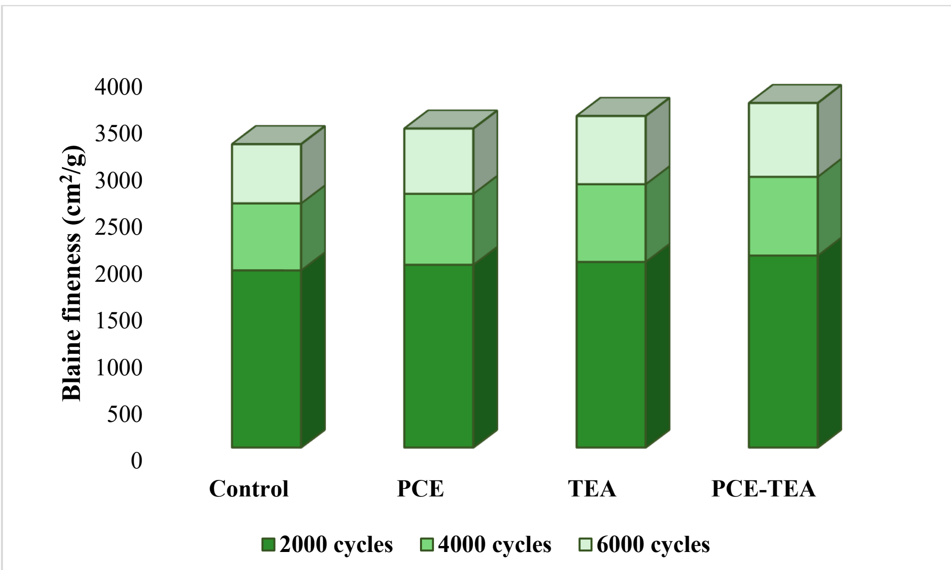

Figure 1: The Blaine fineness values of all cements

As shown in Figure 1, grinding performance, measured by Blaine fineness, improved with the use of GA, regardless of the GA type. Additionally, the Blaine increase relative to the control cement became more pronounced as the number of grinding cycles increased, independent of the GA type.

The use of PCE-based GA resulted in a 3–5% improvement in grinding performance compared to the control, while TEA led to a 5–9% increase. The highest enhancement, ranging from 8% to 14%, was achieved with P-TEA, a blend of PCE and TEA. To better illustrate the effect of increasing grinding cycles on GA performance, Figure 2 presents the relative Blaine values of cements containing GAs at all cycles compared to the control cement.

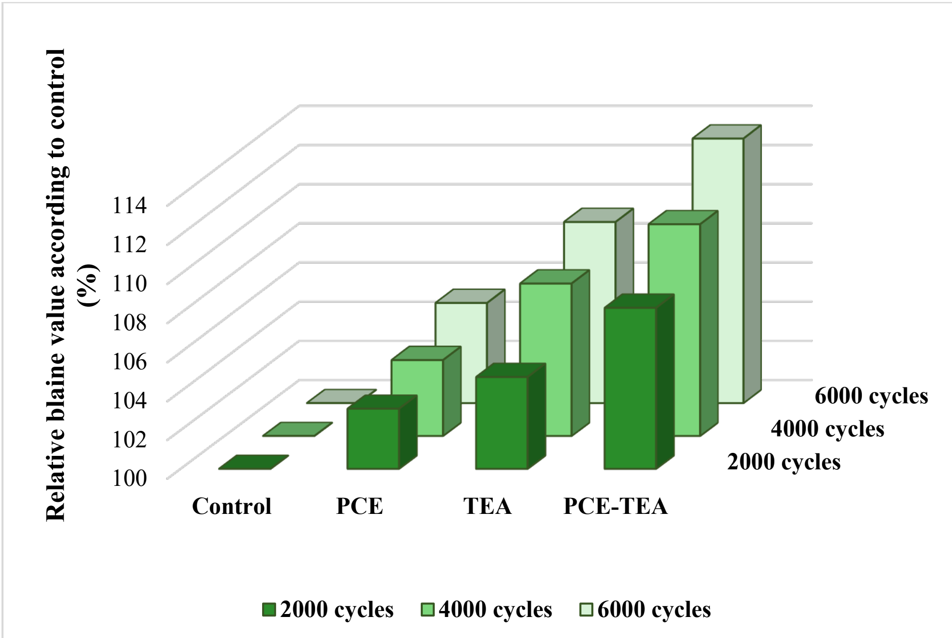

Figure 2: The relative Blaine fineness values according to control

As shown in Figure 2, the grinding performance of all GAs increases with the number of revolutions. When ranked, the performance of the GAs follows the order: PCE < TEA < P-TEA. Previous studies have noted that PCE-based GAs perform less effectively than TEA [16]. This has been attributed to the limited surface coverage at low dosages typical for grinding, which restricts dispersion efficiency compared to low molecular weight compounds [15].

On the other hand, as observed in this study, the grinding performance was improved by the synergistic effect of P-TEA, formed by the PCE-TEA blend. This enhancement was attributed to the increased surface coating efficiency resulting from the combination of PCE with the lower molecular weight TEA [16]. A similar interaction between the PCE-TEA mixture has also been reported in the literature [15].

The improved grinding performance compared to the control, as the number of revolutions increased, may be attributed to the following: as the grains became finer, the non-adsorbed GAs adsorbed onto the newly formed particles, enhancing the dispersing effect.

4. Conclusion

In this study, the time-dependent grinding performance of the GA formed by blending PCE and TEA was compared with PCE-based GA and TEA, based on the Blaine values of the resulting cements. The key findings from the experiments are summarized below:

- Regardless of the GA type, the use of GA improved grinding performance (Blaine values) compared to the control cement.
- PCE-based GA demonstrated lower grinding performance than TEA when used alone.
- The PCE-TEA blend exhibited the highest grinding performance, owing to the synergistic effect it provided.

Future studies should explore the impact of PCE-based additives mixed with various types of GAs commonly used in practice, focusing on their effects on grinding, dispersion, and hydration performance.

Acknowledgements

The authors gratefully acknowledge the support of the Scientific and Technological Research Council of Turkey (TÜBİTAK) under Grant Number: 222M245. They also extend their thanks to the Bursa Uludağ University Science and Technology Centre (BAP) for their contributions, under grant identifier FGA-2024-1754.

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