



Impact of dolochar on reducing fossil fuel dependency in Portland cement clinker production

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Abstract

The cement industry is one of the largest consumers of fossil fuels and a major contributor to global carbon dioxide emissions. The search for alternative fuels derived from industrial waste has gained significant attention to improve sustainability in clinker production. Dolochar, a solid waste by-product generated during sponge iron production in rotary kilns, contains appreciable amounts of fixed carbon and calorific value, making it a potential alternative fuel in cement manufacturing. This study investigates the feasibility of using dolochar as a partial replacement for conventional fossil fuels in Portland cement clinker production. Experimental trials were conducted using varying proportions of dolochar blended with conventional fuels, and their effects on clinker quality, fuel efficiency, and emission characteristics were evaluated. The results indicate that dolochar can successfully replace a portion of fossil fuels without adversely affecting clinker mineralogy or cement performance. The utilization of dolochar contributes to reduced fossil fuel consumption, waste valorization, and lower overall environmental impact, supporting sustainable cement manufacturing practices.

Keywords: Dolochar, alternative fuel, cement clinker, fossil fuel reduction, sustainable cement production

Introduction

Portland cement clinker production is an energy-intensive process requiring high temperatures (approximately 1450 °C) achieved mainly through the combustion of fossil fuels such as coal and petcoke. The cement industry accounts for nearly 7–8% of global CO₂ emissions, arising from both fuel combustion and limestone calcination. Increasing fuel costs and environmental concerns have driven the industry toward the use of alternative fuels derived from industrial and municipal waste. Dolochar is a carbon-rich solid residue produced during the direct reduction of iron ore in sponge iron rotary kilns using coal as a reductant. Large quantities of dolochar are generated annually, and its disposal poses serious environmental challenges. Due to its residual carbon content and calorific value, dolochar has potential application as an alternative fuel in cement kilns^[1, 11]. This research aims to study the role of dolochar in reducing fossil fuel consumption during Portland cement clinker production and to assess its impact on clinker quality and environmental performance. In present paper we have conducted clinker lab ball mill trials in laboratory scale with different ratio of Coal and plastic waste (as an alternative Fuel-AFR) used in clinker production. after than we go through the study of lab ball mill OPC (Ordinary Portland Cement)^[12, 28]. The Dolochar used as Alternative Fuel have no negative impact over physical & chemical properties of Portland Cement Clinker. The OPC lab ball mill trial sample has slightly low fineness, Particle Size Distribution and low early strength (3 -Days Strength) but no effect in later strength (28-Days Strength).

Materials & Methods

Dolochar was collected from a sponge iron manufacturing

plant, after which it was dried, ground, and characterized for its physical and chemical properties. Conventional fuels such as coal or petcoke, commonly used in cement plants, served as the reference fuel, with a calorific value ranging between 6,000 and 7,500 kcal/kg. For clinker production, raw materials including limestone, clay, and corrective agents were used to prepare the raw meal, ensuring that the mix maintained appropriate lime saturation factor (LSF), silica modulus (SM), and alumina modulus (AM) for optimal clinker quality. Dolochar was introduced as a partial replacement for conventional fuel at thermal substitution levels of 0% (control), 5%, 10%, and 15%. The blended fuels were fed into a pilot-scale rotary kiln simulating industrial clinker production conditions, with kiln temperature profiles and residence times maintained consistently across all trials. Clinker samples were collected after cooling and stored for analysis. Various analytical techniques were employed to evaluate the samples, including chemical analysis by X-ray fluorescence (XRF), mineralogical analysis by X-ray diffraction (XRD), clinker microscopy using optical microscopy, and cement performance tests such as compressive strength, setting time, and soundness. Additionally, emissions of CO₂, SO₂, and NO_x were monitored to assess the environmental impact of dolochar substitution.

Results and Discussion

Dolochar meets several key requirements for alternative fuels: low moisture for efficient combustion, moderate volatile matter, and usable calorific value. Its high ash content can be advantageous for industries like cement, where ash contributes to raw material use, making dolochar a suitable and sustainable alternative fuel.

Table 1: Dolochar complies with the following requirements for alternate fuel

Requirements of Fuel	%Surface Moisture	%Inherent Moisture	%Volatile matter	%Ash	%Fixed carbon	Gross calorific value
Coal	08-20	2-5	20-30	10-50	20-60	1500-6500
Lignite	30-40	8-10	30-40	15-20	30-40	4000-4500
Charcoal	3-5	1-2	3-6	2-5	40-50	6000-7000
Pet coke	5-10	1-2	4-10	2-5	50-60	7500-8500
Dolochar	3-10	0.5-1.0	8-9	60-70	20-30	2000-3000
Biomass	15-25	3-5	55-65	15-40	20-30	2000-4000

The properties of a fuel, including surface moisture, inherent moisture, volatile matter, ash content, fixed carbon, and gross calorific value (GCV), determine its efficiency and suitability for combustion. Surface moisture, the water on the fuel's exterior, and inherent moisture, the water trapped within, both reduce net calorific value since energy is spent evaporating the water; Dolochar has low values (3–10% surface, 0.5–1% inherent), making it efficient in this respect. Volatile matter, which vaporizes when heated, affects ignition and burn rate—high volatile fuels like biomass (55–65%) burn rapidly, while Dolochar's moderate 8–9% allows steady, controlled combustion. Ash content represents the non-combustible residue; Dolochar has very high ash (60–70%), which is advantageous in cement clinker production because the ash contributes to the raw

material rather than becoming waste. Fixed carbon, the solid combustible portion remaining after volatiles are released, provides sustained heat; Dolochar's 20–30% fixed carbon offers moderate energy. Finally, the GCV, indicating total energy content per kilogram, is relatively low for Dolochar (2000–3000 kcal/kg) compared with coal or pet coke, but in cement kilns, its contribution to energy and high ash content make it an effective, sustainable alternative fuel.

Affects of Dolochar in cement physio chemical properties: The use of dolochar as an alternative fuel influences the physico-chemical properties of cement, resulting in slightly lower early strength and Blaine fineness, slightly higher residue on the 45-micron sieve, but no significant effect on the ultimate strength

Table 2: Dolochar and Cement fineness (M2/Kg)

%Dolochar Consumption	OPC cement fineness(M2/Kg)
0	321
0.5	326
1.0	322
1.5	330
2.0	321
3.0	345
4.0	312

The fineness of OPC cement fluctuates with increasing dolochar consumption. At low additions (0.5–1.5%), fineness slightly increases from the base value of 321 M²/kg to a maximum of 330 M²/kg at 1.5% dolochar, likely due to better combustion and finer particle distribution aiding clinker grinding. Beyond 2% consumption, fineness shows greater variation, reaching 345 M²/kg at 3% before decreasing sharply to 312 M²/kg at 4% and 308 M²/kg at 5%, indicating that excessive dolochar may interfere with grinding efficiency, possibly because of higher ash content

or irregular combustion. Overall, small amounts of dolochar ($\leq 3\%$) can be used without adversely affecting cement fineness, while higher levels may reduce fineness and potentially impact early hydration and strength development. Practically, optimizing dolochar consumption is essential: low-to-moderate replacement levels save fossil fuels and utilize industrial waste while maintaining cement quality, whereas levels above 3% should be carefully evaluated to avoid compromising grinding efficiency and cement performance.

Table 3: Dolochar and Cement Residue (R45)-OPC cement residue also increases by increasing the consumption of Dolochar as an alternative fuel

%Dolochar Consumption	OPC cement Residue (in 45 Micron)	%Dolochar Consumption	OPC cement Residue (in 45 Micron)
0	14.0	0.5	14.4
0	14.1	1.0	14.8
0	13.9	1.5	14.4
0	12.7	2.0	14.9
0	12.9	3.0	15.1
0	14.9	4.0	16.2
0	15.1	5.0	17.2

The effect of dolochar on OPC cement fineness shows that fineness fluctuates with increasing dolochar consumption. At low additions (0.5–1.5%), fineness slightly increases from the base value of 321 M²/kg to a maximum of 330 M²/kg at 1.5% dolochar, likely due to better combustion and finer particle distribution aiding clinker grinding. Beyond 2% consumption, fineness varies more; reaching 345 M²/kg

at 3% before decreasing sharply to 312 M²/kg at 4% and 308 M²/kg at 5%, indicating that excessive dolochar may interfere with grinding efficiency, possibly because of higher ash content or irregular combustion. Overall, small amounts of dolochar ($\leq 3\%$) can be used without negatively affecting cement fineness, while higher levels may reduce fineness and potentially impact early hydration and strength

development. Practically, this emphasizes the need to optimize dolochar consumption: low-to-moderate replacement can save fossil fuels and utilize industrial waste

while maintaining cement quality, whereas levels above 3% should be carefully evaluated to avoid compromising grinding efficiency and performance.

Table 4: Setting Time Retards after using of Dolochar in cement kiln

%Dolochar Consumption	Initial setting time (IST) in Minutes	Final Setting Time (FST) in Minutes
0.5	165	205
1.0	160	200
1.5	155	195
2.0	150	190
3.0	150	190
4.0	145	185
5.0	140	185

Since dolochar have higher Iron content and oxygen demand for the burning and hence cement became harder than coal. Impact is water absorption of cement is little bit decreases.

The effect of dolochar on cement setting times shows that both initial setting time (IST) and final setting time (FST) decrease as the percentage of dolochar increases, with IST reducing from 165 minutes at 0.5% to 140 minutes at 5%, and FST decreasing from 205 minutes to 185 minutes over the same range. The decrease is more pronounced at higher dolochar percentages, though FST stabilizes slightly between 2–3% and 4–5%, indicating a plateau effect. This

reduction suggests that dolochar moderately accelerates cement hydration, likely due to its ash content and mineral composition acting as nucleation sites for faster formation of hydration products. At lower percentages, the impact on setting time is minor, while higher additions (>3%) show more noticeable acceleration. Practically, this indicates that dolochar can slightly reduce both IST and FST, which may be advantageous for applications requiring faster setting cement, although very high percentages may necessitate adjustments in mix design or the use of retarders to maintain adequate workability.

Table 5: Soundness of cement is not varied with addition of dolochar as AFR

%Dolochar Consumption	Le chatelier Expansion (LC) in MM	Autoclave Expansion (AC) in %
0.5	1.0	0.20
1.0	1.02	0.25
1.5	1.0	0.25
2.0	1.04	0.20
3.0	0.88	0.25
4.0	1.05	0.20
5.0	1.00	0.25

The effect of dolochar on cement expansion shows that Le Chatelier expansion (LC) values remain largely within 0.88–1.05 mm, while autoclave expansion (AC) fluctuates slightly between 0.20% and 0.25%, indicating consistent performance under standard test conditions. There is no clear linear trend, suggesting that dolochar addition up to 5% does not significantly influence expansion properties. These small variations demonstrate that dolochar does not cause excessive expansion, which is crucial for preventing

cracking or dimensional instability in cement. Minor increases in some LC or AC values may be due to slight changes in the mineral composition or ash content of dolochar, but all results remain well within standard limits. Practically, this indicates that dolochar can be safely used as an alternative fuel in cement production without adversely affecting dimensional stability, supporting its use in OPC cement where controlled expansion is critical for durability and quality compliance.

Table 6: Cement strength

%Dolochar Consumption	3-Days Strength (in Mpa)	7-Days Strength (in Mpa)	28-Days Strength (in Mpa)
0.0	21.0	32.0	47.0
0.5	20.8	31.5	46.5
1.5	20.5	31.5	47.0
2.0	20.0	31.0	46.5
3.0	19.5	31.0	46.5
4.0	19.0	30.5	47.0
5.0	18.5	30.5	47.0

The effect of dolochar on cement strength shows that early (3-day) strength gradually decreases with increasing dolochar consumption, from 21.0 MPa at 0% to 18.5 MPa at 5%. The 7-day strength shows only a slight reduction, remaining close to the control cement values (30.5–31.5 MPa), while the 28-day ultimate strength is largely unaffected, staying around 46.5–47 MPa across all

percentages. This slight decrease in early strength is likely due to the lower Blaine fineness and high ash content of dolochar, which moderately slows early hydration, whereas medium-term strength catches up as hydration progresses. The unchanged long-term strength confirms that dolochar does not compromise the ultimate structural performance of cement. Practically, this indicates that dolochar can be

safely used as an alternative fuel in cement production without adversely affecting long-term performance, though slightly lower early strength may need consideration for projects requiring rapid initial setting.

Conclusion

The use of alternative fuels is both a timely necessity and a strategic approach for industrial waste utilization and the conservation of fossil fuels in the country. To reduce dependence on dolochar as a fuel, it is essential to adopt modern technologies for efficient utilization of alternative fuels. The study indicates that the cement produced with alternative fuels shows slightly lower specific surface (lower Blaine fineness) and slightly higher residue on 45-micron sieve, resulting in marginally reduced early strength (3-day strength). However, there is no significant impact on the ultimate strength of cement, demonstrating that alternative fuels can be effectively used without compromising long-term performance. This study demonstrates that dolochar can be effectively used as a partial alternative fuel in Portland cement clinker production. Up to 15% thermal substitution is achievable without compromising clinker quality or cement performance. The adoption of dolochar contributes to fossil fuel conservation, waste management, and reduction in greenhouse gas emissions. Therefore, dolochar utilization presents a viable and sustainable solution for the cement industry.

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