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An Investigation into the performance of Concrete Incorporating Calcite-Cement with Partial Replacement of Cement-by-Cement Kiln Dust

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Abstract

This current work investigates the application of (CD) as an alternative to cement while making concrete at percentage 15%, 20%, and 25%, and the effect of combination of cement kiln dust (CKD) with calcite dust (CD) at percentage of 15% and various amounts of CKD 5%, 10%, and 15%. The findings indicate that excessive use of (CD), particularly at the 15% CD replacement, results in compressive strength reduced to a certain degree. Incorporation of (CKD) with (CD) improves later-age development of the concrete's strength. Furthermore with 25% CD, there is a reduction in absorption rate, indicating improved impermeability and durability. The inclusion of (CD) also enhances the corrosion Resilience of the concrete and makes it suitable for exposure in aggressive conditions. Conversely, it was discovered that at certain replacement level of CKD increases the vulnerability of the concrete to corrosion and at 15% CKD replacement the probability of corrosion become less underscores the need for careful optimization. Importantly, the incorporation of (CD) does not have a detrimental effect on the resilience of the concrete to the ingress of chloride ions. Additionally, the mixture of 15% CKD and 15% CD that offers a combined 30% cement replacement improves the resilience of the concrete against chloride ions. In this study, the capabilities of CD and CKD in the manufacture of concrete are highlighted, offering important insights on their individual and combined effects on mechanical characteristics and durability and hence promoting sustainability in the construction industry.

Keywords: Calcite dust (CD), (CKD), Compressive strength, Durability, Corrosion resistance, Chloride penetration, Sustainable concrete.

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1.1 Introduction

The Procedure of cement Processing is widely regarded as a significant contributor to environmental degradation, primarily attributable to the increment levels of carbon dioxide (CO_2) emissions produced during its manufacturing. [1]. This increase in CO_2 emissions inflicts considerable damage on ecological systems. Therefore, enhancing the determinants that affect the generation of this greenhouse gas is deemed a critical milestone in the pursuit of environmental sustainability [2]. The incorporation of pozzolanic materials constitutes one of the paramount advancements in this domain, as it not only enhances the performance of cement but also simultaneously diminishes CO_2 emissions and curtails clinker consumption. Nevertheless, it is imperative to ascertain that these pozzolanic materials do not negatively impact the strength and durability of the resultant concrete [3-5]. Calcite dust (CD) is acknowledged as a by-product of lime manufacturing operations and is readily available in production facilities [6]. Research has demonstrated that the integration of CD into cement as a substitute for clinker is remarkably efficacious, yielding substantial enhancements in mechanical and durability attributes [7-9]. The improvement of mechanical properties in concrete that incorporates CD is ascribed to the existence of nucleation sites [10, 11]. Additionally, the filling effect of CD particles further facilitates this enhancement [12, 13]. However, the European standard (EN 197-1) stipulates that a substitution of up to 35% of cement with pozzolanic materials is permissible; surpassing this threshold may result in a decline in both mechanical properties and durability attributes. (CKD) is regarded as a secondary outcome of the cement processing and it is typically produced in considerable surplus at manufacturing facilities [14]. Although CKD has been effectively employed as a pozzolanic material, research indicates that the incorporation of more than 6% can detrimentally affect the mechanical features of the concrete [15, 16]. Despite the environmental benefits associated with the combination of pozzolanic materials such as CD and CKD as partial substitutes for clinker in cement production, there exists a discernible deficiency in research concerning the synergistic effects of these two materials on the mechanical and durability of concrete. This study endeavors to examine the characteristics of concrete formulated with (CD) cement, as well as the potential implications of introducing (CKD) into concrete containing CD. By

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tackling the challenge of optimizing sustainability in concrete production while maintaining structural integrity, this research aspires to provide valuable insights to the academic field.

1.1.1 Experimental program

1.1.2 Material

Ordinary Portland Cement (CEMI 32.2N) was used in all concrete mixes. Coarse aggregate with a maximum size19 mm was utilized, in conjunction with natural sand graded within Zone II in accordance with the Iraqi Standard (I.Q.S No. 45/1984). (CD) was procured from the lime production facility located in the Karbala province. The material demonstrated a fineness of 2876 cm^2/g as quantified by the Blaine apparatus. Additionally, it was sourced from the Al-Kufa Cement Factory situated in Najaf Province. Table 1 delineates the main compounds of the cement, CD, and (CKD).

Table 1.1 The chemical compounds of (cement, CD and CKD)

Chemical composition (%)	**Cement %**	**CD %**	**CKD %**
SiO_2	21.33	0.27	12.4
Al_2O_3	4.6	—	4.57
Fe_2O_3	3.37	0.15	2.01
CaO	63.52	56.01	46.03
MgO	3.02	1.12	2.62
K_2O	0.55	0.02	—
Na_2O	0.23	—	—
TiO_2	—	—	—
SO_3	2.42	0.09	7.83
L.O.I.	0.68	42.34	23.07
C3S	53.86	—	—
C2S	20.54	—	—
C3A	6.49	—	—
C4AF	10.25	—	—

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1.1.3 Concrete mix design

The concrete composition was proportioned utilizing the weight method to attain a targeted compressive strength of 25 MPa, in adherence to the stipulated guidelines. The formulation of the mix was executed in alignment with the standards delineated by ACI 211.1. All constituents employed in the mixture underwent rigorous testing to ascertain their conformity with the predetermined permissible thresholds. The material proportions were established as 1:1.84:2.74, with (w/c) of 0.5 and a specified slump range of 75 to 100 mm. The concrete formulations are designated as follows: (CD) denotes the control mix, while (CD15%, CD20%, and CD25%) indicate the replacement percentages of (CD) in the cement component. Additionally, (CD15-CKD5%), (CD15-CKD10%), and (CD15-CKD15%) pertain to the replacement levels of (CKD) and (CD) within the concrete formulation.

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Table1.2 The concrete mix proportions.

Mix- designation	**Cement %**	**CD %**	**CKD %**
CD 0%	100		
CD 15%	85	15	
CD 20%	80	20	
CD 25%	75	25	
CD15-CKD5%	80	15	5
CD15-CKD10%	75	15	10
CD15-CKD15%	70	15	15

1.1.4 Casting and curing of the test samples

Concrete mixing was made in accordance with ASTM C192 (2019) to ensure uniformity and workability. The fresh mix was then placed into molds, compacted, covered with impervious sheet to prevent the evaporation of moisture, and cured in lime saturated water appropriately.

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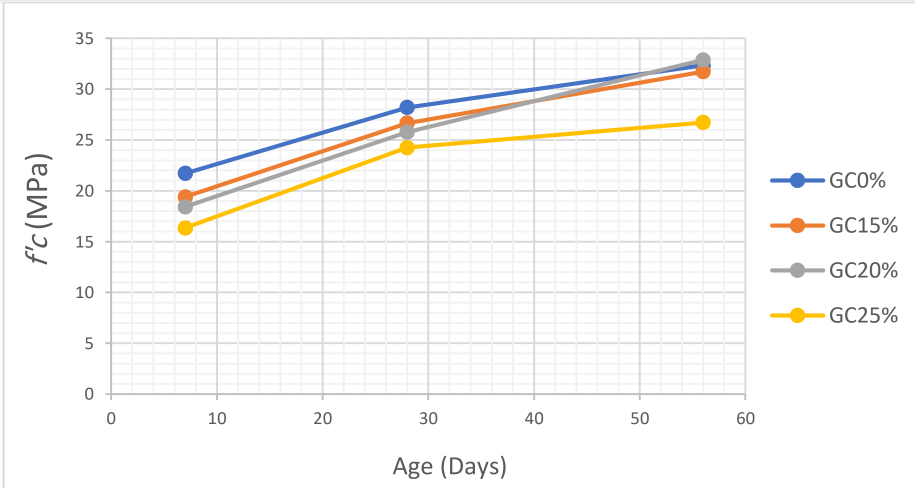
1.1.5 Tests of the samples

The evaluation of the strength tests was made for the mixes that include CKD and (CD) at 7, 28 and 56 age according to the Iraqi Standard No. 284(2015). The half-cell potential test was then performed after 56 days curing in compliance with ASTM C876-22. The determinations of water absorption values of the specimens were made following procedures of ASTM C642-21, after 28 days. Chloride ion penetration tests were also carried out on 56 days according to ASTM C1202-19. In order to determine the long-term durability of the concrete, sulphate attack resistance was measured using the modified method of a high sulphate solution (10% Na_2SO_4).

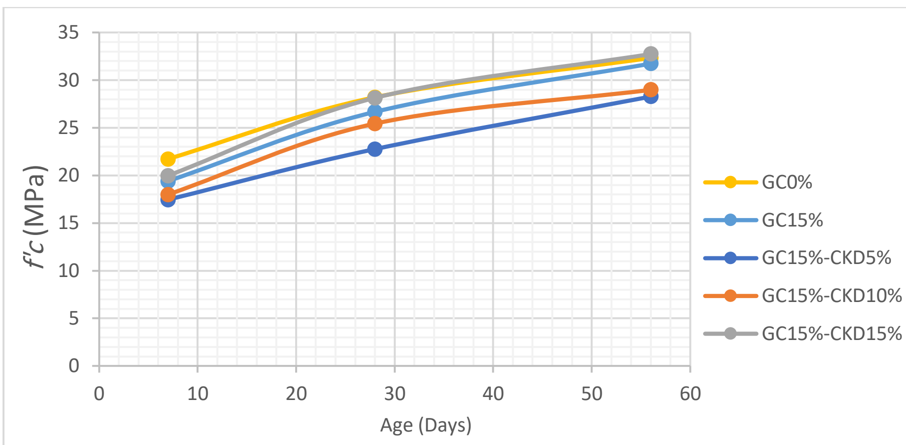
1.1.6 Results and discussions

1.1.7 Compressive strength

In Figure 1.1 (a), show that the compressive strength of such mixes has positive development with age, showing an overall improving tendency with the increase of curing age. However, it should be noted that the strength of the CD-containing mixes remained below or at the same level compared with the reference mix 0% CD, where no additional of CD. In particular, the figures show a considerable loss of compressive strength at 25% CD. This is because the dilution effect where the increase in the CD ratio could lead to a decrease in the proportion of effective cementitious material in the mix. The drop in the compressive strength with the higher CD content shows that even if CD can contribute to favorable properties of the concrete, excessive levels can impair its mechanical performance. This is in line with findings explained in the past works [17].



(a)



(b)

Figure 1.1 (a) The *f'c* of concrete containing (CD); **(b)** the f'c of concrete containing (CD-15%&CKD).

including (CKD) into the concrete mix results in lower strength at 7 days age; however, it subsequently promotes higher strength at both 28- and 56-days age. This initial reduction may be attributed to the time required for the pozzolanic reactions between CKD and CD in the concrete matrix to develop effectively. Notably, the combination of 15% CD (Designated as CD15%-CKD15%) exhibits enhanced strength performance close to the control mix 0% CD at 56-age.

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That augmented performance implies a potentially synergistic interaction between CD and CKD, which may promote enhanced strength development over an extended duration. Such behavior suggests that although the initial influence of CKD may result in diminished early-age strength, the long-term advantages of its pozzolanic activity, when combined with CD. This highlights the significance of selecting suitable supplementary materials and their respective proportions, as their collective effects can markedly affect the mechanical characteristics of concrete throughout its curing ages.

1.1.8 Absorption

Absorption test was performed on concrete samples in the form of cubes measuring 15 cm × 15 cm. The cubes were cast and cured for 28 days, after which the samples dried in laboratory oven for two days to achieve constant weight. Subsequently, the weight readings were recorded. The samples were then completely submerged in water, and after a 24-hour, the weight was recorded again to calculate the absorption rates. **Table 1.3** show the findings of the absorption test. For the mixes that contain (CD) indicate a superior reduction in water absorption as the percentage of CD increases. Specifically, the water absorption decreased from 5.41% in the control mix (CD0%) to 4.22% when 15% of the cement is replaced by CD. This downward trend continued, with further reductions observed at 20% (CD20%) and 25% (CD25%) replacements, showing water absorption rates of 3.042% and 3%, respectively. The observed decrease in water absorption could be due to the filling effect of CD, which effectively occupies the spacing within the concrete cement paste, leading to a reduction in overall porosity. The increased content of CD results in a notable reduction in porosity, supporting the findings in reference [18]. Conversely, samples incorporating CKD exhibited different water absorption rates. The mixture CD15-CKD5 recorded an absorption rate of 6.6%, while CD15-CKD10 resulted in a slightly higher absorption percentage of 6.8%. However, the sample CD15-CKD15 displayed a significant reduction in absorption, lowering to 4.9%, which classifies it as "Low. “The absorption rates for CD15-CKD5 and CD15-CKD10 suggest that, despite the addition of CKD, these mixtures retain some porosity. In contrast, the marked decrease in absorption for the CD15-

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CKD15 sample indicates that higher proportions of CKD effectively enhance the impermeability of the concrete, suggesting that CKD can be a beneficial additive in optimizing water resistance in concrete formulations.

Table 1.3 The result of absorption of concrete containing (CD)&(CKD).

Mix- designation	Absorption%
CD 0%	5.41
CD 15%	4.22
CD 20%	3.042
CD 25%	3
CD15-CKD5%	6.6
CD15-CKD10%	6.8
CD15-CKD15%	4.9

1.1.9 half-cell potential

A half-cell potential assessment was Carried out on cylindrical specimens measuring 150 mm × 300 mm. The samples cured for 56 days and then subjected to saline water for 14 days to testing. The results for the mixes (CD0%, CD15%, and CD20%) consistently stayed above -200 mV, whereas the (CD25%) mix showed a moderate reading. These results clearly indicated that the environment around the reinforcement bars is very passive, demonstrating the effective protective function of CD on steel in the alkaline pore solution of the concrete matrix. This specific collection of samples showed the least likelihood of steel corrosion, thus supporting the idea that CD acts as a suitable primary mineral additive to improve corrosion resistance in the tested environment. **Table 1.4** provides additional illustration of these findings. Nevertheless, the inclusion of (CKD) at percentage of 5% and 10% results in a significant reduction in half-cell potential values, increasing the risk of corrosion at the interface with steel reinforcement. At 5% CKD, and 10% CKD the half-cell readings showed a drop. While at 15% CKD the readings became low in spite of the high replacement of cement with CKD and CD to 30% the synergetic effect appears to be more pronounced at higher replacement levels.

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Table 1.4 The half-cell potential after 56 days curing for concrete containing (CD&CKD).

Mix- designation	Charge (mV)%
CD 0%	400
CD 15%	420
CD 20%	-110.5
CD 25%	-212.8
CD15-CKD5%	-382.3
CD15-CKD10%	-464.7
CD15-CKD15%	190

1.1.10 Chloride Permeability

The test was conducted in accordance with ASTM C1202, utilizing samples sized at 100 mm × 50 mm. Following a 56-day curing period, the sample sides were covered with an impermeable epoxy substance. The Test device was then employed to assess the passing charge, which indicates the samples' permeability to chloride ions. The findings from the test shown in **Table 1.5** offer important information regarding the permeability and durability characteristics of mixes enhanced with different supplementary materials. The reference sample with 0% CD is categorized in the low permeability range, showing a charge of 1841 coulombs. This value signifies a moderate resilience to chloride ions, which is essential for the long-term longevity of concrete in harsh environments. Implementing CD at different percentages (15%, 20%, and 25%) typically produces comparable results regarding chloride ion ingress, with only minor differences noted among these combinations. The charge passed for these blended compositions indicates that adding CD does not markedly change the concrete's resistance to ingress of chloride ions relative to the reference mix. These results indicate that although the incorporation of CD improves specific facets of concrete performance, like water absorption and general durability, its effect on chloride ion resistance stays fairly stable across the evaluated proportions. This perspective reinforces the idea that although additional resources can enhance particular properties, they may not always lead to profound changes in other critical durability characteristics, as noted in reference [19].

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Table 1.5 The result of chloride diffusion test after 56 days.

Mix- designation	charge (Coulomb)
CD 0%	1841
CD 15%	1784
CD 20%	1846
CD 25%	2071
CD15-CKD5%	1794
CD15-CKD10%	2466
CD15-CKD15%	1875

The inclusion of (CKD) in concrete mixes containing 15% CD, particularly CD15-CKD5, CD15-CKD10, and CD15-CKD15, leads to various results concerning chloride permeability. Significantly, the percentage of 5% CKD shows a noticeable enhancement in resistance to the ingress of ions compared to the control mixture without CKD. This enhancement suggests that a careful addition of CKD could positively influence the longevity of the concrete, possibly through processes like improved particle arrangement and pozzolanic effects. However, when the prevalence of CKD rises to 10%, there is a notable rise in the electrical charge measured during the chloride penetration test, noted at 2466 coulombs. This measurement indicates a moderate level of permeability and a corresponding decrease in performance. These observations highlight the complex balance that needs to be preserved when incorporating CKD into concrete mixtures. Although a carefully controlled addition can enhance strength, an overabundance of CKD might introduce inert or disruptive components into the concrete mix. These disruptive elements could change the pore structure, increasing connectivity and thereby raising chloride permeability. This warning emphasizes the importance of carefully adjusting CKD dosage to utilize its beneficial features while minimizing its negative consequences. Reaching this balance is essential for increase the durability and lifespan of concrete in areas prone to chloride exposure

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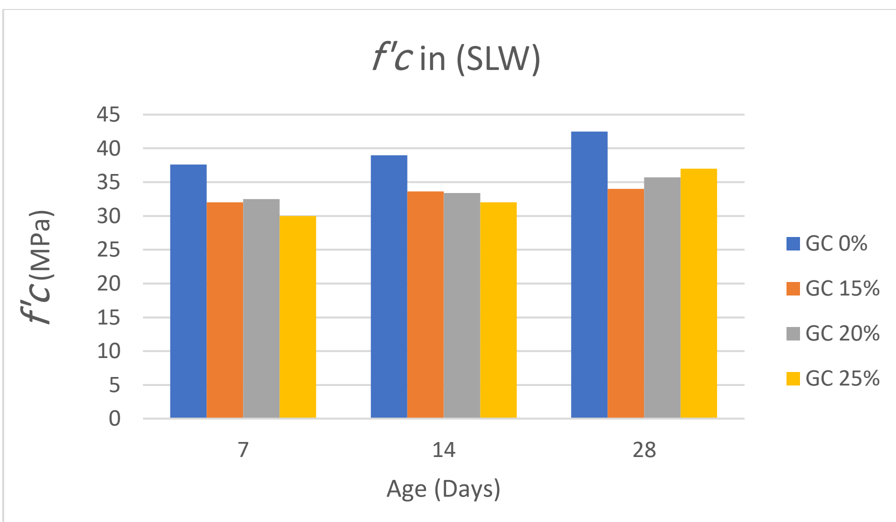
1.1.11 Sulfate attack

A comprehensive examination of sulfate attack was carried out on cement samples through various stages of laboratory testing. The accelerated method and partial immersion technique were employed, utilizing a mixing ratio of 1:2.75 while maintaining w/c 0.5. The samples were prepared using a sodium sulfate solution (Na_2SO_4) and were cast and cured for 14 days. Following this curing period, the samples were split into two separate sets. The first set was fully immersed in lime-saturated water, while the second group underwent partial immersion in (Na_2SO_4) solution with a concentration of 10%. After the exposure to sulfate solution, compressive strength tests were conducted on both groups at three ages: 7, 14, and 28 age. Observations were made regarding changes in strength, with a particular focus on the reduction observed in samples exposed to sulfate. Table1.2 (a, b, c d) shows the compressive strength in saturated lime water (LSW) and the percentage of reduction after exposure to sulfate solution.



(a)

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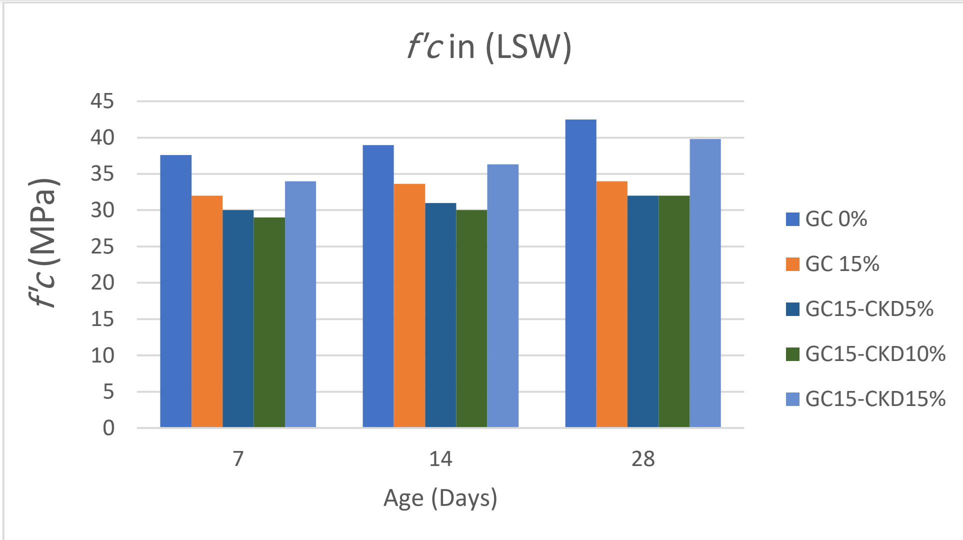

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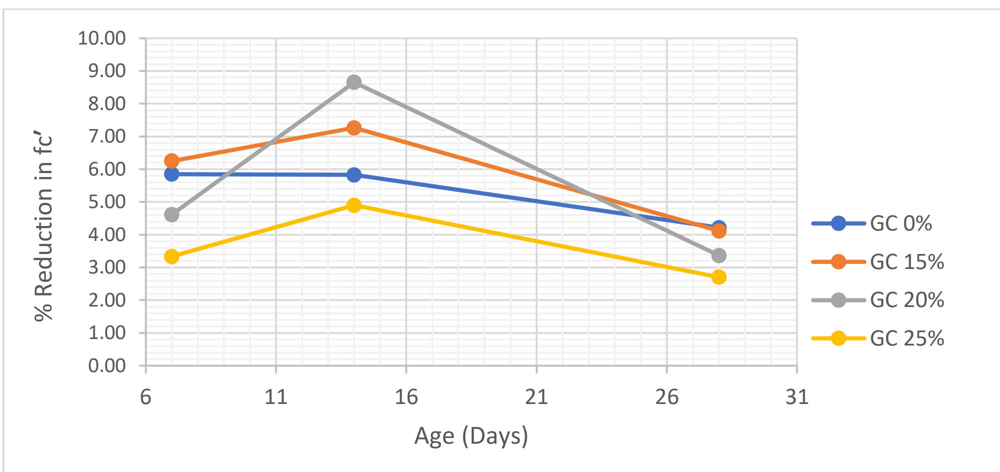
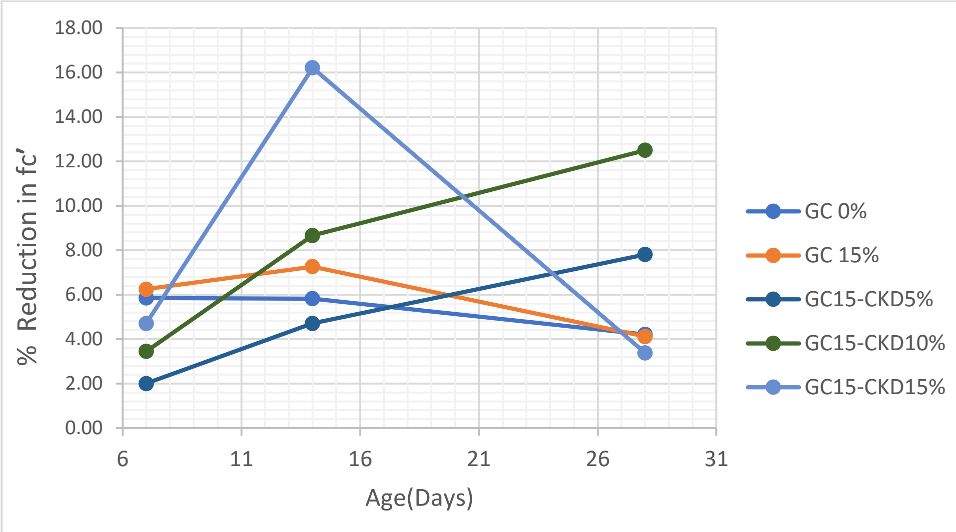


(c)



(d)

Figure 1.2 (a, b) The compressive strength in (LSW),
while (c, d) show the reduction in compressive strength after exposure to sulfate solution.

The growth of the mixes' compressive strength that incorporated CD, when immersed in lime-saturated water (LSW) in figure 1.3 (a), demonstrates a pronounced trend of progressive strength enhancement over time. This phenomenon aligns with the expected behavior of cement-based materials under standard curing conditions, where effective hydration occurs in a controlled environment, fostering optimal conditions for strength gain. While figure 1.2 (b) explain the compressive strength of mixes with CD improves over time. At 7 days, the pure cement mix had the highest strength, while adding 15% CD reduced strength. After 14 days, all mixes gained strength, with the mix containing 10% CD showing improvement. By 28 days, the reference mix reached about 40 MPa, and the mixes with 10% and 15% CD exhibited significant strength gains, indicating that incorporating CD at levels (10%-15%) can enhance durability and strength in cement mortars. Figure 1.2 (C) Following exposure to sodium sulfate, the compressive strength of the reference mix (CD 0%) declined by approximately 14%. This significant reduction demonstrates the susceptibility of plain cement mortars to sulfate attack. In contrast, with a 15% CD, the reduction in strength due to sulfate exposure was lower than that observed in the reference mix. A similar pattern was observed

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with the 20% CD, where the strength loss remained minimal in comparison to the reference. However, at 25% CD, the reduction in strength was less pronounced, indicating that the use of CD at this level may enhance the mortar's resistance to deterioration caused by sulfate exposure [20]. In contrast, the incorporation of (CKD) into mixes containing 15% CD resulted in superior strength loss when exposed to sulfate solutions, as illustrated in Figure 1.2 (d). All tested replacement levels of CKD 5%, 10%, and 15% produced a dramatic reduction in strength, highlighting the detrimental effects of CKD under these conditions.

1.2Conclusions

From the analysis of the test outcomes, the findings may be ascertained:

1. At the percentage levels of (CD15%) and (CD20%), the compressive strength remained unchanged; however, at 25% CD, there was a drop in strength at the early ages and later ages of curing.
2. Applying 15% CD and 15% (CKD) enhance the later strength of concrete, even though there is an initial decline at 7 days.
3. It has been noted that with an increase in the percentage of CD, the total absorption decreases, especially at a replacement level of 25%, where the overall absorption rate dropped considerably
4. Adding CD at percentages of (CD15%, CD20%, and CD25%) can improve the corrosion resistance of concrete.
5. The increasing in CKD amount led to decrease the potential of corrosion.
6.The presence of (CD) does not impair the resilience to chloride ions.
7.The incorporation of 15% (CKD) along with 15% (CD), totaling a 30% cement replacement, leads to an enhancement in the ability of concrete to resist the ingress of chloride ions.

References

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Journal of Science and Engineering Application
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[1] World Business Council for Sustainable Development (WBCSD-CSI), Cement Industry Energy and CO2 Performance: 'Getting the Numbers Right', Washington, DC, 2009. Available: https://wbcsdservers.org/wbcsdpublications/cd_files/datas/Getting_the_Numbers_Right.pdf [Accessed: 24-Jun-2025].

[2] Kronlof, A., Filler Effect of Inert Mineral Powder in Concrete, Technical Research Centre of Finland, Publication 322, 1997.

[3] Lagerblad, B., and Vogt, C., Ultrafine Particles to Save Cement and Improve Concrete Properties, CBI Report/CBI Rapporter, 2004, pp. 1, 40.

[4] Katz, A., and Baum, H., Effect of High Levels of Fines Content on Concrete Properties, ACI Materials Journal, 103(6), 2006, pp. 474-482.

[5] Al-Noora Lime Factory Iraq: https://www.alnoora-iraq.com.

[6] Ghafoori, N., Spitek, R., and Najimi, M., Influence of Limestone Size and Content on Transport Properties of Self-Consolidating Concrete, Construction and Building Materials, 127, 2016, pp. 588-595.

[7] Sezer, G. I., Compressive Strength and Sulfate Resistance of Limestone and/or Silica Fume Mortars, Construction and Building Materials, 26, 2012, pp. 613-618.

[8] Li, L. G., and Kwan, A. K. H., Adding Limestone Fines as Cementitious Paste Replacement to Improve Tensile Strength, Stiffness, and Durability of Concrete, Cement and Concrete Composites, 60, 2015, pp. 17-24.

[9] Marzouki, A., Lecomte, A., Beddey, A., Diliberto, C., and Ouezdou, M. B., The Effects of Grinding on the Properties of Portland-Limestone Cement, Construction and Building Materials, 48, 2013, pp. 1145-1155.

[10] Valcuende, M., Marco, E., Parra, C., and Serna, P., Influence of Limestone Filler and Viscosity-Modifying Admixture on the Shrinkage of Self-Compacting Concrete, Cement and Concrete Research, 42, 2012, pp. 583-592.

[11] Vance, K., Kumar, A., Sant, G., and Neithalath, N., The Rheological Properties of Ternary Binders Containing Portland Cement, Limestone, and Metakaolin or Fly Ash, Cement and Concrete Research, 52, 2013, pp. 196-207.

مجلة العلوم والتطـبيقات الهـندسية

Journal of Science and Engineering Application

ISSN 2521-3911

[12] Ma, K. L., Long, G. C., Xie, Y. J., and Zhu, R., Rheological Properties of Compound Pasts with Cement-Fly Ash-Limestone Powder, Journal of Chinese Ceramic Society (in Chinese), 5(41), 2013, pp. 582-587.

[13] Konsta-Gdoutos, M. S., & Shah, S. P. (2003). Hydration and properties of novel blended cements based on cement kiln dust and blast furnace slag. Cement and Concrete Research, 33(8), 1269–1276.

[14] Heikal, M., Aiad, I., & Helmy, I. M. (2002). Portland cement clinker, granulated slag, and by-pass cement dust composites. Cement and Concrete Research, 32(11), 1805–1812.

[15] Salem, T. H. M., & Ragai, S. H. M. (2001). Electrical conductivity of granulated slag cement kiln dust–silica fume pastes at different porosities. Cement and Concrete Research, 31(5), 781–787.

[16] Ali A. Ramezanianpour, Mohammad Ali Faghih, and Mohammad Javad Mahdikhani. "The Effects of Limestone Powder on the Properties of Portland Cement Concrete." Cement and Concrete Research, vol. 39, no. 4, 2009, pp. 284-290.

[17] A.M. Diab, A.E.M.A. Elmoaty, A.A. Aly. "Long term study of mechanical properties, durability and environmental impact of limestone cement concrete." Alexandria Engineering Journal, vol. 55, 2016, pp. 1465–1482.

[18] Meddah, M. S., Lmbachiya, M. C., & Dhir, R. K. (2014). Potential use of binary and composite limestone cements in concrete production. Construction and Building Materials, 58, 193-205.

[19] Meddah, M. S., Lmbachiya, M. C., & Dhir, R. K. (2014). Potential use of binary and composite limestone cements in concrete production. Construction and Building Materials, 58, 193–205.

الخلاصة

تتناول هذه الدراسة استخدام حجر الكلس المطحون (CD)كبديل جزئي للأسمنت في الخرسانة بنسبة استبدال قدرها 15%, 20%, و25%. كما تستعرض الدراسة التأثيرات المشتركة لإضافة غبار أفران الأسمنت (CKD) مع غبار الكالسيت بنسبة ثابتة قدرها 15%, مع نسب متغيرة من CKD تبلغ 5%, 10%, و15%. تشير النتائج إلى أن الإفراط في استخدام غبار الكالسيت، خصوصًا عند مستوى الاستبدال 25 %يؤدي إلى انخفاض طفيف في مقاومة الانضغاط للخرسانة. ومع ذلك، فإن إضافة CKD مع CD يسهم بشكل إيجابي في تطوير المقاومة على المدى الطويل، خاصة في الاعمار المتأخرة.ومن الجدير بالذكر أن استبدال 25% من الأسمنت ب CD يُؤدي إلى انخفاض معدل الامتصاص، مما يُعزز من مقاومة الخرسانة لنفاذية الماء ويدعم عمرها الافتراضي. كما يُحسّن غبار الكالسيت من مقاومة التآكل، مما يجعله مناسبًا للبيئات ذات الظروف العدائية. بالمقابل، يُلاحظ أن الإفراط في استخدام CKD يحسن من قابلية الخرسانة للتعرض للتآكل، الأمر الذي يُبرز أهمية إدارة نسب الاستبدال بشكل دقيق.وتُظهر النتائج أن وجود CD لا يؤثر سلبًا على مقاومة الخرسانة للاختراق الكلوريدي. بالإضافة إلى ذلك، فإن دمج 15% من CKD مع 15% من غبار الكالسيت، بما يعادل استبدال حوالي 30% من الأسمنت، يُحسن بشكل ملحوظ مقاومة انتشار الأيونات الكلورية في الخرسانة.ختامًا، تُبرز هذه الدراسة الفوائد المحتملة لاستخدام CD وCKD في إنتاج خرسانة أكثر متانة واستدامة، وتوفر رؤى مهمة حول تأثيراتها الفردية والجمعية على الخصائص الميكانيكية والمتانة، مما يسهم في تعزيز الممارسات البيئية المستدامة في صناعة البناء والتشييد.

الكلمات المفتاحية : حجر الكلس المطحون (CD) غبار أفران الأسمنت (CKD) ,قوة الانضغاط, المتانة, مقاومة التآكل, اختراق الكلوريدات, الخرسانة المستدامة.