**INTERNATIONAL JOURNAL OF ADVANCED SCIENTIFIC RESEARCH AND INNOVATION**

Online ISSN: 2785-9541

**Volume 7 , Issue 1, 2024, 64-75**

Print ISSN: 2785-9533

# The Effect of Egyptian Calcined Clay on Residual Compressive Strength after Concrete Exposure to High Temperatures: A Model Case

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## Abstract

Kaolin is a naturally clay mineral, primarily composed of the mineral kaolinite. When kaolin is subjected to the calcination process, it becomes a highly beneficial material with cementitious hardening properties. Certainly, the composition and effect vary depending on the source of the kaolin. Kaolin ore is found in Egypt in several areas and in large quantities. Therefore, Egypt exports kaolin ore and produces calcined clay from kaolin. This scientific paper focuses on studying the impact of Egyptian calcined kaolin clay as an enhancer of concrete's resistance to fire and high temperatures. The purpose was to use calcined clay to produce a special concrete suitable for structures that may be exposed to fire or high temperatures. Nine concrete mixtures were prepared. The control mix was designed to have medium compressive strength. Eight mixtures with partial replacement of Portland cement with Egyptian calcined clay from kaolin (K) were performed. Concrete specimens were subjected to high temperature at 700°C for one hour. After that, specimens were cooled with water. The reduction in compressive strength after heating and cooling was measured. The results show that the addition of Egyptian calcined clay in concrete improves the residual compressive strength after heating and cooling. The research suggests using Egyptian calcined clay in the concrete of facilities that may be exposed to fire or high temperatures.

Calcined clay, Egyptian Kaolin, Concrete residual strength, High temperature

## 1. Introduction

Several research studies have shown that compressive strength decreases after exposure to high temperatures [1-2]. Tanya Kerr noted that concrete compressive strength decreased due to the decomposition of calcium silicate hydrate phase at high degrees of temperatures [3].

The effect of high temperatures on concrete with high performance was the subject of G. F. Peng's research. The X ray diffraction test was conducted on the cement paste specimens after exposure to high temperatures ranging from 400°C to 800°C. They found that the decomposition of the cement paste influenced the strength loss of high-performance concrete [4]. In other research, the effect of different durations (one, two, and three hours) of high temperature vary from 200°C to 950°C on compressive strength of heavy weight concrete were studied. The findings demonstrated that the compressive strength of all mixes was affected with the heating period. [5].

Chi-Sun Poon and others studied Metakaolin concrete. They pointed out that the compressive strength after firing on 200°C and cooling showed high results at 10% and 15% kaolin replacement after 28 days [6]. Morsy found that the residual compressive strength at 400°C showed low results. It was found then that at

Online ISSN: 2785-9541 Volume 7 , Issue 1, 2024, 64-75 Print ISSN: 2785-9533

800°C, a 20% MK replacement resulted in the lowest residual strength [7]. Siddique and Klaus pointed out that fire resistance reached the best result with 20% MK replacement [8]. Nadeem and others investigated that using MK as a partial cement replacement, especially at an early age, improves the concrete mechanical properties [9].

Wang and others studied the effects of adding 10% metakaolin to cement paste with temperatures from room temperature to 800°C. Results showed that compressive strength increased at 200°C and 400°C but decreased rapidly up to 800°C. The addition of metakaolin enhanced compressive strength, reduced shrinkage, and resulted in a denser microstructure, offering better thermal resistance compared to pure cement paste. [10].

Laidani and others examined 10% metakaolin incorporated cement paste exposed to temperatures up to 800°C. They found that the best results were at 200°C [11]. Many studies proved that replacing Portland cement with kaolin up to 20% improves mechanical properties [3-6]. In addition to Kalabsha in Aswan, Egypt have enormous kaolin reserves in the Red Sea and Sinai. [12].

## 2. **Experimental work**

### 2.1 Materials

Portland cement with grade 42.5 MPa was used. It is classified according to the standard EN 197-1. [13] The cement manufactured by Sinai cement meets the European standard EN 197-1 and the Egyptian Standards E.S.S [14]. The initial and the final setting times for cement were measured according to BS EN 196-3:2016. [15] As shown in Fig.1. Cement properties were given in Table 1. The admixtures Sikament 163-M (Super-plasticizer) produced by Sika Egypt factory, was used. It complies with ASTM-C 494 Type F. The study uses crushed dolomite produced by North Sinai quarry, Egypt. The N.M.S of coarse aggregate was 19 mm, which satisfy the Egyptian Standard Specification E.S.S [14]. The study uses siliceous sand as fine aggregate sourced from North Sinai quarry, Egypt. The Fineness modulus was 2.75.

Standard Test for determination of clay and other fine materials in fine aggregate by volume was carried out according to BS 812-124:2015 [16]. The test was done in the New Damietta higher institute of Engineering and technology, Fig. 2.

The used calcined clay is shown in Fig. 3. It was sourced from Asfour factory for refractories, Helwan, Egypt. Asfour factory is using Egyptian kaolin from Sinai in Egypt to produce calcined clay by heating up 1000°C. Chemical and physical characteristics of Kaolin were presented in Table 2 & 3 respectively.

Fig. 1. Initial setting time test for Portland cement

Fig. 2. determination of clay and other fine materials in fine aggregate by volume

Fig. 3. Sample form of calcined clay produced by Asfour factory,Egypt

Table 1: Physical characteristics of Portland cement

| Properties | | Cement |
|---|---|---|
| The initial sitting time [Min.] | | 69 |
| The final sitting time[Min.] | | 180 |
| The specific surface area ($cm^2/gm$) | | 3500 |
| The specific gravity | | 3.15 |
| The compressive strength ($N/mm^2$) | 7 days | 23 |
| | 28 days | 40 |

Table 2: Egyptian Calined Clay Chemical characteristics

| | |
|---|---|
| Al2O3 | From 36 to 40 |
| Fe2O3 | From 1.31 to 0.8 |
| SiO2 | From 54 to 58 |
| $TiO_2$ | From 1.5 to 2.5 |
| CaO | From 0.3 to 0.4 |
| MgO | From 0.1 to 0.2 |
| $K_2O$ , NaO | From 0.2 to 0.4 |

Table3: Egyptian Calcined Clay physical characteristics

| Distribution of particle sizes | Proportion % |
|---|---|
| Greater than 100 microns | From 0.5 to 2 |
| Greater than 63 microns | From 17 to 22 |
| Smaller than 100 microns | From 75 to 82 |

**2.2 Mix Proportions and Specimen**

The aim of the research was to benefit from using Egyptian calcined clay as a fire-resistant material. The experimental program presents calcined clay as a partial cementitious material. Nine concrete mixtures were prepared. Based on fire-resistant construction needs, the control mix was designed to have a compressive strength of 35 MPa at 28 days. The other eight mixtures contained partial replacements of Portland cement with Egyptian calcined clay by percentages of 10%, 15%, 20%, 25%, 30%, 35%, 40%, and 45%.

Eighty-one standard cubes were used. Fifty-four of these specimens were used to measure the compressive strength before exposure to high temperatures at 7 and 28 days of curing. The other twenty-seven standard cubes were used to test compressive strength after heating and cooling.

Twenty-seven standard cylinders were test the splitting tensile strength, and twenty-seven standard beams were prepared for the flexural strength test. The mixture descriptions and the mix proportions are provided in Table 4. All specimen preparation and curing were conducted according to BS EN 12390-2:2019 [22] and E.S.S. [18]. (Fig 4)

Table 4. Concrete mix proportion

| MIX | Cement (kg) | KA (kg) | Fine Agg. (kg) | Coarse.Agg. (kg) | Water Lit. | S.plasticizer. (lit) |
|---|---|---|---|---|---|---|
| Control Mix | 452.38 | - | 625.91 | 1054 | 190 | 2.71 |
| 10%K+90%C | 407.14 | 45.29 | 625.91 | 1054 | 190 | 2.71 |
| 15%K+85%C | 384.51 | 67.85 | 625.91 | 1054 | 190 | 2.71 |
| 20%K+80%C | 361.9 | 90.48 | 625.91 | 1054 | 190 | 2.71 |
| 25%K+75%F.A | 339.29 | 113.1 | 625.91 | 1054 | 190 | 2.71 |
| 30%K+70%F.A | 316.67 | 135.71 | 625.91 | 1054 | 190 | 2.71 |
| 35%K+65%F.A | 294.05 | 158.33 | 625.91 | 1054 | 190 | 2.71 |
| 40%K+60% F.A | 271.43 | 180,95 | 625.91 | 1054 | 190 | 2.71 |
| 45%K+55%F.A | 248.81 | 203.57 | 625.91 | 1054 | 190 | 2.71 |

**2.3 Testing Procedure**

**2.3.1 Mechanical properties**

After 7 & 28 days of casting compressive strength test were done, the indirect tensile strength test and flexural strength test of concrete were according to BS EN 12390-2 [17] as shown in Fig 5&6 to check the mechanical properties.

Compressive strength test were conducted in the laboratories of the higher institute of engineering and technology in new Damietta, Damietta, Egypt, flexural strength test & splitting tensile test were conducted in the laboratories of Horas University, Damietta, Egypt.

2.3.2 Residual compressive strength testing- Model-Case

The model case has been done. Three cubes from each mix were placed in a closed electric furnace up to 700°C; the samples were kept in the electric furnace at 700°C for one hour as shown in Fig.7. As a model case reflecting real- conditions, the concrete was heated for one hour and then cooled with water. The test was done in civil engineering & chemical engineering laboratories of the higher institute of engineering, New Damietta, Egypt. The procedure of the study involved exposing the samples to the temperature, then removing them from the furnace. The heated samples were placed in a water tank for sudden cooling, as done in fired constructions.

Compressive strength was measured after 24 hours of removing the samples from the water tank. The results were shown in Table 6. The residual strength after heating and cooling was measured for each mix.


Fig. 4. specemens preperation

Fig. 5 Flexural Testing

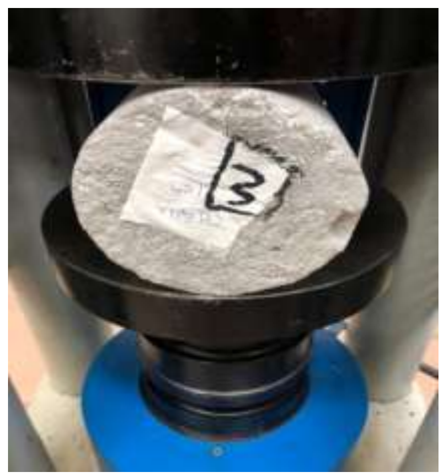

Fig. 6. Indirect Tension Test

Online ISSN: 2785-9541 Volume 7 , Issue 1, 2024, 64-75 Print ISSN: 2785-9533

Fig. (7) Standard cube in electric furnace

**3. Results and dissections**

**3.1 Mechanical properties**

The results of compressive strength test on standard cubes (150 * 150 * 150 mm) showed that in the mix (10%K+90%C ) have a small increase in compressive strength than control mix by 2.7%, while at a 15% replacement of Portland cement with Egyptian calcined clay, the compressive strength remained unaffected. when the replacement ratio was increased from 25% to 35%, the compressive strength decreased by a range of 4% to 10%. The compressive strength reduction reached 18% in the mix with a 45% replacement of Portland cement.

This indicates that when replacing Portland cement with calcined clay, the optimal replacement ratio should be within the range of 5% to 20%.

The results of the flexural strength test showed a slight increase in both mixes with 10% and 15% replacement, with the increase being 1.6% and 5%, respectively. However, the flexural strength decreased as the replacement ratio of Portland cement increased from 20% to 45%, with the decrease ranging from 3.3% to 26%.

As for the indirect tensile strength, it increased in the mixes containing 10% and 15% Egyptian calcined clay, with increases of 6.4% and 3.2%, respectively. Conversely, the indirect tensile strength decreased as the calcined clay ratio increased from 20% to 45%, with the decrease ranging from 3.22% to 35%.

These results align with the findings of the previous test results. However, it is noting that, despite the noticeable decrease in the mechanical properties when replacing more than 20% of kaolin with calcined clay, the results remain somewhat acceptable. Table 5 represents the mechanical properties results.

Table 5. Mechanical properties results

| Mix | Compressive Str. [MPa] | Flexural Str. MPa] | S.Tensile. Str. [MPa] |
|---|---|---|---|
| Control Mix | 37 | 6 | 3.1 |
| 10%K+90%C | 38 | 6.1 | 3.3 |
| 15%K+85%C | 37 | 6.3 | 3.2 |
| 20%K+80%C | 35 | 5.8 | 3.0 |
| 25%K+75%F.A | 33 | 5.8 | 3.0 |
| 30%K+70%F.A | 32 | 5.1 | 2.85 |
| 35%K+65%F.A | 32 | 5.0 | 2.7 |
| 40%K+60% F.A | 31 | 5.0 | 2.2 |
| 45%K+55%F.A | 30 | 4.4 | 2.0 |

**3.2 Residual Compressive Strength in a Model Case**

The compressive strength test results indicate that, for all mixtures, there was a decrease in compressive strength after exposure to high temperature. Because of more than one reason such as evaporation of water bound in the cement paste, dehydration of calcium silicate hydrate (C-S-H) gel, the different thermal expansion coefficients between concrete materials also loosing aggregate strength by decomposing at high temperatures into lime (CaO) and carbon dioxide ($CO_2$).

The percentage of residual compressive strength (R) was determined from the following relation. The residual compressive strength results were shown in Table 6, and Fig. 8.

$$R = \frac{\text{strength after high temperature and cooling}}{\text{strength before high temperature exposing}} \times 100$$

As evident from the results, the higher the percentage of Egyptian calcined clay in the concrete mix, the greater the residual strength after exposure to high temperatures.

As it can be seen in Table 2, the chemical composition of calcined Egyptian clay, made from kaolin found in Sinai, Egypt, primarily consists of two compounds: alumina (AL2O3), accounting for up to 40%, and silica (SiO2), and accounting for up to 58%. These are the most important components for high-temperature resistance.

Table 6. The residual compressive strength results

| Mix | Compressive Str. before fire exp. [MPa] | Compressive Str. after fire exp. [MPa] | R % |
|---|---|---|---|
| Control Mix | 37 | 16.0 | 43% |
| 10%K+90%C | 38 | 19.5 | 51% |
| 15%K+85%C | 37 | 19.0 | 52% |
| 20%K+80%C | 35 | 18.0 | 52% |
| 25%K+75%F.A | 33 | 19.0 | 58% |
| 30%K+70%F.A | 32 | 19.5 | 60% |
| 35%K+65%F.A | 32 | 19.5 | 61% |
| 40%K+60% F.A | 31 | 18.5 | 60% |
| 45%K+55%F.A | 30 | 18.0 | 60% |

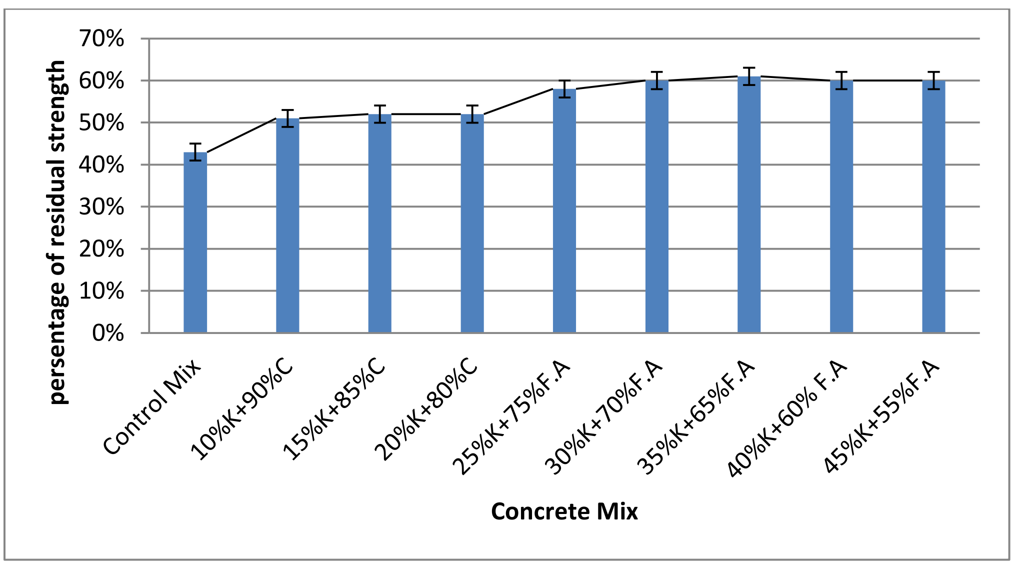


Fig. 8. Residual strength for concrete mixtures.

Alumina ($AL2O_3$) and silica ($SiO_2$) tends to enhance the fire resistance and hardness of the resulting material, when fired. Because of probability of Mullite Formation: Higher concentrations of alumina and silica in kaolin increase the potential for forming more Mullite during the firing process. Mullite provides excellent mechanical strength, thermal stability, and resistance. [18-19].

### 4. Conclusions

Concrete was exposed to a temperature of 700° C for one hour, followed by cooling. Based on the results of the compressive strength test for the concrete before and after exposure to high temperatures followed by cooling, the following conclusions can be drawn.

- As the replacement ratio of Portland cement with Egyptian calcined clay is increased, the residual strength after exposure to high temperatures also increased. The percentage of residual strength ranged from 51% to 61% of the original strength.
- Egyptian Calcined clay can be used for improving fire-resistant concrete. It contains a high ratio 405 of alumina ($AL_2O_3$) and 58% silica ($SiO_2$).
- The mechanical properties result of concrete containing Egyptian calcined clay as a partial replacement was enhanced the mechanical properties up to a replacement ratio of 15% of Portland cement.
- High replacement of cement with calcined clay up to 45% decreased the compressive strength. However, at a 15% replacement of cement with calcined clay, the decrease in compressive strength was zero.
- It is recommended to use Egyptian calcined clay as a replacement of cement up to 15% to improve the mechanical properties of concrete and its fire resistance.

### Conflict of interest statement

On behalf of all authors, the corresponding author states that there is no conflict of interest.

### References

1. It is recommended to increase future studies on the manufacture of Calcined clay cement while avoiding the harmful effects of aluminum oxide on reinforcing steel. Georgali, B., & Tsakiridis, P. E. (2005). Microstructure of fire-damaged concrete: A case study. ***Cement & Concrete Composites, 27***(2), 255–259. https://doi.org/10.1016/j.cemconcomp.2004.02.022
2. Akçaözoğlu, K. (2013). Microstructural examination of concrete exposed to elevated temperature using the plane polarized transmitted light method. ***Construction and Building Materials, 48***, 772–779. https://doi.org/10.1016/j.conbuildmat.2013.06.059
3. Kerr, T., Vetterb, M., & Gonzalez-Rodriguez, J. (2021). Evaluating residual compressive strength of post-fire concrete using Raman Spectroscopy. ***Forensic Science International, 325***, 110874. https://doi.org/10.1016/j.forsciint.2021.110874
4. Peng, G. F., Chan, S. Y. N., & Anson, M. (2001). Chemical kinetics of C-S-H decomposition in hardened cement paste subjected to elevated temperatures up to 800°C. *Advances in Cement Research*, *13*(2), 47–54. https://doi.org/10.1680/adcr.2001.13.2.47
5. Sakra, K., & El-Hakim, E. (2005). Effect of high temperature or fire on heavy weight concrete properties. ***Cement and Concrete Research, 35***(3), 590–596. https://doi.org/10.1016/j.cemconres.2004.05.023

6. Poon, C. S., Azhar, S., Anson, M., & Wong, Y. L. (2003). Performance of metakaolin concrete at elevated temperatures. ***Cement & Concrete Composites, 25***(1), 83–89. https://doi.org/10.1016/S0958-9465(01)00061-0
7. Morsy, M. S., Rashad, A. M., & El-Nouhy, H. A. (2009). Effect of elevated temperature on physico-mechanical properties of metakaolin blended cement mortar. *Structural Engineering and Mechanics*, *31*(1), 1–10. https://doi.org/10.12989/sem.2009.31.1.001
8. Siddique, R., & Klaus, J. (2009). Influence of metakaolin on the properties of mortar and concrete: A review. ***Applied Clay Science, 43***(3), 392–400. https://doi.org/10.1016/j.clay.2008.10.009
9. Nadeem, A., Memon, S. A., & Lo, T. Y. (2013). Mechanical performance, durability, qualitative and quantitative analysis of microstructure of fly ash and metakaolin mortar at elevated temperatures. ***Construction and Building Materials, 38***, 338–347. https://doi.org/10.1016/j.conbuildmat.2012.08.061
10. Wang, W., Liu, X., Guo, L., & Duan, P. (2019). Evaluation of properties and microstructure of cement paste blended with metakaolin subjected to high temperatures. ***Materials, 12***(6), 941. https://doi.org/10.3390/ma12060941
11. Laidani, Z.-E.-A., Benabed, B., Abousnina, R., Gueddouda, M. K., & Khatib, M. J. (2020). Potential pozzolanicity of Algerian calcined bentonite used as a cement replacement: Optimization of calcination temperature and effect on strength of self-compacting mortars. ***European Journal of Environmental and Civil Engineering***, 1–23. https://doi.org/10.1080/19648189.2020.1802177
12. Nagui A Abdel-Khalek. (1999). The Egyptian kaolin: An outlook in the view of the new climate of investment. ***Applied Clay Science*****, 15**(3–4), 325-336. https://doi.org/10.1016/S0169-1317(99)00026-5
13. British Standards Institution. (2011). *BS EN 197-1:2011 - Cement. Composition, specifications and conformity criteria for common cements*. British Standards Institution. https://doi.org/10.3403/30205527
14. Egyptian Code for Design and Construction of R.C. Structures**.** (2020). ***Egyptian Code for Design and Construction of R.C. Structures***. Ministry of Housing, Utilities and Urban Communities.
15. British Standards Institution. (2016). *BS EN 196-3:2016. Methods of testing cement. Determination of setting times and soundness*. British Standards Institution
16. British Standards Institution. *BS 812-124:2015 - Testing Aggregates. Part 124: Methods for Determination of Clay, Silt, and Dust in Fine Aggregates by Sedimentation Method*. British Standards Institution, 2015.
17. British Standards Institution. (2019). *BS EN 12390-2:2019. Testing hardened concrete. Making and curing specimens for strength tests*.

18. Ban, T., & Okada, K. (1994). Crystallization of mullite and immiscibility in $SiO_2$ – $Al_2O_3$ system. *Advanced Materials '93*, 483–486. https://doi.org/10.1016/b978-0-444-81991-8.50122-9

19. Panias, D., Balomenos, E., & Sakkas, K. (2015). The fire resistance of alkali-activated cement-based concrete binders. In F. Pacheco-Torgal, J. Labrincha, C. Leonelli, A. Palomo, & P. Chindaprasit (Eds.), ***Handbook of alkali-activated cements, mortars and concretes*** (pp. 423-461).