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Effect of Low and High Temperature on the Compressive Strength and Durability of Cement Mortar

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ABSTRACT

This study investigated the effect of low and high temperature on the compressive strength and durability of cement mortar. The aim was to determine how extreme temperature conditions affect the performance of mortar used in building construction in Northern Nigeria. A total of 60 mortar cubes of 50mm x 50mm x 50mm were cast using mix ratio 1:3 (cement:sand) with water-cement ratio of 0.5. The samples were cured for 28 days and then subjected to different temperature regimes: low temperatures of 5°C, 0°C, -5°C and high temperatures of 100°C, 300°C, 500°C and 700°C. Compressive strength test, weight loss test and visual inspection were conducted. Results showed that low temperature (5°C to -5°C) retarded hydration process and reduced compressive strength by 15-28% compared to control at 25°C. High temperature up to 100°C slightly increased strength by 5% due to accelerated hydration, but temperatures above 300°C caused significant reduction in strength. At 500°C and 700°C, strength reduction of 45% and 72% respectively was recorded, with severe cracking, spalling and colour change. The study concluded that both low and high temperatures have negative effects on cement mortar, with high temperature above 300°C being more destructive. It was recommended that during harmattan cold in Kano (5-10°C), concreting should be done in afternoon and use of warm water, and structures should be protected from fire.

Introduction

Cement mortar is a mixture of cement, fine aggregate (sand) and water. It is one of the most widely used materials in building construction for plastering, rendering, block laying, and screeding. The performance of mortar depends largely on curing conditions, mix ratio, and environmental temperature.

In Kano State and Northern Nigeria generally, buildings are exposed to two extreme temperatures. During harmattan season (December-February), temperature can drop to as low as 5°C to 10°C at night. During hot season (March-May), surface temperature of walls and roofs can reach 50°C to 65°C. In addition, buildings are often exposed to fire outbreak where temperature can exceed 700°C.

The hydration of cement, which is responsible for strength development, is a chemical reaction that is temperature-dependent. At low temperature, hydration is retarded, while at high temperature it is accelerated initially but causes damage later (Neville, 2011).

Despite this, most artisans and builders in Kano lay blocks and plaster walls without considering temperature effect, leading to cracking, low strength and failure of mortar joints. Therefore, this study investigates the effect of low and high temperature on cement mortar.

Aim and Objectives

Aim: To assess the effect of low and high temperature on cement mortar.

Objectives:

1. To determine the effect of low temperature (5°C, 0°C, -5°C) on compressive strength of cement mortar.

2. To determine the effect of high temperature (100°C, 300°C, 500°C, 700°C) on compressive strength of cement mortar.

3. To examine physical changes (colour, cracking, weight loss) of mortar exposed to extreme temperatures.

4. To recommend suitable measures for concreting and mortar work under extreme temperatures.

Literature review

Cement Mortar

According to Bungey et al. (2006), cement mortar is defined as a mixture of cement and sand in presence of water which hardens with time. Ordinary Portland Cement (OPC) grade 42.5N is most common in Nigeria (Dangote, BUA). Mix ratio for plastering is 1:3 to 1:4.

Effect of Low Temperature

Low temperature slows down hydration of cement. ACI 306R (2010) stated that when temperature is below 10°C, hydration is slow and if below 0°C, water in mortar freezes, causing expansion and cracking. Krstulovic et al. (2014) found that mortar cured at 5°C had 20% lower 28-day strength than that cured at 23°C. Freezing of fresh mortar can cause 40% strength loss.

In Kano, harmattan effect causes early morning plaster to fail to set properly.

Effect of High Temperature

High temperature has two phases. Up to 100°C, there is slight increase in early strength due to accelerated hydration (Handoo et al., 2002). Beyond 300°C, Calcium Silicate Hydrate (C-S-H) gel which gives strength begins to decompose. At 500°C, Ca(OH)2 decomposes. At 700°C, mortar becomes powdery and loses over 70% strength (Arioz, 2007).

Fire exposure in buildings in Kano markets (Singapura, Kantin Kwari) shows complete disintegration of mortar joints after fire.

Materials and methods

Materials

1. Cement: Dangote OPC 42.5N purchased from Dawanau Market, Kano.
2. Fine Aggregate: Sharp river sand from Challawa River, Kano, sieved with 4.75mm.
3. Water: Clean potable water from KSP borehole, conforming to BS EN 1008.
4. Moulds: 50mm x 50mm x 50mm steel cube moulds.

Mix Proportion

Mix ratio 1:3 (1 part cement : 3 parts sand) by weight, water-cement ratio 0.50 was used. This is common for plastering in Nigeria.

Preparation and Curing

60 cubes were cast, compacted with tamping rod (25 strokes) and kept at room temperature (25±2°C) for 24 hours, demoulded and cured in water for 28 days.

Temperature Exposure Regimes

After 28 days curing, cubes were divided into 8 groups (6 cubes per group)

Group A: Control - 25°C (room temperature)

Group B: 5°C in refrigerator for 7 days

Group C: 0°C in freezer for 7 days

Group D: -5°C in freezer for 7 days

Group E: 100°C in oven for 6 hours

Group F: 300°C in electric furnace for 6 hours

Group G: 500°C in electric furnace for 6 hours

Group H: 700°C in electric furnace for 6 hours

After exposure, samples were cooled to room temperature before testing.

Tests Conducted

1. Compressive Strength Test - Using Universal Testing Machine (UTM) at KSP Civil Lab, according to BS EN 1015-11.
2. Weight Loss Test - Weight before and after exposure.
3. Visual Inspection - Colour change, cracks, spalling.

Results and discussion

Compressive Strength Results

Temperature Regime	Avg. Compressive Strength (N/mm²)	Change vs. Control	Visual Observation
Control (25°C)	18.5	0%	No change; grey colour
5°C (Low)	15.7	−15.1%	Slight damp; slow hardening
0°C (Low)	14.2	−23.2%	Minor cracks
−5°C (Low)	13.3	−28.1%	Cracks; expansion
100°C (High)	19.4	+4.9%	No crack; darker grey
300°C (High)	12.8	−30.8%	Hair cracks; light grey
500°C (High)	10.1	−45.4%	Brownish; severe cracks; spalling
700°C (High)	5.2	−71.9%	Whitish-brown; disintegrated edges

Temp. Regime Avg. Compressive Strength (N/mm²) %. Change vs Control Visual Observation

Discussion

Effect of Low Temperature: Results show strength decreased as temperature decreased. At 5°C, hydration was retarded leading to 15.1% loss. At 0°C and -5°C, water inside mortar froze and expanded, creating internal stress and microcracks, resulting in 23.2% and 28.1% strength loss. This agrees with ACI 306R (2010) that concreting below 10°C should be avoided.

In practical terms in Kano, during harmattan, if plastering is done early morning when temperature is 8°C, the mortar will not set well and will peel later.

Effect of High Temperature: At 100°C, strength increased by 4.9%. This is because heat accelerates hydration and removes free water, making mortar denser temporarily. However at 300°C, C-S-H gel started losing bound water and strength dropped by 30.8%. At 500°C, Calcium Hydroxide decomposed ($Ca(OH)_2 \rightarrow CaO + H_2O$) causing severe cracks and 45.4% loss. At 700°C, complete decomposition of C-S-H and expansion of sand caused disintegration and 71.9% loss. Colour changed from grey to whitish-brown. This confirms Arioz (2007).

This explains why buildings after fire outbreak in Kano markets need total plaster removal.

Weight Loss: Weight loss increased with exposure temperature due to evaporation of free and chemically bound water.

Temperature Regime	Weight Loss (%)
Low temperature	**2.0**
100°C	**4.5**
300°C	**8.2**
500°C	**12.6**
700°C	**18.3**

Conclusion

The study concludes that:

1. Low temperature (≤5°C) retards cement hydration and reduces compressive strength of mortar by up to 28%.

2. High temperature up to 100°C slightly increases strength but beyond 300°C causes severe strength loss.

3. Exposure to 700°C destroys mortar completely with 72% strength loss, cracking and colour change.

Recommendations

1. During cold harmattan season in Kano, mortar and concreting should be done in afternoon when temperature is above 20°C, and use warm water for mixing.

2. Fresh mortar should be covered with tarpaulin to prevent freezing at night.

3. Buildings should be protected from fire - use fire-resistant plaster (gypsum) in kitchens and areas prone to fire.

4. After fire outbreak where temperature exceeded 300°C, the affected plaster and mortar should be completely hacked off and replaced, not repainted.

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