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Effect of Curing Temperature on the Compressive Strength Development of Cement Mortar Composition Containing Aluminium Sludge

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ABSTRACT

The present study was designed to investigate the effect of curing temperature on the compressive strength development of cement mortar composition. Other than Ordinary Portland Cement (OPC), the admixture was modified with aluminium sludge, which is produced by the secondary aluminium industry. Identical specimens of OPC and OPC with aluminium sludge were cured at 10 °C, 23 °C, 27 °C, 30 °C, and 33 °C for 2 days and 28 days by submerging underwater. Different temperatures have been decided on as masking the whole range of the temperature in Sri Lanka from five different districts with distinctive weather conditions. The compressive strength of these specimens was determined according to the ISO 679:2009, the International standard method to determine the compressive strength. The results indicated that the compressive strength of OPC mortar tends to increase with the temperature. The replacement of the aluminium sludge caused a negative impact on the strength of the cement mortar.

1. INTRODUCTION

The objective of this study is to investigate the effect of curing temperature on the compressive strength development of cement mortar and the use of aluminium waste as a substitute material with cement. In Sri Lanka, different districts have different temperatures throughout the year, and its annual temperature range is 9°C – 34°C. Therefore this study was carried out to analyze whether the cement mortar with aluminium sludge impact on the compressive strength of the mortar depends on different temperatures of these districts. After observing the strength development of ordinary portland cement at the different curing temperatures (10 °C, 23 °C, 27 °C, 30 °C, and 33 °C) for 2 days and 28 days, the cement composition modifies by adding aluminium sludge with five different ratios. Then the compressive strength of these specimens was determined and compared with the control values.

Cement is one of the primary materials used in the construction field because of their high resistivity on compressive load. Cement has good plasticity, high durability, and high moisture resistance. They are hardened early and easily workable[1].Ordinary Portland Cementis the most widely used form of cement. The main constituent of the Portland cement clinker is a hydraulic material made by sintering a mixture of raw materials containing CaO, SiO_2, Al_2O_3, Fe_2O_3, and small quantities of other elements. The chemical composition of the OPC is shown in the table below[2].

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Table 1: Chemical composition of the Ordinary Portland Cement

Elements	Percentage by weight (%)	Elements	Percentage by weight (%)
SiO_2	17.32	SO_3	2.29
Fe_2O_3	2.77	MgO	2.34
Al_2O_3	3.65	Cl	0.06
CaO	66.2	others	1.2

The above constituents are forming raw materials. During the burning and fusion process, they undergo chemical reactions and form compounds such as Tricalcium silicate ($3CaO.SiO_2$) - C3S, Dicalcium silicate ($2CaO.SiO_2$) - C2S, Tricalcium aluminate ($3CaO.Al_2O_3$) - C3A and Tetracalciumaluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$) - C4AF. The proportions of these four compounds make different types of portland cement. Tricalcium silicate and dicalcium silicates cause ultimate strength. The initial setting of portland cement is varying due to tricalcium aluminate. Tricalcium silicate hydrate presence in the cement contributes more to the early strength[3].
Aluminium is the second most widely used construction metal in the world after steel. A considerable amount of waste is produced during the aluminium production process. Aluminium sludge is produced by the secondary aluminium industry and also called as aluminium salt cake. This residual waste material is formed during the aluminium scrap melting process. This salt sludge is a hazardous and toxic waste that must be disposed of under controlled conditions[4]. The chemical composition of the aluminium is shown below[5].

Table 2: Chemical composition of the Aluminiums ludge

Elements	Percentage by weight (%)	Elements	Percentage by weight (%)
MgO	0.45	Na_2O	0.36
Fe_2O_3	0.32	ZnO	0.93
CaO	20.2	MnO	0.73
Al_2O_3	63.29	Lost in Ignition	5.3
SiO_2	6.36		

Aluminiums ludge, which was received for the testing, was a watery pulp containing 65 - 70 % of moisture, 25 – 30 % of aluminium oxide, and rest of aluminium and impurities. The slug was dried up, crushed, and sieved before mixing with the cement.
ISO standard sand is natural sand, which is siliceous sand consisting of generally isometric and rounded clean particles. The silica content of the sand should be at least 98%, and the maximum moisture content should be 0.2%. This standard sand is Certified by EN 196-1 and Conforming to use in strength measurements ISO 679 [6].
The characteristic of Standard Sand is its specific grain size distribution. It ranges between 0.08 and 2.00 mm. The grain size distribution is listed in the table below [7].

Table 3: Grain size distribution of Standard Sand

Square mesh size (mm)	Cumulative retained (%)	Square mesh size (mm)	Cumulative retained (%)
0.08	99 ± 1	1.00	33 ± 5
0.16	87 ± 5	1.60	7 ± 5
0.50	67 ± 5	2.00	0

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ISO 679:2009 is the International standard test method to determine the compressive strength and optionally the flexural strength of a cement mortar. The standard is reviewed every five years. This standard was last reviewed and confirmed in 2015; consequently, this version remains current. The standard applies to common types of cement and materials, and SLS 107 ordinary Portland cement was confirmed to be used for the compressive strength determination in the laboratory manual. ISO 679:2009 is not appropriate for the cement types with a short initial setting time[8].
The strength of the cement mortar partially depends on the method and duration of curing. Among the methods such as immersion of cement cubes in a curing tank (Ponding method), covering of cubes with a wet rug (Continuous wetting), the use of polythene sheet (Water-barrier) and air-drying, the ponding method appeared to be the best method at curing especially for determining the compressive strength [9][10]. According to the previous studies, it was shown that temperature enhanced the early hydration. The cement pastes cured at higher temperatures generally showed an increase in compressive strength at an early age compared to the cement paste cured at room temperature, but the strength gain decreased at later ages[11].
Different properties such as compressive strength, split tensile strength, flexural strength, and water absorption were tested with aluminium sludge as a substitute material. This study shows that up to 10 % replacement of cement by aluminium slug, the results are practically identical with the controls, and there is no significant damage to mortar characteristics. This study has been continued with other binding materials such as fly ash remains and silica flume and found the enhanced mechanical and durability properties[12].There was a considerable reduction in the workability of concrete with the same water to cement ratio as the control mixture with the incorporation of aluminium sludge as a substitute material because if the high water absorption of aluminium sludge [13]. Test results for compression strength of cement with the percentages 5% to 20% replaced aluminum sludge indicate that a minimum percentage of aluminium could be preferable as a substitute[14].

2. MATERIALS AND METHODOLOGY

2.1 Preparation of Mortar

The mortar should have consisted of one part of cement, three-part of standard sand, and one-half part of water, the proportion by mass. The water to cement ratio should be 1:2. Therefore a batch of mortar composition for three test specimens was made with (450± 2) g of ordinary portland cement, (1350±5) g of ISO standard sand, and (225±1) g of distilled water. Subsequently, the composition of mortar was modified with aluminium sludge in 5 different ratios, as table 4 shown below. The water amount was increased with the sludge percentage due to high water absorption of aluminium sludge.

Table 4: Mix proportion of cement mortar with aluminium sludge

Sample name	Aluminum sludge percentage (%)	OPC (g)	Aliminium Sludge (g)	Water (g)
A1	2	441	9	227
A2	4	432	18	229

A3	6	423	27	231
A4	10	405	45	233
A5	15	382.5	67.5	235

2.2 Selecting Temperature Range

Five different districts in Sri Lanka with different weather conditions were considered to select the temperatures as the curing temperatures of the cement samples. The entire range of the temperature in Sri Lanka was covered by choosing the five different curing temperatures as (10.0 ± 2) °C, (23.0 ± 2) °C, (27.0 ± 2) °C, (30.0 ± 2) °C and (33.0 ± 2) °C and the range of 8 °C – 35 °C was covered by selecting these temperatures.

2.3 Preparation of Test Specimens

The test specimen was prepared with a 40 mm x 40 mm x 160 mm in prism shape. Then the mould was placed in the moisture air cabinet for 24 hours. The moisture air cabinet was maintained at the temperature of 27 °C and the relative humidity of not less than 90%. After 24 hours The specimens were merged in the water and stored at different temperatures (10°C, 23°C, 27°C, 30°C and 34°C) for curing.

Ten batches of mortar were prepared according to the above process to determine the compressive strength for 2 days and 28 days of curing ages for each temperature.

2.4 Determination of Compressive Strength

The age of the specimens was calculated from zero time. The compressive strength of cement mortar was determined for the age of 24 h ± 15 min and 28 d ± 8 h.
The compressive strength test for six prism halves was carried out, and the compressive strength (Rc) of these specimens were calculated according to the following equation.

$$Rc = Fc /1600$$

Where, F_c is the maximum load at fracture (N) and 1600 is the area of the platens (mm^2).
The arithmetic mean of these six individual results was obtained as the average compressive strength for each temperature. If one result within the six individual results was varied by more than ± 10 % from the average, the result was discarded, and the arithmetic mean of the five remaining results was calculated.

3. RESULTS AND DISCUSSION

The average compressive strength of the cement mortar with only OPC at different curing temperatures for the age of 2 days and 28 days is shown in figure 2. The dotted lines in the graph indicate the minimum and maximum average compressive strengths for each temperature. Minimum and maximum values were determined by deducting and adding 10 % of the average value to the arithmetic mean of the six individual results. It can be noted that the compressive strength of the cement mortar is increasing as the curing temperature is increasing for both 2 days and 28 days of curing ages. The temperature has more effect on early strength (2 days) of the mortar than the 28 days curing age.

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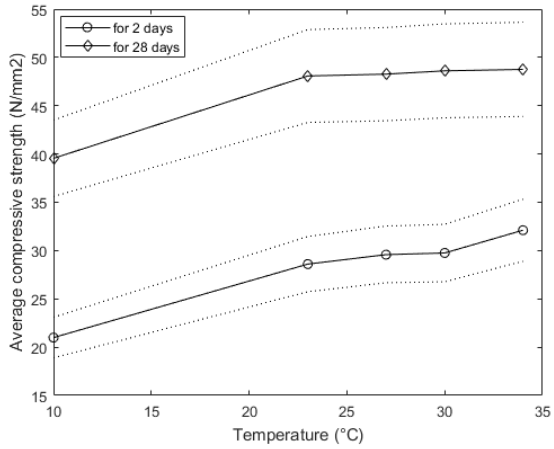

Figure 2: Compressive strength of control samples with temperature

Table 5 contains the obtained experimental results for the compressive strength of control samples at age 2 days and 28 days.

Table 5: Compressive strength of control samples

Sample Name	Curing Temperature (± 2 °C)	Average Compressive Strength (2 day) (N/mm2)	Average Compressive Strength (28 day) (N/mm2)
C1	10	20.99	39.55
C2	23	28.60	48.08
C3	27	29.58	48.27
C4	30	29.75	48.61
C5	33	32.11	48.76

The average compressive strength of the cement mortar with different percentages of aluminium sludge as 2%, 4%, 6%, 10%, and 15% at different curing temperatures for ages of 2 days and 28 days is shown in figure 3(a) and figure 3(b).

It can be observed that the compressive strength of the cement mortar is decreasing as the percentage of the aluminium sludge is increasing for both 2 days and 28 days of curing ages. Even though the strength is lower than the control values, cement composition with 2 % aluminium replacement shows the maximum strength for at 27 °C curing temperature for 2 days curing age and 30 °C curing temperature for 28 days curing age.

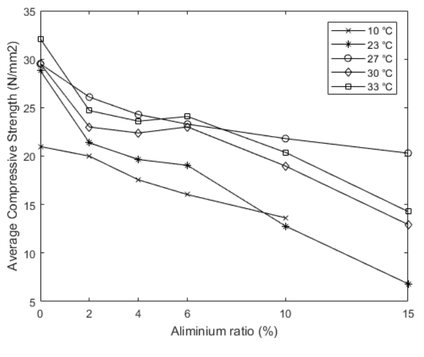

Figure 3(a): Compressive strength of mortar with different aluminium sludge ratios for 2 days

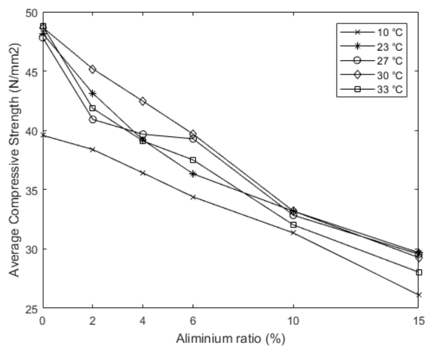

Figure 3(b): Compressive strength of mortar with different aluminium sludge ratios for 28 days.

The average compressive strength of the cement mortar with aluminium sludge at different curing temperatures for the age of 2 days and 28 days is shown in figure 4(a) and figure 4(b). Aluminium sludge decreases the compressive strength as the aluminum percentage increases. Even elevated temperatures do not cause any effect in strength for the cement mortar compositions containing aluminium sludge.

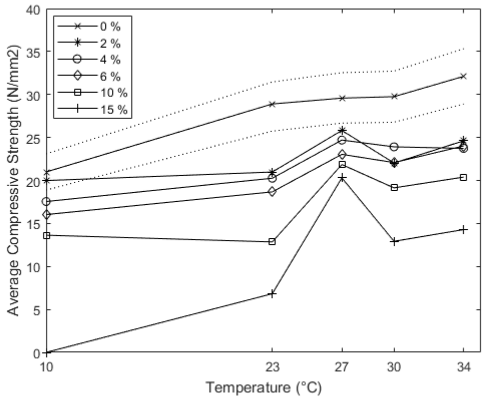

Figure 4(a): Compressive strength of mortar with different aluminium sludge ratios for 2days with temperature.

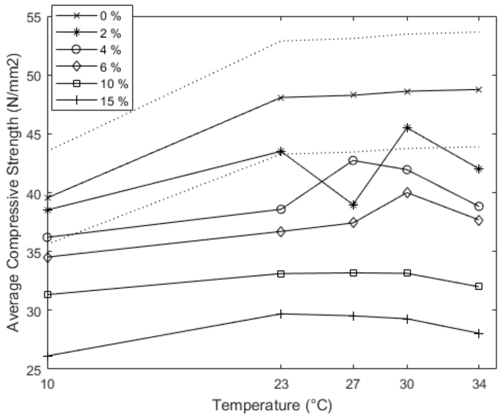

Figure 4(b): Compressive strength of mortar with different aluminium sludge ratios for 2days with

Obtained experimental results for Compressive strength of mortar containing aluminium sludge at age 2 days and 28 days are tabulated in table 6 below.

Table 6: Compressive strength of mortar containing aluminium sludge for 2 days

Sample Name	Average Compressive Strength for2 days (N/mm^2)				
	(10 ± 2)°C	(23 ± 2) °C	(27 ± 2) °C	(30 ± 2) °C	(33 ± 2) °C
control	20.99	28.90	29.58	29.75	32.11
A1	19.99	20.98	25.82	22.03	24.61
A2	17.55	20.26	24.70	23.91	23.73
A3	16.03	18.67	23.04	22.08	24.01
A4	13.63	12.85	21.85	19.14	20.39
A5	-	6.82	20.30	12.92	14.28

Table 7: Compressive strength of mortar containing aluminium sludge for 28 days

Sample Name	Average Compressive Strength for28 days (N/mm2)				
	(10 ± 2)°C	(23 ± 2) °C	(27 ± 2) °C	(30 ± 2) °C	(33 ± 2) °C
control	39.55	48.08	48.27	48.61	48.76
A1	38.52	43.51	38.98	45.51	42.03
A2	36.20	38.58	42.73	41.95	38.83
A3	34.52	36.70	37.42	40.00	37.68
A4	31.33	33.12	33.18	33.14	32.00
A5	26.12	29.70	29.53	29.28	28.05

4. CONCLUSION

In this study, the compressive strength of the ordinary Portland cement mortar and the mortar containing aluminium sludge was determined at the different curing temperatures (10 °C, 23 °C, 27 °C, 30 °C, and 33 °C) for 2 days and 28 days of curing ages. The investigation was carried out according to the ISO 679:2009. The compressive strength of the ordinary Portland cement mortar is increasing as the curing temperature is increasing. This indicates that, differ the temperature is affecting the compressive strength of the OPC mortar. The compressive strength of mortar decreases with increasing aluminium sludge percentage. One of the reasons for this decrease could be due to the entrapped air in the cement cubes due to the replacement of aluminium sludge and causes the reduction in compressive strength.

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REFERENCE

[1] Civiltoday, "Properties of Good Cement," 2018. [Online]. Available: https://civiltoday.com/civil-engineering-materials/cement/45-properties-of-good-cement. [Accessed: 12-Jan-2020].

[2] W. S. S. Jayamanna and N. B. M. Ranathunga, "Chemical Analysis of Some Commonly Used Brands of Ordinary Portland Cement in Sri Lanka," no. Cl, p. 8, 2009.

[3] F. U. Rahman, "Ordinary Portland Cement -Constituents, Properties, Types and Uses," *The Constructor*, 2019. [Online]. Available: https://theconstructor.org/concrete/ordinary-portland-cement/23181/. [Accessed: 08-Jan-2020].

[4] N. G. Ozerkan, O. L. Maki, M. W. Anayeh, S. Tangen, and A. M. Abdullah, "The Effect of Aluminium Dross on Mechanical and Corrosion Properties of Concrete," vol. 3, no. 3, pp. 9912–9922, 2014.

[5] G. Mailar, S. R. N, S. B.M, M. D.S, P. Hiremath, and J. K., "Investigation of concrete produced using recycled aluminium dross for hot weather concreting conditions," *Resour. Technol.*, vol. 2, no. 2, pp. 68–80, 2016, doi: 10.1016/j.reffit.2016.06.006.

[6] "Standard Sand | Standard sand CEN EN 196-1 - Standard Sand." [Online]. Available: https://www.standard-sand.com/en/standard-sand-cen-en-196-1-2/. [Accessed: 12-Jan-2020].

[7] "CEN-Standard Sand EN 196-1." [Online]. Available: https://www.normensand.de/en/products/cen-standard-sand-en-196-1/. [Accessed: 10-Jan-2020].

[8] P. / Preview, "Cement-Test methods-Determination of strength Ciments-Méthodes d'essai-Détermination de la résistance mécanique COPYRIGHT PROTECTED DOCUMENT," 2009.

[9] O. Ogah, "Effect of Curing Methods on the Compressive Strength of Concrete," *Int. J. Eng. Comput. Sci.*, vol. 5, no. 17161, pp. 17160–17171, 2016, doi: 10.18535/ijecs/v5i7.09.

[10] I. I. Akinwumi and Z. O. Gbadamosi, “Effects of Curing Condition and Curing Period on the Compressive Strength Development of Plain Concrete,” *Int. J. Civ. Environ. Res.*, vol. 1, no. 2, pp. 83–99, 2014.
[11] K. P. Teixeira, I. P. Rocha, L. D. S. Carneiro, J. Flores, E. A. Dauer, and A. Ghahremaninezhad, “The effect of curing temperature on the properties of cement pastes modified with TiO2 nanoparticles,” *Materials (Basel).*, vol. 9, no. 11, pp. 1–15, 2016, doi: 10.3390/ma9110952.
[12] D. A. Pereira, B. De Aguiar, F. Castro, M. F. Almeida, and J. A. Labrincha, “Mechanical behaviour of Portland cement mortars with incorporation of Al-containing salt slags,” *Cem. Concr. Res.*, vol. 30, no. 7, pp. 1131–1138, 2000, doi: 10.1016/S0008-8846(00)00272-6.
[13] M. S. Reddy and D. Neeraja, “Mechanical and durability aspects of concrete incorporating secondary aluminium slag,” *Resour. Technol.*, vol. 2, no. 4, pp. 225–232, 2016, doi: 10.1016/j.reffit.2016.10.012.
[14] M. K. Wayase, P. B. Dhage, R. D. Rathod, N. D. Rathod, A. B. Wakchaure, and V. R. Turai, “An Experimental Study on Partial Replacement of Cement By Aluminium Dross In Concrete,” *J. Adv. Sch. Res. Allied Educ.*, pp. 153–158, 2018, doi: 10.29070/15/56804.