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Effect of High Temperature on Mechanical Properties of Concrete Containing Platicizers and Retarding Water Reducing Admixtures

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Abstract: *The properties of concrete exposed to high temperature conditions are considerably influenced by the cooling regime. Therefore, the study investigated the effect of high temperature on mechanical properties of concrete containing admixtures. Mix design was in accordance to ASTM C-494 Type B with uniform water/binder (w/b) ratio of 0.5 and mix ratio of 1:2:4 was adopted. Furthermore, the additives used was mls/100kg of cement. Specimens were cured for 7, 14, 21 and 28 days at room temperature. At the end of the curing periods, the specimens were left to dry in the air for (2 hrs) prior to heating. The concrete specimens heated to different levels of controlled high temperatures after curing; the average compressive strengths under the 6 different elevated temperatures for 7, 14, 21, and 28days age concretes were found to be 35.89 N/mm², 39.71 N/mm2, 44.03 N/mm² and 46.01 N/mm² respectively. Therefore, higher compressive strength was recorded in 28 days' age concrete containing Super Plasticizer. However, the average compressive strengths under the 6 different elevated temperatures for 7, 14, 21, and 28 days' age concretes were found to be 33.18 N/mm², 36.80 N/mm², 40.20 N/mm² and 42.15 N/mm² respectively. Therefore, higher compressive strength was recorded in 28 days' age concrete containing plasticizer. The average compressive strengths under the 6 different elevated temperatures for 7, 14, 21, and 28 days' age concretes were found to be 34.52 N/mm², 38.97 N/mm², 41.42 N/mm² and 41.77 N/mm² respectively. Therefore, higher compressive strength was recorded in 28 days' age concrete containing retarding and water reducing agent.*

Keywords: *Additives, Particle Size, Concrete, Temperature and Strength*

Introduction

Concrete is a composite construction material, composed of cement (commonly Portland cement) and other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate made of gravels or crushed rocks such as limestone, or granite, plus a fine aggregate such as sand), water, and admixtures. Material scientists, chemists, engineers, and manufacturers' technical representatives have helped the concrete industry to improve ability to control work times, workability, strength, and durability of Portland cement concrete by adding some supplementary substances named admixtures. The function of each admixture focuses on aa specific need, and each has been developed independently of the others. Some admixtures already have chemistry that affects more than one property of concrete, and some have simply been combined for ease of addition during the batching process.

The properties of concrete exposed to high temperature conditions are considerably influenced by the cooling regime. The specimens were either dry cooled (in air) or wet cooled (quenched) in water (Xiao, 2004; Kowalski 2008; Husem 2006). Rapid cooling (quenching) was found to have a much more deteriorating effect on the mechanical properties of concrete as compared to dry cooling (Xiao, 2004; Husem, 2006). The differences are particularly pronounced at lower

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temperatures to become hardly noticeable at the test temperature of 600 °C (Xiao, 2004). Similarly, the influence of cooling method (dry or wet) on the mechanical properties of concrete becomes insignificant when the time of quenching is shortened to about 10 sec.

The different tests to determine the high temperature performance of concrete use different specimens in terms of shape and size (Behnood & Ghandehari 2009; Noumowe 2005; Drzymała & Bednarek 2011a) with cylindrical specimens expected to enhance obtaining uniform temperature distribution throughout the specimen. However, cubes and rectangular prisms of various sizes are also used in such tests (Poon et al. 2001; Arioz 2007; Ergün et al. 2013). It has been demonstrated that the specimen size has no effect on the properties of concrete exposed to high temperature simulating fire conditions.

According to EN 1992-1-2:2008/NA:2010P (2010) the tensile strength of concrete exposed to elevated temperature decreases linearly from 100 °C up to 600 °C at which it has no tensile strength at all. Actually, while it is true that exposure to elevated temperature affects the tensile strength of concrete, this decrease is not as big as to lead to zero tensile strength at 600 °C (Neville 2012; Xiao, 2004; Saad et al. 1996).While according to Neville (2012) the decrease of tensile strength of concrete exposed to elevated temperature follows a similar pattern to the decrease of compressive strength. Many researchers found it to be much greater as compared to the decrease in compressive strength, resulting in a considerable increase in brittleness of concrete (Xiao, König 2004; Chen et al. 2009). Exposure to elevated temperature affects also the flexural strength of concrete. The increase in temperature results in a decrease in flexural strength (Husem 2006; Pliya et al. 2011; Ergün et al. 2013). According to Bazant and Kaplan, (1996) results, which indicated that for a wide variety of ordinary concrete mixes made with conventional aggregates, there was a reduction in strength after heating to 500ºC from a minimum 15% to a maximum 60%. Results also indicated that there is an approximately linear reduction in the strength ratios as the temperature increases from 200ºC to 500ºC. The result at higher temperatures indicated that at 600ºC, the residual compressive strength ratios vary between about 80 and 25%. At 700ºC, the ratios vary between 70 and 20%. At 800ºC, the ratios vary between 50 and 20% of the initial unheated compressive strength.

Methodology

Concrete Mix Design

Mix design was in according to ASTM C-494 Type B with uniform water/binder (w/b) ratios of 0.5 and mixes ratio of 1:2:4 was adopted. Furthermore, curing ages of 7, 14, 21 and 28 days were used. The additives used was based on amount recommended by the manufacturer and as shown in Tble 1.

Table 1: Admixtures Dosage

Concrete Mix Design	Concrete Mix Design (Rheobuild 800)	Concrete Mix Design (Pozzolith 322N)	Concrete Mix Design (Retarding and Water Reducing Agent 100Ri)
Dosage (mls/100kg of cement)	1000	327.5	195

Table 2: Experimental Specimens

Types of Specimen	Super plasticizer (Rheobuild 800)	Plasticizer (Pozzolith 322N)	Retarding and Water Reducing (Pozzolith100Ri)	Control
No. of Cubes	3x4	3x4	3x4	1x4x3
Total required cubes	**48X6**			

A total of two hundred and eighty-eight (288) concrete cubes of different Admixtures and elevated temperatures of 100,150,200,300,400 and 600 ^{0}c were used. Thirteen (6) run experiments, 3 replications and 4 different curing ages (7, 14, 21 and 28days) which makes a total of 288 cubes. Figure 1 shows cube cast and curing.

a b

Figure 1: Cubes cast and Curing

Concrete Heating and Cooling Process

The concrete specimens heated to different levels of high temperatures after curing; using an electrical furnace with a maximum temperature of (1000 ^{0}C). The electric furnace was consisted of wide chamber of a double metal containing auto-control thermal probes; with built in thermocouples. The temperature of the furnace increases by an average value of (5°C/min) at its primary stage up to (200° C), becoming faster to about (10° C/min) at the required temperature. The concrete specimens then placed inside the furnace for one hour at a constant temperature; then specimens were left for (24 hrs) to be air cooled.

Results and Discussion

Grain size distributions from sieve analysis

Table 3: Fine Sand Grain size distributions from sieve analysis

Diameter (mm)	Mass of Sieve (g)	Mass of Sieve & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
2.36	468.00	491	23.0	5.3	94.7
1.00	506.00	534	28.0	6.5	88.2
0.60	498.00	564	66.0	15.3	72.9
0.40	447.00	513	66.0	15.3	57.5
0.30	323.00	351	28.0	6.5	51.0
0.21	352.00	401	49.0	11.4	39.7
0.15	443.00	487	44.0	10.2	29.5
0.080	502.000	598	96.0	22.3	28.8
Pan	490	521	31.0	7.2	32.5
		TOTAL:	431.0	100.0	

Fine Modules = 3.6

ASTM D422-63(2007) classified fine aggregates range from a Fineness Modulus (FM) 2.00 to 4.00. Therefore, the soil classified as fine aggregate.

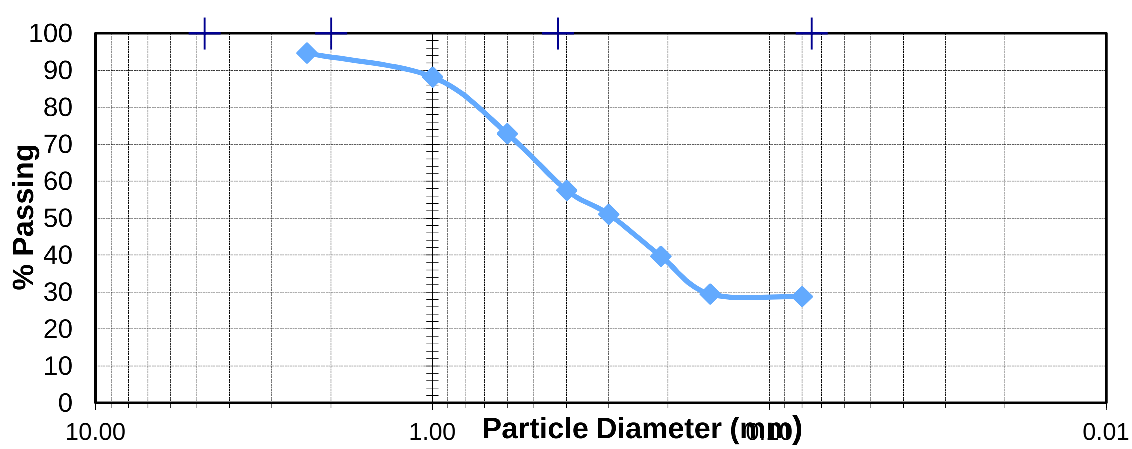

Figure 2: Graph for grain size distribution for fine sand

Table 4: Compressive Strength of Concrete containing Super Plasticized Under Elevated Temperature

Temperature (°C)	Identification of Specimen	Weight before placing in electric Oven (Kg)	Weight after placing in electric Oven (Kg)	Density of cube (Kg/m³) (after heating)	Average Density of cube (Kg/m³)	Average compressive strength (KN/mm²): 7 days Age	Average compressive strength (KN/mm²) 14 days age	Average compressive strength (KN/mm²): 21 days age	Average compressive strength (KN/mm²): 28 days age	Average compressive strength (KN/mm²) (Control)
100	1JU 1 1JU 2 1JU 3	8.54 8.56 8.45	8.52 8.53 8.54	2524 2527 2530	2527	20.56	23.04	25.07	26.67	26.59
150	1JU 11 1JU 12 1JU 13	8.55 8.53 8.56	8.46 8.52 8.51	2507 2524 2521	2517	20.08	23.64	25.67	26.17	26.01
200	1JU 21 1JU 22 1JU 23	8.56 8.55 8.57	8.42 8.45 8.44	2495 2504 2501	2500	19.78	22.33	24.79	25.01	22.52
300	1JU 31 1JU 32 1JU 33	8.58 8.56 8.54	8.39 8.38 8.37	2486 2483 2480	2483	18.22	19.24	21.56	22.56	23.24
400	1JU 41 1JU 42 1JU 43	8.57 8.55 8.58	8.26 8.14 8.28	2447 2412 2453	2437	15.60	16.33	18.82	19.34	18.19
60 0	1JU 51 1JU 52 1JU 53	8.56 8.54 8.57	8.16 8.17 8.14	2418 2421 2412	2417	13.44	14.56	16.18	18.27	15.45

Table 5: Compressive Strength of Concrete containing Plasticized under Elevated Temperature

Temperature (°C)	Identification of Specimen	Weight before placing in electric Oven (Kg)	Weight after placing in electric Oven (Kg)	Density of cube (Kg/m³) (after heating)	Average Density of cube (Kg/m³)	Average compressive strength (KN/mm²) 7 days age	Average compressive strength (KN/mm²)14 days age	Average compressive strength (KN/mm²) 21 days age	Average compressive strength (KN/mm²) 28 days age	Average compressive strength (KN/mm²) (Control)
100	2JU 1 2JU 2 2JU 3	8.58 8.57 8.58	8.58 8.56 8.57	2542 2536 2539	2539	20.05	22.41	23.87	24.22	24.85
150	2JU 11 2JU 12 2JU 13	8.59 8.58 8.57	8.51 8.52 8.51	2521 2524 2521	2522	20.01	21.82	23.51	24.35	24.67

200	2JU 21 2JU 22 2JU 23	8.59 8.58 8.59	8.43 8.46 8.47	2498 2507 2510	2505	18.91	20.33	22.41	23.02	23.42
300	2JU 31 2JU 32 2JU 33	8.57 8.59 8.58	8.42 8.39 8.37	2495 2486 2480	2487	17.11	19.43	20.45	22.12	22.76
400	2JU 41 2JU 42 2JU 43	8.57 8.58 8.58	8.29 8.18 8.34	2478 2587 2512	2526	13.34	15.24	17.01	18.11	19.36
600	2JU 51 2JU 52 2JU 53	8.58 8.57 8.57	8.17 8.16 8.14	2406 2457 2445	2436	10.12	11.18	13.34	14.62	15.14

Table 6: Compressive Strength of Concrete Containing Retarding and Water Reducing Agent Under Elevated Temperature

Temperature (^oC)	Identification of Specimen	Weight before placing in electric Oven (Kg)	Weight after placing in electric Oven (Kg)	Density of cube (Kg/m³) (after heating)	Average Density of cube (Kg/m³)	Average compressive strength (KN/mm²) 7 days age	Average compressive strength (KN/mm²) 14 days age	Average compressive strength (KN/mm²) 21 days age	Average compressive strength (KN/mm²) 28 days age	Average compressive strength (KN/mm²) (Control)
100	3JU 1 3JU 2 3JU 3	8.52 8.52 8.55	8.50 8.51 8.54	2519 2521 2530	2523	20.35	22.92	23.98	24.72	25.85
150	3JU 11 3JU 12 3JU 13	8.53 8.54 8.53	8.51 8.53 8.52	2521 2527 2524	2524	20.15	22.80	23.67	24.44	25.52
200	3JU 21 3JU 22 3JU 23	8.52 8.54 8.57	8.50 8.53 8.54	2519 2527 2530	2525	19.81	21.43	22.72	23.37	24.36
300	3JU 31 3JU 32 3JU 33	8.56 8.52 8.53	8.49 8.48 8.49	2516 2513 2516	2515	18.75	20.84	21.41	21.02	23.12
400	3JU 41 3JU 42 3JU 43	8.57 8.55 8.58	8.26 8.14 8.28	2447 2412 2453	2437	14.25	16.65	18.12	17.83	20.68
60 0	3JU 51 3JU 52 3JU 53	8.56 8.54 8.57	8.16 8.17 8.14	2418 2421 2412	2417	10.25	12.28	14.35	13.92	15.25

Table 7: ANOVA Analysis for compressive strength variation between the curing ages of Concrete containing Super Plasticizer

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	245.05	11	22.28	2.75	0.048	2.72
Within Groups	97.35	12	8.11			
Total	342.40	23				

Alpha value = 0.05
Alpha value > P – value
The difference is significant

Therefore, compressive strength between the concrete of 7, 14, 21 and 28 days are not the same. However, the average compressive strengths under the 6 different elevated temperatures for 7, 14, 21, and 28days age concretes were found to be 35.89 N/mm^2, 39.71 N/mm^2, 44.03 N/mm^2 and 46.01 N/mm^2 respectively. Therefore, higher compressive strength is recorded in 28 days age Concrete containing Super Plasticizer.

Table 8: ANOVA Analysis for compressive strength variation between the curing ages of Concrete containing Plasticizer

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	256.04	11.00	23.28	6.05	0.019	4.03
Within Groups	23.07	6.00	3.85			
Total	279.11	17.00				

Alpha value = 0.05
Alpha value > P – value
The difference is significant

Therefore, compressive strength between the concrete of 7, 14, 21 and 28 days are not the same. However, the average compressive strengths under the 6 different elevated temperatures for 7, 14, 21, and 28 days age concretes were found to be 33.18 N/mm^2, 36.80 N/mm^2, 40.20 N/mm^2 and 42.15 N/mm^2 respectively. Therefore, higher compressive strength is recorded in 28 days age Concrete containing Plasticizer.

Table 9: ANOVA Analysis for compressive strength variation between the curing ages of Concrete containing Retarding and Water Reducing Agent

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	333.10	11	30.28	6.88	0.0011	2.71
Within Groups	52.77	12	4.39			
Total	385.88	23				

Alpha value = 0.05
Alpha value > P – value

The difference is significant
Therefore, compressive strength between the concrete of 7, 14, 21 and 28 days are not the same. However, the average compressive strengths under the 6 different elevated temperatures for 7, 14, 21, and 28 days age concretes were found to be 34.52 N/mm^2, 38.97 N/mm^2, 41.42 N/mm^2 and 41.77 N/mm^2 respectively. Therefore, higher compressive strength is recorded in 28 days age Concrete containing Retarding and Water Reducing Agent.

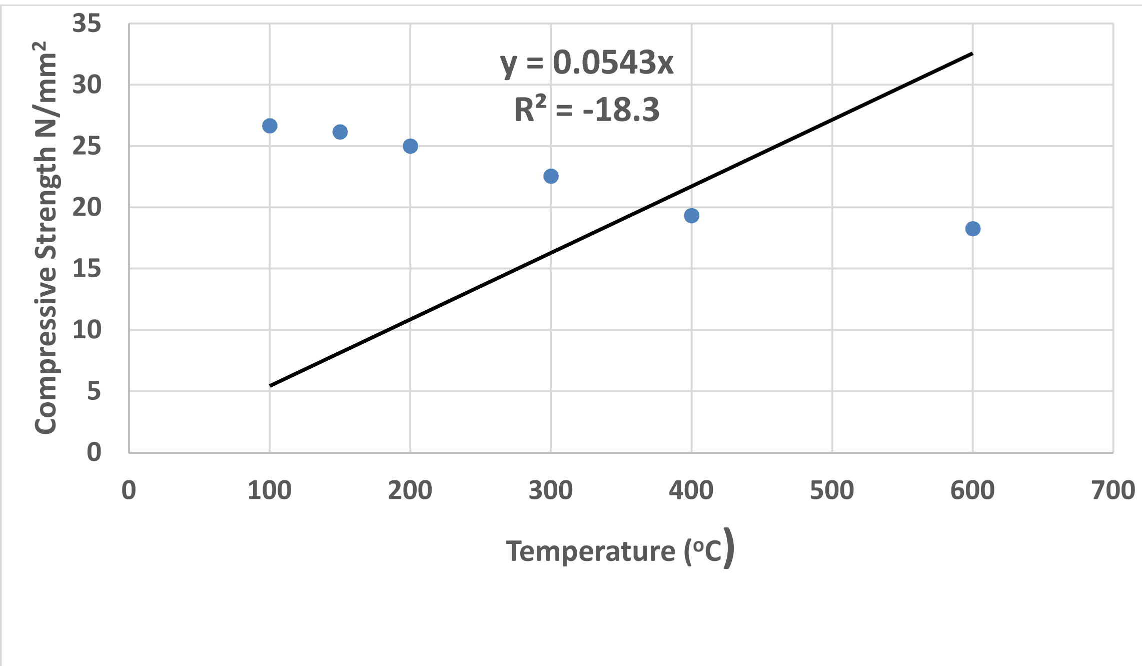

Figure 3: Compressive Strength of Concrete containing Super Plasticized Under Elevated Temperature
Figure 3 is regression graph showing inverse relationship between temperature and compressive strength of concrete containing Super Plasticizer with a R^2 value of -ve 18.3. Meaning, the higher the temperature the lower the compressive strength as shown in the figure.

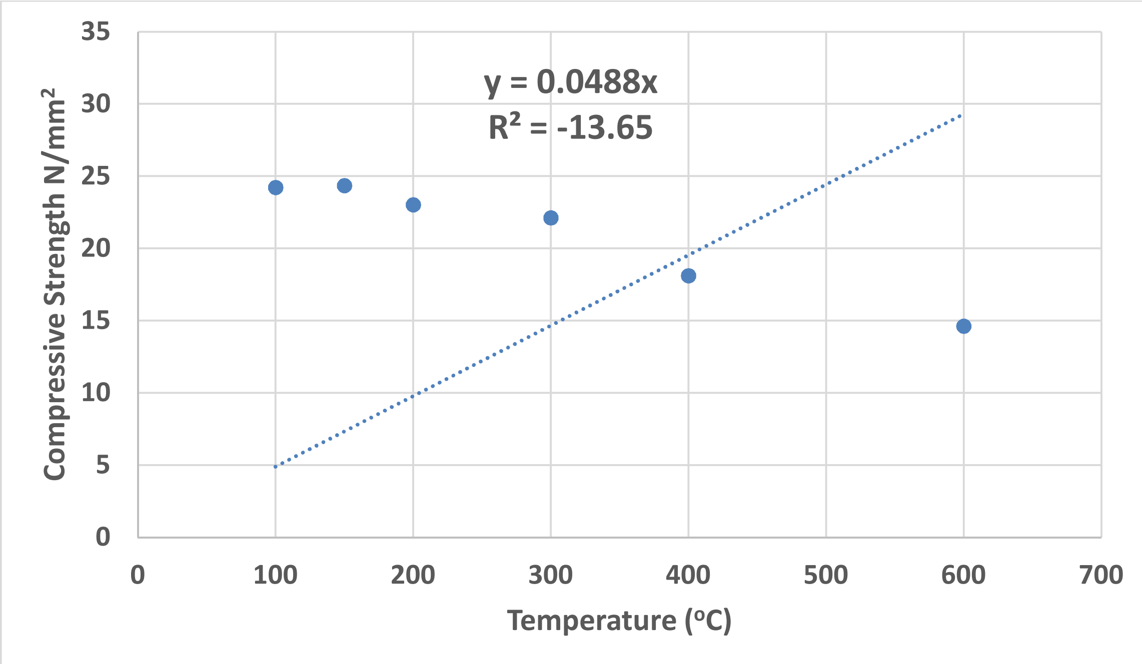

Figure 4: Compressive Strength of Concrete containing Plasticized Under Elevated Temperature

Figure 4 is regression graph showing inverse relationship between temperature and compressive strength of concrete containing Plasticizer with a R^2 value of -ve 13.65. Meaning, the higher the temperature the lower the compressive strength as shown in the figure.

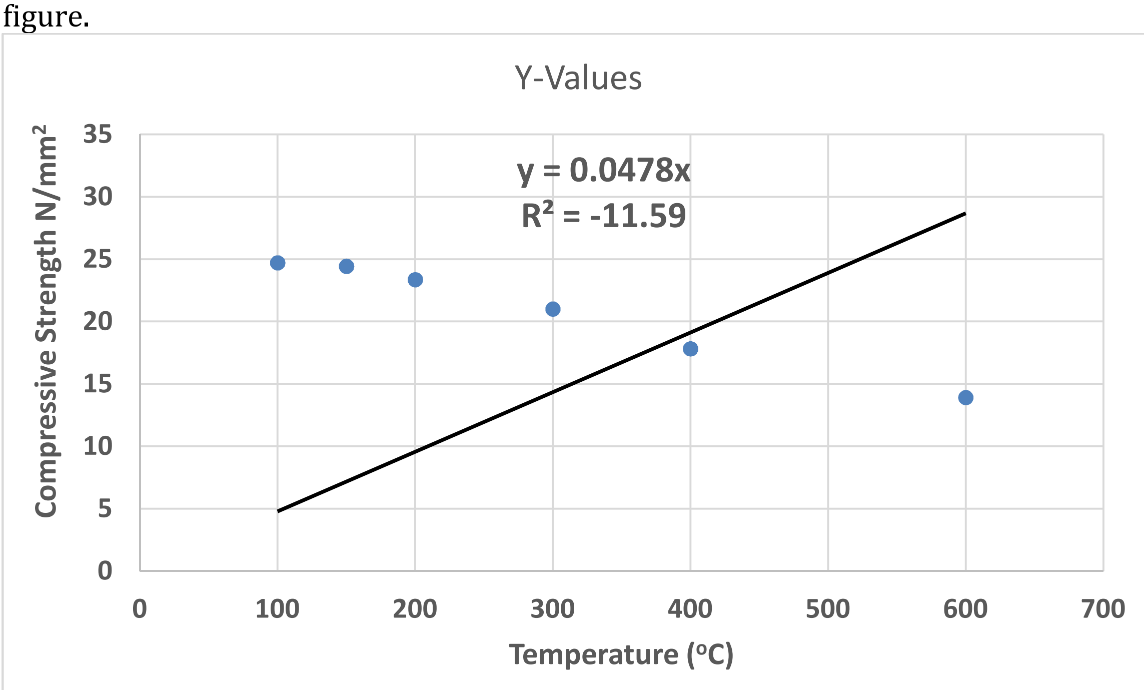

Figure 5: Compressive Strength of Concrete containing Water Reducing Agent Under Elevated Temperature

Figure 5 is regression graph showing inverse relationship between temperature and compressive strength of concrete containing Retarding and Water Reducing Agent with a

R^2 value of -ve 11.59. Meaning, the higher the temperature the lower the compressive strength as shown in the figure.

Table 10: ANOVA analysis on effects of Super Plasticizer, Plasticizer, Retarding and Water Reducing Agent on Concrete compressive strength

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	903.48	11	82.13	18.37	2.52E-15	1.95
Within Groups	268.29	60	4.47			
Total	1171.77	71				

Alpha value = 0.05
Alpha value > P – value
The difference is significant

Therefore, effect of the three additives used are not the same on compressive strength of concrete containing Super Plasticizer, Plasticizer, Retarding and Water Reducing Agent. However, highest average value of 46.01N/mm^2 was observed at 28 days age concrete containing Plasticizer.

Conclusion

The study determined the compressive strength of concrete containing superplasticizer, plasticizer and retarding water reducing admixtures at varying Temperature. Therefore, the following conclusions were drawn:

i. The compressive strength between the concrete of 7, 14, 21 and 28 days are not the same. However, the average compressive strengths under the 6 different elevated temperatures for 7, 14, 21, and 28days age concretes were found to be 35.89 N/mm2, 39.71 N/mm2, 44.03 N/mm2 and 46.01 N/mm2 respectively. Therefore, higher compressive strength is recorded in 28 days' age Concrete containing Super Plasticizer.

ii. The compressive strength between the concrete of 7, 14, 21 and 28 days are not the same. However, the average compressive strengths under the 6 different elevated temperatures for 7, 14, 21, and 28 days' age concretes were found to be 33.18 N/mm2, 36.80 N/mm2, 40.20 N/mm2 and 42.15 N/mm2 respectively. Therefore, higher compressive strength is recorded in 28 days' age Concrete Containing Plasticizer.

iii. The compressive strength between the concrete of 7, 14, 21 and 28 days are not the same. However, the average compressive strengths under the 6 different elevated temperatures for 7, 14, 21, and 28 days' age concretes were found to be 34.52 N/mm2, 38.97 N/mm2, 41.42 N/mm2 and 41.77 N/mm2 respectively. Therefore, higher compressive strength is recorded in 28 days' age Concrete Containing Retarding and Water Reducing Agent.

iv. Therefore, effect of temperature on the three additives used are not the same on compressive strength of concrete containing Super Plasticizer, Plasticizer, Retarding and Water Reducing Agent. However, highest average value of 46.01N/mm2 was observed at 28 days' age concrete containing Super Plasticizer.

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