The impact on high strength concrete properties using curing methods

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***Abstract*—Curing significantly impacts concrete properties, especially durability, by influencing the hydration of cement. Advances in curing technologies and the introduction of various chemical compounds have greatly improved concrete performance. Self-curing agents are particularly effective in dry climates. This paper focuses on evaluating the efficiency of various curing methods typically employed in the construction sector.**

Keywords—Hardened characteristics, longevity, curing agents, and the effectiveness of curing component.

I. Introduction

Concrete has become an essential material in modern construction, with its composition playing a critical role in determining strength and durability. As the most commonly used man-made material worldwide, concrete is found in pavements, dams, bridges, buildings, tunnels, and more. In 1999, Lambert Cooperation introduced the concept that curing involves treating freshly placed concrete during its hardening phase to retain sufficient moisture, helping to reduce cracking and shrinkage. Curing is widely recognized as a key factor in achieving the desired structural strength and durability in concrete.

There are two main curing methods: one focuses on maintaining water availability, while the other involves sealing the concrete's surface to minimize water loss. The choice of curing method depends on factors such as the availability of curing materials, the size and shape of the structure, and environmental conditions. Traditionally, the quality of concrete in construction is measured by its compressive strength after 28 days. If the quality of the concrete is questionable at that point, subsequent construction may have already covered it up create these components, incorporating the applicable criteria that follow.

Extreme heat-related situations are prevalent in many parts of the world, including India, where temperatures can rise to 45°C to 50°C. The performance of both fresh and hardened concrete is impacted by hot weather, which presents several difficulties for the manufacture, shipping, construction, and maintenance of concrete and concrete structures. The lifespan of concrete structures is shortened and their decay is accelerated by high temperatures, which also weaken and threaten the resilience of concrete. Extreme weather, inferior building materials, and subpar construction techniques are the main causes of concrete deterioration in hot, dry areas. Through these elements, the environment has a significant impact on how well concrete performs. Regretfully, not enough research has been done on the effects of these disorders.

Materials & Methods

A. Materials

Ordinary Portland Cement (OPC), classified as P.O. 42.5 by JTG E30-2005-GB175-2007 and having a specific surface area of 355 m²/kg, was one of the materials used in the experiment. Concrete compositions were supplemented with 33% fly ash (FA) and varying proportions of silica fume (SF) at 1%, 6%, and 11%. The OPC was partially substituted with these extra cementing chemicals. The chemical composition of OPC and the other components is shown in *Table 1*.

Natural river sand was utilized as the fine aggregate, and crushed limestone as the coarse aggregate. The crushing value was 19.46%, the specific gravity was 2.58, and the absorption rate was 1.81% for the coarse aggregate (>4.75 mm). The specific gravity of the fine aggregate (less than 4.75 mm) was 2.50 and its absorption rate was 2.31%. In accordance with JTG/T F30-2014, the Technical Guidelines for Construction of Highway Cement Concrete Pavements, the coarse aggregates were categorized as shown in Table 2. Additionally, 0.4:0.6 by weight was chosen as the fine-to-coarse aggregate ratio. In order to mix and cure the concrete samples, concrete mixtures with water-to-binder (W/B) ratios of 0.30, 0.35, and 0.40 were made using potable water..

B. Materials preparation

Using variable proportions of a water reducer, the concrete mixtures were made in the lab to produce different slump values (200 mm for mix No. 1 and 400 ± 10 mm for the other mixtures) as determined by the flow test. Trial combinations were used to establish these dosages prior to creating the final mixtures. Table 3 displays the ratios of the blends.

C. Curing and Exposure

The concrete samples were poured at 20°C room temperature. Following casting, they were kept in the lab for a whole day before the molds were taken out. After that, the samples were exposed to four distinct curing environments. Prior to the day of testing, the first group was subjected to the usual curing process from casting. Steam curing was applied to the second group at steady temperatures of 30°C or 50°C till testing. Prior to testing, the third group was kept at a steady 30°C or 50°C in a dry oven. For 3, 7, 21, and 28 days, the fourth group was cured in water. After that, they were moved to a dry oven (an alternative to an oven) set at 30°C or 50°C, and after 28 days, they were examined. On the 31st day, however, specimens that had been cured in water for 28 days and then put in an oven were evaluated to determine how long the curing process affected the strength of concrete exposed to hot, dry conditions following initial moist curing.

TABLE: 1 Cement's chemical composition and additional cementing ingredients

Oxide Compounds	PC	Silica Fume	Fly Ash
SiO_2	21.12	90.97	59.1
Al_2O_3	5.62	0.47	38.9
Fe_2O3	3.22	0.91	—
CaO	65.95	0.42	0.87
MgO	1.82	0.93	0.71
SO_3	2.30	0.60	0.42
Loss on ignition (LOI)	—	5.7	—
Density (g/cm^3)	2.77	2.48	2.71
Physical properties			
C_3A	7.14	—	—
C_4AF	11.4	—	—
C_3S	59.2	—	—
C_2S	18.8	—	—
Ignition loss	0.5	—	—

TABLE: 2 coarse aggregate grading.

JTG/T F30-2014 limits		
Sieve size (mm)	Passed (%)	Remaining (%)
26	100	0-5
19	70	25-40
16	40	50 – 70
9.5	20	70 – 90
4.75	5	90 – 100
2.36	0	95 – 100

II. RESULTS

A. Comprehensive strength

The compressive strengths of concrete specimens made and cured under various conditions are shown in Figures 1-3. As the curing temperature rises, the compressive strength generally tends to increase over time.

The difference in compressive strength under various curing conditions—dry oven curing with a relative humidity of less than 10%, steam curing at 30°C, and standard curing at 21 ± 1°C with a relative humidity of 85 ± 5%—is depicted in Figure 1(a). Concrete specimens from mix No. 1 that were cured in water for up to 21 days and then subjected to conventional curing had the maximum compressive strength. After three days, specimens treated in a dry oven had the second-highest compressive strength, whereas specimens that were steam-cured at seven and twenty-one days had the second-highest compressive strength. The best compressive strength, however, was obtained after 28 days of steam curing.

The oven replacement test findings are shown in Figure 1(b) for specimens that were first cured in water for 3 and 7, 21 and 28 days. They were then placed in a dry oven and tested at 28 days. The group that had a 28-day water cure and a 3-day oven cure prior to testing was the exception. Comparing specimens cured in water for 3, 7, and 21 days with those cured in a dry oven, it was shown that the latter had a higher compressive strength at 28 days. Though still higher than that of the specimens treated in water for 28 days and then placed in the oven for 3 days, the specimens cured by steam at 28 days had a lower compressive strength. curing conditions.

TABLE 3: Mixture proportions.

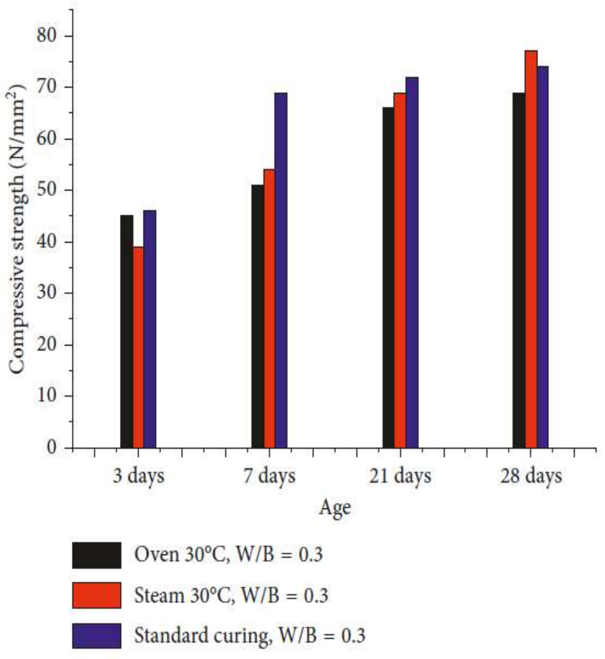
	W/B ratio	W	Binder (kg/m^3)	Cement (kg/m^3)	FA (kg/m^3)	SF (kg/m^3)	Sand (kg/m^3)	Aggregate (kg/m^3)	Water reduces(%)	Density (kg/m^3)
Mix 1	0.30	135	450	315	30% 135	0% 0	706	1060	1.8	2351
Mix 2	0.35	182	520	338	30% 156	5% 26	660	990	1.5	2352
Mix 3	0.4	192	480	288	30% 144	10% 48	682	1023	1.5	2377

D. Evaluation

By taking measurements of the concrete's flexural strength at 7 and 28 days and its compressive strength at 3, 7, 21, and 28 days, the effects of various curing conditions and the addition of additional cementing materials were assessed. Furthermore, a chloride penetration test was performed after 28 days to measure permeability, and Vickers hardness tests were used to determine the hardness of the interfacial transition zone (ITZ) at 7, 14, and 28 days. Using 100 mm cubic specimens for compressive strength testing and 40 × 10 × 10 mm concrete beams for flexural strength testing, the Standard Test Method for Mechanical Properties of Ordinary Concrete (GB/T 50081-2002) was followed. Three specimens of each concrete property and age were examined for each mix, and the average of the three results was reported.

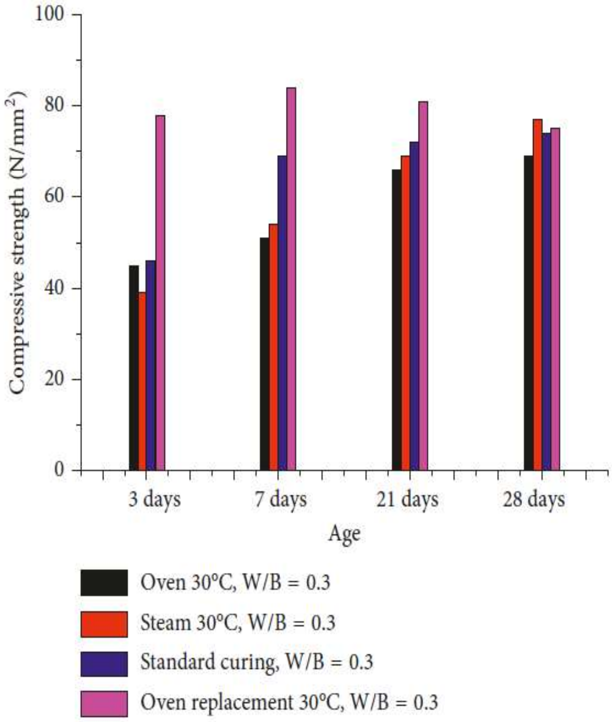
The fluctuation in compressive strength for fly ash (FA) concrete specimens cured at 50°C under various conditions is shown in Figure 1(c). According to the findings, normal curing produces lesser compressive strength at three days, whereas oven and steam curing at 50°C produce higher early-age compressive strength. The higher temperature, which speeds up the development of early-age strength, is responsible for this rise in early strength.

The impact of oven replacement on compressive strength is seen in Figure 1(d). When examined at 28 days, specimens that had been cured in water for 7 and 21 days before being put in an oven showed increased compressive strength. In contrast to specimens cured with steam or under normal conditions, those treated in a dry oven had an even higher compressive strength.



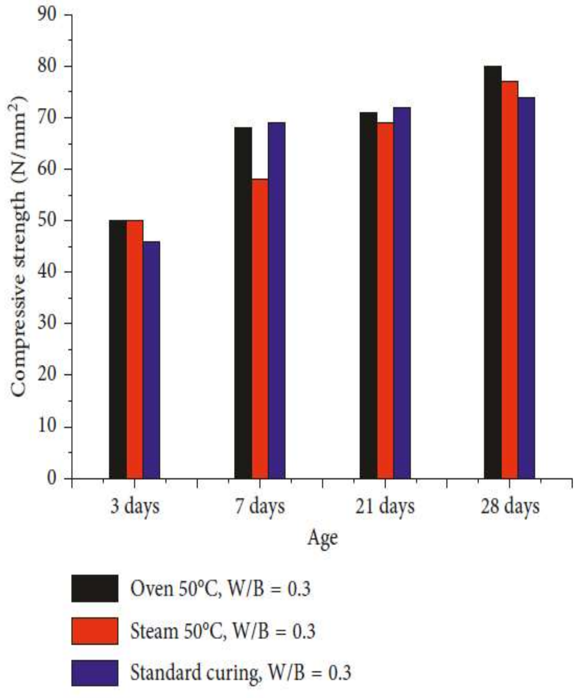
(a)

Figure 1: (a) compressive strengths of concrete specimens made and cured at 30°C under varied conditions, using a water-to-binder (W/B) ratio of 0.3.



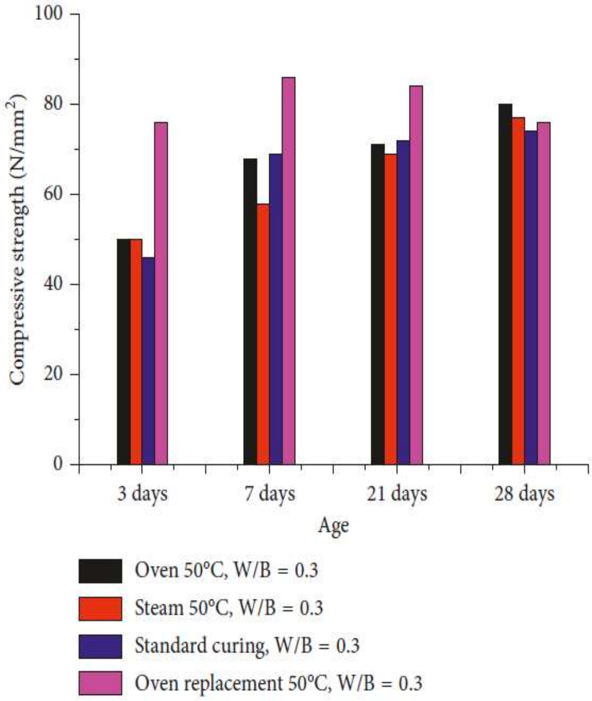
(b)

Figure 1: (b) Compressive strengths of concrete specimens cured with oven replacement and a W/B ratio of 0.3 at 30°C were compared to various curing circumstances.



(c)

Figure 1: (c) Compressive strengths of concrete specimens prepared and cured at 50°C under various conditions, using a W/B ratio of 0.3.



(d)

Figure 1: (d) Compressive strengths of concrete specimens cured with oven replacement and a W/B ratio of 0.3 were compared to various curing conditions at 50°C.

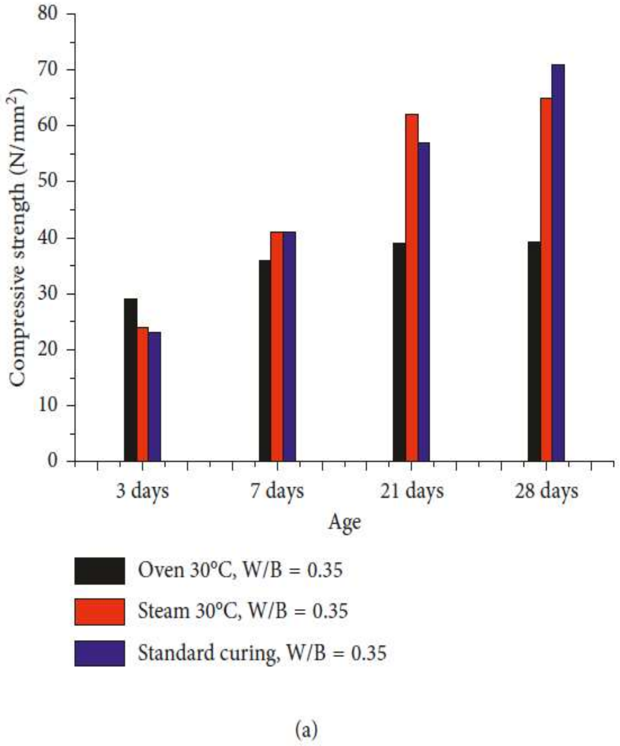


Figure 2: (a) compressive strengths of concrete specimens made and cured at 30°C under varied conditions, using a water-to-binder (W/B) ratio of 0.35.

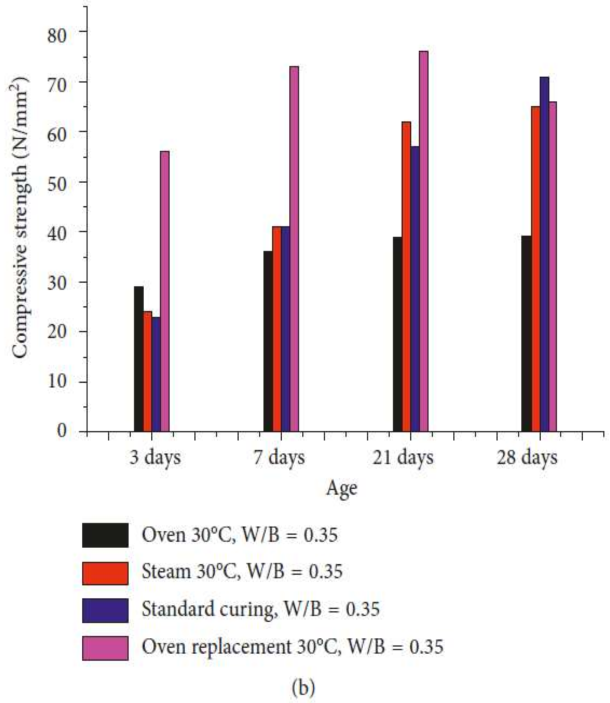


Figure 2: (b) Concrete specimens with a W/B ratio of 0.35 that were cured by oven replacement and compared to various curing conditions at 30°C were measured for compressive strengths.

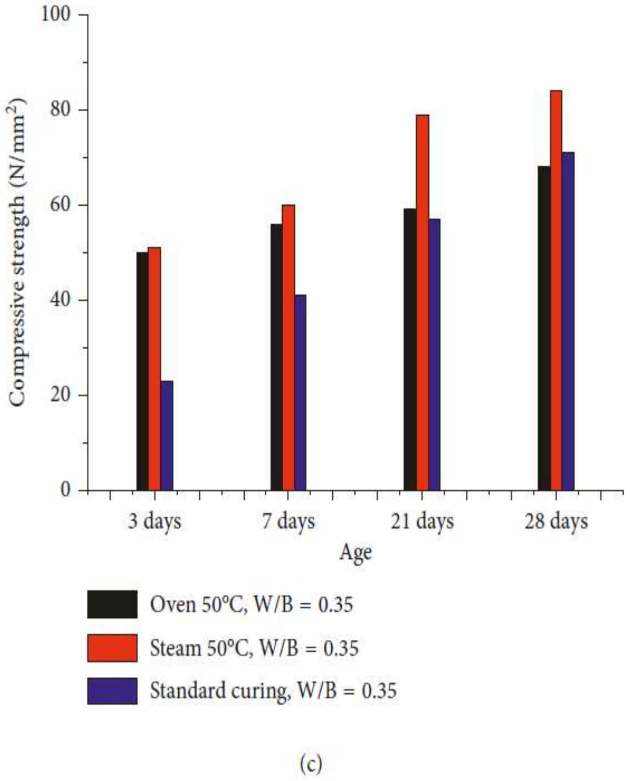


Figure 2: (c) Compressive strengths of concrete specimens produced and cured at 50°C under various conditions and with a W/B ratio of 0.35.

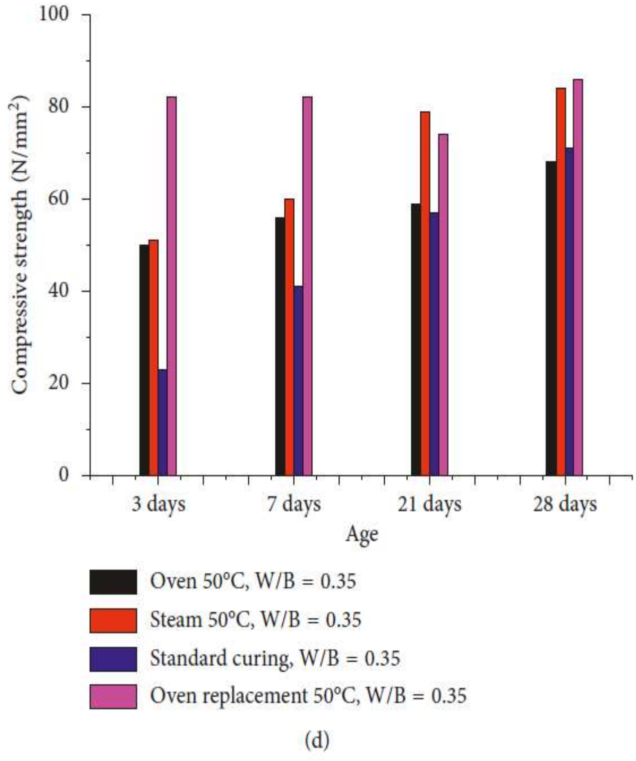


Figure 2: (d) Concrete specimens with a W/B ratio of 0.35 that were cured by oven replacement and compared to various curing conditions at 50°C in terms of compressive strengths..

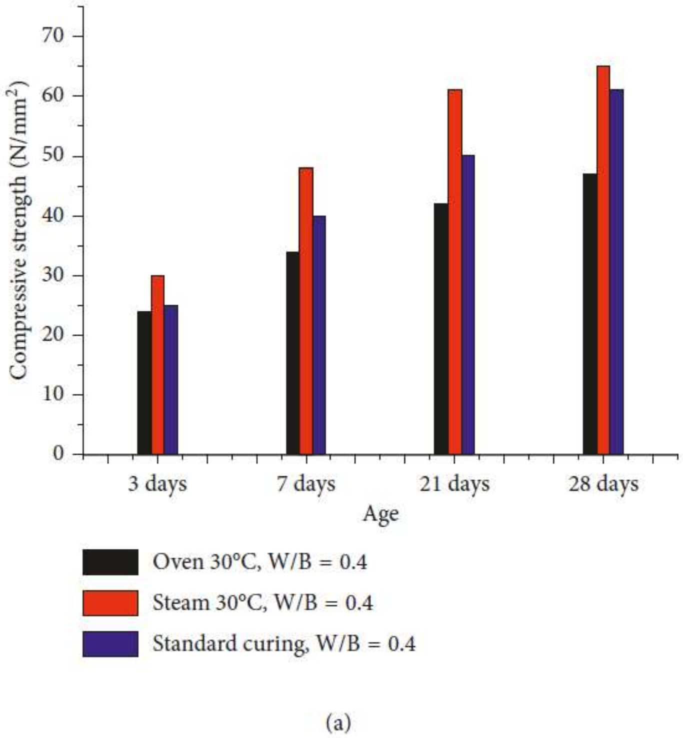


Figure 3: (a) compressive strengths of concrete specimens made and cured at 30°C under varied conditions, using a water-to-binder (W/B) ratio of 0.4.

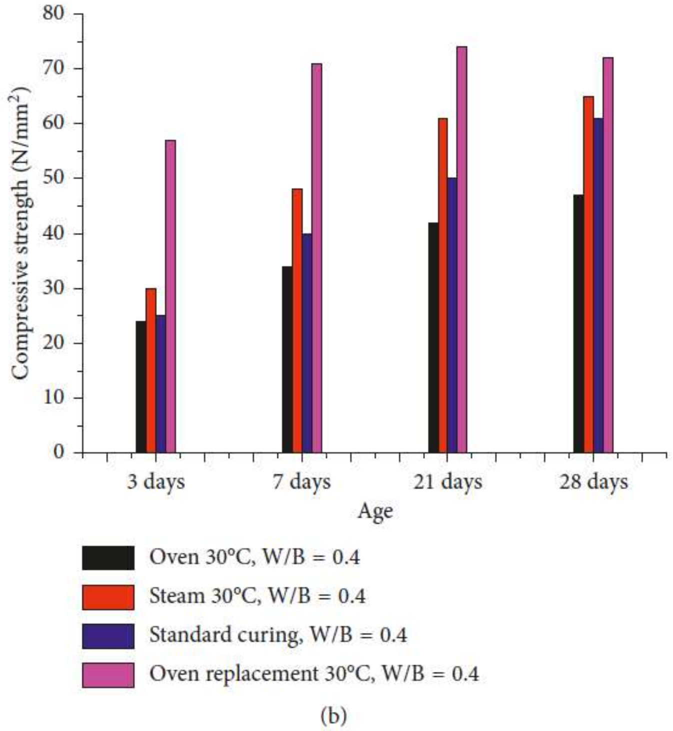


Figure 3: (b) Concrete specimens with a W/B ratio of 0.4 that were cured by oven replacement and compared to various curing conditions at 30°C were measured for compressive strengths.

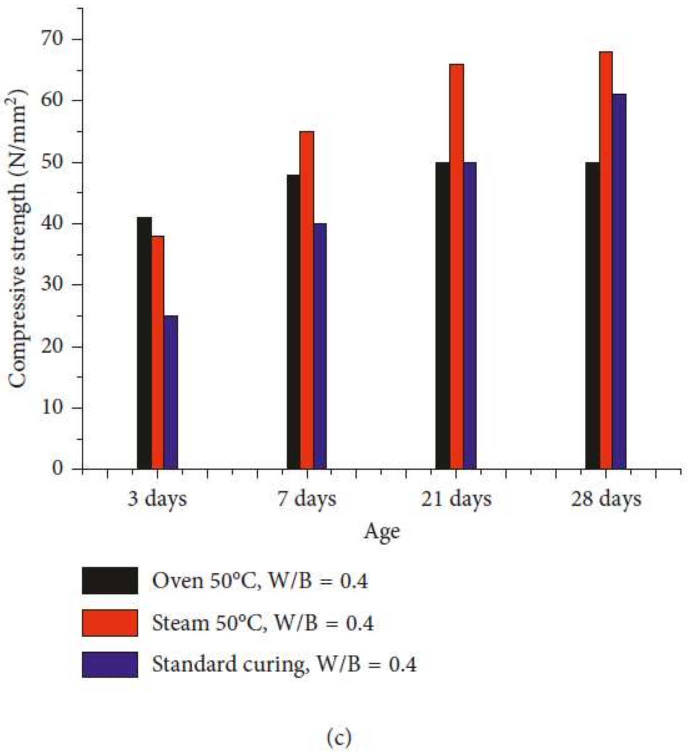


Figure 3: (c) Compressive strengths of concrete specimens prepared and cured at 50°C under various conditions, with a W/B ratio of 0.4.

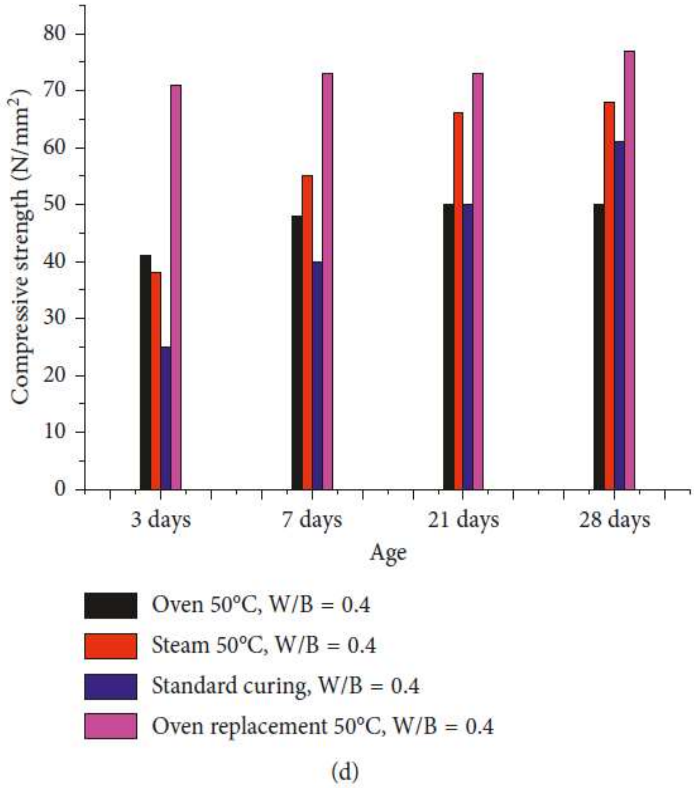


Figure 3: (d) Compressive strengths of concrete specimens cured with oven replacement and a W/B ratio of 0.4 at 50°C were compared to various curing conditions.

Depending on the curing technique, the compressive strength changed. Comparable compressive strength was demonstrated by specimens cured for three days in an oven or with steam at 50°C; this strength was higher than that of specimens cured under normal circumstances. Furthermore, specimens cured at 50°C by steam, dry oven, or oven replacement had a higher compressive strength than specimens cured at 30°C.

The findings for mix No. 2 under standard curing, thirty degrees Celsius, and fifty degrees Celsius are shown in Figure 2. In comparison to other curing techniques, Figure 2(a) demonstrates that dry oven curing at 30°C produced a better compressive strength at three days. While regular curing and steam treatment produced comparable compressive strengths after seven days, standard curing outperformed the others at 28 days, while steam treatment provided a higher compressive strength by 21 days.

The findings under oven replacement circumstances are displayed in Figure 2(b), which indicates that at 28 days, the compressive strength was greater than under other curing techniques. The results of curing at 50°C are shown in Figures 2(c) and 2(d). With the exception of 28 days, it was found that oven and steam treatments resulted in higher compressive strengths at every stage. Standard curing produced a compressive strength at 28 days that was lower than steam curing but higher than dry oven treatment. At all ages, steam curing consistently produced the highest compressive strength. With the exception of specimens that were cured in water for 21 days before being placed in a dry oven, oven replacement also yielded the best compressive strength after 28 days.

The results for mix No. 3 are displayed in Figure 3, which demonstrates how all specimens' compressive strengths rose over time under various curing circumstances. Specimens cured at 50°C exhibited greater compressive strength than those cured at 30°C, as was the case with the other mixes. With the exception of specimens cured for 21 days and exposed to a dry oven, which had lower compressive strength than those cured at 30°C, specimens cured at 50°C were shown to have superior compressive strength when oven replacement at both temperatures was compared. Additionally, at 28 days, the compressive strength was stronger under oven replacement at both temperatures than under any other curing condition.

cured for three and seven days in water (normal curing) before being subjected to hot and dry conditions, the data shows that oven replacement significantly improves compressive strength, especially at 50°C. It was found that early standard curing followed by exposure to hot and dry circumstances was more successful than standard curing for 21 or 28 days before to exposure to these conditions for all combinations.

III. Discussion

It is possible to draw the conclusion that concrete's decreased strength at lower temperatures results from its abrupt exposure to hot temperatures, which causes microcracks to form and/or an uneven distribution of hydration products. The development of porous areas or microcracks at the interfacial transition zone—where concrete meets mortar—can result from the uneven diffusion of these hydration products as well as the thermal expansion coefficient of the concrete's constituent parts. This has a substantial effect on the concrete's overall structure and long-term strength.

Concrete's early strength is increased by higher curing temperatures because to improved hydration and the effects of pozzolanic elements. Because of their increased temperature tolerances, these materials—aside from silica fume—are advantageous for usage in hot environments. In the comparison of curing procedures, dry oven curing enhanced permeability while steam curing decreased permeability in all combinations. Mix No. 1 with only fly ash (FA) has significant permeability after moist curing. While moist curing had the second-highest permeability and dry oven curing the greatest, steam curing once more produced poor permeability for other mixtures containing silica fume and FA. However, every mixture satisfied the ASTM C1202 permeability requirements.

The amount of silica fume in the mixtures has a significant impact on the variable permeability levels seen with various curing techniques. However, dry curing considerably enhanced the permeability of concrete containing silica fume, mostly because of the shrinkage and breaking that come with this curing process.

Table 4: Percentage increase in compressive strength with oven replacement compared with other curing conditions.

W/B	Curing age	Specimens cured at 30°C			Specimens cured at 50°C			Rep 50°C vs Rep 30°C (%)
		Rep vs standard (%)	Rep vs dry ov (%)	Rep vs steam (%)	Rep vs standard (%)	Rep vs dry ov (%)	Rep vs steam (%)	
0.3	3 days	41	42.3	50	39.47	34.21	34.21	**−2.63**
	7 days	18	39.3	35.7	19.77	20.93	32.56	2.33
	21 days	11.11	18.5	14.8	14.29	15.48	17.86	3.57
	28 days	1.3	8	**−2.67**	2.63	**−5.26**	**−1.32**	1.31
0.35	3 days	58.9	48.2	57.14	71.95	39	37.8	31.71
	7 days	43.8	50.7	43.8	49.75	31.37	26.47	10.54
	21 days	25	48.7	18.4	22.97	20.27	**−6.76**	**−2.7**
	28 days	1.39	45.56	9.7	17.44	20.93	2.33	16.28
0.4	3 days	56.1	57.89	47.37	64.79	42.25	46.48	19.72
	7 days	43.66	52.11	32.39	45.21	34.25	24.66	2.74
	21 days	32.4	43.24	17.57	31.51	31.51	9.59	**−1.37**
	28 days	15.28	34.72	9.72	20.78	35.1	11.69	6.49

Rep = oven replacement; Standard = standard curing; dry ov = dry oven.

Comparing oven replacement at 30°C and 50°C to alternative curing conditions, Table 4 displays the percentage increase in compressive strength. When specimens are first

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when exposed to dry curing, mostly because to the shrinkage and cracking that come with this curing process. Due in large part to increased water evaporation and decreased hydration effects from drying, silica fume in high-strength concrete is negatively impacted by hot and dry conditions, which is similar to the detrimental effects of curing normal-strength concrete under similar conditions.

IV. CONCLUSION

(1) The compressive and flexural strengths at later ages (28 days) improved over time for all curing conditions. Notably, an increase in compressive strength at 28 days was observed due to moisture curing at early ages (3 and 7 days) prior to exposure to hot and dry conditions. The compressive and flexural strengths for steam curing and dry oven curing at two temperatures also showed improvement over time. However, early moisture curing before exposure to hot and dry conditions, particularly at 50°C, resulted in higher strength values across all curing methods compared to curing at 30°C. Furthermore, oven replacement at 30°C demonstrated that moisture curing for up to 21 days, followed by exposure to dry and hot conditions, yielded greater strengths than 28 days of curing in water for mixes containing silica fume and/or fly ash.

(2) Hot conditions negatively impacted the workability of the concrete, leading to a loss in slump. Consequently, this study focused on a low susceptibility mixture (mix No. 1) to examine the effects of hot and dry environments with various curing methods on the mechanical properties of low workability high-strength concrete. The results for the mechanical properties were satisfactory.

(3) Utilizing silica fume and fly ash in hot and dry conditions proved to be more effective, particularly with moisture curing during the first seven days before exposure to these conditions.

(4) The permeability of concrete containing silica fume and/or fly ash that was subjected to hot and dry curing significantly increased due to cracking associated with this curing method.

(5) This research is particularly relevant for precast concrete, as precast concrete is not adversely affected by solar radiation and wind speed during the curing process.

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