MATEC Web of Conferences **409**, 12002 (2025) https://doi.org/10.1051/matecconf/202540912002
Concrete Solutions 2025

Wear resistance of fast-track Type III Portland cement concrete

Nader Ghafoori [1], Mathew Tays[1], and Aderemi Gbadamosi[1]*

[1]Department of Civil and Environmental Engineering and Construction, University of Nevada, Las Vegas, 4505 Maryland Parkway, Box 454015, Las Vegas 89154-4015, USA.

Abstract. This study investigated the wear resistance of selected fast-track Type III Portland cement concrete (FTC) under early opening times (6, 8 hours) and at full maturity (28 days). The effects of varying Type III Portland cement content (386, 445, and 505 kg/m³), with and without an accelerating admixture, were analysed to assess wear depth and deterioration rate. These factors were examined across different opening-time categories and maturity duration. The coefficients of variation and abrasion index from the abrasion tests were also evaluated. Additionally, the correlation between abrasion resistance (wear depth) and bulk strength was explored at both early and maturity durations. Results indicated that the studied FTCs showed improved wear resistance and compressive strength with higher cement content, longer curing periods, and the addition of an accelerating admixture. Test results also revealed that cement content, curing time, and accelerating admixture influenced depth of wear more than compressive strength.

1 Introduction

The construction industry continuously seeks to enhance durability and longevity in concrete infrastructure. One viable approach to address deteriorating pavements is the use of early-opening-to-traffic Portland cement concrete, commonly referred to as fast-track concrete (FTC). This technology enables roadways to be ride-ready within hours of placement, minimizing traffic disruptions, maintaining volume flow, and ensuring quick public access. Fast-track concrete mixtures and curing techniques are designed to achieve sufficient opening strengths within 4–24 hours after placement [1].

Fast-track concrete was first introduced in Iowa in 1986, with the goal of producing a mix that could attain a flexural strength of at least 2.4 MPa and a compressive strength of 17.2 MPa within 24 hours [2, 3]. A developed mix containing 421 kg/m³ of Type III cement, a water-to-cement ratio of 0.43, 6.5 % air content, and a slump of 38 mm exceeded these requirements, achieving 4.2 MPa in flexural strength and 23.9 MPa in compressive strength. The Federal Highway Administration [4] advises that opening times should not be determined arbitrarily but rather based on the achieved strength of the concrete. For automobile traffic, a third-point flexural strength of 1.0 MPa is required [5], while thin slabs subjected to truck traffic should attain at least 4.5 MPa in flexural strength before opening. Using the ACI Committee 363 conversion equation [6], a compressive strength equivalent of approximately 20.7 MPa was determined as the opening-time strength requirement for this study.

Fast-track concrete relies heavily on Portland cement content, which significantly influences mechanical properties, including abrasion resistance. A higher cement content generally yields a denser, less porous matrix, enhancing early-age strength and wear resistance [5]. However, Yetgin and Avdar [7] highlight that while a compact cement matrix enhances durability, the inclusion of mineral additives may compromise abrasion resistance. Despite its benefits, excessive cement use introduces economic and environmental concerns, necessitating an optimal balance between performance and sustainability [1].

Accelerating admixtures are widely used in fast-track concrete to expedite setting and early strength gain, directly influencing microstructure and wear performance. These admixtures improve paste cohesion and density, leading to enhanced abrasion resistance [8]. However, their dosage and type must be carefully considered, as certain formulations may adversely affect long-term durability [1]. Further investigation is needed to evaluate the trade-offs between early-age strength development and long-term wear performance across various admixture types [9].

Curing time plays a critical role in hydration and microstructure formation. Prolonged curing improves strength and abrasion resistance by reducing porosity and enhancing material density [10]. Xu et al. [1] demonstrated that extending the curing duration up to 28

1 Corresponding author : nader.ghafoori@unlv.edu

days significantly enhances abrasion resistance in fast-track concrete. Meanwhile, Hanif et al. [8] investigated steam curing, revealing complex interactions between curing methods and cement types. Additionally, differences in surface and bulk hydration processes may influence wear resistance, warranting further exploration [1]. Compressive strength is a widely accepted indicator of concrete durability and often correlates well with abrasion resistance [7]. A denser, more cohesive matrix typically exhibits better wear resistance. However, surface properties, shaped by cement content, curing time, and admixtures, appear to have a greater impact on wear performance than compressive strength. Additionally, surface treatments and finishing techniques may further influence resistance to abrasion. Understanding the microstructural differences between the surface and bulk regions will provide deeper insights into their respective contributions to overall wear performance.

This study examined the wear resistance and compressive strength of fast-track Type III Portland cement concrete, focusing on the effects of cement content, curing periods (opening time and 28 days), and accelerating admixtures. The relationship between abrasion resistance and compressive strength is also analysed.

2 Materials and Experimental Methods

2.1 Raw materials

The materials used in this study included Type III Portland cement, siliceous fine aggregate, crushed limestone coarse aggregate, chemical admixtures, and tap water. The Type III Portland cement chemical composition is shown in Table 1. The siliceous fine aggregate had physical properties of SG-OD = 2.6, SG-SSD = 2.63, absorption = 1.10 %, and fineness modulus (FM) = 2.56, meeting the ASTM C33 gradation requirements. The coarse aggregate, classified as ASTM C33 Grade 57, had a nominal maximum size of 19 mm, with physical properties of SG-OD = 2.64, SG-SSD = 2.67, absorption = 1.20%, and dry rodded unit weight = 1567 kg/m³. Tap water, preheated to 49 ± 1°C, was used in all concrete batches. A high-range water-reducing admixture and air-entraining admixture were incorporated to achieve the desired workability and air content of freshly-mixed concretes. An accelerating admixture ($CaCl_2$), conforming to ASTM D98, was used at a fixed dosage of 2% by weight of cement in selected fast-track concrete mixtures.

2.2 Mixture Proportions and Design

The constituents and proportions of the studied FTCs are shown in Table 2. The water-to-cement ratio (w/c) was mostly maintained at 0.4.

Table 1. Chemical Properties of Type III Portland Cement.

Chemical Composition	(%)
Tricalcium Aluminate (C_3A)	10
Tricalcium Silicate (C_3S)	59
Magnesium Oxide (MgO)	0.98
Sulfur Trioxide (SO_3)	4.02
Na_2O	0.58
Loss on Ignition	2.15
Insoluble Residue	0.45
Total Alkali	0.56

The amount of water-reducing admixture was determined through trial batches, ensuring a target slump of 127 ± 6 mm. The air-entraining admixture was adjusted to produce 6 ± 1 % air content across all mixtures. A constant amount of an accelerating admixture (2 % by weight of Portland cement) was used for the selected FTCs. The introduction of the accelerating admixture increased the required amount of water-reducing admixture in order to maintain a constant slump for the mixture containing an identical cement factor and water-to-cement ratio.

Table 2. Mixture constituents and Proportions of Fast-Track Concretes (kg/m^3).

Mix ID	CF	w/c	FA	CA	WR	AE
III-386	386	0.4	679	1060	3.05	0.81
III-445	445	0.4	569	1060	2.81	1.55
III-505	505	0.375	492	1060	3.59	1.76
III-386 AA	386	0.4	679	1060	5.18	0.81
III-445 AA	445	0.4	569	1060	4.57	1.55
III-505 AA	505	0.375	492	1060	5.58	1.76

Notation: w/c - water-to-cement ratio; FA - Fine Aggregate; CA - Coarse Aggregate; WR- High Range Water reducing Admixture; AE- Air Entraining Admixture. CF; Cement Factor

2.3 Mixing, Sampling, Curing, and Testing Procedures

Concrete batches were prepared using a rotating counter-current pan mixer, with a uniform volume of 0.017 m³ per mix. The fresh concrete was used to cast 102 × 102 × 355 mm beam-shape and 102 × 204 mm cylindrical specimens. The test specimens were initially cured in insulated boxes with a thermal resistance (R-value) of 2.45 × 10^{-5} hm² °C/J. The time that specimens remained in the insulation boxes varied depending on their opening time classification. The temperature of the test samples was monitored with a temperature-monitoring device that downloaded information to a computer at designated intervals. To assess the matured concrete properties, a subset of specimens was subjected to 28-day moist curing in a lime-saturated water tank maintained at 23 ± 2 °C. The Compressive strength (ASTM C39) and Abrasion resistance (ASTM C779, Procedure C – Ball

Bearings Method mixtures, were evaluated at two curing periods, of opening time and 28 days.

3 Results and Discussion

3.1 Opening-to-Traffic Time

Using the specified flexural strength of 4.5 MPa and the equation provided by ACI Committee 363, the corresponding compressive strength was estimated to be approximately 20.7 MPa [9]. Therefore, all opening-time categories in this study were defined based on achieving a minimum compressive strength of 20.7 MPa. The findings indicated opening times of 6 hours for mixtures containing the accelerating admixture and 8 hours for those without, as presented in Table 4.

3.2 Fresh Properties

The setting time and heat of hydration of the studied fast-track concretes are shown in Tables 3a and b. Both initial and final setting times exhibited reductions with increasing cement content. As the cement content increased from 386 to 445 to 505 kg/m³, the initial setting times decreased by approximately 9% and 1%, respectively, for mixtures without an accelerating admixture. The final setting times showed reductions of about 9% and an increase of 6%, respectively, under the same conditions. Incorporating an accelerating admixture further reduced setting times. For the same increase in cement content, the initial setting times decreased by approximately 6% and 6%, respectively, while the final setting times decreased by about 9% and 11%, respectively. Comparing mixtures with and without the accelerating admixture, the initial and final setting times dropped by an overall average of 24% and 28%, respectively, indicating the accelerating admixture's significant impact on expediting the setting process. This result suggests that higher cement content accelerates the hydration process, leading to faster setting times.

The adiabatic temperature profiles of the selected fast-track concretes as shown in Table 3b shows that as the cement content increased from 386 to 445 to 505 kg/m³, the peak temperatures rose by approximately 6% and 5%, respectively, while the time-to-peak temperature decreased by about 4% and 0%, respectively, for mixtures without an accelerating admixture. For mixtures containing an accelerating admixture, the peak temperatures increased by approximately 6% and 7%, respectively, as cement content increased. The time-to-peak temperature decreased by about 9% and an increase of 1%, respectively. The accelerating admixture did not significantly affect peak temperatures compared to the increase in cement content alone. However, it did influence the time-to-peak temperature, generating an average reduction of 13% compared to concrete without the accelerating admixture. The result highlights that while both increased cement content and the use of accelerating admixtures elevate peak temperatures, the accelerating admixture primarily served to reduce the time required to reach these peak temperatures, thereby facilitating faster strength development in the studied FTCs.

Table 3a. Setting time of Fast-Track Concrete.

Mix ID	ITS (hrs.)	FTS (hrs.)
III-386	3.85	4.77
III-445	3.52	4.33
III-505	3.51	4.6
III-386 AA	2.91	3.61
III-445 AA	2.73	3.28
III-505 AA	2.56	2.93

Notation: ITS - Initial Setting Time; FTS - Final Setting Time.

Table 3b. Temperature of Fast-Track Concrete.

	P.T (°F)	P.T (°C)	Time to Peak (hrs)
III 386	137.3	52.94	10.13
III-445	145.3	62.94	9.75
III- 505	152.4	66.89	9.75
III- 386 AA	138.5	59.17	9.25
III-445 AA	146.5	63.16	8.38
III-505 AA	156.7	69.28	8.5

Notations: P.T – Peak Temperature

3.3 Bulk Properties

3.3.1. One-day Demolded Unit Weight

As shown in Table 3, the unit weight of the selected fast-track concretes at the opening time marginally increased with higher cement content. A similar trend was observed with the inclusion of an accelerating admixture. The demolded unit weight increased from 2330 to 2342 kg/m³ (0.5 %) as the cement content increased from 386 to 505 kg/m³ for the mixtures without accelerating admixture. Similarly, for the mixtures with accelerating admixture, the unit weight increased from 2348 to 2370 kg/m³ (0.9 %) for the same cement content range, indicating a denser matrix formation due to accelerated hydration.

3.3.2. Compressive Strength

The compressive strength results at different curing ages are presented in Table 4. In general, the compressive strengths of the studied FTCs improved with increasing cement content at both the designated opening time and at 28 days.

3.3.2.1. Effect of cement content

The influence of cement content on both opening time and 28-day compressive strength is evident in the studied FTCs. The opening time to traffic is defined by the minimum compressive strength required to ensure structural integrity before allowing vehicular loads. As shown in Table 4, FTCs with an accelerating admixture achieved the minimum 20.7 MPa threshold within 6 hours, whereas FTCs without an accelerating admixture required 8 hours to reach the required opening time strength. This difference is attributed to the accelerator's ability to expedite hydration reactions, particularly the hydration of C_3S and C_3A, which accelerated C-S-H gel formation and promoted early strength development.

At the 6-hour opening time, increasing the cement content from 386 to 445 and 505 kg/m³ resulted in 28 % and 42 % strength gains, respectively, for FTCs with an accelerating admixture. Meanwhile, at the 8-hour opening time, FTCs without an accelerating admixture exhibited 8 % and 22 % strength gains, reflecting a slower rate of early-age strength development. By 28 days, strength gains slowed, with compressive strength increasing by 3 % and 9% in non-accelerating admixture FTCs and 5 % and 9 % in accelerating admixture FTCs, as cement content increased from 386 to 445 and 505 kg/m³.

3.3.2.2. Effect of Curing Time from Opening to-Traffic-Time to Maturity (28 days)

Curing duration significantly influenced compressive strength development between opening time and 28-day maturity. FTCs without an accelerating admixture, at the opening time of 8 hours, experienced a 147% strength increase by 28 days, whereas FTC counterparts with an accelerating admixture, opened at 6 hours, exhibited a 64% strength gain over the same period. This shows the impact of accelerating admixtures on hydration kinetics as accelerating admixtures containing FTCs achieved higher early-age strengths due to rapid hydration, but their rate of strength gain diminished as hydration neared completion. In contrast, non-accelerating admixture FTCs followed a more gradual strength development pattern, benefiting from the continuous formation of hydration products over time.

Table 4. Bulk Properties of Fast-track concrete

Mix ID	OT (hrs)	UW (kg/m³)	Compressive strength (Mpa)		
			6 hrs	**8 hrs**	**28 days**
III-386	8	2330	-	26.06	46.37
III-445	8	2337	-	28.1	47.82
III-505	8	2342	-	31.73	50.64
III-386 AA	6	2348	26.37	-	56.47
III-445 AA	6	2357	33.61	-	59.09
III-505 AA	6	2370	37.13	-	62.23

Notation: OT- Opening Time; UW - Unit Weight.

3.4 Resistance to wear

The test results for the abrasion resistance of the studied FTCs at their designated opening times and after 28 days of combined blanket and moist curing are presented in Tables 5a and 5b. The effects of cement content, curing age, and accelerating admixture on abrasion resistance are discussed in the following sections.

3.4.1. Influence of Cement Content on Wear Resistance

The wear resistance of FTCs at opening time of 6 and 8 hours was evaluated based on the terminal depth of 3 mm, representing the failure threshold of ASTM 779 C Ball Bearing. For FTCs without accelerating admixture, the III-386, III-445, and III-505 mixtures reached depths of 3 mm, 2.344 mm, and 2.220 mm, respectively, within 5 and 10 minutes of testing. This represented 25 % increase as cement factor increased from 386 to 505 kg/m³. However, in accelerating admixture containing FTCs, the III-386AA, III-445AA, and III-505AA mixtures reached terminal depths of 3.076 mm, 3.019 mm, and 3.280 mm, but only after 15 and 20 minutes of testing.

At 28 days, the effect of cement content remained significant. All fast-track concrete completed 20 minutes without reaching the terminal depth of 3mm. The non-accelerating admixture 445 and 505 kg/m³ FTCs demonstrated 23% and 27% reductions in wear depth, respectively, compared to the 386 kg/m³ FTC. With the inclusion of an accelerating admixture, these gains were further increased to 40% and 47%, respectively.

The improved resistance to wear with increased cement content is attributed to the formation of additional binder-rich microstructure, which enhanced surface integrity by minimizing porosity and strengthening the cement paste-aggregate bond. This effect was most pronounced at opening time, when the cement paste was still in its early hydration phase and more susceptible to abrasion. However, after 28 days of curing, the cementitious matrix had undergone substantial hydration and densification, making further improvements from additional cement content, while less dramatic, but still beneficial.

3.4.2. Effect of Curing Age on Abrasion Resistance

As discussed in Section 3.4.1, the difference in wear resistance between opening time (6 and 8 hours) and maturity (28 days) was substantial. No FTC samples at opening time withstood the full 20-minute test without reaching the 3 mm wear threshold, whereas at 28 days of curing, all FTCs remained below the wear limit for the entire test duration. For FTC without an admixture, wear resistance improved significantly with curing. At 5 minutes, wear depth reductions were 120%, 135%, and 137% for 386, 445, and 505 kg/m³ cement contents, respectively. By 10 minutes, higher cement content FTCs (445 and 505 kg/m³) exhibited further gains, with wear depth reductions of 150% and 160%, respectively. At 15 minutes, the 505 kg/m³ FTC demonstrated the highest improvement, achieving a 180% reduction in wear depth compared to opening time.

For accelerated admixture containing FTCs, wear resistance gains were even more pronounced. At 5 minutes, wear resistance increased by 300%, 425%, and 465% for 386, 445, and 505 kg/m³ mixtures, respectively, after 28 days of curing. By 10 minutes, the 445 and 505 kg/m³ admixture containing FTCs showed 475% and 510% improvements. At 15 minutes, the 505 kg/m³ admixture FTC exhibited a 550% increase in wear resistance. Comparing ultimate wear depth at opening time versus 28 days, FTCs without an accelerating admixture exhibited 12%, 35%, and 43% reductions in wear depth for cement contents of 386, 445, and 505 kg/m³, respectively. Accelerating admixture containing FTCs, however, displayed greater wear resistance gains of 245%, 370%, and 445%, reinforcing the role of accelerating admixtures in enhancing hydration kinetics and microstructural densification.

Table 5a. Depth of wear at different time intervals.

TI	Depth of wear at Opening time (mm)					
(min)	III-386	III-445	III-505	III-386 AA	III-445 AA	III-505 AA
.5	0.34	0.36	0.31	0.35	0.24	0.20
1	0.84	0.68	0.61	0.59	0.47	0.42
2	1.67	1.22	1.14	0.99	0.88	0.75
3	2.26	1.67	1.57	1.32	1.20	1.02
4	2.68	2.04	1.93	1.59	1.47	1.27
5	2.96	2.34	2.22	1.80	1.69	1.49
10	0	0	2.97	2.58	2.46	2.32
15	-	-	-	3.08	3.02	2.83
20		-	-	-	-	3.28

Notation: TI - Time Interval; "-" - depth of wear exceeds 3 mm.

Table 5b. Depth of wear at different time intervals

TI	Depth of wear at 28 days (mm)					
(min)	III-386	III-445	III-505	III-386 AA	III-445 AA	III-505 AA
0.5	0.25	0.22	0.19	0.14	0.10	0.09
1	0.39	0.32	0.28	0.19	0.14	0.13
2	0.66	0.50	0.46	0.29	0.20	0.19
3	0.90	0.68	0.63	0.37	0.26	0.24
4	1.11	0.84	0.78	0.43	0.31	0.28
5	1.30	0.99	0.93	0.47	0.35	0.31
10	1.96	1.60	1.49	0.62	0.48	0.41
15	2.39	1.99	1.88	0.76	0.57	0.49
20	2.74	2.25	2.14	0.88	0.65	0.57

Notation: TI - Time Interval; "-" - depth of wear exceeds 3 mm.

3.4.3. Influence of Accelerating Admixture

The inclusion of an accelerating admixture significantly improved wear resistance, by expediting hydration and refining the microstructure of the concrete. At opening time, the benefit of the accelerating admixture was evident across all cement content levels as shown in Fig. 1 and Fig. 2. Compared to mixtures without an accelerating admixture, the accelerating admixture containing FTCs made with 386, 445, and 505 kg/m³ of cement exhibited 165%, 82%, and 60% greater abrasion resistance, respectively. At 28 days, the effect of the accelerating admixture remained significant, with improvements of 200%, 250%, and 280% in wear resistance for the 386, 445, and 505 kg/m³ cement mixtures, respectively. A further comparison of time-to-failure measurements (3 mm depth limit) further highlights the advantages of the accelerating admixture. At opening time, the accelerating admixture containing 386, 445, and 505 kg/m³ FTCs delayed terminal wear depth by 12%, 20%, and 10% longer, respectively, than when compared to their non-accelerating admixture FTCs. By 28 days, these differences became even more pronounced, with wear depth reductions of 32%, 56%, and 70%, respectively, for the same cement content levels. The better wear resistance at maturity suggests that the accelerating admixture not only enhanced wear resistance at early age but also contributed to a more resilient long-term microstructure, particularly in high-cement-content matrices where hydration continues to refine the microstructure over time.

The comparison of depth of wear overtime reinforces this trend. At 5 minutes of abrasion testing, the opening time, non-accelerating admixture 386, 445, and 505 kg/m³ FTC exhibited wear depths of 2.96 mm, 2.34 mm, and 2.22 mm, respectively, whereas their counterparts containing accelerating admixture displayed significantly lower values of 1.80 mm, 1.69 mm, and 1.49 mm—indicating a 39%, 28%, and 33% reduction in depth of wear, respectively. By 20 minutes of testing, the 28 days, the improvements were even more distinct, with non-admixture concrete showing wear depths of 2.74 mm, 2.25 mm, and 2.14 mm, compared to 0.89 mm, 0.65 mm, and 0.56 mm for the admixture containing concrete representing a 67%, 71%, and 74% reduction in wear depth, respectively.

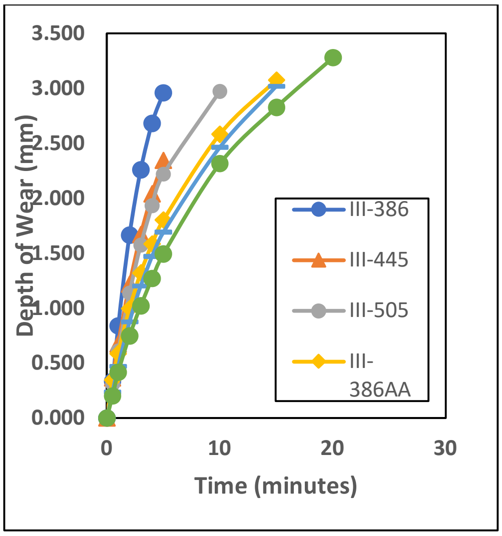

Fig 1. Abrasion resistance of type III cement fast track concrete with and without accelerating admixture at opening age.

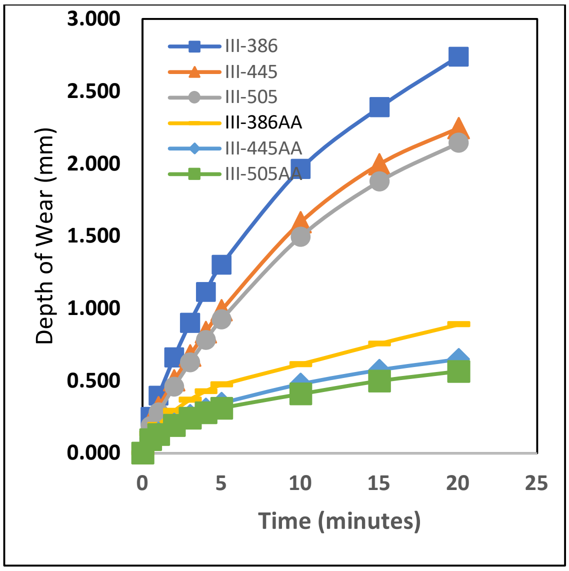

Fig 2. Abrasion resistance of type III cement fast track concrete with and without accelerating admixture at 28 days curing.

3.5 Relative gain of abrasion

The relative gain of abrasion depth over the testing duration was analyzed for both opening-time and 28-day curing conditions, as shown in Table 6a and 6b. The progression of wear resistance in the tested fast-track Type III cement concretes varied significantly between opening time and 28-day maturity, influenced by cement content and the presence of an accelerating admixture. The trends observed across different time intervals highlight the rapid deterioration at early ages and the substantial improvements following prolonged curing.

Table 6a. Relative Gain of Abrasion Depth of Fast-Track Concrete at Opening.

TI (min)	III 386	III-445	III-505	III 386 AA	III 445 AA	III 505 AA
0.5	0.11	0.16	0.1	0.11	0.08	0.06
1	0.28	0.29	0.2	0.19	0.16	0.13
2	0.56	0.52	0.38	0.32	0.29	0.23
3	0.77	0.71	0.53	0.43	0.4	0.31
4	0.91	0.87	0.65	0.52	0.49	0.39
5	1.0	1.0	0.75	0.59	0.56	0.46
10	-	-	1.0	0.84	0.82	0.71
15	-	-	-	1.0	1.0	0.86
20	-	-	-	-	-	1.0

Notation: TI - Time Interval; “-” - depth of wear exceeds 3 mm.

Table 6b. Relative Gain of Abrasion Depth of Fast-Track Concrete at 28 days.

TI (min)	III 386	III-445	III-505	III 386 AA	III 445 AA	III 505 AA
0.5	0.09	0.1	0.09	0.15	0.16	0.17
1	0.14	0.14	0.13	0.22	0.22	0.23
2	0.24	0.22	0.21	0.33	0.31	0.34
3	0.33	0.3	0.29	0.42	0.4	0.43
4	0.41	0.37	0.36	0.48	0.47	0.5
5	0.47	0.44	0.43	0.53	0.53	0.55
10	0.72	0.71	0.7	0.69	0.74	0.72
15	0.87	0.89	0.88	0.85	0.88	0.88
20	1	1	1	1	1	1

Notation: TI - Time Interval; “-” - depth of wear exceeds 3 mm.

3.5.1. Initial Wear Progression: 0.5–2 Minutes

At opening time, concrete surfaces exhibited rapid wear, with 6–16% of total wear depth occurring within 0.5 minutes. Non- accelerating admixture FTCs like III-386 and III-445 were fastest (11% and 16%), while accelerating admixture containing concrete (e.g., III-505AA) showed greater resistance (6% wear) due to early accelerating hydration enhancement. By 2 minutes, wear depth reached 23–56%, with III-386 deteriorating the fastest (56%), while III-505AA remained the most resilient (23%). At 28 days, wear accumulation slowed significantly. After 0.5 minutes, wear depth ranged from 9–17%, slightly higher than at opening but much lower in absolute terms. III-505AA remained the most durable (17%), while III-386, which had degraded fastest initially, showed the least wear (9%). By 2 minutes, wear progression was 21–34%, with all FTCs demonstrating improved wear resistance.

3.5.2. Mid-Test Wear Resistance: 5–10 Minutes

By 5 minutes, the difference between opening time and 28-day maturity was clear. At opening time, most concrete had sustained 46–100% of their total wear depth, with III-386 not reaching the 3 mm limit. In contrast, accelerating admixture containing FTCs, particularly III-505AA (46%), showed superior resistance, demonstrating hydration-promoting accelerating admixtures effectively delayed surface degradation. After 28 days, wear progression was significantly slower, with only 43–55% of total wear depth accumulated, confirming the benefits of prolonged curing. III-505AA remained the most durable, reaching just 55% of its total wear depth. By 10 minutes, at opening time, non-accelerating admixture concrete had reached their ultimate wear depth, while FTCs containing accelerating admixture (III-386AA, III-445AA, III-505AA) continued resisting wear (71–84%). At 28 days, wear accumulation remained more controlled (69–74%), highlighting the role of hydration in strengthening the concrete's microstructure against prolonged abrasion.

3.5.3. Final Wear Progression: 15–20 Minutes

By 15 minutes, at opening time, accelerating admixture containing concretes had nearly reached their wear limit (85–100%), with III-505AA maintaining the highest resistance (86%). The benefit of early hydration enhancement was evident, as FTCs containing accelerating admixture significantly outperformed the companion FTCs without accelerating admixtures ones. After 28 days, wear resistance had further improved. At 15 minutes, wear accumulation was limited to 85–89%, indicating that hydration had strengthened the concrete surface and slowed wear progression. Beyond this point, additional wear was minimal, confirming that fully hydrated cement pastes resisted abrasion more effectively than their partially hydrated counterparts. By 20 minutes, all samples had reached their ultimate wear depth, but the rate of wear accumulation differed significantly. The improved microstructure at 28 days allowed the concrete to sustain abrasion for longer before reaching its limit, reinforcing the importance of adequate curing in enhancing resistance to wear.

3.6 Coefficient of variation

The coefficient of variation (CV) provides insight into the consistency and variability of wear depth across different time intervals as shown in Table 7a and 7b.

In contrast, accelerating admixture containing FTCs exhibited a higher degree of variation, averaging 35% at 1 minute, which was 2.6 times greater than non- accelerating admixture FTCs. By 5 minutes, the variation increased moderately to 44%, possibly due to the more refined microstructure resisting uniform surface degradation. As testing progressed, the CV values dropped to 14% at 10 minutes, then declined to nearly 8% at 15 minutes and about 4% at 20 minutes.

Table 7a. Coefficient of Variation for Abrasion Test of Fast-Track Concrete at Opening

TI (min)	III-386	III-445	III-505	III 386 AA	III 445 AA	III 505 AA
0.5	21.0	15.7	7.8	13.4	18.3	36.8
1	21.9	8.5	8.7	13.2	33.3	56.6
2	7.8	18.0	21.0	24.4	35.9	65.4
5	6.5	12.8	14.9	29.4	13.4	14.1
10	-	0	11	14.6	7.6	11.3
15	-	-	-	6.06	3.1	8.8
20	-	-	-	-	-	5.4

TI – Time Interval : - depth of wear exceeds 3mm

Table 7b. Coefficient of Variation for Abrasion Test of Fast-Track Concrete at 28 days

TI (min)	III-386	III-445	III-505	III-386 AA	III 445 AA	III 505 AA
0.5	20.9	23.7	31.7	24.8	21.4	28.0
1	21.5	9.42	33.1	20.4	16.7	34.4
2	26.1	25.9	31.9	21.2	9.3	36.3
5	37.8	37.8	26.8	26.3	7.3	12.2
10	30.0	25.8	15.8	12.9	8.5	13.7
15	19.8	12.9	14.1	9.69	4.9	11.3
20	10.5	8.5	8.54	7.52	6.5	5.5

TI – Time Interval : - depth of wear exceeds 3mm

At 28 days, CV values remained higher than those recorded at opening time, reflecting the influence of prolonged hydration on surface refinement. The densified microstructure formed over time enhanced abrasion resistance, making it more difficult for the ball bearings to establish a consistent wear path during the early testing intervals. This contrasted with opening time conditions, where the cement paste was still in the early hydration phase, allowing for easier material displacement and more consistent initial wear paths.

3.7 Comparison of compressive strength and wear resistance as affected by various Variables

The results presented in Tables 4 and 5a-b demonstrate that cement content, curing duration, and the use of an accelerating admixture had a more pronounced impact on wear resistance than on compressive strength. The influence of these factors on both surface (depth of wear) and bulk (compressive strength) properties is discussed in the following sections.

3.7.1. Effect of Cement Content

At opening time, as the cement content increased from 386 to 445 and 505 kg/m³, the time to reach the ultimate wear depth limit of 3 mm improved by approximately 58% for non-accelerating admixture FTCs and 55% for accelerating admixture containing FTCs. In contrast, the corresponding compressive strength gains were limited to 16% and 6%, respectively.

After 28 days of curing, the abrasion resistance of the same mixes improved by 32% and 12%, while the compressive strength gains were only 6% and 4%, respectively. Similar to the earlier observations, the influence of cement content on wear resistance was more pronounced at early ages. At opening time, the concrete matrix was still developing, making it more responsive to variations in cement content. However, at 28 days, hydration had progressed sufficiently, minimizing the additional benefits of increased cement content on bulk properties.

3.7.2. Effect of Curing Age

The curing period from opening time to 28 days significantly influenced wear resistance more than compressive strength. Two assessment methods were used to evaluate this effect.

In the first method, abrasion resistance improvement was measured based on the time required for the weakest mix to reach the terminal wear depth of 3 mm at opening time, compared to all others at the same time interval. As the curing period extended to 28 days, the overall compressive strength increased by 112%, whereas abrasion resistance improved by 195%. The second method compared the ultimate depth of wear (3 mm) at opening time with that at 28 days. As curing time increased, both wear resistance and compressive strength improved by 142%, indicating that hydration had a substantial impact on surface and bulk properties. However, the greater improvement in early-age abrasion resistance suggested that surface property benefited more from extended hydration than bulk strength.

3.7.3. Effect of Accelerating Admixture

While accelerating admixtures are primarily used to enhance early-age strength development, the results confirm that their impact on abrasion resistance was significantly greater than on compressive strength. Across all tested FTCs, wear resistance increased by approximately 102%, while compressive strength improved by just 7%. The enhanced early-age wear resistance can be attributed to the accelerator's ability to refine the cement paste structure by promoting faster hydration and increased binder cohesion, resulting in a denser and more durable surface. However, its effect on compressive strength remained limited, as the primary influence of the accelerating admixture is promoting early hydration rather than enhancing long-term matrix densification.

4 Conclusions

Based on the results of the study presented herein, the following conclusions can be drawn:

1. An increase in cement factor significantly enhanced abrasion resistance, particularly at early ages. With every 60 kg/m³ increase in cement content, wear resistance improved by 42 % at opening time. However, at 28 days, the effect of cement content on wear performance diminished, with an average improvement of only 14 % per 60 kg/m³ increase in cement content. When an accelerator was introduced, the benefits became more pronounced, yielding 11 % and 26 % improvements at opening and 28 days, respectively.
2. The impact of curing duration on wear performance was evaluated using two different assessment methods, both demonstrating significant reductions in depth of wear as hydration progressed. When the time required to reach the 3 mm depth threshold at opening time was compared to the corresponding time for 28-day cured FTCS, wear depth decreased by nearly 270 %. A second comparison, evaluating the ultimate wear depth of 28-day cured samples relative to the 3 mm threshold at opening time, showed a 195 % reduction.
3. The addition of an accelerating admixture significantly improved early-age and long-term resistance to wear. At opening time, wear resistance increased by an average of 102 % in accelerating admixture FTCs compared to their non-accelerating admixture counterparts. By 28 days, this improvement became even more substantial, with a 243 % increase in wear resistance.
4. The results suggest that surface property was more influenced by cement content, curing time, and accelerating admixture than bulk property. On average, the depth of wear improved by 28 % per 60 kg/m³ cement increment, while compressive strength increased by only 7 %. Over the entire curing period (opening time to 28 days), wear resistance improved by 265%, compared to 78 % for compressive strength. Similarly, at opening time, the inclusion of an accelerator enhanced wear resistance by 102%, while compressive strength improved by just 23 %. After 28 days, these enhancements reached 243% and 23 %, respectively.

Acknowledgments: This research was funded in part by a faculty research grant made possible by the Tennessee Technological University.

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