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Analysis of Abrasion Depth and Rates in Concrete

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Abstract

Abrasion is a major problem in hydraulic structures as they are continuously exposed to various types of water. Henceforth, these structures are susceptible to damage and require heavy maintenance. There is a significant demand in finding new techniques for improving the resistance towards the erosion of the concrete used in the construction of hydraulic structures. This work put forth a comparative analysis of the performance of two different types of concretes towards resistance namely, high-performance fiber reinforced concrete (HPFRC) [steel fibers (30 mm and 50 mm) and polypropylene fibers (19 mm)] and high-performance concrete (HPC). A comparative study was carried out based on their resistance towards wearing and hydro-abrasion erosion. The analyses were conducted using the WMP ECLIPSE method and ASTM C 1138 method. The results indicated that the rate of abrasion could be diminished by 18% based on the types of cement, fibers, concrete and modifications like the addition of silica fume.

Keywords: abrasion, fiber-reinforced concrete mix, concrete wearing, compressive strength

1. Introduction

The hydraulic structures constructed under the flowing water are subjected to abrasion after a certain period (Creegan et al., 1987), (Liu, Yen, & Hsu, 2006), (Kryžanowski, Mikoš, Šušteršic, & Planinc, 2009). The solids present in the water collide with the surface of the concrete, subsequently weakening and destroying the concrete structure. This process of damage to the concrete structure is called abrasion. The hydraulic structures are always at a high risk of abrasion and require a huge budget in the rehabilitation of these damaged structures.

2. Factors Affecting the Abrasion of Concrete Surface

The rate of abrasion of the hydraulic structures depends on the characteristics of the concrete, like the ratio of the water to the composition of the cement (Rahmani, Shamsai, Saghafian, & Peroti, 2012), (E. Horszczaruk, 2004), (Abid, Abdul-Hussein, Ayoob, Ali, & Kadhum, 2020), (Zhou, Xie, Jia, & Wang, 2020), (Somogyi & Pezelj, 2012) grade of the cement, shape and hardness of the aggregates, size, type of fibres, and curing of the surface. Additionally, the environmental factors affecting abrasion are characteristics of the particles responsible for abrasion, the velocity of water, and impact angle.

3. Literature Review

3.1 Use of Fibers into the Cement Matrix

The concrete constructed under pressure by the water-hauled rubble method is subjected to disintegration caused by wearing. Additionally, they are also affected by other mechanical factors like unique loadings or various variable loadings. In this line, even the cement with high mechanical strength cannot endure the external natural activities for a long duration. Thus, the introduction of different filaments into the concrete structure appears as a good alternative to improve the resistance of the concrete grid towards erosion from natural activities like wind, water and soil.

3.2 Types of Fibers

3.2.1 Steel Fibers

The introduction of the steel strands as a primary element in concrete prevents it from twisting thus preventing the formation of cracks and cavities. The construction carried out under the water generally uses numerous variable loadings and stun loadings made of steel fibres, as they enhance the mechanical properties like flexural strength of the structure. Moreover, the steel strands prevent the movement and formation of cracks (Abbass, Abid, & Özakça, 2019), (Abid et al., 2020), (Ali, Kadhim, Ayoob, & Abdul Hussein, 2021), (Bodnárová et al., 2020). However, the steel fibers are not capable of preventing resistance to corrosion of the concrete in most of the hydraulic structures. The formation of cavities was found to be averted in water hauled rubble at a speed slower than 10 m/s in concrete equipped with steel strands as compared to that in absence of steel strands. However, the presence of steel fibers in HPC at a low aspect ratio (≤ 50) has no resistance to abrasion. Their anti-resistive properties were found to be lower than that of simple concrete devoid of steel.

3.2.2 The Synthetic Fibers

The synthetic fibers are presently used in the surface layers of the concrete structures as they possess the capability to augment the resistance to fatigue, impact, temperature shock and corrosion (Abid, Shamkhi, Mahdi, & Daek, 2018), (Grdic, Curcic, Ristic, & Despotovic, 2012), (Ristic, Toplicic-Curcic, & Grdic, 2015), (Abid et al., 2020), (Zhou et al., 2020). The cavitation and water-hauled rubble activity are frequently recognized as grating activities. However, the mechanism of corrosion is different for both the processes of cavitation and water-dragged rubble. The engineered synthetic fibers [carbon fibers and polypropylene (PP)] escalate the resistance to erosion and cavitation of the concrete. The resistance to cracking in concrete during bending is upgraded by the introduction of synthetic fibers.

3.3 Abrasion of Various Types of Concrete Mixtures

A summary of the materials present in various types of concrete mixtures is shown in Table 1. Ordinary Portland Cement with different classes goes well with the treatment of the silica fume and polypropylene fiber is also make a difference when it is used in the mix. When interviewing with operators and builders in the field before making decision to experimental procedures. The information towards using the types of mix were known to be that the reduction of the rate of abrasion is directly affected by the selection of cement, inclusion of fibers, the addition of silica fume and selection of the proper concrete type. The durability of concrete is one the builders concerns and were reported that its most important properties, apart after its compressive strength, for the reason that distresses in concrete are habitually due to durability failures more accurately than unsatisfactory strength. Permeability is become to be one of the most valuable properties influencing concrete durability for the reason that numerous concrete degradation mechanisms are a function of the rate of water or solution flow through the concrete, and it controls the rate of entry of moisture that may contain aggressive chemicals and the undertaking of water during the process.

Table 1. Proportioning of mixtures and properties of the concrete under test

	Types of mix			
Combination proportioning and properties of the solid	ME 30/60	ME 50/2.0	PP	HPC1
Cement (kg/m^3)	460	460	460	460
Water (l/m^3)	125	125	125	125
Sand (kg/m^3)	540	540	540	540
Basalt (kg/m^3)	1280	1280	1280	1280
Silica fume (kg/m^3)	55	55	55	55
Superplasticizer (% mass of cement)	1.6	1.6	1.6	1.6
Steel fibers (kg/m^3)	90	90	–	–
Polypropylene fibers (kg/m^3)	–	–	1.85	–
Water/Cement (w/c) ratio	0.35	0.35	0.35	0.35
Slump (mm)	135	120	145	145
Compressive strength (MPa)	92.5	97.5	99.5	99
Absorbability (%)	1.25	1.25	1.35	1.85

The effect of silica fume and ash was studied using different synthetic fibers or metallic fibres (K. Turk & M. Karatas, 2014), (Liu, 2007), (Yen, Hsu, Liu, & Chen, 2007), (Mohebi, Behfarnia, & Shojaei, 2015), (Gesoğlu, Güneyisi, & Özbay, 2009), (Bodnárová et al., 2020), (Zhou et al., 2020). A fixed ratio of water/cement (w/c) at 0.3 was maintained in line with the general practice of the mix. The percentage of absorption by the mixture proportioning of the concretes under test in the Kingdom of Bahrain was set at 1.2%. Therefore, we have carried out the research accepting the limits according to reference (Abid et al., 2020), (Bodnárová et al., 2020), (Ali et al., 2021), (Rahmani et al., 2012). The amount of the polypropylene fibers (kg/m^3) was not allowed to exceed 3% in the mixtures. It was observed that the compressive strength is highest in the case of HPC (100.1 MPa) followed by f ME 50/2.0 (99.3 MPa), PP (98.2 MPa) and ME 30/60 (91.8 MPa) (Table 1).

3.4 Use of Recycled Materials and New Concrete Mixtures

The application of recycled materials has been a focus of the present research trend heeding the environmental concerns [20]. Simultaneously, a few analysts zeroed in on the combination grade or new solid blends like geopolymer solid, elite cement, or designed cementitious materials.

3.5 Wear Resistance of Self-Compacting Concrete (SCC)

The resistance to wear of the concrete grades (30, 40 and 50 MPa) of the self-compacting concrete (SCC) was evaluated in geographically different areas. A mixture was prepared by adding the silica fume (70 kg/m^3) of the highest grade to micro-steel fibers (0.50, 0.75 and 1.0%) of the lowest grade. Different ages were tested for each casting sample, between the period from 7 to 28 days and 28 to 90 days. It was reported that the period of 7 to 28 days is an optimum period to improve the wear resistance (Abid et al., 2020), (Bodnárová et al., 2020), (Ali et al., 2021), (Rahmani et al., 2012). These experiments and preparation summarise the importance of the protocols of conducting on-site work and study. (Ali et al., 2021) studied the wear resistance of flowing SCC concrete that does not require vibration during its preparation. Superplasticizers along with stabilizers were added to considerably increase the smoothness of the flow rate. It compacts into every bit and part of the mould or framework exclusively on its own without the addition of any coarse aggregate. The resistance to abrasion and upgrade during the first period was 78% for SCC (50 MPa) after maturing in 90 days as compared to 7 days. Additionally, the supplement and add-on of the fiber increased the abrasion resistance. The percentages of the resistance to wearing were 8, 14 and 26% after a period of 90 days after the addition of 0.50, 0.75 and 1.0% of fibres respectively. The wear resistance was enhanced to 23.8 and 77.8% for concrete strengths with 40 MPa and 50 MPa respectively within the aging period of 90 day.

3.6 Engineered Cementitious Composites (ECC)

(Zhou et al., 2020) and (Abid, Hilo, & Daek, 2018) studied the abrasion process of engineered cementitious composites (ECC). They added different amounts (0, 0.50, 1.0, 1.5 and 2.0%) of polyvinyl alcohol fibers (PVA) of 6mm length to the mixtures along with silica sand (455 kg/m^3) and fly ash (684 kg/m^3) to the plant. The materials were cast for 3, 7 and 28 days while the time of testing varied from 72 hours to 48 hours. The obtained compressive strength for all samples was around 47 MPa. They revealed that the addition of PVA (0.50 and 1%) upgraded the resistance to wear by about 20%. Additionally, the presence of 1.5% and 2% of fibre improved the resistance individually by 50 and 95%. The ECC containing PE fibers (PE-ECC) are used as repairing material for primary fixing. The properties like tension and malleability can be easily modulated in PE-ECC. The influence of PE fibres on the flexural, compressive strength, shear and elastic properties of ECC was found to be positive. Furthermore, the columns, beams and walls of the PE-ECC renovated structures were sustainable. Thus PE-ECC is a promising material for fixing based on its restoration capabilities of the concrete which is destroyed due to sway stacking, dampness, forceful substances and huge inelastic deformity. A comparative study indicated that the flexural strength, rigidity, and flexibility of PE-ECC are superior to that of plain concrete. The cracks in PE-ECC are scattered and appear consistently along a narrow width. The composite is also resistant to temperature alteration. The interfacial hydrophobic bond between the cementitious lattice and the PE fibres increases the integration of the energy. The addition of the PE strands into the solid enhances the rigidity and reduces the breaking tendency of the concrete. The PE fibres act as support in shear-basic solid shafts. A higher proportion of PE leads to higher fiber content which modifies the flexural/shear strength, modulus and decreases the stress of the concrete. However, an optimal value of the amount of PE fibre and angle of proportion is required for exhibiting the best properties. The composite beyond the optimal value of PE leads to the scattering of the PE fibres within the concrete to form a non-homogeneous network with low potency.

In another study, (E. K. Horszczaruk, 2009) examined the effect of three fibres with different weight, length and angle proportion [snare finished steel fibre (70 kg/m^3, 30 mm, 60); snare finished steel fibre (70 kg/m^3, 50 mm, 50); PE fibre (1.8 kg/m^3, 19 mm) on the resistance of the scraped area of the fiber-supported elite cement and plain cement. The mixtures contained a constant amount of silica smolder (45 kg/m^3). The compressive qualities were obtained for the plain cement with three fibres ere100.1, 91.8, 99.3 and 98.2 MPa respectively. The steel fibre with 50 mm length was found to wear 3.27 mm after 120 hours of testing. The steel fibre with 30 mm length corroded for 2.89 mm. The corrosion was found to be minimum for the PE fibre as compared to that of the steel fibres.

3.7 Abrasion Damage of High Strength Concrete (HSC)

The results of the evaluation of the abrasion damage of HSC during 120 hours of testing time and 28 days of maturing age are presented by (Elzbieta Horszczaruk, 2005) by examining three different cement (CEM I 42.5R, 52.5R and CEM III 42.5R). Furthermore, steel fibre (70 kg/m^3, 30 mm, 50), PE fibers (1.8 kg/m^3, 19 mm) and silica fume (46 kg/m^3) were added to the cement. The technique of submerged test is appropriate for the assessment of wear resistance for solids with high strength and compressive strength up to a value of 120 MPa. The values of wear resistance for plain cement (CEM I 42.5R, 52.5R and CEM III 42.5R) were found to be 3.96, 4.25 and 9.21 mm. The area (2.89 mm) damaged by abrasion was highest in the case of 52.5R concrete and steel filaments of 30 mm.

3.8 ASTM C 1138 Abrasion Test Method

ASTM C 1138 scraped spot test technique is ordinarily applied to assess the scraped spot pace of cement in submerged tests. In particular, the ASTM C 1138, called the submerged strategy, is the most utilized scraped spot test that can more readily mimic the wonder that happens during the activity of water-powered constructions (E. Horszczaruk, 2012). The general absolute trial broadened to six twelve-hour spans. The mass of the solid example is weighted when every span to record the deficiency of gauge, addressing the measure of abrasion damage and harm (AMERICAN SOCIETY FOR TESTING AND MATERIALS. ASTM C1138, 2019).

3.9 Literature Gaps

Based on the results of the literature review, it can be identified a lack of information regarding the influence of age on the porosity of concrete and the abrasion rate along the concrete's life cycle.

3.9.1 Rate of Abrasion During the Life Cycle of the Concrete

The surface abrasion was explored based on the parameters like abrasion depth or abrasion weight loss (E. Horszczaruk, 2012), (Abid, Hilo, Ayoob, & Daek, 2019), (Abid, Hilo, et al., 2018), (Ghafoori, Najimi, & Aqel, 2014), (Kang, Zhang, & Li, 2012), (Elzbieta Horszczaruk, 2008). However, the existing literature is devoid of the propensity at which abrasion takes place during the initial or final period of the abrasion. The variation of the rate of abrasion with time may concentrate on the parameters that positively or negatively affect the abrasion rate. The parameters will also influence the abrasion with time and along with the service life of the surfaces of the concrete. This is an important gap of knowledge.

3.9.2 Effect of Age on the Porosity of Concrete

The porosity of the concrete influences its durability and compressive strength. The ratio of the water to cement is the major parameter dictating the number of pores and the nature within the matrix. The duration of moist curing and the degree of cement hydration affects the porosity. The standard moisture curing period is 28 days for concrete. However, the porosity of the accurately cured concrete decreases due to temperature and relative humidity. The reduction of concrete porosity with age in presence of relative humidity and temperature of the surrounding has not been reported earlier. This instigated us to carry out a study on the effect of the porosity of concrete due to temperature and relative humidity.

4. This Research

This research started with the study of state-of-art literature and the use of the ASTM C 1138 method [1]. The literature was collected, reviewed, and analyzed. A comprehensive comparative analysis was conducted to study the influence of different parameters on abrasion.

4.1 Aim of the Current Research

This study aimed to understand the mechanism of abrasion on the surface of the concrete with high compressive strength which was reinforced with different types of fibers. Another objective of the study was to determine whether the variation in the water-loss rate with different water-cement (w/c) had a similar trend as porosity variation with a different w/c ratio.

4.2 Research Methodology

The decrease in the porosity of the mortar was studied using different water-cement (w/c) ratios when exposed to air. The Portland Composite Cement was used in the study. The sample was examined after curing for 28 days. The relationship between the age of the mortar with different w/c ratios to porosity was also investigated. The resistance to erosion of two kinds of high-strength concrete (HPC and HPFRC) used in hydraulic structures was studied. The HPFRC were prepared with three different types of fibers with different lengths as shown in Table 2.

Table 2. The different fibres and length

Entry	Fibres	Length (mm)
1	Steel	30
2	Steel	50
3	Polypropylene (PP)	19

Both the concrete samples were prepared by mixing the Portland cement with basalt aggregate, sand, silica fumes and superplasticizer. The water to cement (w/c) ratio was maintained constantly at 0.3. The hydro-abrasion–erosion resistance of concrete was estimated under simulated conditions in the laboratory following the underwater method ASTM C 1138 (ASTM, 1999). According to previous results, we conducted an in-depth analysis to identify the effect of different factors associated with the abrasion rate of concrete. Furthermore, we analyzed the samples' surface microstructure using a WMP ECLIPSE machine to measure the depth of wear damage. Notwithstanding the anticipated dynamic and static burdens in the plan of water-powered constructions, the uncommon ecological impacts were thought about. One of the viable potential solutions to prevent the hazard is to employ a solid combination with appropriate scraped area obstruction. ASTM C779 (ASTM International, 2011), ASTM C1138 (I, 2014), ASTM C418 (Method, 2005) and ASTM C944 (ASTM, 1999) are the most generally used standard scraped spot tests. Furthermore, different studies suggest various devices to study the hydraulic concrete's resistance against abrasion. WMP ECLIPSE machine was selected for this research work over other devices after examining all the factors. The mechanism of the wearing due to abrasion was modelled for simulating the wearing of the hydraulic structures by the rubble dragged by water (E. Horszczaruk, 2012), (Ayoob & Abid, 2020), (Bodnárová et al., 2020), (Zhou et al., 2020), (Abid et al., 2020).

4.2.1 Measurement of Abrasion Rate

The term abrasion rate is defined as the change of the abrasion occurring on the concrete during a specific period. This abrasion rate is considered during the abrasion testing. It is affected by the type of compressive strength, cement, water to cement ratio, tensile strength, fibers and silica fume. The abrasion rate is measured in mm/time in hours according to equation 1 based on the abrasion depths of each two successive time steps.

$$AR = (AD_{T+1} - AD_T)/P \qquad 1$$

Where AR = rate of abrasion (mm/hr); AD_T and AD_{T+1} = abrasion depths (mm) from starting to end measurements; P = period between two successive events (hr)

4.3 Data Collection and Analysis

The collection of data collection and analysis were carried out in the following six areas of the study:

a) Influence of Plastic Fiber Reinforced Concrete (PFRC) and silica fume
b) Influence of the cement type on the abrasion and its rate
c) Influence of inclusion of fiber.
d) Influence of tensile strength.
e) Influence of compressive strength
f) Influence of ratio of the water to cement (w/c) under humid conditions

4.3.1 Effect of the Cement Type on the Abrasion and Abrasion Rate

Three high strength concrete (HSC) of 470 kg/m3 were selected as follows:

1) Portland concrete CEM I 52.5 R
2) Portland concrete CEM II 42.5R
3) Impact heater concrete CEM IIIA 42.5

The assessment of the scraped area rate and scraped area profundity was carried out after 28 days for each sample. The blast furnace cement showed the most noteworthy abrasion rate during the testing time frame, while the scraped spot pace of 52.5R and 42.5R sorts of concrete were fluctuating all through the testing length (Figure 2). The rate of the scraped area toward the completion of the analyses was 0.023, 0.0321 and 0.061 mm/hr. for sample I 52.5R, II 42.5R and IIIA 42.5 respectively. Thus, the impact heater concrete exhibited the highest and constant damage to the scraped spot while I 52.5R, displayed minimum scraped area rate and the scraped spot profundity.

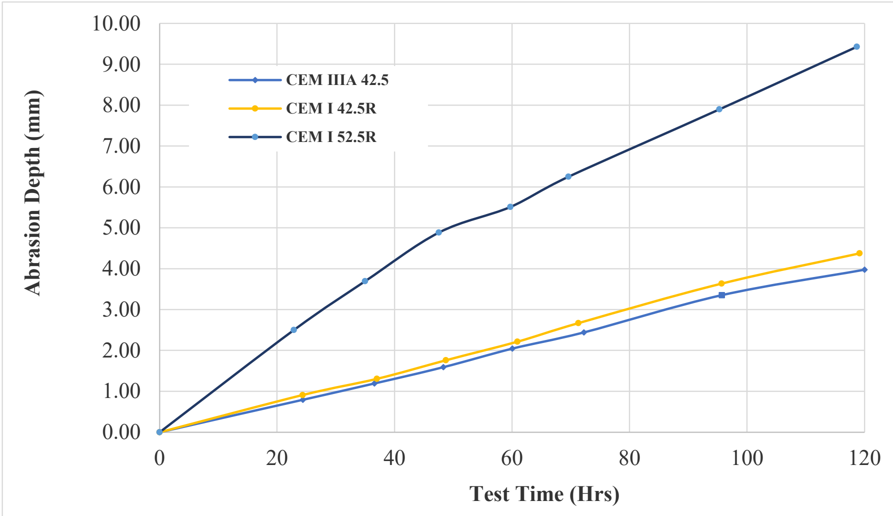

Figure 1. The Effect of cement type on abrasion rate

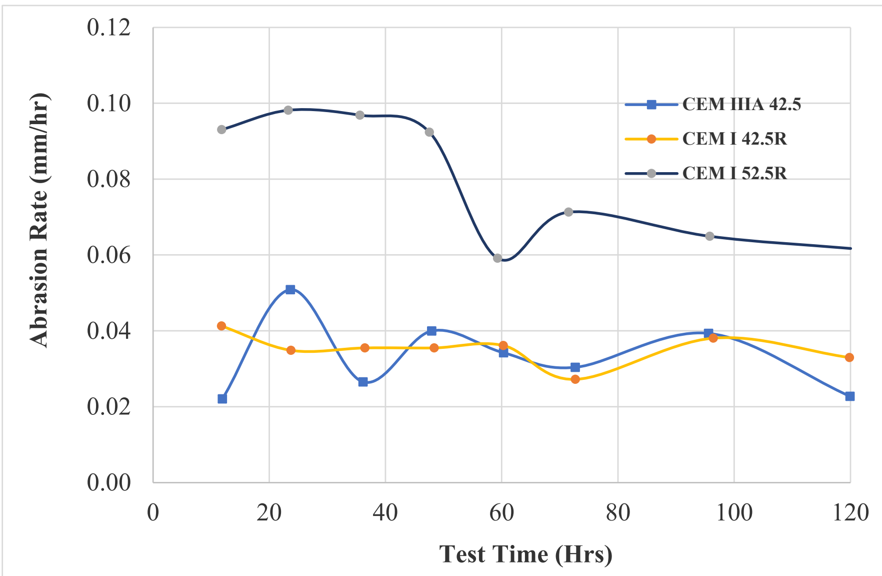

Figure 2. The effect of cement type on abrasion depth

Table 3 depicts that the standard deviation for IIIA 42.5 is 1.32 while for CEM II 42.5 is 1.44 and CEM I 52.4 R is 2.99 corresponding to the highest value of 9.43. The standard deviation is equal to 0.0099 for IIIA 42.5 while the same is 0.0041 for II 42.5R and 0.016 for I 52.5R. In both cases, the highest values are shown by I 52.5 R. Accordingly, the standard deviation exhibits that the abrasion rate is lowest for I 52.5R in both cases while II 42.5 R gave acceptable results.

Table 3. Effect of Cement type on Abrasion Rate and Abrasion Depth

Effect of Cement type on						
	Abrasion Rate			Abrasion Depth		
	CEM IIIA 42.5	CEM I 42.5R	CEM I 52.5R	CEM IIIA 42.5	CEM I 42.5R	CEM I 52.5R
Mean	1.924716	2.109375	5.021307	0.033274	0.035192	0.079696
Standard Error	0.465998	0.507907	1.059219	0.003489	0.001434	0.005989
Median	1.818182	1.988636	5.198864	0.032315	0.035511	0.081854
Standard Deviation	1.318041	1.436577	2.995923	0.009867	0.004057	0.016941
Sample Variance	1.737232	2.063752	8.975555	9.74E-05	1.65E-05	0.000287
Kurtosis	-0.62579	-0.53791	-0.09748	-0.23422	2.097782	-2.41973
Skewness	0.224509	0.23733	-0.23666	0.606647	-0.7777	-0.09817
Range	3.977273	4.375	9.431818	0.028764	0.014063	0.038991
Minimum	0	0	0	0.022088	0.027202	0.059162
Maximum	3.977273	4.375	9.431818	0.050852	0.041264	0.098153
Sum	15.39773	16.875	40.17045	0.266193	0.281534	0.637571

4.3.2 Effect of Water to Cement Ratio (w/c) Under Humid Condition

The effect of the humidity in the hydraulic structures can be analyzed based on the w/c ratio and the conditions of the climate where the structure is built. In this case, we considered the humidity conditions of the Kingdom of Bahrain. We identified August 2020 as the month with the highest humidity. During this month, daily high temperature ranges from 96°F to 107°F, with the highest value of the daily average low temperature was 89°F on August 4. Moreover, we identified that the length of the day shortened on a daily average (1 minute, 20 seconds) and weekly average (9 minutes, 21 seconds), leading to a daily reduction of 40 minutes. The longest day was 1st August with the daylight of 13 hours, 21 minutes while the shortest day was 31st August with the daylight of 12 hours, 41 minutes. The comfort level of humidity comfort level on the dew point determines the evaporate rate of perspiration. A higher dew point indicates more humidity while a lower dew point indicates less humidity. The level of humidity varies significantly between day and night. The dew point changes slowly with the temperature being lower at night. The humidity in the Kingdom of Bahrain was highest during August 2020. The abrasion depth and the abrasion rate of three specimens having different w/c ratios for the same age of 28 days are presented in Figure 3. Statistical data of the effect of the w/c ratio on abrasion depth (mm) and rate of abrasion (mm/hr.) are depicted in Table 4. It was found that the higher value of w/c displayed more prominent corrosion in the scraped spot with a higher scraped spot rate. These results were completely in line with the findings of previous studies. It is well known that the enhancement of the value of w/c diminishes the strength and surface hardness of cement. Thus, the scraped area rates following 72 hours of testing were found to be 0.075, 0.0275, and 0.025 mm/hr for w/c proportions of 0.61, 0.29, and 0.3 respectively.

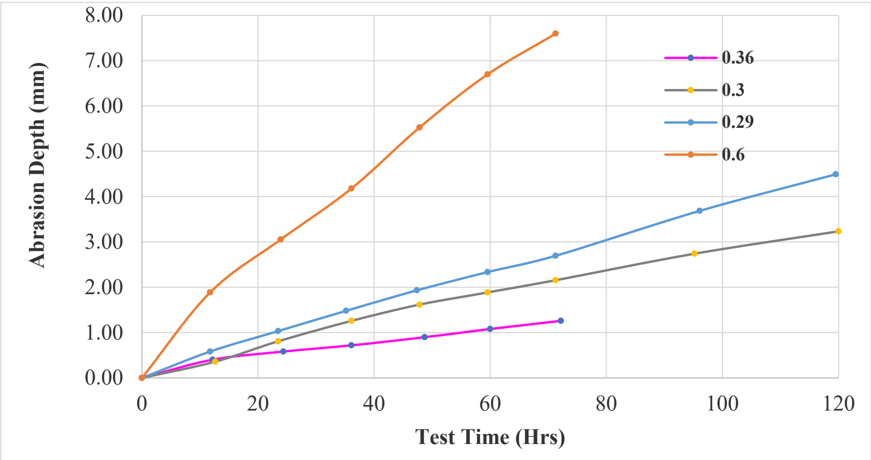

Figure 3. The effect of w/c ration on abrasion depth (mm)

Part of the concerns as well as of the builder's were met during the preparation of the experiment that dry shrinkage, one of the primary triggers of cracks that directly impact the strength and durability of concrete, commonly happens in hot and dry environments appropriate to the loss of internal water in the concrete to the environment. This outcomes in the reduction of concrete volume and take the lead to crack formation in hardened concrete. Furthermore, the majority of this drying shrinkage cannot be reclaimed by rewetting the concrete.

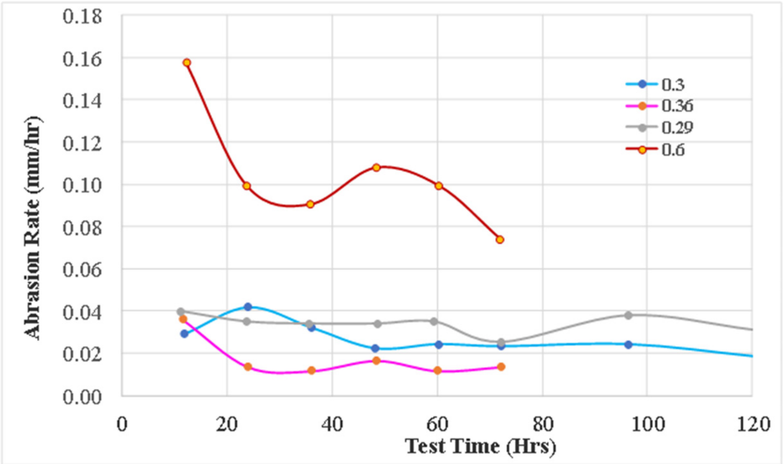

Figure 4. The effect of w/c on abrasion rate (mm/hr)

It can be observed that the value of the rate of scrapped spot and corrosion of the scrapped area in our case was lower than that of the earlier reported cases with the same amount of w/c. This was because of the type of cement utilized where the solid was given a role as self-compacting concrete. The SCC shows higher scraped area resistance than that of a standard vibrated cement of a lower w/c proportion and higher compressive strength.

Table 4. Statistical data of the effect of w/c ratio on abrasion depth (mm) and abrasion rate (mm/hr.)

Depth (mm) with w/c			Rate (mm/hr.) with w/c		
0.3	0.4	0.6	0.3	0.4	0.6
1.43	1.864	3.692	0.063	0.068	0.175
0.34	0.462	0.988	0.029	0.041	0.071
1.43	1.707	3.617	0.035	0.024	0.099
1.087	1.462	2.796	0.088	0.124	0.188
1.18	2.138	7.817	0.007	0.015	0.035
1.039	0.559	1.461	8.944	8.922	6.57
0.278	0.557	0.058	2.987	2.982	2.546
3.235	4.494	7.595	0.274	0.381	0.526
3.235	4.494	7.595	0.3	0.4	0.6
14.367	18.64	29.543	0.572	0.615	1.228
2.741	3.685	6.696	0.039	0.041	0.157
0.3	0.4	0.6	0.031	0.022	0.090

4.3.3 Effect of Silica Fume and Plastic Fiber Reinforced Concrete

Plastic Fiber Reinforced Concrete (PFRC) consists of filler and cement binder, usually in the form of natural aggregates. A scrap of plastic pot was added as fibers. The sand and CA properties include specific gravity, fineness modulus and water absorption, which respectively amount to 2.5(equally for each sample), and 2.65, 4.50 and 1.25 for samples (1), (2) and (3).

The increase of plastic waste has been an environmental concern throughout the world. The main waste from plastic bottles is synthetic resin polyethylene terephthalate (PET). PET possesses significant properties like flexible, light-weight, cheap, resistant to moisture and strong. Thus, the PET obtained from the waste plastic has been mixed with concrete to reduce the abrasion. Conversely, the addition of PET to concrete was limited to non-structural uses as they exhibited larger creep and shrinkage, low strength/stiffness and durability when mixed with natural mixture concrete (NAC). There has been an effort to increase the parameters like workability and density along with the ripping and compressive strength of the concrete.

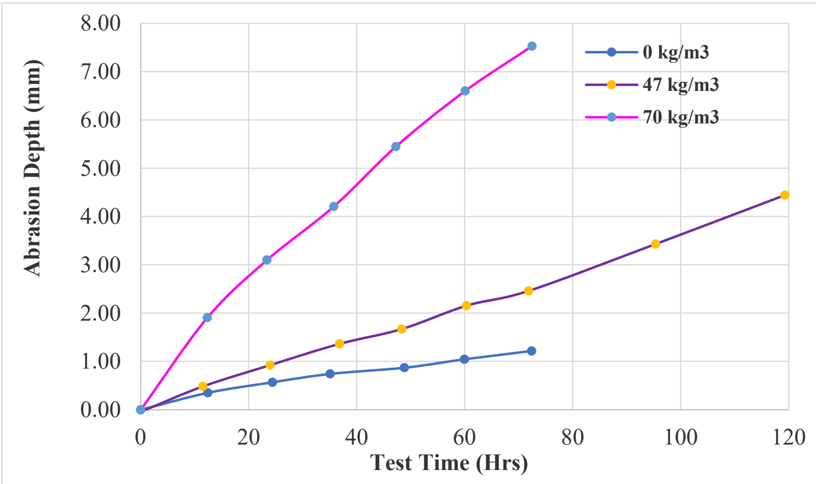

Figure 5. The effect of Effect of silica fume and PFRC on abrasion Depth (mm)

The Waste Plastic Fiber (Figure 5) are used in concrete to control cracks formed due to shrinkage and drying of plastic. Waste Plastic Fibers acts as an impermeable layer to the concrete to control the permeability. However, fibers cannot increase the flexural strength and therefore they cannot substitute the structural steel. The amount of added waste fibres is within a range (0.1% to 3%) of the total volume of the composite. The waste fibres were obtained from waste plastic pot having an aspect ratio of 20. The amount of silica fume was varied and studied. The rate of abrasion was lower for the mixture samples [CEM I 42.5R + silica fume (0 kg/m^3, 47 kg/m^3 and 70 kg/m^3) + waste fibre] through the testing period of 72 hours. The average rate of damage was 0.105, 0.035 and 0.0176 mm/hr respectively. The statistical data of the effect of silica fumes, PFRC abrasion depth (mm) and abrasion rate (mm/hr.) are shown in Figure 5 and Table 5.

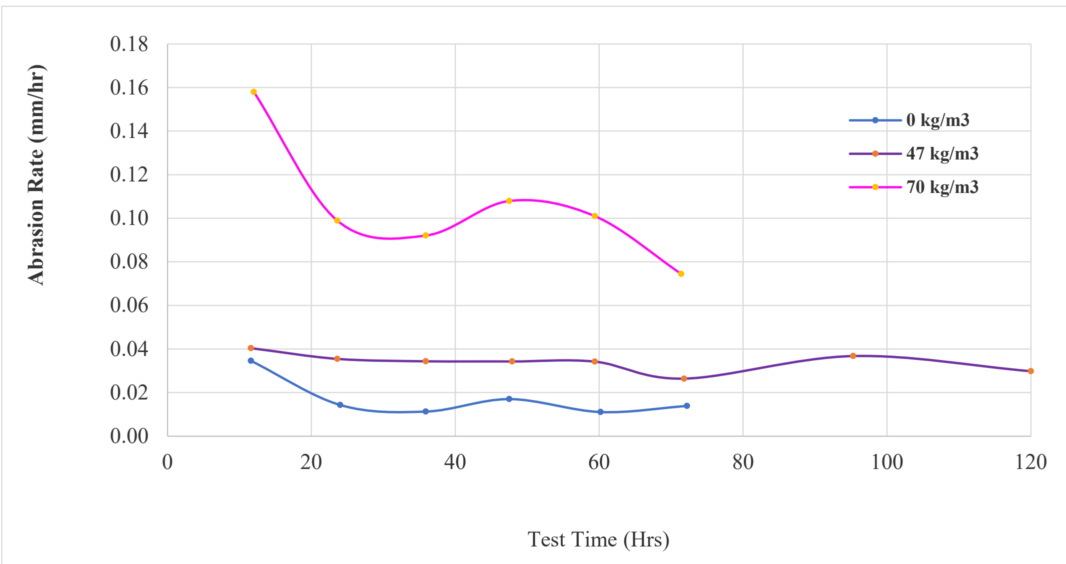

Figure 6. Effect of silica fume and PFRC abrasion rate(mm/hr)

Table 5. Statistical data about effect of Silica fume and PFRC abrasion depth (mm) and abrasion rate (mm/hr)

	Depth (mm)			Rate (mm/hr.)		
	0 kg/m^3	47 kg/m^3	70 kg/m^3	0 kg/m^3	47 kg/m^3	70 kg/m^3
Mean	0.685023	1.881959	4.113688	0.0334	0.033975	0.105417
Standard Error	0.157743	0.472946	1.00538	0.0036238	0.001504	0.011499
Median	0.742567	1.670981	4.208975	0.0141	0.03435	0.09995
Standard Deviation	0.41735	1.418838	2.659985	0.0088764	0.004255	0.028167
Sample Variance	0.174181	2.013101	7.07552	7.879E-05	1.81E-05	0.000793
Kurtosis	-0.30543	-0.18958	-0.84593	4.7663144	0.716399	3.30596
Skewness	-0.50128	0.581978	-0.29532	2.1328947	-0.53404	1.518823
Range	1.217638	4.44503	7.528715	0.0235	0.014	0.0835
Minimum	0	0	0	0.0111	0.0264	0.0745
Maximum	1.217638	4.444701	7.528715	0.0346	0.0404	0.158
Sum	**4.79516**	**16.93763**	**28.79582**	**0.1022**	**0.2718**	**0.6325**
Largest (2)	1.044466	3.431346	6.599971	0.017	0.0368	0.108
Smallest (2)	0.350954	0.484619	1.906541	0.0113	0.0298	0.0921

From the above table of statistical data about the effect of of Silica fume and PFRC abrasion depth (mm) and abrasion rate (mm/hr) that it was evident that the rate of abrasion was reduced by 66% and 83% with the addition of 47 kg/m^3 and 70 kg/m^3 of silica fume, respectively since the rheological properties are improved. Additionally, the risk of cracking in concrete by the heat of hydration was also decreased (Ayoob & Abid, 2020), (Bodnárová et al., 2020), (E. Horszczaruk, 2012).

The contact between the surface of the concrete and particles with a size less than mm causes rough wearing. The service life of the structure is shortened due to the formation of temporary surface layers within the concrete structure. This leads to the accumulation of fluid within the concrete and is destructive for high-rise buildings.

4.3.4 Effect of Compressive Strength Concrete Tensile Strength and Fiber Inclusion

It is evaluated here for the effect of compressive strength, tensile strength and fiber inclusion on the abrasion rate (mm/hr) and abrasion depth (mm) of the examined samples. The results of this evaluation are shown in Figures 7, 8 and 9 respectively. Furthermore, we conducted the statistical analysis of each experiment, and the results are given in Table 4. As observed from Figure 5 which identified the compressive strength was highest and abrasion depth was lowest for concrete (48 MPa). We compared the parameters (abrasion loss of the concrete surface and the compressive strength) for the same concrete and concluded that the rate of wearing decreased with an increase of the compressive strength. Nevertheless, this characteristic is not consistent for all mixtures (Ayoob & Abid, 2020), (E. Horszczaruk, 2012). The tensile strengths of concrete with 3.8 MPa, 4.5 MPa and 5 MPa corresponded to abrasion rate of 0.059 mm/hr, 0.046 mm/hr and 0.015 mm/hr respectively (Figure 8). These results were supported by the information presented in (Abid et al., 2019), (Abid Hilo et al., 2018), (Bodnárová et al., 2020), (Ayoob & Abid, 2020). A reduction of 18.5% and 38.4% in the average abrasion rate of the samples was observed after the addition of 1% by volume of steel fibres [78 kg/m^3 ,15 mm] and PVA (13 kg/ m^3) to the mixture (Abid et al., 2019), (Abid, Hilo, et al., 2018). The results were in accordance with the reported results (Horszczaruk, 2009), (Bodnárová et al., 2020), (Ayoob & Abid, 2020) which reported a reduction of 16.3%, 0% and 10.7% of the rate of abrasion after the addition of 0.1% of PP (1.8 kg/m^3), steel fiber (70 kg/m^3, 50 mm) and steel fibers (70 kg/m^3 of 30 mm).

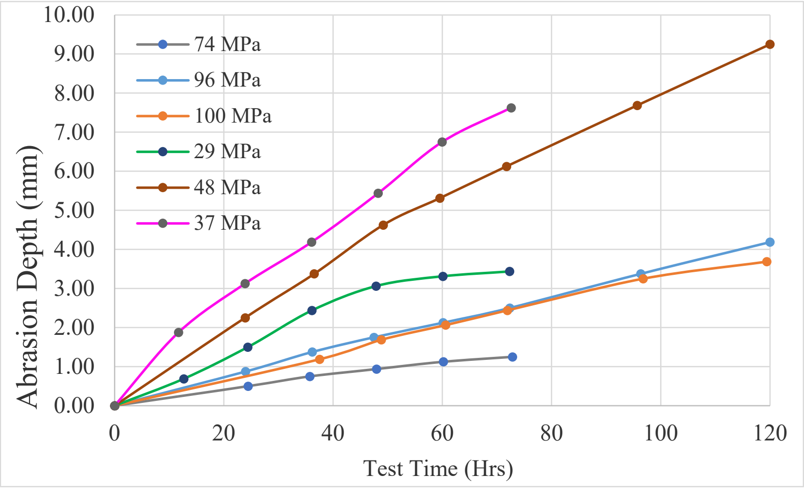

Figure 7. Effect of compressive strength on abrasion depth

From the figure above, the abrasion depth varies from 0 to 10 scale in mm and at the 75 hours the rates sometime can not exceeds max 8 mm while others compressive strength is in the position to exceeds even 9 mm in the scale. Concrete mechanical properties play an important role in the abrasion of concrete. It is observed that an increase in compressive strength and modulus of elasticity of concrete enhances the overall abrasion resistance. Experimental work on the abrasion resistance of endangered to heavy mixtures from studded the carried out experiment.

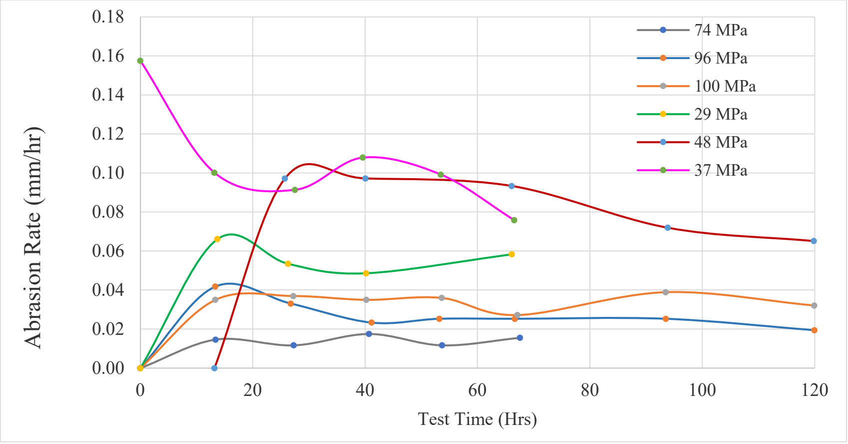

Figure 8. Effect of compressive strength on abrasion rate

From figure 8 can conclude that the three 100 MPa, 48 MPa and 96 MPa were able to pass the 120 hours test time with lower abrasion rate. Abrasion is an important operational threat to the quality and durability of existing concrete structures leading to deterioration and premature failure. Concrete performance is more commonly valued with respect to the engineering or mechanical properties such as compressive/flexural strengths and modulus of elasticity, and less frequently, tensile strength, shrinkage and creep. Even though carbonation, sulphate and chloride penetration resistance, and less frequently, water absorption and air/oxygen permeability need obtained extraordinary awareness, abrasion resistance is in fact one of the least investigated durability properties of hardened concrete. Nevertheless, this is essential in hydraulic structures, floors.

Table 6. Effect of compressive strength on abrasion depth (mm) and abrasion rate (mm/hr)

	Abrasion Depth (mm)						Abrasion Rate (mm/hr.)					
	30 MPa	40 MPa	50 MPa	70 MPa	90 MPa	100 MPa	30 MPa	40 MPa	50 MPa	70 MPa	90 MPa	100 MPa
Mean	2.06	0.76	4.14	4.83	2.04	1.58	0.05	0.04	0.11	0.01	0.02	0.03
Standard Error	0.51	0.19	1.02	1.05	0.47	0.35	0.01	0.01	0.01	0.00	0.00	0.00
Median	2.44	0.84	4.19	4.97	2.06	1.56	0.05	0.04	0.10	0.01	0.03	0.04
Standard Deviation	1.36	0.46	2.71	2.97	1.25	1.06	0.03	0.03	0.03	0.01	0.01	0.01
Sample Variance	1.84	0.21	7.32	8.82	1.56	1.12	0.00	0.00	0.00	0.00	0.00	0.00
Kurtosis	-1.44	0.34	-0.89	-0.30	-0.12	-0.86	3.87	-2.12	3.40	3.49	2.57	6.19
Skewness	-0.55	-0.89	-0.26	-0.15	-0.36	0.02	-1.89	0.09	1.59	-1.74	-0.90	-2.43
Range	3.44	1.25	7.63	9.25	3.69	3.19	0.07	0.08	0.08	0.02	0.04	0.04
Maximum	3.44	1.25	7.63	9.25	3.69	3.19	0.07	0.08	0.16	0.02	0.04	0.04
Sum	14.44	4.56	29.0	38.63	14.31	14.19	0.23	0.25	0.63	0.07	0.19	0.24
Count	7.00	6.00	7.00	8.00	7.00	9.00	5.00	6.00	6.00	6.00	8.00	8.00
Largest (2)	3.31	1.13	6.75	7.69	3.25	2.75	0.06	0.07	0.11	0.02	0.03	0.04
Smallest (2)	0.69	0.50	1.88	2.25	1.19	0.38	0.05	0.01	0.09	0.01	0.02	0.03

The above table Effect of compressive strength on abrasion depth (mm) and abrasion rate (mm/hr) shows that the mechanical properties of concrete like compressive strength and flexural strength were augmented after the addition of steel fibers. The porosity and absorption capacity of the concrete were decreased as compared to pristine concrete. Our experiments revealed that the addition of 2.5 % hooked end steel fibers to concrete modified its intrinsic properties. However, the maximum increase in the strength of concrete depended on the optimal amount of the added fiber. With an increase in the fiber content, the mode of failure is altered from brittle to ductile when subjected to compression and bending. As Both are measures of where the center of a data set lies defined as the Central Tendency in statistics, but it is usually different numbers. So here sometimes indicated to be between 0.03 and 4.14 where showing the lowest at 70 MPa. The largest and smallest numbers indicate inconsistencies where required another statistical study for those sets. Now the kurtosis is matching the assumed expectation of the smallest to indicate the right figures and usually does not exceed the 10 times as usual appearance in such experiments.

Table 7. Effect of tensile strength on abrasion depth (mm) and Rate (mm/hr.)

	Abrasion Depth (mm)						Abrasion Rate (mm/hr.)					
	7 MPa	5.8 MPa	3 MPa	5 MPa	4.5 MPa	3.8 MPa	7 MPa	5.8 MPa	3 MPa	5 MPa	4.5 MPa	3.8 MPa
Mean	1.26	0.77	1.76	2.08	2.10	4.15	0.03	0.01	0.05	0.05	0.04	0.09
Standard Error	0.34	0.17	0.51	0.55	0.68	1.02	0.01	0.00	0.01	0.01	0.01	0.02
Median	1.61	0.76	1.74	2.15	1.88	4.20	0.02	0.01	0.06	0.05	0.04	0.10
Standard Deviation	0.90	0.45	1.34	1.45	1.80	2.69	0.03	0.01	0.03	0.02	0.02	0.05
Sample Variance	0.82	0.20	1.80	2.10	3.23	7.23	0.00	0.00	0.00	0.00	0.00	0.00
Kurtosis	-1.12	0.16	-1.33	-1.06	-0.81	-0.87	-1.04	2.97	0.69	5.70	3.99	2.66
Skewness	-0.37	-0.58	0.15	-0.11	0.51	-0.29	0.66	1.08	-0.91	-2.31	-1.77	-0.90
Range	2.46	1.34	3.66	4.07	4.96	7.60	0.08	0.03	0.09	0.06	0.06	0.16
Maximum	2.46	1.34	3.66	4.07	4.96	7.60	0.08	0.03	0.09	0.06	0.06	0.16
Sum	8.80	5.36	12.29	14.57	14.70	29.05	0.21	0.10	0.38	0.34	0.29	0.63
Largest (2)	1.88	1.12	3.04	3.40	3.71	6.66	0.05	0.02	0.08	0.06	0.05	0.11
Smallest (2)	0.18	0.49	0.54	0.72	0.40	1.92	0.01	0.01	0.03	0.05	0.04	0.07

The table above shows the effect of tensile strength on abrasion depth (mm) and Rate (mm/hr) which indicates the abrasion resistance of constructions from concrete with cement mixture is very significant for their service life, especially in industrial enterprises. Deterioration of concrete exteriors is initiated by forms of wear due to numerous exposures, like erosion, cavitation, and abrasion. Abrasion wear happens due for to rubbing, scraping, skidding or sliding of bits and pieces on concrete surface. This kind of wear currently detected in pavements, floors or other surfaces on which friction forces are employed due to comparative motion among the surfaces and stationary entities. There are numbers in the statistical standard deviation shown in the table above to move within the acceptable limits such as 1.35, 1.45 and 2.69 which still not odd to be looked at when comparing with figures exceeds to 7 shown in many situations. Normally the standard deviation in statistics indicates to measure of the amount of variation or dispersion of a set of values. A low standard deviation indicates that the values tend to be close to the mean and is defined as expected value of the set, whilst a high standard deviation indicates that the values are spread out over a wider range and worth studying the effect of it on the decision of the reliability of the information's.

The primary factors affecting the abrasion resistance of concrete can be the environmental situations, aggregate type, dosage of aggregate, the concrete strength, the mixture proportioning, the use of special cement, the use of supplementary cementitious materials, water/binder (*w*/*b*) ratio and the addition of fiber which is not taken into consideration since the origin of the experimentation deviate from this study but considered in the practical work of this research. Two other crucial factors influence abrasion resistance: surface finishing and curing conditions.

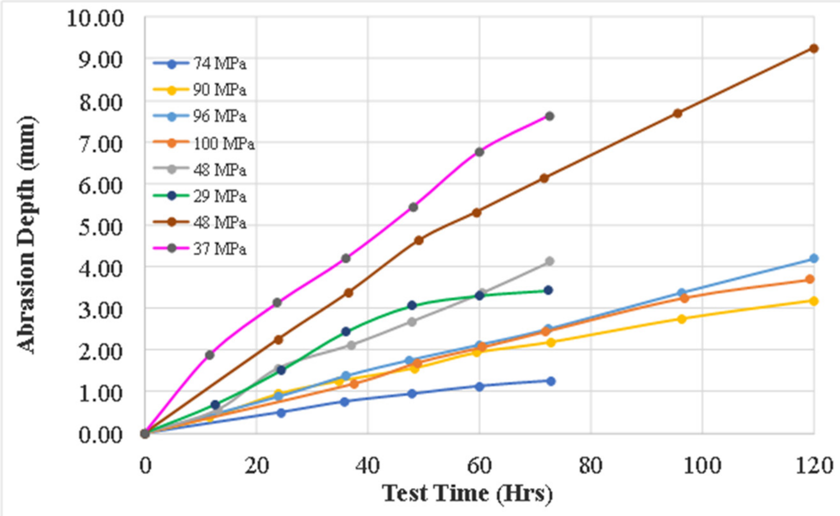

Figure 9. Effect of compressive strength on abrasion depth

It is obvious that interpretation of mechanics of concrete surface fracture is essential to mitigate its damaging influence on concrete. A discrepancy in constituent of a concrete reveals discrepancy in assets containing abrasion resistance which substantially be contingent upon the microstructural qualities. It is obvious that, compressive strength performs very important role in abrasion resistance of concrete and performed by water-cement ratio, aggregate type, finishing and curing. Inclusion of strong aggregates, silica fumes and fibers are influencing on mechanical properties, potential to generate high abrasion resistive concrete as per requirement. Abrasion assessment is provoked by testing procedure, age of concrete and environment circumstances. The sound effects of environment and age of concrete on concrete surface is complicated for the reason that of changeable conditions.

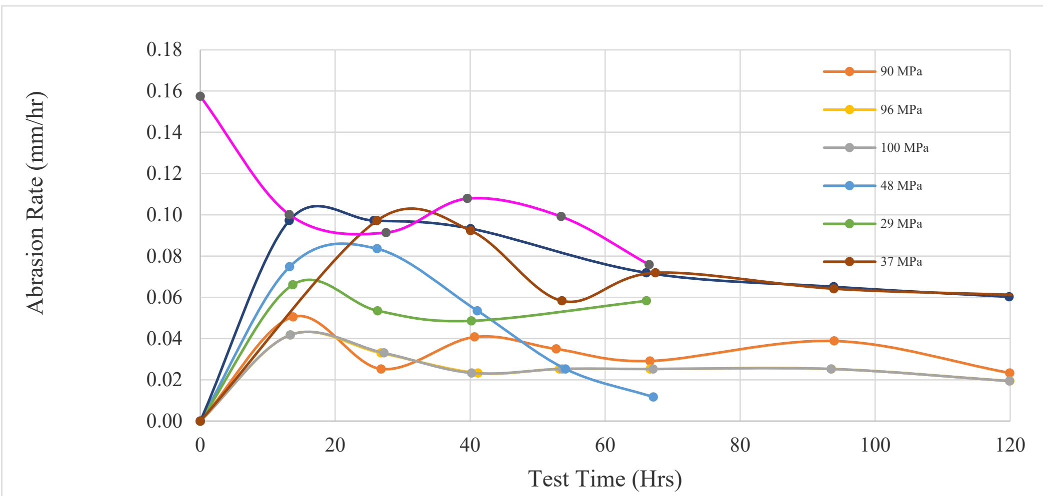

Figure 10. Effect of compressive strength on abrasion rate

The influence of curing age and cement type on the compressive strength are shown in Figure above. When different type cement was used, the 120 hours compressive strength of the concrete increased by 48%, as compared to the 120-hour compressive strength of the different mixture. A significant improvement was observed in abrasion resistance for the cement concrete mixture with 54% lower abrasion depth at 120 hours testing in comparison with different testing. As it is locally available fine and coarse aggregates were used here in the experimental works.

Table 8. Effect on fiber inclusion on abrasion depth (mm) and rate (mm/hr.)

	Abrasion depth (mm)					Abrasion rate (mm/hr.)				
	19 mm PP 1.8 kg/m3	30 mm steel 70 kg/m3	50 mm steel 70 kg/m3	6 mm PVA 13 kg/m3	0 kg/m3	19 mm PP 1.8 kg/m3	30 mm steel 70 kg/m3	50 mm steel 70 kg/m3	6 mm PVA 13 kg/m3	0 kg/m3
Mean	1.04	1.49	1.56	2.07	2.04	0.02	0.02	0.05	0.04	0.05
Standard Error	0.29	0.37	0.45	0.65	0.54	0	0	0.01	0.01	0.01
Median	0.88	1.5	1.37	1.82	2.04	0.02	0.02	0.06	0.04	0.05
Standard Deviation	0.87	1.12	1.19	1.72	1.43	0.01	0.01	0.03	0.02	0.02
Sample Variance	0.75	1.26	1.42	2.95	2.05	0	0	0	0	0
Kurtosis	-0.54	-1	-1.13	-1.06	-1.03	1.45	3.12	-0.98	1.19	5.88
Skewness	0.56	0.04	0.26	0.42	-0.07	-1.16	-1.63	-0.14	-1.29	-2.34
Range	2.59	3.22	3.32	4.71	4.04	0.03	0.03	0.09	0.06	0.07
Maximum	2.59	3.22	3.32	4.71	4.04	0.03	0.03	0.09	0.06	0.07
Sum	9.39	13.37	10.9	14.47	14.25	0.15	0.19	0.44	0.23	0.34
Largest (2)	1.93	2.69	2.66	3.69	3.28	0.03	0.03	0.08	0.05	0.06
Smallest (2)	0.13	0	0.53	0.49	0.67	0.01	0.02	0.02	0.03	0.05

The table above express the Effect on fiber inclusion on abrasion depth (mm) and rate (mm/hr.) which according to it the results shows that averaged sum of the smallest values is at averaged 0.195 where for largest is calculated to be 1.45. The mean and standard error is 0.838 and 0.233. The standard deviation shows 0.642 representing the 0.87 value of 19 mm PP 1.8 kg/m^3. So, when comparing the standard deviation of 6 mm PVA 13 kg/m^3 with zero mm then 1.43 is lower than 6 mm.

5. Results of Laboratory Investigations

The impact of abrasion on the scraped spot (mm) and the rate of the scraped area (mm/hr.) for hydrophobic cement were studied. The impact heater cement displayed noteworthy anti-abrasion properties on the scraped area rate within the testing time. The abrasion rate on the scraped area for concrete (52.5R and 42.5R) varied all through the test span of time. After the completion, scraped area rates were 0.023, 0.0321 and 0.061 mm/hr for concrete I 52.5R, II 42.5R and IIIA 42.5. The blast furnace cement showed the highest abrasion rate. The activity of water to solidify (w/c) under damp conditions proved that a higher value of w/c showed good results. The abrasion was higher in the scraped area with a higher scraped spot rate. It can be established that an increase in the amount of the w/c essentially diminishes the strength and surface hardness of the concrete. The scraped area rates were 0.075, 0.0275, and 0.025 mm/hr with w/c amounts of 0.61, 0.29, and 0.3 after 72 hours. The SCC demonstrated higher resistance to abrasion for the scraped area as compared to vibrated cement of a lower w/c amount and higher compressive strength. We found under humid conditions that sample (II 42.5R) with a higher w/c ratio exhibited greater abrasion losses and higher abrasion rate which was similar to the literature report.

The destruction rate of the normal scraped area rate was 0.105, 0.035 and 0.0176 mm/hr with silica smolder substance of 0, 47 and 70 kg/m3, respectively within 72 hours. In addition, it was found that the scraped area rate diminished by 66% and 83% with 47 kg/m3 and 70 kg/m3 of silica smolder. The increase of silica smolder considerably upgrades the rheological properties and decreases the cracking probability due to hydration heat. The effect of compressive strength as in example 4 indicated that the most elevated and the least scraped spot profundities were recorded for two samples with similar compressive strength (48 MPa) but with different compositions. The loss of the scrapped solid surface is linked with its compressive strength. All blends with upgraded compressive strength might not have a lower rate of the scraped area [7, 14]. The effect of cement rigidity on example 5, exhibited that the scraped spot rates for tests with elastic qualities of 3.8, 4.5 and 5 MPa were 0.059, 0.046 and 0.015 mm/hr, individually. The scraped area rate is identified with its parting elasticity. The effect of fiber incorporation on example 6, 1% of steel strands (78 kg/m^3, 15 mm), 1% PVA (3 kg/m^3), 0.1% PP filaments (1.8 kg/m^3), steel fiber (70 kg/m^3, 50 mm) and steel strands (70 kg/m^3, 30 mm) consolidated the scraped spot rate by 18.5%, 38.4%,16.3%, 0% and 10.7%. We also confirmed that the PP strands of 19 mm length are the best filaments that can diminish the abrasion rate in concrete, while the steel fiber of 50 mm length exhibited the lowest abrasion resistance. The steel filaments can improve the flexural, elastic, and shear properties of the cement.

6. Conclusions

Through comprehensive research, the impact of the type of aggregate used in the concrete in the Kingdom of Bahrain was studied considering the annual variation in humidity and temperature. Based on the results obtained through this research can be concluded the following:

i. The blast furnace cement (CEM IIIA 42.5) showed a higher scraped spot rate by 55.7% and 58.5% as compared to Portland concrete (CEM I 42.5R and 52.5R).

ii. The increase of silica fume diminished the scraped spot rate. Our study revealed that silica fume (47 kg/m^3 and 70 kg/m^3) decreased the rate by 66% and 83%. The self-compacting solid had a lower scraped area rate as compared to that of vibrated concrete with higher compressive strength.

iii. The addition of PP fibers of 19 mm length diminished the abrasion rate among the studied different types of fibres. Besides, we discovered a relation between the amount of w/c and compressive strength towards the improvement of the abrasion resistance. An augmentation in the compressive strength or rigidity with a lower amount of w/c proportion would diminish the rates of the scraped spot.

iv. It is concluded that the reduction of the rate of abrasion is directly affected by the selection of cement, inclusion of fibers, the addition of silica fume and selection of the proper concrete type.

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