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Laboratory study on the properties of concrete pavement containing blast furnace slag and Gilsonite

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Abstract

This study evaluated the mechanical properties and abrasion resistance of the concrete pavement when cement was replaced by the blast furnace slag (BFS) and Gilsonite at levels of 20%, 25%, and 30%, as well as 5%, 7%, and 9%, respectively. For this purpose, a total of ten mixing designs were made and cured for 28 days. The results showed that the compressive strength of mixtures containing two additives decreased. In contrast, the BFS20-G7 (i.e., sample containing 20% BFS and 7% Gilsonite) mixture satisfied the proposed minimum compressive strength. However, the flexural strength and tensile splitting of the BFS20-G7 containing 20% BFS and 7% Gilsonite increased by about 4 and 7 percent. The Wide Wheel Abrasion Test results showed that the mixture containing 20% BFS-7% Gilsonite increased the abrasion resistance by about 5% and 17% in 100 and 300 revolutions, respectively. Conclusively, using BFS20-G7 in low traffic areas such as park and driveway can be suggested.

Keywords

Gilsonite, Blast Furnace Slag (BFS), Concrete Pavement, Abrasion test, Mechanical Properties.

1. Introduction

A proper design of pavements' type can reduce the costs of the road (Zarei and Zahedi, 2016; Miryalad and Nokken, 2015; Zahedi and Zarei, 2016; Rahman et al, 2014; Zahedi et al, 2017; Zarei et al, 2020a; Zarei et al, 2021; Zarei et al, 2022a; Zarei et al, 2022b; Zarei et al, 2022c) and improve technical performances (Zahedi et al, 2017; Zarei et al, 2019; Rezaei et al, 2020; Barati et al, 2020; Zahedi et al, 2020; Rassafi et al, 2021; Zarei et al, 2020b; Xiong et al, 2023; Tabasi et al, 2023a; Tabasi et al, 2023b; Fatemi et al, 2023). The main purpose of using pavement is to provide safety, convenience, and traffic control (Huang, 2004). Concrete is one of the most widely used building materials in the world due to its technical properties (Holman et al, 2013). Adding additives to concrete mixtures can reduce the environmental impact (Zarei et al, 2020c; Madandoust et al, 2011). From 2011 to 2015, annual cement production increased by about 14 percent to a value of 4.1 billion tons worldwide (Cement Statistics and Information, 2018). Also, during the cement production process, NO, CO, SO2, and other hazardous pollutants are released into the atmosphere (Turner et al, 2013). Therefore, many tools have been considered to reduce the usage of cement. Pozzolanic material derived from industrial waste, including fly ash, blast furnace slag (BFS), and etcetera, is considered such materials (Siddique et al, 2020). BFS is one of the by-products suggested by researchers to improve the technical properties of concrete. BFS has hidden hydraulic properties and reacts with water in an alkaline environment (Kandiri et al, 2020; Ramezanianpour et al, 2016). BFS is generated by cooling down the slags during the extraction process to create a granular material (such as glass sand), which consists of calcium oxide (30-50%), silicon dioxide (28–38%), aluminum oxide (8–24%), and magnesium oxide (1–18%) (Yüksel et al, 200; Saha et al, 2016; Berndt et al, 2009). The heat generated by the BFS hydration process is lower than the Portland cement. Therefore, increasing the amount of cement replaced by BFS can limit the heat generation rate and the maximum temperature achieved in the concrete (Ramezanianpour et al, 2016).

Bilim et al. investigated the effect of BFS on the compressive and flexural strength of concrete. Concrete mixtures were cured at 7, 28, 90, and 180 days and BFS replaced cement at the percentages of 20, 40, 60, 80, and 100%. Based on the results, it can be said that using 80% of this material leads to the best results (Bilim and Atis, 2012). Qu and Yu studied the effect of BFS on the mechanical properties of lightweight concrete. BFS replaced the cement in different percentages (5, 10, 15, and 20). The specimens were tested for compressive and flexural strength for the curing period of 1, 7, and 28 days. Based on the results, the curing time significantly affected the increase of compressive strength and flexural strength. Using 5% of BFS has the highest increase in compressive and flexural strength. Also, using this additive significantly reduced water absorption (Qu and Yu, 2018). The effect of BFS on the properties of concrete was evaluated in another study. However, in this study, two concrete mixtures containing ordinary Portland cement with densities of 450 and 520 kg/m3 and two mixtures containing 30% BFS were investigated. The results show that BFS improves the hydration and pozzolanic reactions of concrete. Based on these results, the compressive strength, elasticity modulus, and electrical resistance of concrete mixtures increases (Teng et al, 2013). Wawrzeńczyk et al. studied the effect of BFS on the impermeability and freeze-thaw resistance of concrete. In this study, two additives, including BFS and polymer, were added to the concrete at different percentages. According to the results, as the water to cement ratio increased, the concrete's permeability increased, and as a result, the compressive strength and freeze-thaw resistance decreased. Also, the polymer improved frost resistance due to the absence of water absorption (Wawrzeńczyk et al, 2016).

The abrasion between moving vehicles and pavement occurs due to slipping and scraping as a result of friction between the surface and the wheels, which can be caused mainly by the slippery nature of the pavement and its resistance to traffic loads in a particular traffic situation (Garcia et al, 2012). It is estimated that the abrasion resistance of concrete depends mainly on factors such as strength, aggregate properties, the finishing method of the concrete surface, and the type of hardeners or toppings. Besides, additives have been used to improve mechanical properties and abrasion test results (Adewuyi et al, 2017).

A few standard test methods have been introduced to quantify abrasion susceptibility of concrete pavements, which are different in some features (ASTM C779, 2012; ASTM C944, 2012; ASTM C1138, 2012). Depending on the type of contact, some simulate abrasion progress by rubbing (ASTM C779, 2012; BS EN 1338, 2003), while the others implement rolling action (e.g., ASTM C944; ASTM C779 – Procedure B and C). Simulating real conditions is performed on some standards using wheel crossings (e.g., BS EN 1338). In a study, the Wide Wheel Abrasion Test was conducted according to the BS EN 1338 Standard, to abrade the base and modified specimens. The use of this method has been reported in other studies. Jalal Kamali et al. investigated the abrasion resistance of concrete pavements using Rotational Abrasion and Wide Wheel Abrasion Tests. The results showed that the presence of aggregates in the Wide Wheel Abrasion Test will affect the results. As a result, both types of tests yielded relatively similar results (Jalal-Kamali et al, 2019). Sadek, and El Nouhy (2014) evaluated the properties of paving blocks incorporating crushed ceramic. For this purpose, a total of eight mixes were made, compressive, tensile splitting, and abrasion tests were performed on them. The results showed that using this additive led to improved mechanical strength and abrasion resistance of mixtures. According to practice in the UK pertaining to abrasion, mixtures 2 and 7 can be used for normal pedestrian and vehicular areas (Class 3), while mixtures 1, 3, 4, 5, 6, and 8 can be used for light pedestrian and vehicle use (Class 4). Hence, it is feasible to use fine crushed ceramic to produce paving blocks (Sadek and Nouhy, 2014). Lam et al. investigated the effect of fly ash and electric arc furnace slag (EAFS) on the properties of roller compacted concrete pavement (RCCP). The results showed that the use of EAFS increased the water absorption and abrasion resistance of the RCCP. The use of fly ash improved the abrasion resistance; hence, the obtained mixture can be used in the medium-traffic areas (class 3) (Lam and Jaritngam, 2018). Nehrani et al. evaluated the effect of Rice Husk Ash and Gilsonite on mechanical strength and abrasion resistance of concrete pavement. The results showed that the compressive strength of concrete pavement decreased, and the tensile splitting strength and flexural strength improved. The reason for the decrease in compressive strength was the presence of Gilsonite in the mixtures, which reduced the hydrated reaction of the concrete. Therefore, mixtures containing both additives should be used in low-traffic areas. On the other hand, the results of abrasion resistance showed that the additives increased the abrasion resistance. As a result, the use of these additives in the concrete pavement can be used in areas with light traffic that is prone to slipping (Nehrani et al, 2021).

Few studies have been performed on modified concrete pavements to evaluate the modified concrete pavement's abrasion properties. Therefore, in addition to investigating the mechanical properties, this study evaluated the abrasion resistance of concrete pavement modified with BFS and Gilsonite. Although some researchers recommend using BFS, the existing evidence suggests that the results are not sufficient (Ramazanianpour et al, 2016); hence, in this study, Gilsonite additive was used to evaluate the mixture containing BFS. Gilsonite, brittle material with high luminosity, is a type of ore and formally classified as a natural bitumen. Using Gilsonite in asphalt pavement has been approved by researchers (Sobhi et al, 2020); however, it has not been used in concrete. Moreover, Gilsonite contains an amount of SiO2 that may improve the performance of the concrete pavement. Therefore, in this study, BFS and Gilsonite were used to study the properties of concrete pavement. To achieve the article's objectives, first, the required materials and additives are prepared; then, the mixing design of concrete is performed. Finally, different samples were made using BFS-G additives. After making the samples, various tests, including slump test, mechanical strength, and abrasion resistance, were performed.

2. Material and Mix Design

2.1 Materials

2.1.1 Cement

In this Research, Portland cement type II was used to make the specimens. The technical specifications, as well as the chemical analysis of the used cement, are given in Table 1.

Table 1. Chemical properties of cement and Additives

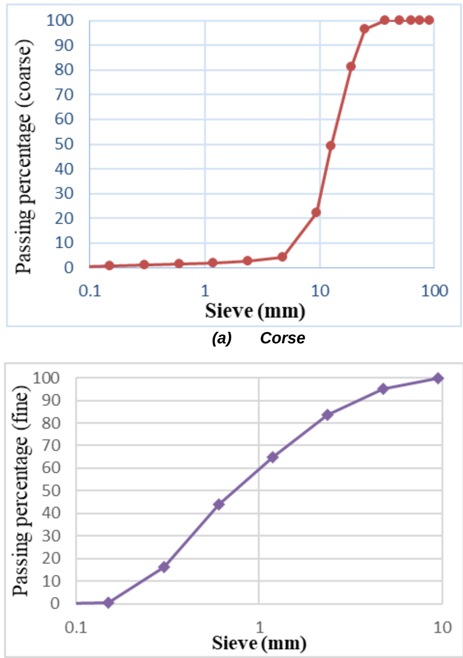
Compound	Amount (%) Portland Cement	Gilsonite	Blast Furnace Slag
SiO_2	20.279	15.95	35.08
CaO	62.28	35.48	38.46
Al_2O_3	4.76	6.82	13.47
Fe_2O_3	3.86	4.36	0.51
MgO	3.22	0.62	-
SO_3	1.89	22.23	0.1
$K_2O + Na_2O$	1.05	-	-
Na_2O	-	1.36	-
Other	2.66	3.45	12.38
Loss of Ignition	-	9.73	-
Specify gravity	3.14	-	2.89
Surface area (cm^2/g)	2616	-	440
Setting time, initial (min)	140	-	-
Setting time, final (min)	210	-	-

2.1.2 Aggregates

Fine and coarse aggregates with a nominal maximum size of 19 mm are used to make the specimens. These materials were obtained from a factory located in Tehran. The ASTM standard was used to determine these materials' specifications (ASTM C33) (ASTM C33, 2016). The technical specifications of the used aggregate are presented in Table 2. Also, the gradation limit of these materials is presented in Fig. 1.

Table 2. Physical properties of original aggregates

Specifications of aggregates	standard	Type of aggregates: Coarse aggregate	Fine aggregate
Specify gravity (kg/m3)	ASTM C127, 128	2550	2600
Water absorption (%)	ASTM C 127,128	1.43	1.75
Sand equivalent (%)	ASTM D2419	-	83.96
Moisture (%)		3.41	2.45



(a) Corse

(b) fine

Fig 1. Gradation of aggregates

2.1.3 Additives

BFS and Gilsonite additives were used to study their simultaneous effects on the concrete pavement. Gilsonite was prepared from Kermanshah mine. Table 1 and Table 3 present the physical properties of Gilsonite. Gilsonite requires an appropriate solvent because of its inherent properties and insolubility in water (Ameri et al, 2011). Therefore, in this study, gas oil was used to solve the problem. By combining these two materials together, gel-like materials are formed that can be added to concrete and have a hydration bond. Also, Superplasticizer was used to increase the concrete slump (Table 4).

BFS as a pozzolanic material was obtained from the Science and Technology Park of Hamadan and transferred to the sample production site. The technical specifications of this material are presented in Table 1.

Table 3. Properties of Gilsonite

Experiment	Result
Specific gravity at 25 degrees (kg/m^3)	780
Flash point (°C)	316
Color in the huddle mode	Black
Solvency percentage	Less than 70
Softness (^{o}C)	190-210
Degree of penetration at 25 °C	0-1

Table 4. Technical Specifications of Superplasticizer

Superplasticizer characteristic	Specification
Shape	Light brown liquid
Type	Polycarboxylate
Specific weight (kg/lit)	1.03
PH	7

2.2 mixing design

In this research, a total of 120 specimens were made and tested for experiments. The details of the mixing design are given in Table 5. The cement content used is 400 kg/m3. Also, the used water and the volume of concrete were determined to be 0.16 m3 and 4.3 kg/m3, respectively. The Superplasticizer to cement ratio used is 0.0005.

Gilsonite gel is produced by trial and error and by combining gas oil (16% by weight Gilsonite) and Gilsonite. Also, the specific gravity of BFS was 2240 kg/m3. The results (number of additives in mixing design) are presented in Table 6. Each mixing design's cement content would be determined according to Tables 5 and 6 (Table 7). Finally, Table 8 presents the number of materials, including cement, Gilsonite gel, BFS, gravel, sand, and water, for making the specimens.

Table 5. Proportions of concrete pavement

Row	Design Number	Content
1	W1	Base mix
2	BFS20 - G5	20% Blast Furnace Slag + 5% Gilsonite gel
3	BFS25 - G7	25% Blast Furnace Slag + 7% Gilsonite gel
4	BFS30 - G9	30% Blast Furnace Slag + 9% Gilsonite gel
5	BFS20 - G5	20% Blast Furnace Slag + 5% Gilsonite gel
6	BFS25 - G7	25% Blast Furnace Slag + 7% Gilsonite gel
7	BFS30 - G9	30% Blast Furnace Slag + 9% Gilsonite gel
8	BFS20 - G5	20% Blast Furnace Slag + 5% Gilsonite gel
9	BFS25 - G7	25% Blast Furnace Slag + 7% Gilsonite gel
10	BFS30 - G9	30% Blast Furnace Slag + 9% Gilsonite gel

Table 6. Use of additives in mixing design (1 m3)

Percentage of Additive		Cement (kg)	Weight of Gilsonite (kg)	Weight of Gas Oil (kg)
Gilsonite	5	400	20	3.2
	7	400	28	4.48
	9	400	36	5.76
	20	400	80	-
	25	400	100	-
Blast furnace slag	30	400	120	-

Table 7. Content of cement

Row	Design Number	Content of cement
1	W1	400
2	BFS20 - G5	300
3	BFS25 - G7	272
4	BFS30 - G9	244

Table 8. Different mixing designs to make 1 m^3 of concrete

mix	Cement	Gilsonite	BFS	Gravel	Sand	Water
1	400	0	0	696	1044	160
2	300	20	80	696	1044	160
3	292	28	80	696	1044	160
4	284	36	80	696	1044	160
5	280	20	100	696	1044	160
6	272	28	100	696	1044	160
7	264	36	100	696	1044	160
8	260	20	120	696	1044	160
9	252	28	120	696	1044	160
10	244	36	120	696	1044	160

2.3 Casting Procedure

In this research, BFS and Gilsonite were used to make concrete specimens. The specimens were made following the ASTM C1557 standard (ASTM D1557, 2002). Table 9 and Fig. 2 show the standards and performed tests.

Fig. 2. Preparation of specimens: a. Mixing specimens; b. Concreting the specimens; c. curing of specimens

Table 9. The experiments performed in this study

Tests	Standards	Type of Molds	Dimensions of Molds	Number of Specimens	Curing Period (25°C)
Gradation test	ASTM C-136	-	-	-	-
Compressive strength test	ASTM C 39	Cubic	15×15×15	30	28 days
Tensile splitting strength test	ASTM C-496-96	Cylindrical	30×15	30	28 days
Flexural strength test	ASTM C-293	Prismatic	10×10×50	30	28 days
Slump test	ASTM C-143	-	-	-	-
abrasion test	EN 1338	Cubic	10×10×15	20	28 days

3. Test Method

3.1 Slump Test

In this research, the slump test is performed to determine the consistency of the fresh concrete or workability, which is based on ASTM C-143 (ASTM C43, 1997). The slump test is a criterion to determine the water to cement ratio. The word efficiency refers to the ease of casting, compressibility, and segregation resistance (Nehrani et al, 2021).

3.2 Mechanical Properties

Compressive strength (cube 150 mm ×150 mm ×150 mm), flexural strength (cube 10 mm × 10 mm × 50 mm), and tensile splitting strength (cylinder 150 mm × 300 mm) were performed at the age of 28 days. For more details, please see table 10.

Fig. 3. Devices used in research: a. Compressive strength device; b. Tensile splitting strength; c. Flexural Strength device; d. Abrasion Testing device

3.2.1 Abrasion Test

One of the critical factors affecting pavement performance is the damage caused by abrasion (Rezaei Lori et al, 2019). In this study, the wide wheel abrasion test was used to calculate pavement concrete's abrasion resistance following the BS EN 1338 (2003). The abrasion of concrete in this test occurs through the interaction between the concrete specimen and the steel wheel. During the test, abrasives are required. For this purpose, alumina powder with a particle size of 80 microns was used. The effect of 100, 200, 300, 400, and 500 revolutions on the abrasion resistance of concrete were evaluated by Adewuyi et al. According to the results, the abrasion depth in 100 and 200 revolutions was relatively similar, and by increasing the number of revolutions to 300 to 500, the results were relatively similar; hence, in this research, the abrasion test was conducted at two different levels, including 100 and 300 revolutions on the samples (Adewuyi et al, 2017). After 100 and 300 revolution wheels, the average groove in the wheel path was reported for each of them. Fig. 3 shows the test apparatus for testing specimens.

According to methods and tradition related to the usage of concrete pavement in the UK, the blocks are classified into different classes. Hence, it is suggested to use Class 4 in areas with very heavy pedestrian and vehicular traffic. Class 3 is recommended for areas with normal pedestrians and cars. Class 1 should be used in areas subject to light vehicles and pedestrians (driveway, garden). Table 10 shows the requirements for each class.

Table 10. Abrasion resistance class

Class	Requirement
1	No performance measured
3	⩽23 mm
4	⩽20 mm

4. RESULTS AND DISCUSSION

4.1 Slump test

Concrete workability was determined by slump test before performing compressive, flexural, and tensile splitting strength and abrasion tests. As can be seen in Table 11, the slump for concrete specimens decreases. Also, the reason for decreased slump can be the water absorption capability of the Blast furnace slag (Nehrani et al, 2021). Due to the spherical surface of the BFS, the friction between the fine grains and the cement has decreased (Laskar et al, 2008). The presence of Gilsonite in concrete also justifies this. Due to the presence of bitumen around grains, Gilsonite reduces the fastening of the aggregates.

Before performing the mechanical tests, the specific gravity for the tensile and compressive specimens was compared (Fig. 4). The results of the specific gravity of the compressive and tensile specimens showed that using both additives leads to similar results. This means that the compaction of the concrete is done uniformly.

Table 11. Slump Test Results

Type of Mixture	Slump (cm)
W1	8
BFS20 - G5	6
BFS20 - G7	8
BFS20 - G9	7
BFS25 - G5	6
BFS25 - G7	8
BFS25 - G9	7
BFS30 - G5	6
BFS30 - G7	8
BFS30 - G9	6

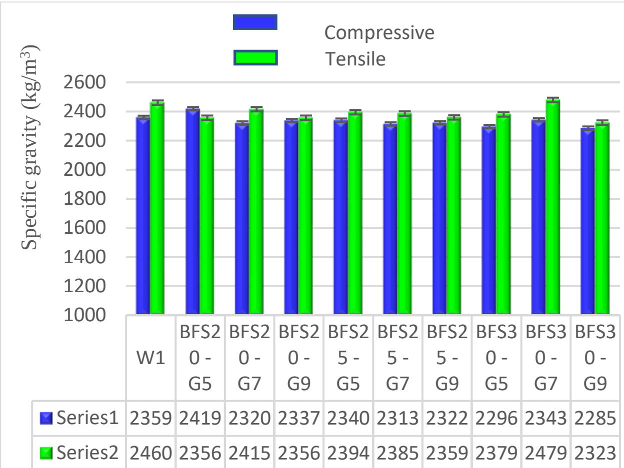


Fig. 4. Results of specific gravity for compressive and tensile specimens

4.2 Compressive Strength

The results of the compressive strength of the cubic specimens are presented in Fig. 5. According to the results, BFS and Gilsonite's simultaneous use reduced the compressive strength. However, the BFS20-G7 satisfied the proposed minimum compressive strength. By increasing the percentages of BFS, the compressive strength of specimens decreases. The reduction of compressive strength using BFS additive has been reported in other studies (Zhao et al, 2015). In addition to hydration reactions (Zhao et al, 2015), the spherical surface of the BFS and lack of friction between the materials have resulted in decreased resistance (Laskar et al, 2008).

Moreover, another reason for the decrease in compressive strength is Gilsonite. The presence of Gilsonite between aggregates reduces the adhesion of the aggregates. As shown in Fig. 5, specimens containing 7% Gilsonite had a slightly increased compressive strength (BFS20-G7, BFS25-G7, and BFS30-G7). This slight increase in strength may be due to the presence of SiO2 and the secondary chemical reaction. However, by increasing the share of Gilsonite in the mixture and increasing the presence of materials containing bitumen membranes, the mixture's strength decreased again. The BFS30-G9 had the worst performance by about a 44% decrease in compressive strength. However, the BFS20-G7 was the best mixture by about a 13% reduction in compressive strength. The comparison between the compressive strength and the specific gravity of the mixes is presented in Fig. 6. As shown in Figure 6, the reduction in specific gravity and compressive strength was somewhat similar.

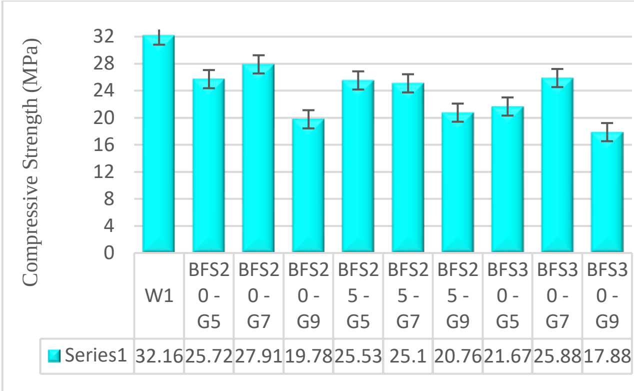


Fig 5. Result of compressive strength (cured for 28 days)

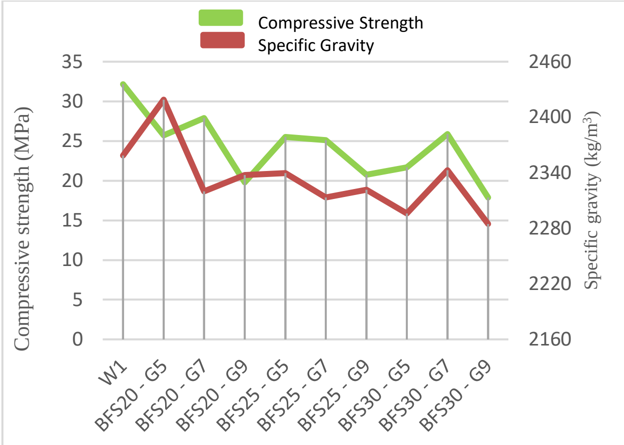


Fig.6. Comparing the results of compressive strength and specific gravity

4.3 Analysis of the flow results of Marshall

In this study, a total of 30 specimens were manufactured and tested for tensile splitting strength test treatment with different percentages of Gilsonite and BFS. For this goal, the famous equation $T=2P/\pi LD$ was used. In this equation, T is the tensile splitting strength in kPa, P is the applied load in the laboratory (KN), L is the specimen length (m), and D is the specimen diameter (m). The results showed that the two additives' simultaneous effect reduced the mixtures' tensile splitting strength (except for the BFS20-G7 mixture). The decrease in tensile strength may be related to the presence of BFS in the mixture. It seems that the reduction in tensile splitting strength is due to the presence of the BFS in the mixture. However, BFS20-G7 has led to additional improvement of the tensile splitting strength by about 7%. The reason for this slight increase could be related to chemical reactions. The high concentration of SiO2 densifies the Interfacial Transition Zone (ITZ), concrete' microstructure, and formations of extra Calcium Silicate Hydrate (C-S-H) gels (Nehrani et al, 2021). This will lead to improved tensile splitting strength. The results are presented in Fig. 7.

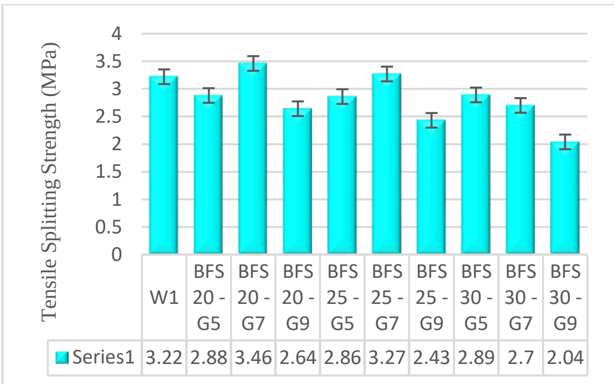


Fig 7. Result of tensile splitting strength

4.4 Flexural Strength

The results of the flexural strength of the cubic specimens are shown in Fig. 8. These results are similar to the tensile splitting strength. As shown in Figure 9, BFS20-G7 has led to increased flexural strength by about 4%. The decrease in flexural strength may be related to the presence of BFS in the mixture (Chen et al, 2019). However, the presence of Gilsonite in the mixture partially improved the flexural strength (BFS20-G7). The slight increase in flexural strength is due to the chemical reaction of Gilsonite, which contains an amount of CaO and SiO2. The force-displacement changes over time for one of the specimens are presented in Fig. 9.

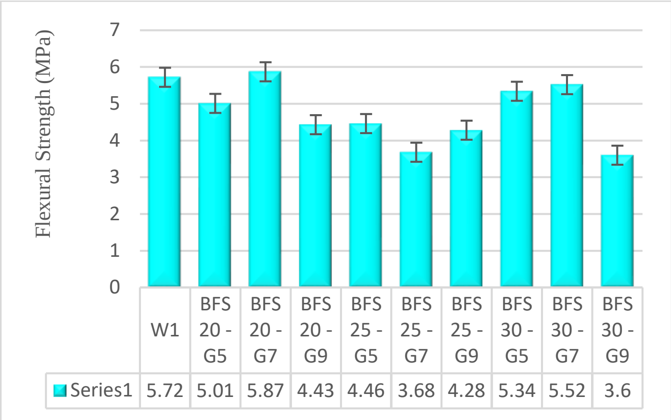


Fig 8. Result of flexural strength

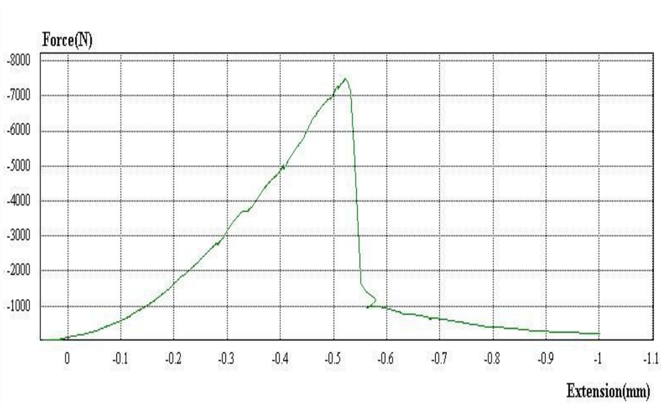


Fig. 9. Force–Extension curve obtained for concrete mixture

4.5 Wide Wheel Abrasion Test

4.5.1 Wide Wheel Abrasion Test results at 100 revolutions

Abrasion resistance is the most important indicator to determine the service life of the pavement (Zaetang et al, 2016). Based on the abrasion mechanism used in abrasion machines, the amount of abrasion is directly affected by the intensity and frequency of the effect between the surface and wheel. For a particular type of pavement, the textures that cause the higher frequency and/or impact intensity are subject to higher abrasion (Jalal-Kamali et al, 2019).

Specimen abrasion value is obtained by measuring the rectangular groove's length formed on the concrete surface (Fig. 10). The results of the abrasion resistance test with levels of 100 revolutions are presented in Table 12. As shown in Table 12, using BFS and Gilsonite (excluding BFS25-G7) can improve the abrasion resistance. The BFS20-G5 and BFS20-G7 samples with 13% and 5% reduction in abrasion resulted in better outcomes.

Rezaei Lori et al. demonstrated that there is a linear relationship between the groove length and the number of cycles (Rezaei Lori et al, 2019). After calculations (for 75 revolutions), it was concluded that the BFS10-G5 and BFS30-G7 mixes meet the requirements of the EN 1338 presented in Table 9 (for classes 3); hence, Class 3 can be used in moderate pedestrian and vehicular areas. Other mixtures did not meet the BSEN 1338 requirements presented in Table 9 (for classes 3 and 4). Hence, Class 1 can be used in light pedestrian and vehicular areas for other mixtures. This classification was also reported in a study performed by EN 1338 standard. Again, when comparing the results of the base mixture and BFS20-G7, it was found that using additives in the mixture enhanced the abrasion resistance of concrete pavement.

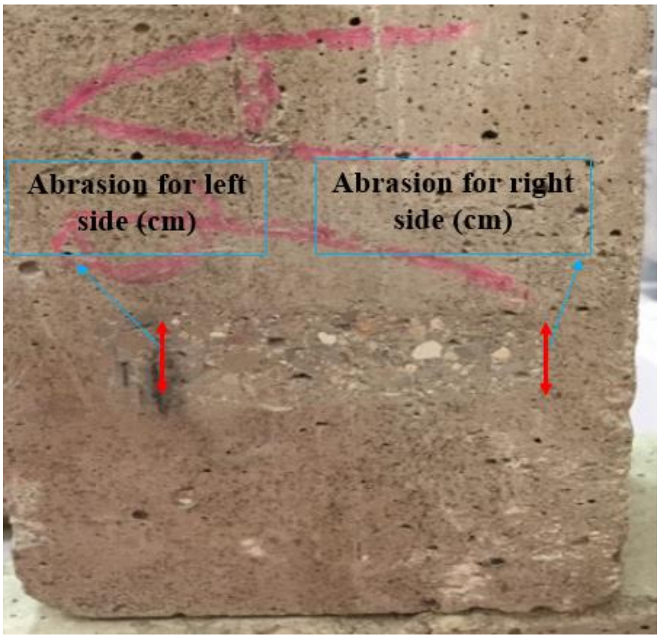


Fig. 10. Concrete specimen after Wide Wheel Abrasion Test

Table. 12 Result of Wide Wheel Abrasion Test for 100 revolutions

Mixes	Abrasion for left side (cm)		Abrasion for right side (cm)		Average abrasion on both sides (cm)
	The first specimen	The first specimen	The first specimen	The first specimen	
1	2.50	3.00	2.50	3.00	2.75
2	2.50	2.40	2.30	2.40	2.40
3	2.70	2.70	2.50	2.50	2.60
4	2.50	2.40	2.50	2.60	2.50
5	2.80	2.60	2.60	2.80	2.70
6	3.00	2.90	3.00	3.10	3.00
7	2.50	2.60	2.60	2.80	2.63
8	2.20	2.40	2.40	2.40	2.35
9	2.50	2.60	2.70	2.60	2.60
10	2.30	2.40	2.60	2.50	2.45

4.5.2 Wide Wheel Abrasion Test results at 300

The results of the Wide Wheel Abrasion Test on the specimen surface are presented in Table 13. It was observed that the BFS30-G7 had the best performance by about a 4% increase in the abrasion. The comparison between the results is presented in Fig. 11. Overall, the abrasion test's resistance development trend was a bell-shaped curve with the increment of Gilsonite addition from 0% to 9%.

Although it has been reported that abrasion resistance is dependent on the type of materials (Öz, 2018), there are reports that the quality of the binder and aggregates-paste have an impact on the abrasion resistance (Tataranni, 2019). Therefore, it seems that BFS and Gilsonite's simultaneous effect increases abrasion (BFS30-G7). However, The BFS20-G5 and BFS20-G7 samples with 11% and 17% reduction in abrasion resulted in better outcomes.

Table. 13 Result of Wide Wheel Abrasion Test for 300 revolutions

Mixes	Abrasion for left side (cm)		Abrasion for right side (cm)		Average abrasion on both sides (cm)
	The first specimen	The first specimen	The first specimen	The first specimen	
1	3.50	3.50	3.80	3.40	3.55
2	3	3.1	3.2	3.3	3.15
3	3.00	3	2.90	2.9	2.95
4	3.20	3.40	3.40	3.30	3.325
5	3.10	3.00	3.40	3.50	3.25
6	3.20	3.30	3.30	3.30	3.275
7	3.20	3.40	3.10	3.30	3.25
8	3.20	3.20	2.80	3.30	3.125
9	3.70	3.50	3.80	3.70	3.675
10	3.60	3.50	3.40	3.50	3.5

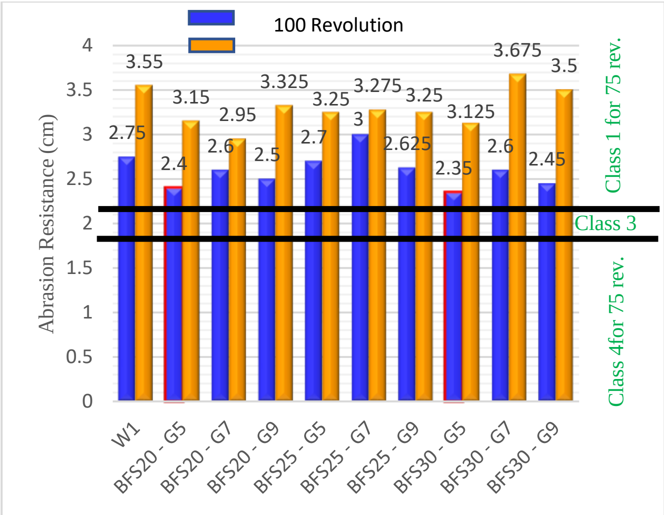


Fig. 11. Comparing of Wide Wheel Abrasion Test results at 100 and 300 revolutions

5. Conclusions

Using additives to improve the performance of concrete pavement has been extensively studied; however, using environmentally friendly additives, in addition to improving the technical properties, can also be environmentally justified. The present study evaluates the effect of BFS and Gilsonite on the properties of concrete mixtures. For this purpose, a total of ten different mixtures were made by replacing cement with BFS and Gilsonite. Considering that engineers welcome the use of concrete pavement modified with additives; therefore, in this study, a superior type of mixture was proposed according to the type of area and based on the abrasion resistance criterion. The results showed that using BFS and Gilsonite in the mixture protects natural resources and decreases environmental problems; therefore, this result can be recommended for cleaner production. Also, it was concluded that using BFS and Gilsonite did not affect the specific gravity. The reason may be related to the specific gravity of the additives. It seems that the correlation between specific gravity and compressive strength is quite noticeable. Although using BFS and Gilsonite in the concrete mixture reduced the compressive strength; however, the BFS20-G7 mixture satisfied the minimum recommended value. Moreover, the tensile splitting and flexural strength of the BFS20-G7 mixture increased. Therefore, the BFS20-G7 can be recommended as a mixture that has higher flexural and tensile splitting strength. Also, using BFS and Gilsonite had a positive effect on the abrasion resistance of concrete mixtures. All mixtures had higher abrasion resistance for samples with 100 and 300 rpm. As a result, the BFS20-G7 samples with a 17% reduction in abrasion resulted in better results, and its use in low traffic areas such as Park and driveway was recommended.

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