Using The Taguchi Technique To Examine Concrete Durability By Applying Forta, Polyester, And Micro Silica Fibers In Freeze-Thaw Cycles

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ABSTRACT
The goal of this study was to examine the durability of concrete using Forta, polyester, and micro-silica fibers against freeze-thaw cycles by employing the Taguchi technique. To this end, the experimental Taguchi technique was employed to achieve an optimum mix design with certain percentages of fibers and micro-silica, as following a 28-day age, [concrete] cubic specimens were subjected to 50 freezing and thawing cycles. These specimens were then compared to conventionally cured concrete at ambient temperature. As indicated by the National Mix Design, compressive strength experiments were conducted in line with the ISIRI 3206 Regulation, and the Brazilian Tensile Strength experiment followed the ASTM C496. For each experiment, 6 concrete specimens with fibers and admixtures and 6 more without fibers and admixtures were fabricated and then compared. As revealed by the findings, to test compressive strength in the C25 Mode, the simultaneous use of both Forta (Forta= 1.5) and polyester (Polyester= 3) fibers at the highest level, i.e., in Specimen No. 4, exhibited a significant increase in compressive strength. Also, to test tensile strength in the C25 Mode, the simultaneous use of both Forta (Forta= 1.5) and polyester (Polyester= 3) fibers at the highest level, i.e., in Specimen No. 4, exhibited a good increase in tensile strength.

Keywords: concrete durability, Forta, polyester, micro silica, fibers, freeze-thaw cycles.

INTRODUCTION

Specific techniques and primary technical requirements are provided to create concrete that resists freezing and thawing cycles. This type of concrete makes use of air-entraining admixtures that enhance it against damage caused by freezing and thawing cycles. Freezing-thawing-resistant concrete can be applied anywhere exposed to open air and a freezing climate. This study aimed to apply polyester and micro-silica fibers to examine the extent to which concrete may endure freezing and thawing cycles [1]. Fibrous concrete is conventionally cementitious concrete reinforced with discrete fibers. In fibrous concrete, there are thousands of smaller fibers that are randomly dispersed in a mix design and are then mixed with other materials. This will thus lead to an improvement in concrete properties in all directions. Fibers also help the ductility, tensile strength, and fatigue strength of concrete while strengthening it against impacts and controlling shrinkage cracks [2].

Ultra-high performance concrete features key compressive strength properties of over 150 MPa, ultra-strong fibers to achieve a ductile behavior, a greater cement content, and a special type of aggregates like quartz and hard basalt. In ultra-high-performance concrete, uniformity and density increase as coarse grains are eliminated and granular behavior is optimized. Here, matrix properties are improved using pozzolanic admixtures as the water-to-cement content ratio is less than 0.25. Meanwhile, fine metal fibers help enhance the tensile strength and ductility of this type of concrete. The fibers used in ultra-high-performance concrete are commonly shorter, softer, and straighter, whereas hooked fibers are typically used in high-performance and conventional concrete. To make ultra-high-performance concrete, fibers with 0.1 to 0.2 mm in diameter and 3 to 20 mm in length are applied. The modulus of elasticity of steel fibers features around 200 GPa, tensile strength of 1000 and 3000 MPa, while their deformations at rupture stand at 3 to 4%. Ultra-high-performance concrete typically applies 2% v/v fibers. In the meantime, the flexural behavior of ultra-high-performance concrete is enhanced by improving granular density and admixing fibers to it, which will bind together the cement paste on both sides of the cracks- a phenomenon called the bridging effect. High-performance concrete lacks fibers and involves coarser granulation than ultra-high-performance concrete [3]. Due to its greater specific

surface, micro silica works much more like a core, forming a highly strong binding effect with cement. Micro silica interacts with calcium hydroxide and prevents the excessive growth of calcium hydroxide crystals, filling out like pozzolans fine cracks and capillary pores, ultimately causing the cement structure to densify, permeability to decrease, strength to increase, and the useful lifespan and durability of the concrete structure to increase [4].
Polyesters have been widely used in resin systems in recent years, providing extraordinary mechanical properties against corrosion and resistance to water. Polymerized polyester resins have made polyester an attractive material in civil engineering areas. Inorganic fillers such as cement, sand and gravel, silica fume, fly ash, and granulated blast furnace slags are admixed to polyester resins to enhance some of the physical and mechanical properties of concrete composites. Many researchers have also examined the properties of polyester-reinforced concrete, such as thermal stability, modulus of elasticity, ultrasonic pulse velocity, compressive and bending strength, thermal expansion, chemical strength, abrasive strength, thermal conductivity, tensile strength, durability, and morphology. Much research has focused on one or two properties of polyester-reinforced concrete composites (POREC), i.e., their mechanical, thermal, and water strength [5-17].
As stated, to enhance the compressive and tensile strength of concrete against freezing and thawing cycles, this study embarked on the concurrent application of two types of fibers and an admixture, as well as a superplasticizer to provide an optimum mix design using the experimental Taguchi Technique.

Materials and Procedure

The procedure adopted by the study was a laboratory experiment. First, the materials required for making the concrete were provided and then weighed. The concrete mix design was then written. Aggregates were initially poured into the mixer. After a minute, Forta and polyester fibers were added and mixed for four minutes. Cement and micro silica were then added to the mixture, which took a minute. The water required was then added to the mixture. After the concrete mixture was prepared, cubic molds were greased with oil and had concrete cast in them. Then, by striking the molds with a metal rod, they got compacted. After the molds were filled with the concrete mixture and after 24 hours, the molds had their concrete removed. Next, the concrete specimens were placed in a curing pond for 28 days. After the 28 days, the specimens were taken out of the pond and exposed to the open air to dry.
This study applied Forta-type steel fibers (Fig. 1). These fibers are entangled multifilament fibers. These fibers enhance the concrete against freeze-thawtag, prevent cracking and fatigue, and increase its compressive, bending, and shear strengths.

Figure 1: Forta fibers

Adding a large amount of water could decrease concrete strength. To avoid this, a plasticizer can be used. This study applied the ALEN-PCE 200 plasticizer, which helped reduce water to make the concrete. As stated above, polyesters have been widely used in resin systems in recent years, providing extraordinary mechanical properties against corrosion and resistance to water. Polymerized polyester resins have made polyester an attractive material in civil engineering areas.
This study also used cement Type 325-1 for the concrete mix design, and the aggregates used were made of the crushed mountain type. The largest dimension of the aggregates featured 12.7 mm, while the maximum specific gravity of the fine- and coarse-grained aggregates were 2.544 and 2.571 mm, respectively.
The Iranian National Concrete Standard was used to determine the mix design. Since the concrete used in the study was a typical one, the Iranian national concrete standard was used. The mix design specifications are listed in Table 1. Table 2 also gives the amounts of the fibers and admixtures.

Table 1: Concrete mix design (C25)

Water (Kg/m^3)	175
Cement (Kg/m^3)	291.66
Coarse grain (Kg/m^3)	809.48
Fine grain (Kg/m^3)	809.48

Table 2: Amounts of fiber and admixture used

Forta fibers (Concrete volume percentage)	0.5-1-1.5
Polyester fibers (Kg of concrete volume)	3-2-1
Micro silica (Cement weight percent (wt%))	15-10-5
Superplasticizer (Cement weight percent)	0.8

Compressive Strength Experiment

The ISIRI 3206 Standard was used to perform the compressive strength experiment, as a compression jack apparatus was used for cubic concrete specimens. This experiment can be carried out on cylindrical and cubic specimens. The ISIRI 3206 Standard was formulated by the Iranian Institute of Industrial Research and Standards in 1970. This experiment was conducted at the laboratory of the Islamic Azad University of Sanandaj, Iran, where a Digimax Plus apparatus was employed. The procedure was as follows: initially, the concrete specimens were taken out of water and placed in a compression jack apparatus, which was switched on to apply the required force to the concrete specimens. Finally, after the concrete specimens were broken down, the apparatus provided us with values of force and compressive strength.

Brazilian Tensile Strength Experiment

The ASTM C496 Standard proposed using cylindrical concrete specimens to carry out tensile strength, which can be performed using a compression jack. The procedure is as follows: The specimens were removed from the pond and then weighed. The specimens were then placed inside a special tensile experiment mold, which was put inside the compression jack apparatus. After the required force was applied, the broken concrete specimen had its tensile strength calculated as follows:

$T=2P/\Pi LD$

Where:

T= The concrete’s tensile strength (MPa)

P= Maximum load applied represented by the testing device (N)

D= The specimens’ diameter (mm)

L= The specimens’ length (mm)

The experiment was carried out as follows: First, stone materials and Forta and polyester fibers of certain amounts were added to the mixer. Water and the superplasticizer were added to the mixture after 5 minutes. Cement and micro-silica were also added after a minute. After another 1 minute, the concrete mixture was poured into three layers, each layer was hit 25 times to remove the bubbles inside the concrete. Ultimately, the concrete specimens were prepared. The number of concrete specimens in all the experiments under the C25 Mode was 6 for each row of the materials used. Table 3 below gives the bending strength of the specimens under study.

Table 3: Number of specimens

Bending Strength (C25)	Polyester	Forta	Micro-silica
Six specimens	0	0	0
Six specimens	1	0.5	0
Six specimens	2	1	0
Six specimens	3	1.5	0
Six specimens	1	0	0.05
Six specimens	0	0.5	0.05

Six specimens	3	1	0.05
Six specimens	2	1.5	0.05
Six specimens	2	0	0.1
Six specimens	3	0.5	0.1
Six specimens	0	1	0.1
Six specimens	1	1.5	0.1
Six specimens	3	0	0.15
Six specimens	2	0.5	0.15
Six specimens	1	1	0.15
Six specimens	0	1.5	0.15

Brazilian Tensile Strength (C25)	**Polyester**	**Forta**	**Micro-silica**
Six specimens	0	0	0
Six specimens	1	0.5	0
Six specimens	2	1	0
Six specimens	3	1.5	0
Six specimens	1	0	0.05
Six specimens	0	0.5	0.05
Six specimens	3	1	0.05
Six specimens	2	1.5	0.05
Six specimens	2	0	0.1
Six specimens	3	0.5	0.1
Six specimens	0	1	0.1
Six specimens	1	1.5	0.1
Six specimens	3	0	0.15
Six specimens	2	0.5	0.15
Six specimens	1	1	0.15
Six specimens	0	1.5	0.15

Compressive Strength (C25)	**Polyester**	**Forta**	**Micro-silica**
Six specimens	0	0	0
Six specimens	1	0.5	0
Six specimens	2	1	0
Six specimens	3	1.5	0
Six specimens	1	0	0.05
Six specimens	0	0.5	0.05
Six specimens	3	1	0.05
Six specimens	2	1.5	0.05
Six specimens	2	0	0.1
Six specimens	3	0.5	0.1
Six specimens	0	1	0.1
Six specimens	1	1.5	0.1
Six specimens	3	0	0.15
Six specimens	2	0.5	0.15
Six specimens	1	1	0.15
Six specimens	0	1.5	0.15

Electrical Specific Resistivity (C25)	**Polyester**	**Forta**	**Micro-silica**
Six specimens	0	0	0
Six specimens	1	0.5	0
Six specimens	2	1	0
Six specimens	3	1.5	0
Six specimens	1	0	0.05

Six specimens	0	0.5	0.05
Six specimens	3	1	0.05
Six specimens	2	1.5	0.05
Six specimens	2	0	0.1
Six specimens	3	0.5	0.1
Six specimens	0	1	0.1
Six specimens	1	1.5	0.1
Six specimens	3	0	0.15
Six specimens	2	0.5	0.15
Six specimens	1	1	0.15
Six specimens	0	1.5	0.15

These tables were designed using the Taguchi technique. The experimental design procedure aimed to find the optimal state of using materials, and the best outcome was also achieved.

Findings

Compressive Strength Experiment Results

The chief goal of the study was to improve the compressive strength andte tensile strength, of the concrete using Forta, polyester, and micro-silica fibers. The results are given in the following tables and plots. Figure 2 demonstrates how cubic specimens are put inside the compression jack apparatus. After the specimens were placed inside the device, loading was started, and the compressive strength of the specimens was provided.

Figure 2: Placing the cubic specimen inside the compression jack apparatus

Table 4: Compressive strength of the concrete specimens

Compressive strength (C25)	Weight (g)	Height (mm)	Width (mm)	Length (mm)	Specimen No.	Curing	Polyester	Forta	Microsilica
294.89 kg/cm^2	7445	150	150	150	1	28-day	0	0	0
337.36 kg/cm^2	8003	150	150	150	2	28-day	1	0.5	0
384.37 kg/cm^2	8182	150	150	150	3	28-day	2	1	0
395.77 kg/cm^2	7719	150	150	150	4	28-day	3	1.5	0
241.09 kg/cm^2	7532	150	150	150	5	28-day	1	0	0.05
276.62 kg/cm^2	7645	150	150	150	6	28-day	0	0.5	0.05
388.51 kg/cm^2	7881	150	150	150	7	28-day	3	1	0.05
391.43	7853	150	15	150	8	28-	2	1.5	0.0

kg/cm^2			0			day			5
256.05 kg/cm^2	7171	150	150	150	9	28-day	2	0	0.1
284.55 kg/cm^2	7642	150	150	150	10	28-day	3	0.5	0.1
336.51 kg/cm^2	7873	150	150	150	11	28-day	0	1	0.1
385.22 kg/cm^2	7862	150	150	150	12	28-day	1	1.5	0.1
278.3 kg/cm^2	7207	150	150	150	13	28-day	3	0	0.15
282.43 kg/cm^2	7764	150	150	150	14	28-day	2	0.5	0.15
363.68 kg/cm^2	8123	150	150	150	15	28-day	1	1	0.15
340.06 kg/cm^2	7985	150	150	150	16	28-day	0	1.5	0.15

Table 5: Analyzing C25 Compressive strength values

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
	Micro Silica	**Forta**	**Polyester**	**Compressive strength C25**	**SNRA1**	**STDE1**	**MEAN1**
1	0.00	0.0	0	294.89	49.3932	*	294.89
2	0.00	0.5	1	337.36	50.5619	*	337.36
3	0.00	1.0	2	384.37	51.6950	*	384.37
4	0.00	1.5	3	395.77	51.9489	*	395.77
5	0.05	0.0	1	241.09	47.6436	*	241.09
6	0.05	0.5	0	276.62	48.8377	*	276.62
7	0.05	1.0	3	388.51	51.7880	*	388.51
8	0.05	1.5	2	391.43	51.8531	*	391.43
9	0.10	0.0	2	256.05	48.1665	*	256.05
10	0.10	0.5	3	284.55	49.0832	*	284.55
11	0.10	1.0	0	336.51	50.5400	*	336.51
12	0.10	1.5	1	385.22	51.7142	*	385.22
13	0.15	0.0	3	278.3	48.8903	*	278.3
14	0.15	0.5	2	282.43	49.0182	*	282.43
15	0.15	1.0	1	363.68	51.2144	*	363.68
16	0.15	1.5	0	340.06	50.6311	*	340.06

Table 6: Signal-to-noise response ratio (C25 Compressive Strength) (Response table for signal to

noise ratios)

Level	Micro silica	Forta	Polyester	The larger is better
1	50.90	48.52	49.85	
2	50.03	49.38	50.28	
3	49.88	51.31	50.18	
4	49.94	51.54	50.43	
Delta	1.02	3.01	0.58	
Rank	2	1	3	

Table 7: Factor response (C25 compressive strength) (Response Table for Means)

Level	Micro silica	Forta	Polyester
1	353.1	267.6	312.0
2	324.4	295.2	331.8
3	315.6	368.3	328.6
4	316.1	378.1	336.8
Delta	37.5	110.5	24.8
Rank	2	1	3

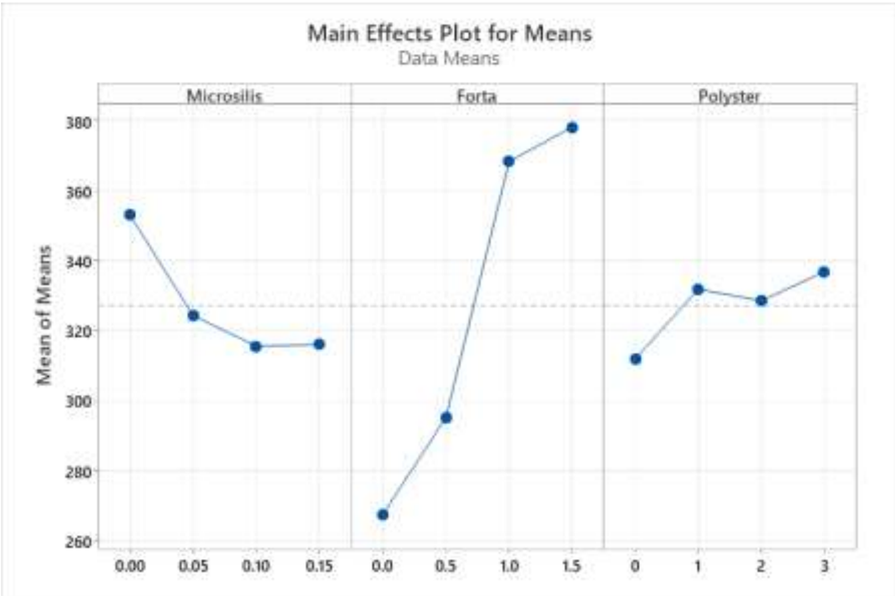

Figure 3: Main effects plot (C25 compressive strength)

The specimens were ruptured and broken down after the conduct of the compressive strength experiment. Figure 4 exhibits the broken specimens after the experiment.

Figure 4: Breaking of the cubic specimens after the compressive strength experiment is conducted

As noted, when laboratory results were entered into the Minitab software and the experimental Taguchi technique was used, optimal material values were provided. As exhibited by Figure 3 (C25 compressive strength), compressive strength changes using Forta, polyester, and micro silica fibers are noted. This plot features the levels on the longitudinal axis, and the latitudinal axis shows the SN, the fiber amounts, and the materials used. The more the SN amounts, the closer the target will be. This plot also exhibits that the less the micro silica amount or the lower its levels, the better it will be. As well, the amount of using micro silica at 2 or 0.05 could be better than 0.1 and 0.15, yielding a better response. Concerning Forta fibers, the greater the amount of Forta fibers or the higher their levels, i.e., at 1.5, the better they will be, thereby enhancing compressive strength. As for polyester, fiber levels at 4 and 2 (i.e., 1 and 3 kilograms), which are the best amounts to be used, could enhance compressive strength, though these two levels may differ, and the difference can be ignored. The plot also shows that since Forta fibers exhibit many changes, they will be more critical for us. Figure 3 also shows how factor effects have changed under various modes of experiment. In this connection, the enhanced compressive strength of concrete has always been one of the main concerns of construction engineers because the compressive strength of concrete represents the main feature of concrete used.

Brazilian Tensile Strength Experiment Results

The tensile strength of concrete represents a positive strength parameter of concrete. Experiment results are given in tables and plots below. Figure 4 shows the cylindrical specimens under the tensile strength experiment.

Figure 4: Cylindrical specimens tested and broken by the apparatus

Table 8: Brazilian tensile strength results

Tensile strength (C25)	Weight (g)	Height (mm)	Diameter (mm)	Specimen No.	Curing	Polyester	Forta	Micro silica
42.57	12395	300	150	1	28-day	0	0	0
48.71	13535	300	150	2	28-day	1	0.5	0
55.49	13180	300	150	3	28-day	2	1	0
57.14	12465	300	150	4	28-day	3	1.5	0
34.81	11976	300	150	5	28-day	1	0	0.05
39.94	12180	298	150	6	28-day	0	0.5	0.05
56.09	13400	300	150	7	28-day	3	1	0.05
56.51	13378	300	150	8	28-day	2	1.5	0.05

36.97	11830	300	150	9	28-day	2	0	0.1
41.08	12345	300	150	10	28-day	3	0.5	0.1
48.58	12600	299	150	11	28-day	0	1	0.1
55.62	12800	300	150	12	28-day	1	1.5	0.1
40.18	12318	300	150	13	28-day	3	0	0.15
40.78	12360	300	150	14	28-day	2	0.5	0.15
52.51	12765	300	150	15	28-day	1	1	0.15
49.10	12899	300	150	16	28-day	0	1.5	0.15

Table 9: Analyzing C25 tensile strength values

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
	Micro Silica	**Forta**	**Polyester**	**Tensile strength C25**	**SNRA1**	**STDE1**	**MEAN1**
1	0.00	0.0	0	42.57	32.5830	*	42.5744
2	0.00	0.5	1	48.71	33.7516	*	48.7059
3	0.00	1.0	2	55.49	34.8847	*	55.4929
4	0.00	1.5	3	57.14	35.1386	*	57.1388
5	0.05	0.0	1	34.81	30.8333	*	34.8070
6	0.05	0.5	0	39.94	32.0274	*	39.9366
7	0.05	1.0	3	56.09	34.9778	*	56.0906
8	0.05	1.5	2	56.51	35.0428	*	56.5122
9	0.10	0.0	2	36.97	31.3563	*	36.9669
10	0.10	0.5	3	41.08	32.2729	*	41.0815
11	0.10	1.0	0	48.58	33.7297	*	48.5832
12	0.10	1.5	1	55.62	34.9039	*	55.6156
13	0.15	0.0	3	40.18	32.0800	*	40.1792
14	0.15	0.5	2	40.78	32.2080	*	40.7755
15	0.15	1.0	1	52.51	34.4041	*	52.5058
16	0.15	1.5	0	49.10	33.8209	*	49.0957

Table 10: Signal-to-noise response ratio (C25 tensile strength) (Response table for signal to noise ratios)

Level	**Micro silica**	**Forta**	**Polyester**	The larger is better
1	34.09	31.71	33.04	
2	33.22	32.56	33.47	
3	33.07	34.50	33.37	
4	33.13	34.73	33.62	
Delta	1.02	3.01	0.58	
Rank	2	1	3	

Table 11: Factor response (C25 tensile strength) (Response Table for Means)

Level	**Micro silica**	**Forta**	**Polyester**
1	50.98	38.63	45.05
2	46.84	42.62	47.91
3	45.56	53.17	47.44
4	45.64	54.59	48.62
Delta	5.42	15.96	3.58
Rank	2	1	3

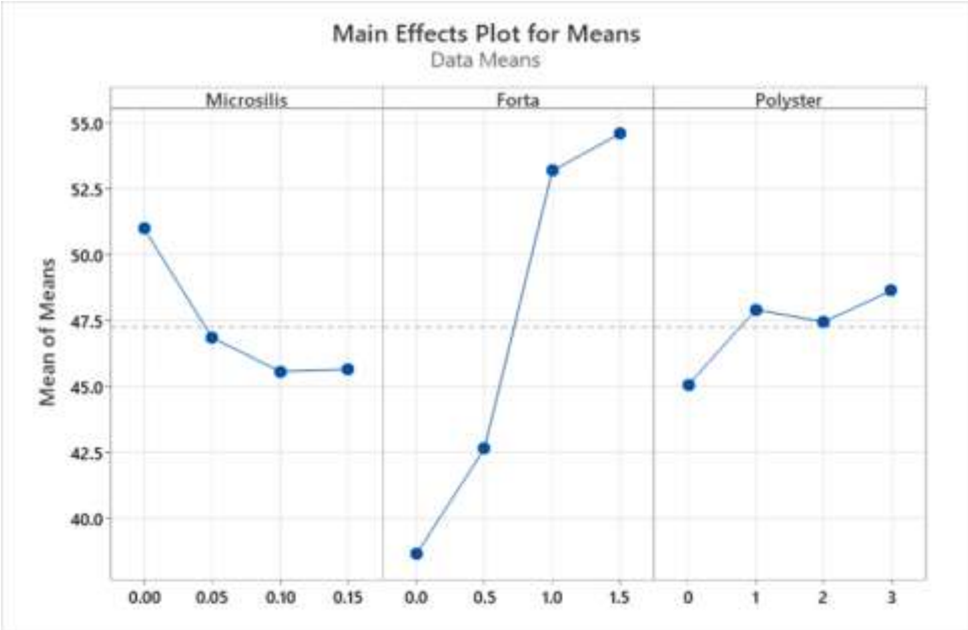

Figure 5: Main effects plot (C25 tensile strength)

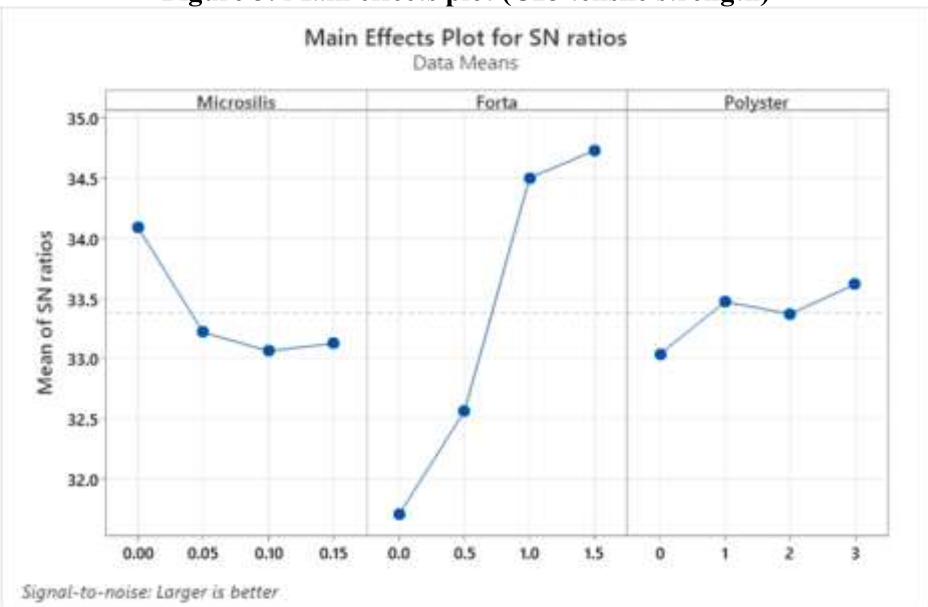

Figure 6: Main effects on the SN plot (C25 tensile strength)

As noted, as laboratory results were entered into the Minitab software and the experimental Taguchi technique was used, the optimal material values were provided. As exhibited by Figure 6 (C25 tensile strength), tensile strength changes using Forta, polyester, and micro silica fibers are noted.

This plot features the amounts on the longitudinal axis, and the latitudinal axis shows the SN, the fiber amounts, and the materials used. The more the SN amounts, the closer the target will be. This plot also exhibits that the less the micro silica amount or the lower its levels, the better it will be, as much difference is noted in level 1 than in other levels. As well, the amount of using micro silica at level 2 could be better than 0.1 and 0.15, yielding a better response. Concerning Forta fibers, the greater the amount of Forta fibers or the higher their levels, i.e., at 1.5, the better it will be, thereby enhancing tensile strength. As for polyester, fiber levels at 4 and 2 (i.e., 1 and 3 kilograms), which are the best amounts to be used, could enhance tensile strength, though these two levels may differ, and the difference can be ignored. The plot also shows that since Forta and the micro silica fibers exhibited many changes, they will be more critical for us. Figure 5 also shows how factor effects have changed under various modes of experiment. In this connection, the enhanced tensile strength of concrete has always been one of the main strength parameters.

Conclusion

Findings showed that concerning the C25 compressive strength experiment, the simultaneous use of both Forta (Forta= 1.5) and polyester (Polyester= 3) fibers at the highest level intended, i.e., Specimen No. 4, under the C25 compressive strength, contributed to a significant rise in compressive strength. Considering saving cement consumption, good compressive strength is reported in the concrete specimens Nos. 8 and 24, with the addition of micro silica. Finally, the presence of Forta fibers helped reduce surface and deep cracks and increase the life and durability of the concrete, thereby increasing its compressive strength. Polyester fibers also improved and reduced cracks on the concrete and increased its compressive strength. The use of micro silica led to an increase in compressive strength by reducing porosity and enhancing the durability of the concrete.

Findings showed that concerning the C25 tensile strength experiment, the simultaneous use of both Forta (Forta= 1.5) and polyester (Polyester= 3) fibers at the highest level intended, i.e., Specimen No. 4, under the C25 tensile strength, contributed to an acceptable rise in tensile strength. Considering saving cement consumption, good tensile strength is reported in the concrete specimens Nos. 8 and 24, with the addition of micro silica. Finally, the presence of Forta fibers helped reduce surface and deep cracks and increase the life and durability of the concrete, thereby increasing its tensile strength. Polyester fibers also improved and reduced cracks on the concrete and increased its tensile strength. The use of micro silica led to an increase in tensile strength by reducing porosity and enhancing the durability of the concrete.

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