

Article

Research on the Performance of Steel Strand-Reinforced Reactive Powder Concrete with Mixed Steel Fibers and Basalt Fibers under the Salt Dry–Wet Erosion

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Abstract: In this study, the properties of steel strand-reinforced reactive powder concrete (RPC) with mixed steel fibers and basalt fibers were investigated. The volume ratios of steel fibers and basalt fibers ranged from 0% to 2%. The reinforcement ratio of steel strands was 1%. The flexural strength and toughness were measured. Moreover, the impact toughness was determined. The studies were carried out under an erosion environment with chlorides and sulfates. The electrical resistance and the ultrasonic velocity were obtained to assess the salt corrosion resistance performance of steel strand-reinforced RPC. The results show that the addition of basalt fibers and steel fibers can improve the mechanical strength, ultrasonic velocity, flexural toughness, and impact toughness and decrease the performance degradation of the steel strand-reinforced RPC under the conditions of dry–wet alternations of NaCl and Na₂SO₄ solutions. Basalt fibers and steel fibers can improve the steel strand-reinforced RPC's flexural strength by rates of up to 13.1% and 28.7%, respectively. Moreover, the corresponding compressive strength increases by 10.3% and 18.3%. The flexural strength decreases by 11.2%~33.6% and 7.3%~22.7% after exposure to the NaCl and Na₂SO₄ dry–wet alternations. Meanwhile, the corresponding compressive strength decreases by 22.1%~38.9% and 14.6%~41.3%. The electrical resistance increases with the addition of basalt fibers and decreases with the increasing dosages of steel fibers. The steel strand-reinforced RPC with the assembly units of 1% steel fibers and 1% basalt fibers shows the optimal mechanical properties and salt resistance considering its wet–dry alternation performance. The properties of steel strand-reinforced RPC decrease more rapidly after undergoing NaCl erosion than Na₂SO₄ erosion.

Keywords: steel strand; steel fibers; flexural toughness; impact toughness; salt corrosion



Citation: Wang, D.; Xu, Z.; Cao, Z.; Xu, N.; Li, C.; Tian, X.; Wang, H. Research on the Performance of Steel Strand-Reinforced Reactive Powder Concrete with Mixed Steel Fibers and Basalt Fibers under the Salt Dry–Wet Erosion. *Coatings* **2024**, *14*, 833. <https://doi.org/10.3390/coatings14070833>

Academic Editor: Paolo Castaldo

Received: 17 June 2024

Revised: 28 June 2024

Accepted: 2 July 2024

Published: 3 July 2024



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1. Introduction

With the development of science and technology, building structures with large spans and super high-rise structures have become the theme of contemporary civil engineering and architectural structures. Steel strands are often used in bridge construction to enhance the bearing capacity and toughness of bridges [1]. Since the mid-1950s, with the gradual maturation of the production technology of steel strands, the bonding performance between steel strands and concrete has been of high interest among scholars, and considerable research results have been achieved. Hyun et al. [2] compared the bond strength between steel strands and reactive powder concrete (RPC) with that of ordinary concrete and found that the bond strength could be increased by 180% using RPC. RPC can efficiently improve the bonding performance with steel strands and reduce the corresponding anchorage length, which greatly increases the performance of the structure and saves a certain amount of cost [3]. Although several studies on RPC with steel strands have been published, there

have been no reports on the study of steel strand-reinforced RPC with mixed fibers under salt environmental conditions.

Marine structures are usually exposed to salt environments during use. Salts can easily corrode the steel of building structures, leading to a decrease in bearing capacity [4–6]. Therefore, it is necessary to conduct systematic research in this area. Concrete, as a material that cracks easily, is prone to corrosion by ions when applied in salt environments [7,8]. Based on these reasons, researching the effect of salt erosion on the performance of steel strand-reinforced concrete is very necessary.

Usually, fibers are added to concrete to enhance its crack resistance performance. Previous researchers have pointed out that steel fibers, basalt fibers, polypropylene fibers, carbon fibers, etc., are applied to enhance the crack resistance performance [9]. Steel fibers have been proven to increase flexural and compressive strengths by rates of up to 71.2% and 34.1% [10]. The flexural toughness and impact toughness increased by 66.7% and 54.1% [11]. According to these research findings, steel fibers have excellent mechanical properties. However, they are prone to corrosion. The bearing capacity of steel fiber-reinforced concrete markedly decreases after NaCl erosion [12–14]. Basalt fibers, polypropylene fibers, carbon fibers, etc., have high resistance to corrosion [15–17]. Unfortunately, cement concrete with these fibers shows weak mechanical properties. Based on these reasons, the use of mixed steel fibers and basalt fibers in cement concrete can combine the advantages of the two types of fibers. Heretofore, little attention has been paid to the performance of steel strand-reinforced reactive powder concrete with mixed steel fibers and basalt fibers.

The static mechanical properties of materials have been widely explored to determine their conventional mechanical properties [18–20]. The performance of steel strand-reinforced concrete is prone to degradation under dynamic loads and salt erosion during the operation of engineering structures in coastal cities [21–23]. The effect of the dynamic performance of concrete mixed with fiber-reinforced steel strands can provide a reference for the application of such concrete in marine environments. However, little attention has been paid to this aspect.

The compressive strength, flexural strength, and toughness of steel strand-reinforced reactive powder concrete (RPC) with mixed steel fibers and basalt fibers are studied in this paper, and the impact toughness is determined. The volume ratios of steel fibers and basalt fibers are 0%~2%. The steel strands' reinforcement ratio is 1%. The specimens are exposed to the dry–wet alternations of NaCl and Na₂SO₄. The electrical resistance and the ultrasonic velocity of the specimens are measured.

2. Materials and Experimental Methods

2.1. Raw Materials

The granulated blast furnace slag powder (GGBS) was procured from the Lingshou County Qiangdong Mineral Products Processing Factory, Shijiazhuang, China. The density of SF and GGBS were 2.2 g/cm³ and 2.91 g/cm³, respectively, while the specific areas were 14.8 m²/g and 436.2 m²/g. Quartz sands (Qs) with particle sizes range of 0.68 mm~1.21 mm, 0.33 mm~0.61 mm, and 0.14 mm~0.31 mm, provided by the Lingshou Tuolin mineral products processing plant (Shijiazhuang, China), were utilized as aggregates. The density and content of fly ash (FA) were 2.55 g/cm³ and 55%. Ordinary Portland cement (OPC) with a strength grade of 42.5, produced by Jiangsu Baling Conch Cement Co., Ltd., Nanjing, China, was used in the test. The initial setting time and final setting time of OPC were 161 min and 316 min, respectively. The content of SiO₂ in the quartz sands was higher than 98%. A polycarboxylic water-reducing agent, with a water-reducing rate of 40%, was employed to enhance the flowability of the fresh RPC mixture. Tables 1 and 2 exhibit the chemical composition and particle size distribution of the powder materials, respectively. The density, elongation rate, elastic modulus, and tensile strength of short-cut basalt fibers were 2.65 g/cm³, 2.3%~3.0%, 95 GPa~115 GPa, and 3000 MPa~4000 MPa, respectively. Fiber sizes were typically 10 µm~20 µm in diameter or 3 mm~130 mm. The density, length, equivalent diameter, and tensile strength of steel

fiber were 7.85 g/cm³, 6 mm, 0.12 mm, and 2830 MPa, respectively. The nominal diameter, cross-section area, maximum tensile force, yield strength, elastic modulus elongation rate, and weight per meter of steel strand were 15.2 mm, 140 mm², 271 kN, 258 MPa, 195 GPa, 5.5%, and 1100 g/m, respectively.

Table 1. The properties of cement (%).

Types	SiO ₂	Al ₂ O ₃	Fe _x O _y	MgO	CaO	SO ₃	K ₂ O	Na ₂ O	Ti ₂ O	Loss on Ignition
OPC	20.9	5.5	3.9	1.7	62.2	2.7	/	/	/	3.1
GGBS	34.1	14.7	0.2	9.7	35.9	0.2	3.5	/	/	/
QS	99.6	/	0.02	/	/	/	/	/	/	/
FA	55.00	20.00	6.00	10.20	4.50	0.11	1.26	2.13	0.06	0.74

Table 2. Mixture design of RPC per one cubic meter (volume %).

Types	Steel Fiber Volume	Basalt Fiber Volume
A1	0	0
A2	0	0.5
A3	0	1
A4	0	1.5
A5	0	2
A6	0.5	0
A7	0.5	0.5
A8	0.5	1
A9	0.5	1.5
A10	1	0
A11	1	0.5
A12	1	1
A13	1.5	0
A14	1.5	0.5
A15	2	0

2.2. The Manufacturing Methods

Table 2 outlines the mixing ratios of the RPC specimens. Initially, all powder materials were introduced into a UJZ-15 mixer and stirred for 30 s. Subsequently, an identical mixture containing the water-reducing agent and water was incorporated and mixed for 210 s. After mixing, the fresh RPC was poured into the molds. The mass of OPC, FA, GGBS, and QS was maintained at 244.4 kg/m³, 740.7 kg/m³, 185.2 kg/m³, 111.1 kg/m³, 977.9 kg/m³, and 16.3 kg/m³ in each group.

2.3. The Measuring Methods

During the casting of the specimens, compression test blocks (70.7 mm × 70.7 mm × 70.7 mm) and tensile plates (100 mm × 100 mm × 400 mm) were used, and the specimens were subjected to standard curing for 28 days. In each test, six samples were used.

2.3.1. The Measurement of Mechanical Strength

The measuring methods of the mechanical strength were used according to Chinese standard GB/T 50081-2002 [24]. In the compressive strength test, the load was continuously and uniformly loaded at a speed of 0.55 MPa per second until the specimen was damaged, and then the failure load was recorded. In the flexural strength test, the load was continuously and uniformly loaded at a speed of 0.06 MPa per second until the specimen was damaged, and then the failure load was recorded. The compressive strength and flexural strength were calculated using Formulas (1) and (2), respectively. Figure 1 exhibits the measuring process of the mechanical strength. P_c , P_t , A , f_c , and f_t are the compressive failure load, flexural failure load, compressive bearing area, compressive strength, and

flexural strength, respectively, while l represents the span between supports. b and h are the cross-sectional width and height of the specimen, respectively.

$$f_c = \frac{P_c}{A} \quad (1)$$

$$f_t = \frac{P_t l}{bh^2} \quad (2)$$

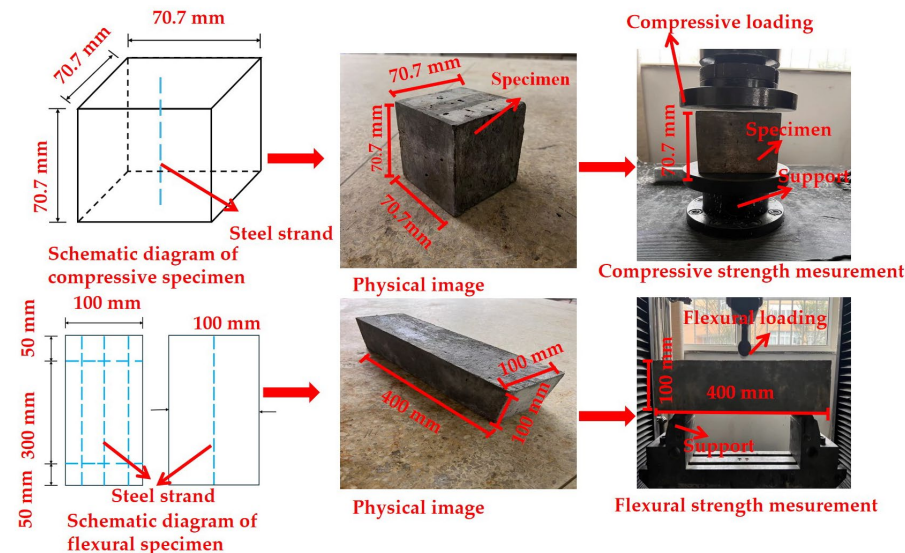


Figure 1. The measurement of steel strand-reinforced RPC's mechanical strength.

2.3.2. Flexural Toughness

The midspan deflection was tested using an SDVH8B pen-type LVDT displacement sensor (Shenzhen Xinwei Technology Development Co., Ltd., Shenzhen, China) at a flexural loading speed of 0.1 mm/min. A notch with dimensions of 100 mm in width and 40 mm in depth was used in the midspan of the beams. The integral of stress, ranging from 0 to the peak value, was determined, and the displacement curve reflects the flexural toughness [25,26]. Figure 2 shows the measurement of steel strand-reinforced RPC's flexural toughness.

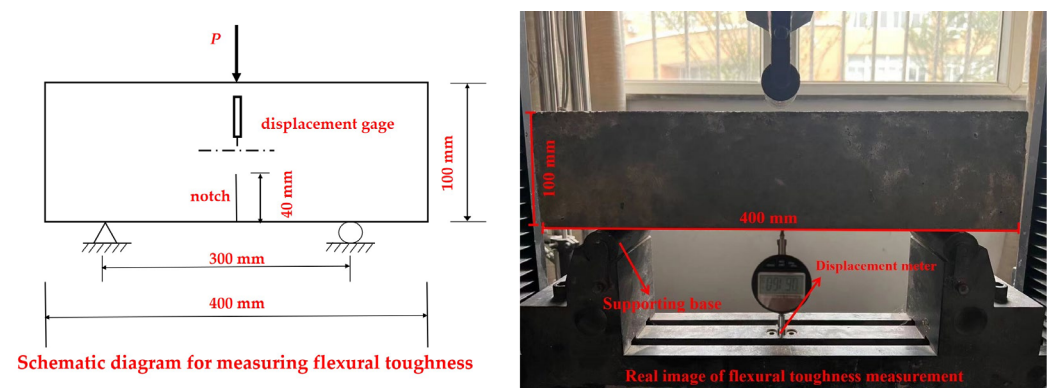


Figure 2. The measurement of steel strand-reinforced RPC's flexural toughness.

2.3.3. The Ultrasonic Velocity Test

An ultrasonic detector developed by Peidun (Shanghai) Testing Technology Co., Ltd., Shanghai, China, was used for the measurement of ultrasonic velocity passing through the steel strand-reinforced RPC specimens. Vaseline was coupled with the surface of the specimens before testing. Figure 3 exhibits the ultrasonic velocities' measuring process.

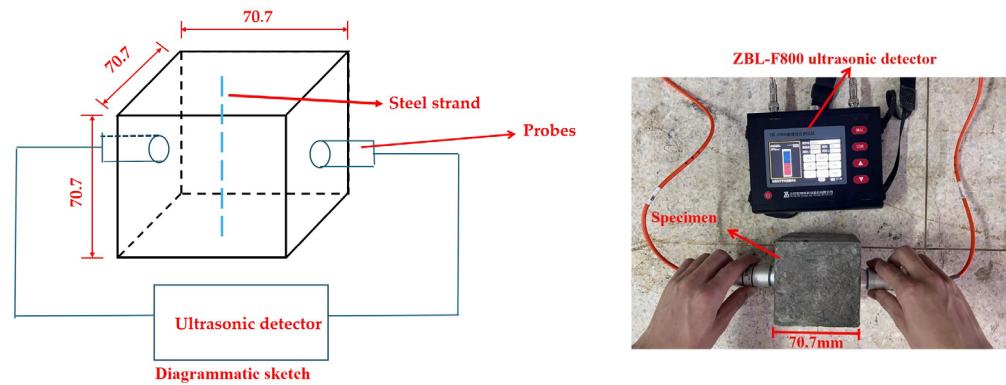


Figure 3. The measurement of steel strand-reinforced RPC's ultrasonic velocity.

2.3.4. The Impact Toughness

The JLW-100 drop hammer standard was employed to obtain the impact toughness of steel strand-reinforced RPC. The specimen size, drop hammer's mass, drop rod's mass, and the beam's clear span were $100 \times 100 \times 400 \text{ mm}^3$, 2.5 kg, 5 kg, and 360 mm. The upper loading section had a span of 120 mm, and the specimens were subjected to an impact load in a four-point loading mode.

In the testing process, a 2.5 kg drop hammer (5 kg rod weight) was employed to strike the side of the force sample from a height of 400 mm. The crack propagation width on the specimen surface was observed using a crack width detector in order to determine the impact time at the initial crack. The impact test was repeated until the specimen was destroyed. The experimental procedures for each test were as follows: First, the bottom of the sample was wiped with alcohol, after which the impact time was recorded and detected. Once the crack width detector identified the first crack with a width of 0.05 mm, the impact time of failure was recorded. The impact energy consumption (W) of the specimen throughout the impact test was determined as the accumulation of work per impact. A total of three specimens were included in each group, and the impact toughness was calculated in accordance with Formula (3).

$$W = (M + m)gHN \quad (3)$$

where N represents the total number of impact failures, and M and m are the mass values of the falling rod and hammer, respectively. H and g stand for the dropping height and gravitational acceleration. Figure 4 shows the measuring process and loading mode of the impact test.



Figure 4. The steel strand-reinforced RPC's impact test.

2.3.5. The Dry–Wet Alternations

The specimens were cured in the standard environment for 24 days. After that, all specimens were immersed in a 3% NaCl or 3% Na₂SO₄ solution for 4 days. Then, the specimens were air-dried by placing them in an oven at a temperature of 30 °C~40 °C for eight hours until the water on the surface of the specimens evaporated. Afterward, the specimens were cooled at room temperature for 2 hours and then immersed in a 3% NaCl solution for 14 hours. This constituted a dry–wet alternating cycle. Various dry–wet alternating cycles were conducted. In the dry–wet cycle test, the mean value of the six specimens in each group was calculated. The experiment was conducted according to Chinese standard GB/T 50082-2009 [27].

2.3.6. The Electrical Resistance

A TH2810D LCR digital electric bridge was used for the measurement of electrical resistance. The testing frequency was 10⁴ Hz, and the voltage was 1 V. The steel stands and stainless steel wire mesh were used as the two electrodes. The spacing between the steel strands and stainless steel mesh was 30 mm. Figure 5 exhibits the measurement process of the electrical resistance.

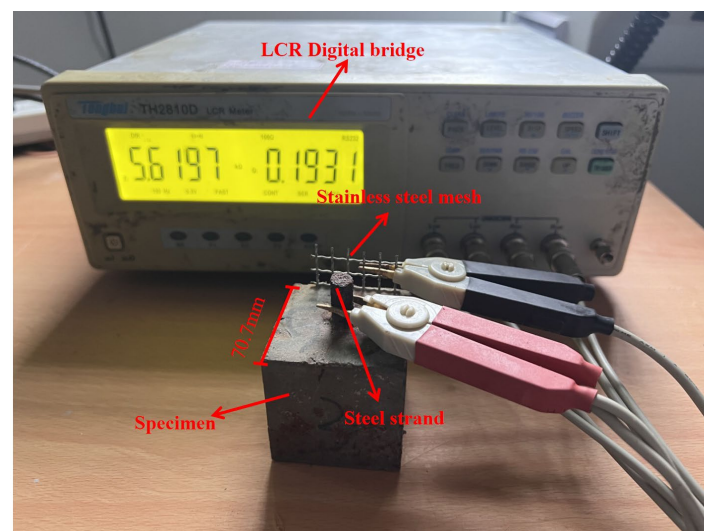


Figure 5. The measurement of steel strand-reinforced RPC's electrical resistance.

3. Results and Discussion

3.1. The Mechanical Strengths

The flexural strength and compressive strength of the steel strand-reinforced reactive powder concrete with mixed steel fibers and basalt fibers under salt dry–wet erosion are shown in Figure 6. It can be observed from Figure 6 that the mechanical strength demonstrated increasing trends with the added dosages of basalt fibers and steel fibers. After the specimens were cured for 28 days, the flexural strength increased by rates of up to 13.1%, 28.7%, and 37%, respectively, corresponding to the specimens with 2% basalt fibers, 2% steel fibers, and assembly units of 1% basalt fibers and 1% steel fibers, while the corresponding compressive strengths increased by 10.3%, 18.3%, and 20.2%, respectively, corresponding to the same specimens as those used in flexural strength. After NaCl dry–wet alternation and Na₂SO₄ dry–wet alternation, the increase in flexural strength by fibers could reach up to 49% in the specimens with the assembly units of 1% basalt fibers and 1% steel fibers. This can be explained by the fact that steel fibers can limit the propagation of cracks in concrete when subjected to stress [28,29]. Therefore, the mechanical strength is improved by the increasing dosages of fibers. As illustrated in Figure 6, the steel strand-reinforced reactive powder concrete mixed with steel fibers had higher mechanical strength than that with basalt fibers. Due to the fact that steel fibers have higher elastic modulus

and tensile strength [30], steel strand-reinforced reactive powder concrete with steel fibers has higher mechanical strength [31,32]. When the total fiber content was constant, the steel strand-reinforced reactive powder concrete composed of the assembly unit of steel fibers and basalt fibers had higher mechanical strength than the specimens with the single addition of basalt fibers or steel fibers. The assembly unit of steel fibers and basalt fibers can improve the density and dispersion of fibers, thereby leading to an increase in the strength of reactive powder concrete [33]. The steel strand-reinforced reactive powder concrete with the volume ratios of 1% steel fibers and 1% basalt fibers had the highest mechanical strength. It was found that the mechanical strength of the specimens decreased after the actions of NaCl and Na₂SO₄ dry-wet alternations [34]. The decreasing rates of flexural strength were 11.2%~33.6% and 7.3%~22.7% after dry-wet alternations using NaCl and Na₂SO₄ solutions, respectively. The corresponding decreasing rates of compressive strength were 22.1%~38.9% and 14.6%~41.3%. The dry-wet actions of NaCl and Na₂SO₄ solutions can increase the crystalline stress of salt solutions [35]. Moreover, salt action can corrode the steel strands, thereby accelerating the attenuation of concrete's mechanical strength [36]. As can be seen from Figure 6, the mechanical strength of steel strand-reinforced RPC after NaCl dry-wet alternation was lower than that after Na₂SO₄ dry-wet alternation due to chloride ion corrosion on the passivation film of steel strands. The errors of all mechanical strength values were less than 10% of the actual values, indicating the accuracy of experimental data.

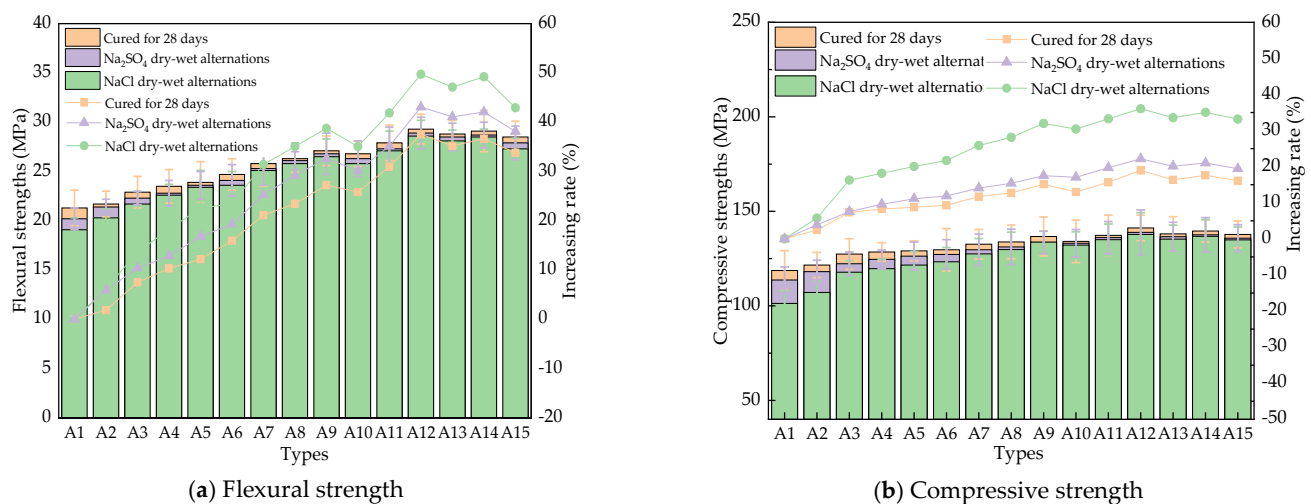


Figure 6. The mechanical strength of steel strand-reinforced RPC.

3.2. The Ultrasonic Velocity

The ultrasonic velocity passing through the steel strand-reinforced RPC is shown in Figure 7. It can be seen in Figure 7 that the ultrasonic velocity increased with the increasing dosages of basalt fibers and steel fibers. The increasing rates of ultrasonic velocity by basalt fibers and steel fibers could reach up to 5.7% and 7.8%, respectively. This is due to the fact that fiber networks become increasingly dense with the increasing dosages of fibers [37]. Therefore, the ultrasound speed will increase with an increase in the fibers' volume ratios. Specimens with steel fibers had a higher ultrasound speed. This can be explained by the fact that steel fibers have higher compactness than that of basalt fibers [38]. Consequently, specimens with steel fibers exhibited higher ultrasonic velocity. The ultrasonic velocity of specimens with the combination of fibers was higher than that of specimens with a single type of steel fibers or basalt fibers. The ultrasonic velocity of the steel strand-reinforced reactive powder concrete with the volume ratios of 1% steel fibers and 1% basalt fibers was the highest. As illustrated in Figure 7, the ultrasonic velocity decreased by 0%~31.2% and 0%~21.3%, respectively, after 30 dry-wet alternations with NaCl and Na₂SO₄, respectively. This is attributed to the fact that salt dry-wet erosion can accelerate the propagation of concrete cracks [39,40]. The cracks can block the propagation of ultrasonic velocity, leading

to a decrease in the ultrasonic velocity. The ultrasonic velocity of the specimens after 30 NaCl dry-wet alternations was less than that of the specimens after 30 Na₂SO₄ dry-wet alternations due to the erosion on the passivation film of steel strands caused by chlorine ions [41]. Finally, as shown in Figure 7, the addition of fibers could delay the decline in ultrasound speed. The effect of the reduction in the ultrasound attenuation of the specimens comprising the assembly unit of 1% steel fibers and 1% basalt fibers was the highest. The effect of basalt fibers was higher than the steel fibers' effect, due to the corrosion resistance of basalt fibers.

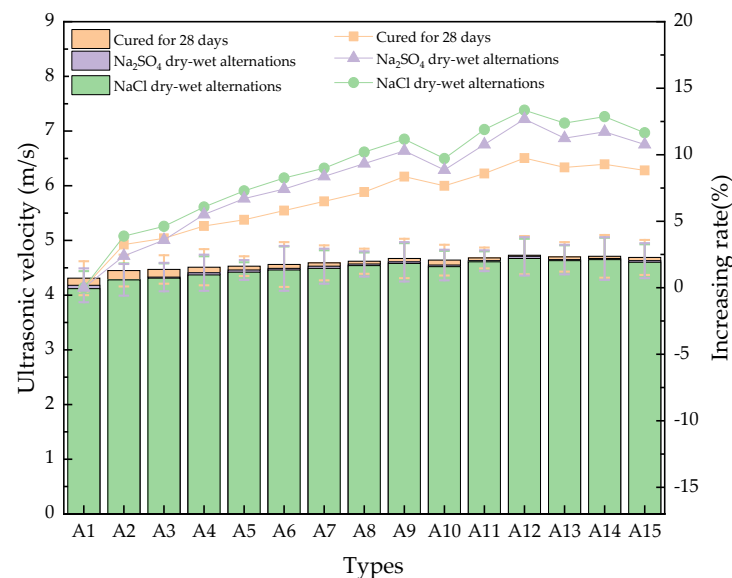


Figure 7. The ultrasonic velocity of steel strand-reinforced RPC.

3.3. The Flexural Toughness

The load–displacement curves of steel strand-reinforced RPC are exhibited in Figure 8. As can be seen in Figure 8, the load increased with the increasing flexural deflection. The ultimate flexural load showed an increasing trend with the increasing dosages of basalt fibers and steel fibers. The ultimate flexural load of steel strand-reinforced RPC with steel fibers was higher than that with basalt fibers. The assembly unit of steel fibers and basalt fibers demonstrated higher ultimate flexural load than the steel strand-reinforced RPC with a single type of steel fibers or basalt fibers due to the denser fiber networks [42,43]. NaCl and Na₂SO₄ dry-wet alternations had a decreasing effect on the ultimate bearing capacity. This can be attributed to the internal damage caused by the dry-wet alternations of NaCl and Na₂SO₄ solution. Meanwhile, the addition of fibers can delay the decline in the ultimate bearing capacity [44]. Compared to steel fibers, basalt fibers had a higher effect on the specimens' resistance to the attenuation of the ultimate bearing capacity. The assembly unit of steel fibers and basalt fibers demonstrated a higher effect on the resistance of the specimens to the ultimate bearing capacities' attenuation than the single type of steel fibers or basalt fibers. Specimens with the assembly unit of 1% steel fibers and 1% basalt fibers demonstrated the highest resistance to the ultimate bearing capacities' attenuation, due to the highest compactness of fiber networks and the strong corrosion resistance of basalt fibers [45].

The flexural toughness of steel strand-reinforced RPC is shown in Figure 9. As can be seen in Figure 9, the flexural toughness shows an increasing trend with the increasing dosages of basalt fibers and steel fibers [46]. The added basalt fibers and steel fibers increased the flexural toughness by rates of up to 11.2% and 35.3%. Moreover, when the assembly units of basalt fibers and steel fibers were added, the flexural toughness was higher. Specimens with the assembly unit of 1% steel fibers and 1% basalt fibers had the highest flexural toughness. When the steel strand-reinforced RPC was subjected to dry-wet alternations with NaCl and Na₂SO₄ solutions, the corresponding flexural toughness

decreased by 14.3% and 11.2%, due to the damage caused by alternation of dry and wet conditions, thus reducing the flexural toughness of steel strand-reinforced RPC. The added basalt fibers and steel fibers could reduce the rate of flexural toughness attenuation. The addition of the assembly unit of 1% steel fibers and 1% basalt fibers reduced the degree of flexural toughness attenuation.

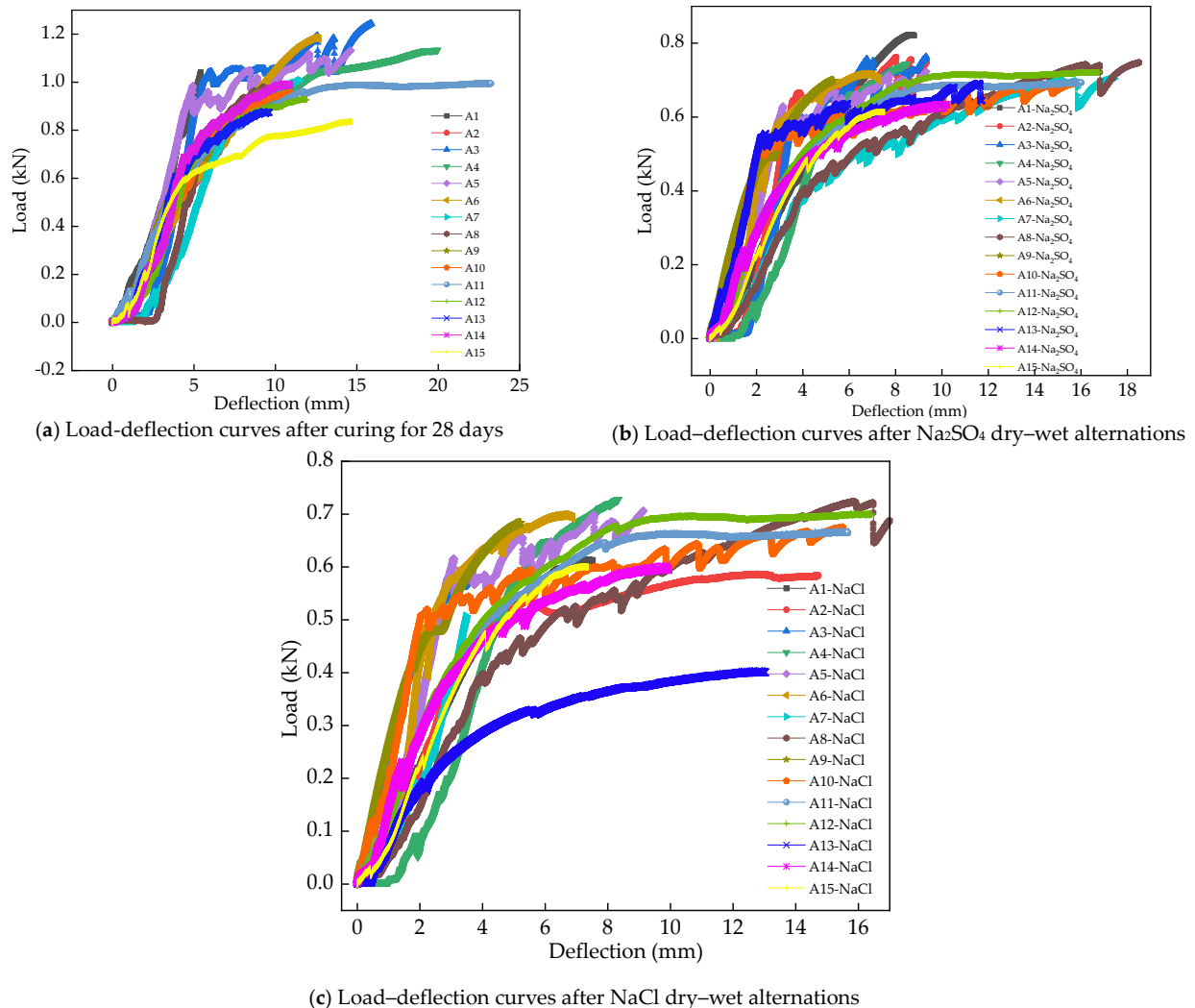


Figure 8. The load–deflection curves of steel strand-reinforced RPC.

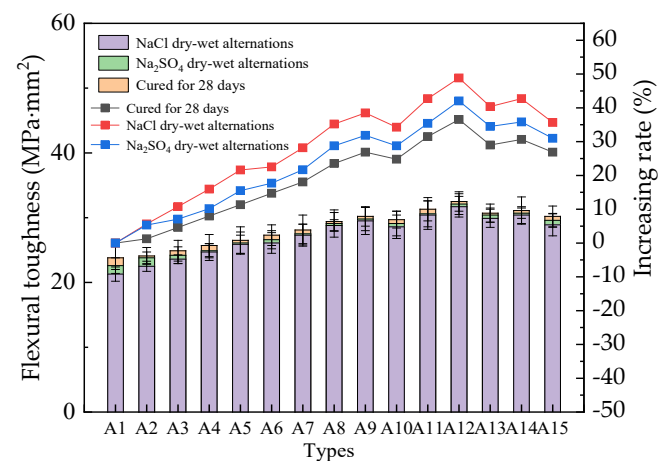


Figure 9. The flexural toughness of steel strand-reinforced RPC.

3.4. The Impact Toughness

The impact toughness of the steel strand-reinforced RPC is shown in Figure 10. Figure 11 shows the cracking times and the destruction times. From Figure 10, it can be observed that the impacted cracking and failure times are increased by adding the steel fibers and basalt fibers [47,48]. The steel strand-reinforced RPC with steel fibers had higher impact times than that with basalt fibers. However, the impacted times of steel strand-reinforced RPC with the assembly units of basalt fibers and steel fibers were higher than those of the specimens with steel fibers. The steel strand-reinforced RPC with the assembly unit of 1% steel fibers and 1% basalt fibers had the highest impacted cracking and failure times. The impact toughness increased by 7.1% and 16.3% with the addition of basalt fibers and steel fibers. The impact toughness demonstrated a downward trend after 30 dry-wet alternations with NaCl or Na₂SO₄ solutions. The impact toughness decreased by 0%~13.6% and 0%~10.7%, respectively, after the specimens were subjected to NaCl and Na₂SO₄ dry-wet alternations. The addition of fibers can hinder this attenuation process. The steel strand-reinforced RPC with the assembly unit of 1% steel fibers and 1% basalt fibers had the highest optimum limiting effect.

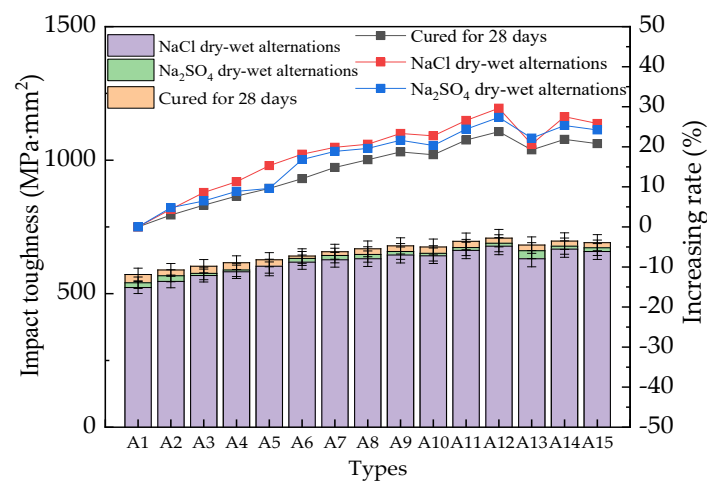
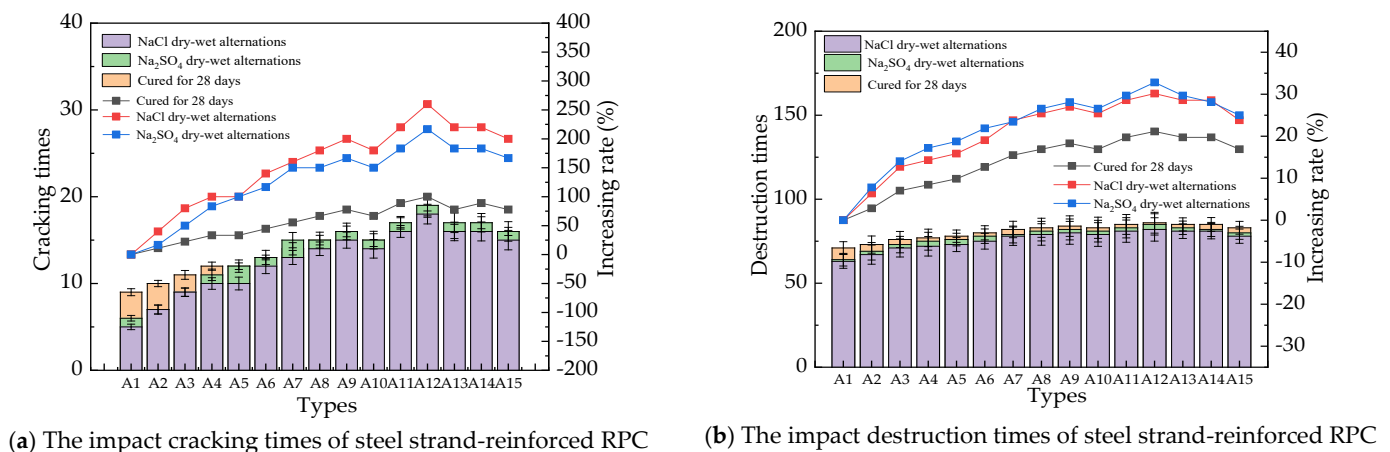


Figure 10. The impact toughness of steel strand-reinforced RPC.



(a) The impact cracking times of steel strand-reinforced RPC

(b) The impact destruction times of steel strand-reinforced RPC

Figure 11. The impact times of steel strand-reinforced RPC during the dry-wet alternations.

3.5. The Electrical Resistance

The electrical resistance of the steel strand-reinforced RPC is exhibited in Figure 12. As can be seen in Figure 12, the electrical resistance increased with the addition of basalt fibers and decreased with the addition of steel fibers. This is attributed to the fact that basalt fibers have poor conductivity; therefore, the electrical resistance increases with the addition

of basalt fibers [49]. However, the electrical conductivity of steel fibers is higher than that of basalt fibers and the RPC matrix, eventually leading to a decrease in the electrical resistance of the steel strand-reinforced RPC. As observed in Figure 12, the electrical resistance of the steel strand-reinforced RPC increased undergoing dry–wet alternations with NaCl and Na₂SO₄ solutions. This is ascribed to the fact that the dry–wet alternations of NaCl and Na₂SO₄ can increase the inner cracks of the steel strand-reinforced RPC, obstructing the migration of charged particles in the specimens. Consequently, the steel strand-reinforced RPC's electrical resistance increased with the dry–wet alternations of NaCl and Na₂SO₄.

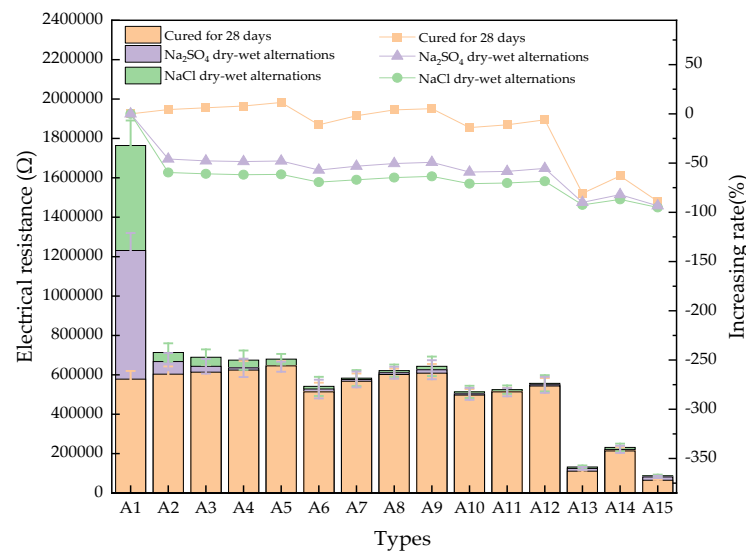


Figure 12. The electrical resistance of steel strand-reinforced RPC.

4. Conclusions

The performance degradation of steel strand-reinforced reactive powder concrete with mixed steel fibers and basalt fibers is summarized as follows:

The flexural strength of the steel strand-reinforced reactive powder concrete increased by rates of up to 13.1% and 28.7%, respectively, with the addition of 0%~2% basalt fibers or 0%~2% steel fibers. The corresponding increasing rates of compressive strength were 10.3% and 18.3%. The NaCl and Na₂SO₄ dry–wet alternations decreased the flexural strengths by 11.2%~33.6% and 7.3%~22.7%, respectively. However, the corresponding compressive strength's decreasing rates were 22.1%~38.9% and 14.6%~41.3%. The addition of basalt fibers and steel fibers improved the steel strand-reinforced reactive powder concrete's resistance to mechanical strength attenuation. The steel strand-reinforced reactive powder concrete with 1% steel fibers and 1% basalt fibers had the highest mechanical strength and resistance to mechanical strength attenuation after NaCl and Na₂SO₄ dry–wet alternations.

The ultrasonic velocity passing through the steel strand-reinforced reactive powder concrete increased by 5.7% and 7.8%, respectively, with the addition of basalt fibers and steel fibers. The ultrasonic velocity decreased by rates of up to 31.2% and 21.3%, respectively, due to the actions of NaCl and Na₂SO₄ dry–wet alternations. The addition of basalt fibers or steel fibers could delay the reduction in ultrasonic velocity. The specimens with the assembly unit of 1% steel fibers and 1% basalt fibers demonstrated the highest ultrasonic speed and optimal anti-ultrasonic attenuation performance under the conditions of NaCl and Na₂SO₄ dry–wet alternations.

The steel strand-reinforced reactive powder concrete's flexural toughness increased by adding basalt fibers and steel fibers with increasing rates of 11.2% and 35.3%, respectively. The dry–wet alternations of NaCl and Na₂SO₄ decreased the flexural toughness by 0%~14.3% and 0%~11.2%, respectively. The specimens with 1% steel fibers and 1% basalt fibers had optimal flexural toughness and resistance to flexural attenuation.

The steel strand-reinforced reactive powder concrete's impact toughness increased by rates of up to 7.1% and 16.3% with the addition of basalt fibers and steel fibers. The impact toughness demonstrated a downward trend after 30 dry–wet alternations with NaCl or Na₂SO₄ solutions. After the specimens were subjected to NaCl and Na₂SO₄ dry–wet alternations, their impact toughness decreased by 13.6% and 10.7%, respectively. The specimens with 1% steel fibers and 1% basalt fibers had the highest impact toughness and the corresponding attenuation performance.

Author Contributions: Methodology, Z.X. and C.L.; Software, N.X. and X.T.; Validation, N.X. and H.W.; Formal analysis, Z.C. and H.W.; Investigation, D.W. and Z.C.; Resources, Z.X.; Data curation, D.W. and Z.X.; Writing—original draft, D.W.; Writing—review & editing, H.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Liaoning Science and Technology Plan joint program project 2023JH2/101700001, Liaoning Science and Technology Plan Joint plan project 2023JH2/101700002, Basic scientific Research Project LJKMZ20221753 of Liaoning Education Department in 2022 and Zhejiang Provincial Natural Science Foundation grant number LY22E080005.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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