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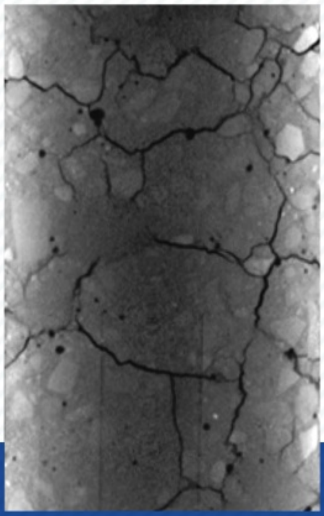

Advances in Construction Materials
Proceedings of the ConMat'20

Editors: N. Banthia, K. Takewaka, C. Miao, and H. Hamada

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Sixth International Conference on Construction Materials
- Performance, Innovations, and Structural Implications -

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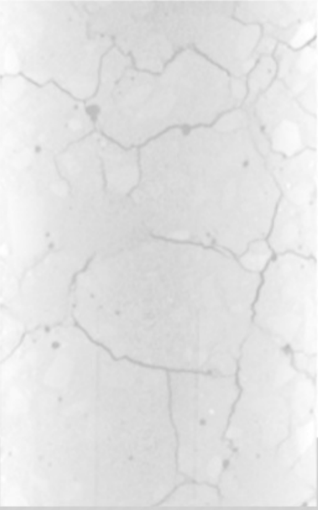

Advances in Construction Materials
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Preface

Covid19 has affected our world in more than one way. One casualty was the cancellation of ConMat'20, The Sixth International Conference on Construction Materials: Performance, Innovations and Structural Implications, be held in Fukuoka, Japan, August 27-29, 2020. While an in-person meeting would have provided an excellent platform for exchange of ideas, we nevertheless congratulate the Organizing Committee for "salvaging" the grim situation by bringing out the Proceedings of the ConMat'20. These Proceedings are in your hands now.

Sustainable Global Development remains a key priority for the world. Today, nearly a billion people in the world live in extreme poverty without access to healthcare, water, transportation infrastructure, communications networks and power. Our construction industry is at the heart of alleviating these problems and providing a foundation for global development. As part of the large industry, we build civil infrastructure – the set of interconnected structural elements such as roads, water supply, sewers, electrical grids, telecommunications networks, and the built infrastructure of residential, commercial and public buildings – and create the underpinnings for community's health, productive living, safety and economic prosperity.

While we often discuss the carbon footprint of the construction sector and the insurmountable GHG emissions from the cement industry, we often forget about the negative effects of climate change—like the rapidly rising CO_2 in our atmosphere, increasing saturation levels in foundation soils, rising sea-levels, scour in our bridges, loss of permafrost in the north and the anthropogenic rise in atmospheric temperatures— on the durability of our structures. Some recent models predict that rebar corrosion in cities like Mumbai and Tokyo can be initiated nearly nine years sooner. This is indeed worrying, and the situation is further exacerbated by lack of timely maintenance, use of non-durable construction materials, exposure to aggressive environments, poor construction practices and rapid increases in live-loads.

The construction materials industry, with an annual turnover of nearly $500 billion, is one of the most important segments of the global construction market. This thriving industry, however, faces insurmountable challenges ahead. Production and processing of materials such as concrete, wood, steel and polymers utilizes large amounts of both natural resources and energy, making the materials industry an environmentally sensitive sector. The double-digit growth in construction activity in both India and China has created an unparalleled demand for construction materials casting a doubt over our ability to maintain a sustainable growth. There is thus a critical need to find innovative solutions to these insurmountable challenges. Diverse disciplines must join hands in developing interdisciplinary solutions that are sustainable, globally responsible and in tune with the long-term needs of mankind. Sensing, 3Dprinting, robotics, data-analytics and artificial intelligence must interface with materials science and structural engineering to produce elegant solutions.

ConMat'20 Proceedings provide thought-provoking papers in the areas of: Performance of Materials; Deterioration Mechanisms; New Design Concepts; Specialized Materials; Operations, Maintenance and Repairs; and, Sensors and Cyber-Physical Interfaces. While, unfortunately, personal interactions between and with the authors of these papers could not occur due to Covid19, we still hope that the Proceedings will help spur conversations amongst various groups, and industry will benefit from a transfer of technology.

We are also proud and privileged to honor five of our outstanding colleagues—Prof. Frank Vecchio, Prof. Toyoaki Miyagawa, Prof. Yoshiaki Sato, Prof. Koichi Maekawa and Professor Caijun Shi—and recognize their many intellectual and professional contributions to the field of Construction Materials. Over the last thirty-five years, these stalwarts have not only contributed enthusiastically to the understanding of various construction materials from both fundamental and applied perspectives, but have also mentored numerous young minds. We salute these great role-models, and are delighted and proud to pay them the highest tribute.

Finally, we would like to take this opportunity to thank the many reviewers who have so generously given their time to ensure that the papers accepted for the Proceedings are of the highest quality, stand the rigorous scrutiny of scientific accuracy, depict sound logic and represent a true advancement in our state-of-the-art.

N Banthia, K Takewaka, C Miao and H. Hamada
Editors

ConMat'20

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Performance, Innovations, and Structural Implications

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EFFECT OF FLY ASH IN CONCRETE ON THE REBAR CORROSION

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ABSTRACT

Since the Great East Japan Earthquake in 2011, the dependence on coal-fired power generation has increased. Along with this, the emission rate of fly ash (FA), a by-product of coal combustion, has increased. FA can be used in a number of applications, including concrete structures. However, it is believed that the incorporation of FA in structural concrete accelerates the carbonation process, which is the reason FA is not typically used in concrete structures. Here we have studied the possibility of expanding the use of FA in concrete structures. The effects of binder type, carbonation, and external water on rebar corrosion is investigated herein. Results suggest that the use of FA has an insignificant effect on rebar corrosion. In addition, rebar corrosion rapidly progresses when both conditions of carbonation and external water are satisfied; therefore, we found that it can be suppressed by excluding either one of these conditions.

Keywords: Mortar, Fly ash, Carbonation, Rebar corrosion, Exposure test

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SUSTAINABLE UTILIZATION OF AIR-COOLED FERRONICKEL SLAG IN CONCRETE: COMPRESSIVE STRENGTH AND CORROSION RESISTANCE

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ABSTRACT

Utilization of waste materials in concrete without sacrificing the strength and durability properties of the concrete has been promoted in order to produce sustainable concrete. In this study, natural aggregates is replaced with air-cooled ferronickel slag (ACFS) in concrete by 15%, 30%, 50%, 70%, and 100% volume. Concrete specimens were cured with different curing conditions, namely water and air curing (WC and AC, respectively) and tested for compressive strength and corrosion resistance after curing for 28 days. The results indicate that the compressive strength and corrosion resistance of concrete was influenced by the curing conditions. The highest compressive strength and corrosion resistance were obtained by 30% replacement of ACFS by volume with WC, while no significant different in compressive strength and corrosion resistance were observed with AC for all replacement levels of coarse aggregates with ACFS.

Keywords: Waste Materials, Ferronickel Slag, Concrete, Compressive Strength, Corrosion

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1. INTRODUCTION

Concrete is a construction material whose use continues to increase along with the development of infrastructure in developing countries such as Indonesia. As coarse aggregate, the concrete industry usually uses crushed stone, which is a non-renewable natural resource whose quantity is in decline. Incorporating industrial waste material as either partial or full replacement of coarse aggregate in concrete can limit the use of natural resources and also reduce the landfill disposal of waste materials.

Air-cooled ferronickel slag (ACFS) can be used as an alternative material for coarse aggregate in concrete. ACFS is an industrial by-product of the processing of nickel ore. The ore is smelted at 1500–1600 °C, and the by-product ACFS is granulated by air and tap water cooling. Indonesia has very large nickel deposits, amounting to 4.5 billion tons of ore in 2016 [1]. The production of 1 ton of nickel produces around 8 tons of ACFS as a by-product, which is stacked in an open area near the site as shown in Figure 1. In addition, the ACFS can pollute the environment if exposed to acid rain, there being many harmful substances therein. Therefore, ACFS waste treatment should be carried out to avoid serious environmental challenges.

Figure 1. Storage of ferronickel-slag waste.

Attempts have been made to use ACFS for either partial or full replacement of concrete materials. It has been reported that ACFS can be used to replace the aggregate in concrete. Liu et al. [2] studied the durability of concrete containing ferronickel slag with different storage times as sand replacement; they found little difference in the properties of concrete with different storage times and recommended replacement sand with 40% ferronickel slag to improve the durability of concrete. Saha and Sarker [3] evaluated the properties of concrete containing 50% and 100% ferronickel slag as fine-aggregate replacement and concluded that the concrete strength improved when the replacement of fine aggregate with ferronickel slag was within 50%. Mustika et al. [4] studied the use of ferronickel slag as coarse aggregate in concrete; they concluded that concrete with ferronickel slag exhibits higher compressive strength than that of normal concrete. Sriyani et al. [5] reported that adding 15% rice husk ash in ferronickel-slag concrete increased the compressive strength by 6.5% compared with that of normal concrete.

Although using ferronickel slag as aggregate in concrete can improve the compressive strength, how the curing condition affects the compressive strength of ferronickel-slag concrete is yet to be studied, as is the resistance against corrosion of ferronickel-slag concrete. Therefore, the present study investigates how curing affects the compressive strength and corrosion resistance of concrete containing ACFS as coarse aggregate.

2. MATERIALS AND METHODS

2.1. Raw materials

2.1.1. Cement

The cement that was used was Portland composite cement (PCC) containing 80% clinker and 20% mineral admixture in accordance with SNI 15-7064-2004 [6]. The physical properties and chemical compounds in PCC are given in Table 1.

Table 1. Physical properties of and chemical compounds in Portland composite cement (PCC)

Material	PCC						
Specific gravity	3.08						
Maximum particle size	45 µm						
Chemical compounds	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	LOI
(%)	18.39	5.15	3.41	61.79	1.81	0.99	4.61

2.1.2. Fine and coarse aggregates

Natural river sand with a fineness modulus of 2.77 and a specific gravity of 2.58 was used as fine aggregate. Crushed stone with a specific gravity of 2.83 and a maximum aggregate size of 20 mm was used as coarse aggregate.

2.1.3. Air-cooled ferronickel slag

The ACFS aggregate was obtained after several processes. The melted slag from the furnace was transported to the dumping area near the site using a haul master. In the dumping area, the slag melt was poured and allowed to flow under gravity, whereupon it cooled and solidified. After 3–6 months of air cooling, the solid nickel slag was sprayed with tap water until it cooled to below 135 °C. It was then gathered by an excavator machine and brought to a jaw crusher to obtain the desired aggregate size. Figure 2 shows photographs of the procedures used to obtain the ACFS.

Figure 2. Processing of air-cooled ferronickel slag (ACFS) aggregate: (a) dumping; (b) cooling; (c) gathering; and (d) crushing.

2.2. Specimen preparation and testing methods

Concrete specimens were produced with a water-to-cement ratio of 0.4. Coarse aggregates were replaced by 15%, 30%, 50%, 70%, and 100% ACFS by volume. Also, a specimen without ACFS was prepared as control concrete. Table 2 lists the mixture proportions of the concrete that was used. Each specimen was cast in a cylindrical steel mold that was ∅100 mm × 200 mm in size. For the corrosion test, a deformed steel bar with a diameter of 16 mm was located centrally in a specimen with an embedded length of 150 mm (Figure 3). After 24 h of casting, the specimens were removed from the molds and then subjected to one of two curing conditions, namely, either water curing (WC) or air curing at 25±2°C with relative humidity of 50 – 60% (AC) until the testing age.

Table 2. Mixture amounts in 1 m^3 of concrete

Mix ID	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	ACFS (kg/m^3)
C	205	513	640	990	0
15% ACFS	205	513	640	842	179
30% ACFS	205	513	640	693	357
50% ACFS	205	513	640	495	596
70% ACFS	205	513	640	297	834
100% ACFS	205	513	640	0	1191

Figure 3. Specimens for corrosion test.

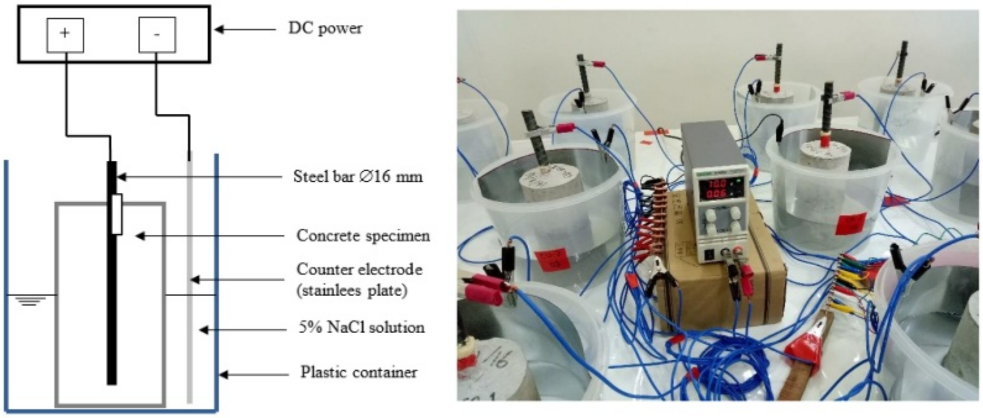

Figure 4. Setup for corrosion test.

Figure 5. Appearances of ACFS.

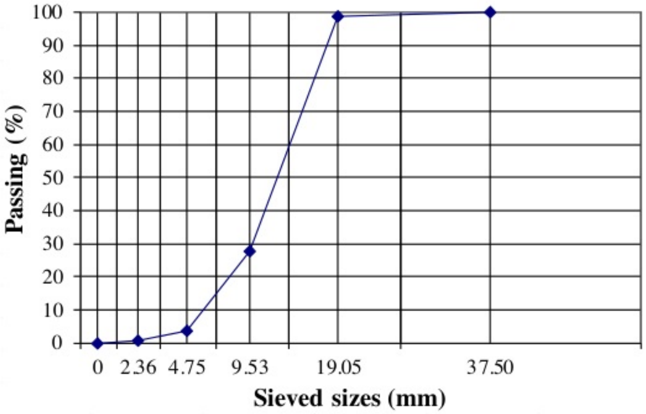

Figure 6. Particle sizes distribution.

The slump and density of the fresh concrete were measured according to ASTM C143 [7] and ASTM C642 [8], respectively. The compressive strength of the concrete was determined in accordance with ASTM C39 [9]. The impressed voltage method (10 V) was used for the corrosion test. A concrete specimen was immersed partially in a 5% NaCl solution; then, its steel bar was connected to the positive terminal of a DC power supply, with the negative terminal connected to a stainless-steel plate as shown in Figure 4. The condition of the concrete specimen was monitored continuously, and the initiation time of the first crack was recorded to determine the corrosion resistance of the specimen.

3. RESULTS AND DISCUSSION

3.1. Characterizations of ACFS

Figure 5 shows some of the ACFS used in this study. Its shapes varied from subrounded to subangular with both bulky and platy sizes, and distinct asperities and edges were visible in the subangular bulky particles. Most of the platy particles had irregular shapes with very low sphericity and sharp edges and were dominated by a porous surface texture. The ACFS had a specific gravity of 3.25 and water absorption of 1.19%. The specific gravity of the ACFS was higher than that of the coarse aggregate, thereby increasing the density of the concrete. Figure 6 presents the particle sizes distribution of ACFS.

The chemical compounds in the ACFS as obtained from X-ray fluorescence (XRF) are given in Table 3. The ACFS comprised 71.64% Fe_2O_3 along with 18.62%, 2.81%, 2.51%, 1.73%, and 1.10%

of SiO_2, MnO, Cr_2O_3, CaO, and TiO_2, respectively. Other oxides including NiO, ZnO, and K_2O were also present in small quantities. The X-ray diffraction pattern of the ACFS is shown in Figure 7, showing the presence of the crystalline phases of wuestite (FeO), quartz (SiO_2), manganite (MnO_2), calcite ($CaCO_3$), and chromium(VI) oxide (CrO_3). These results are consistent with the XRF data.

Table 3. Chemical compounds in ACFS

Compounds	Fe_2O_3	SiO_2	MnO	Cr_2O_3	CaO	TiO_2	NiO	ZnO	K_2O
Mass, %	71.64	18.62	2.81	2.51	1.73	1.10	0.92	0.29	0.20

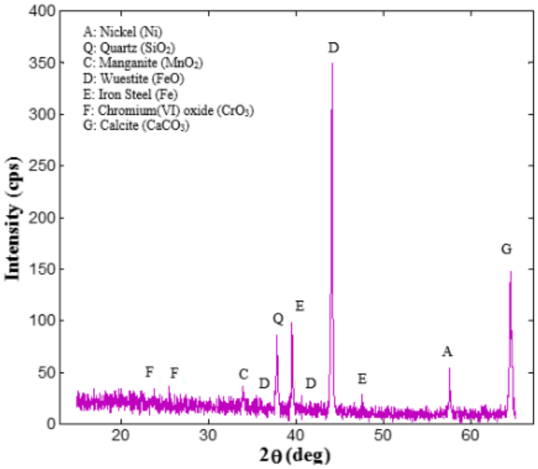

Figure 7. X-ray diffraction pattern of ACFS.

3.2. Physical properties

The workability of the fresh concrete was measured using a slump test. Figure 8 shows the slump test results for the different concrete mixtures. As observed, replacing the coarse aggregate with up to 30% ACFS increased the slump value, but the slump value decreased beyond 30% ACFS replacement. The latter was due to the highly porous nature of the ACFS, which at higher replacement levels consumed more cement–sand paste and entrapped a significant part of the mixing water in its pores, thereby lowering the workability of the concrete [10].

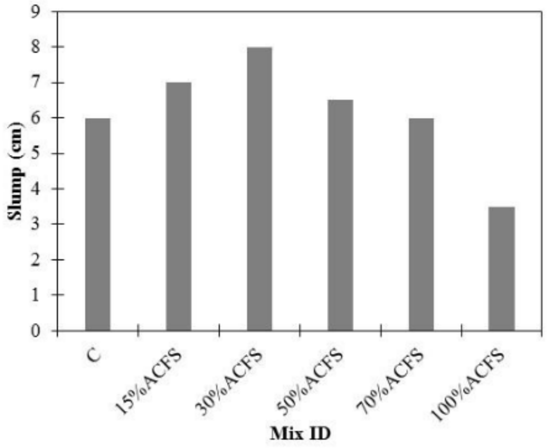

Figure 8. Slump values of concrete.

Figure 9 shows the density of fresh concrete with different ACFS content. The fresh density increased with increasing ACFS content: the fresh density increased by 4.07%, 6.27%, 8.21%, 9.50%, and 11.39% corresponding to 15%, 30%, 50%, 70%, and 100% ACFS. This increase in fresh density can be attributed to the fact that the density and specific gravity of the ACFS were higher than those of the natural coarse aggregate.

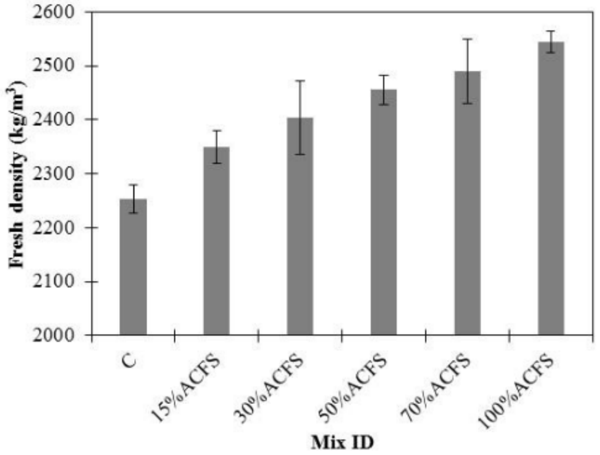

Figure 9. Density of fresh concrete.

3.3. Compressive strength

Compressive strength is a key factor in the durability of concrete and is influenced by the aggregate properties and the curing conditions. Figure 10 shows how the compressive strength at 28 d varied with the ACFS content and curing condition. Generally, the compressive strength of the concrete with WC was higher than that with AC for each ACFS replacement level. For the concrete with WC, the highest compressive strength was obtained with 30% ACFS, beyond which the compressive strength decreased. With WC, the improvement in the compressive strength with 30% ACFS was found to be 12.06% in comparison with that of the control concrete. The porous surface texture of the ACFS aggregate, which enhanced the interaction between ACFS aggregate and the cement matrix, could be the reason behind the higher strength of the concrete containing 30% ACFS. Meanwhile, there was no significant difference in compressive strength between the control concrete and the ACFS concrete with AC.

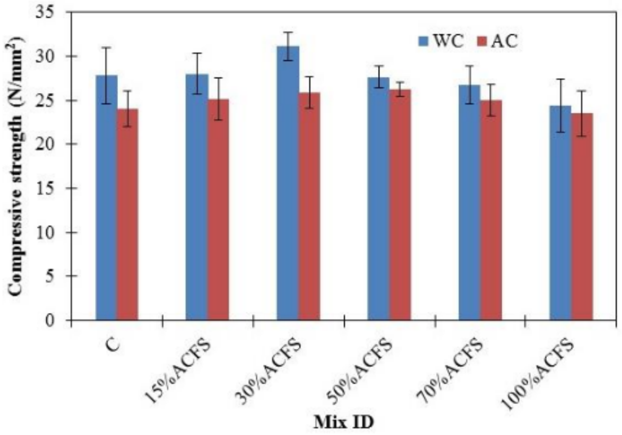

Figure 10. Compressive strength of concrete with water curing (WC; blue) and air curing (AC; red).

3.4. Corrosion resistance

Figure 11 shows the crack initiation times of the ACFS concrete, which were influenced by the curing condition. With WC, the concrete with 30% ACFS was found to have the highest crack initiation time of 240 h compared with that of 180, 193, 150, and 158 h with 15%, 50%, 70%, and 100% ACFS, respectively. However, the concrete specimens with 70% and 100% ACFS had slightly lower crack initiation times compared with that of the control concrete.

For the concrete specimens with AC, the results show that incorporating ACFS as a coarse aggregate replacement had little influence on the crack initiation time. Nevertheless, it is interesting to note that with AC, the concrete specimens with ACFS had higher crack initiation times compared with that of the control concrete.

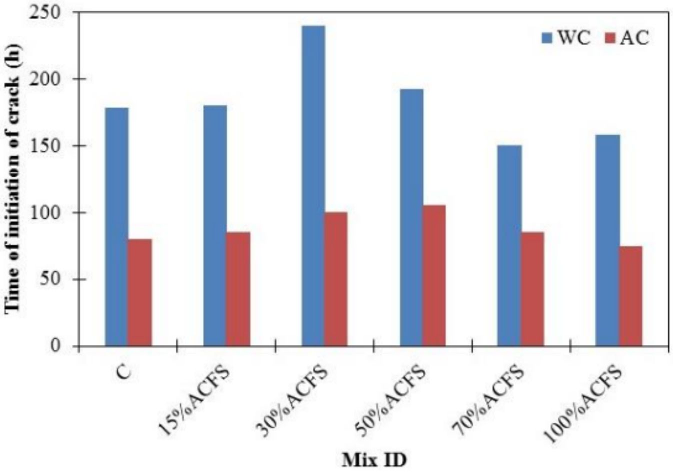

Figure 11. Crack initiation times of ACFS concretes with WC and AC subjected to accelerated corrosion test.

4. CONCLUSIONS

On the basis of the results obtained from the compressive strength and accelerated corrosion tests, the following conclusions can be drawn:

1. The workability of concrete is increased by replacing 30% of the coarse aggregate with ACFS, beyond which the workability is decreased. Furthermore, the density of fresh concrete is increased by increasing the ACFS content.
2. The highest compressive strength is obtained by replacing the coarse aggregate by 30% ACFS with WC. Meanwhile, adding ACFS aggregate has little influence for concrete with AC.
3. The corrosion resistance of concrete is improved by adding 30% ACFS aggregate with WC. However, there is no significant difference in corrosion resistance with AC for all levels of replacing coarse aggregate with ACFS.

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