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Investigating the Effect of Pozzolan on the Strength of Concrete Containing Hybrid Fibers with FRP Screws

Seyyed Amin Razavian Amrei[1,*], Siavash Jahandar Lashki[2]

[1] Ceo at Design Rehabilitation of the North Consulting Engineer; seyedalirazavianamrei@pnu.ac.ir.

[2] Department of Civil Engineering, Ayandegan Institute of Higher Education, Tonkaban, Iran; siavashjahandar4@gmail.com.

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Abstract

Time, cost and quality are important factors in the implementation, which have a significant impact on the construction industry. Any type of progress and development that leads to the improvement of the level of these three factors always receives the attention and interest of civil engineers. The use of pozzolan and FRP systems is one of the important factors in increasing the resistance properties of concrete. In such a way that consumable resins are used for the purpose of gluing the composite layers to the concrete surface that is placed below it and the coatings are also used to protect the materials. Strengthening building columns with the help of screws is one of the common methods of increasing the strength and strength of these columns. This research aims to investigate different percentages of pozzolan and the number of turns of FRP in increasing the resistance properties of concrete. For this purpose, having three mixing plans, A, B and C, the required samples are taken from these three plans. Mixing plan A has no pozzolan, and mixing plans B and C have 10 and 20% pozzolan, respectively. Samples No. 1 without a screw and samples No. 2 and 3 have one and two turns. By conducting compressive strength tests, it has been observed that the highest percentage increase in strength is seen in sample B, which has 10% pozzolan. The results have shown that the simultaneous use of 10% pozzolan and 2 rounds of FRP had a significant effect on increasing the compressive strength of the samples at the age of 90 days. The results for the tensile strength test show that the use of pozzolan and FRP screw has a small effect on its increase, and this effect is about 6% in the highest case. The slump test results have shown that the slump of fresh concrete samples is reduced by adding 20% pozzolan. The test of the modulus of elasticity shows that the addition of pozzolan causes a decrease in the modulus of elasticity, and the use of FRP wrap partially compensates for this decrease in the modulus of elasticity.

Keywords: FRP wrap, Pozzolan, Compressive strength, Tensile strength, Permeability, Slump, Modulus of elasticity.

1 | Introduction

One of the most important types of structures is reinforced concrete structures. A combination of concrete with high compressive strength and steel with high tensile strength results in an ideal composite material that

Corresponding Author: seyedalirazavianamrei@pnu.ac.ir

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is widely used compared to other materials. Buildings, slabs, beams, bridge decks, tanks and pipes can all be built and implemented with reinforced concrete [1]. In the various stages of designing structures, architects and structural engineers are jointly involved and must recognize and consider the factors that may affect the structure in the long term and cause disturbances in the use of the structure. These conditions and factors refer to the limit states of the structure's operation. For an architect, the beauty of the structure is important, which is at the center of the audience's attention, and for a structural engineer, the safety and reliability of the structure against applied mechanical loads are important [2]. For an architect, the beauty of the structure, which is at the center of the attention of the viewers, is important, and for a structural engineer, the safety and reliability of the structure against applied mechanical loads are important [3].

But the important point here is that it is not only the mechanical loads that should be considered in the design of a complete structure, but it is also important to consider the effects and different atmospheric conditions that are effective on the useful life of the structure. In *Fig. 1*, factors that cause damage and deterioration of reinforced concrete structures are shown schematically.

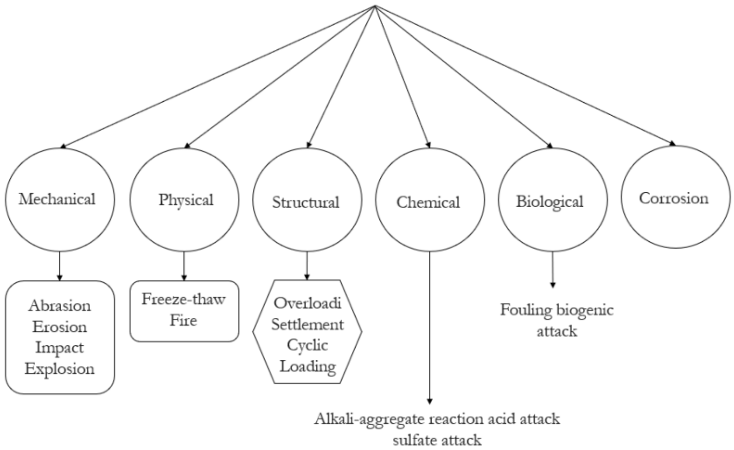
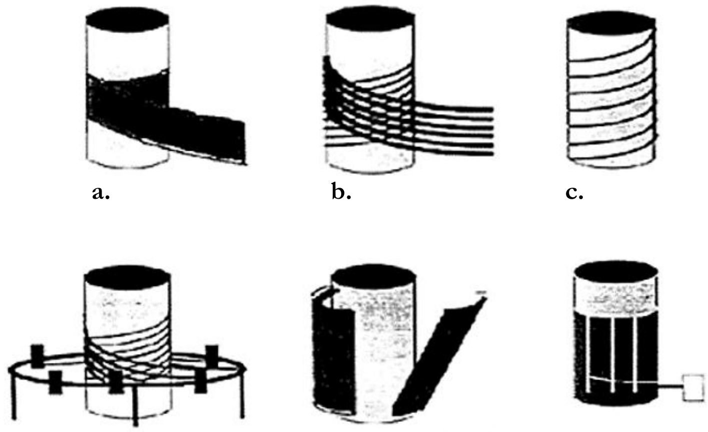


Fig. 1. Effective factors in the destruction of structures.

When an earthquake occurs, the low displacement capacity of the column causes a weak floor in the building and causes the overall behavior of the structure to be affected by this factor. To prevent these accidents, all buildings must be constructed, evaluated and calculated according to the strength of the earthquake in the area. Based on Code 360 regulations, these evaluations are classified into two groups for members controlled by force and by displacement. Normally structures are evaluated through force control methods. In this method, gravity loads and earthquake loads are applied to the structure in a combined manner, and the force due to these loads is calculated, and structural members are determined based on these forces. Currently, the method of estimating force in structural members is replaced by control methods based on force [4].

Fig. 2. The failure of the columns.

Before the 1990s, two methods of implementing an additional reinforced concrete sheath around the existing column and using a steel sheath with grout injection were among the usual methods for reinforcing reinforced concrete columns. Reinforced concrete sheath required more space and also increased the weight of the structure. For this reason, the steel sheath method was used more. Of course, using both methods required a lot of labor, and it wasn't easy to implement in the workshop. The steel sheath method has little resistance to weather attacks. With the development of the strengthening method of Masih concrete columns using FRP materials widely in recent years, the use of the steel sheath method has decreased. Wrapping the outside of the column using an FRP sheet or tape is one of the most common forms of reinforcing reinforced concrete columns with FRP materials [5].



a. b. c.

d. e. f.

Fig. 3. How to use FRP materials for concrete columns: a. Wrapping of fabric, b. Winding of tow, c. Use of composito cables/strips, d. Automated wrapping, e. Bonding of prefabricated shells, f. Resin infusion.

2 | Pozzolan

Compounds with the amount of silica and silicate in the form of a glass phase (amorphous) are called pozzolans, and this silica and amorphous silicate gave them acidic properties and caused them to have a strong affinity with lime and alkalis. Pozzolans are mainly divided into natural and artificial. Natural pozzolans are composed of tuffs and volcanic ash with a combination of dacite and Rio-dacite, which were deposited in the land or water environment due to explosive activities. Artificial pozzolans include metal smelting slags, baked clay and shale, and ashes from coal fuel, which have a glassy phase due to melting and then rapid cooling and are very similar to natural pozzolans in terms of physical and chemical properties. According to Iranian Standard No. 3433, pozzolans are natural siliceous and aluminosilicate materials that do not have cement properties by themselves, but in the presence of water with calcium hydrate, they produce materials with cement properties and show hydraulic properties [6].

2.1 | History of Pozzolans

2.1.1 | Natural Pozzolans

These materials have been used in the construction industry for many years. Use of lime mortar: Before the use of Portland cement became common, pozzolans were used in 1824. On the island of Crete, calcined clay and lime were used in 2000 BC. In ancient Greece, concrete with lime and pozzolan was used in 700 BC.

The Romans discovered volcanic ash and its uses about 2000 years ago in the Pozzoli region of Naples, Italy. The discovery of the Renn and Adernach terraces was also by Germans during the Roman period and dates back to about 2000 BC. The use of lime-pozzolan mortar by the Romans in most structures in palaces and durable waterworks has been very extensive.

In 1984, about 40% of cement in Italy was made with 25% natural pozzolan (3 million tons of pozzolan).

In 1910, rhyolite tuff was first used in the United States in the construction of a bridge in Los Angeles along with Portland cement. After that, natural pozzolans were used to build many dams. The major consumers of natural pozzolans after 1930 were China, Mexico and India. According to research, China consumes 12 million tons of pozzolan per year. The pozzolans of Jajrud Terrace, Lomar Red Soil and Haraz Pumice were discovered in Iran from 1320 onwards by the late engineer Hami. He continued to work on the pozzolans of Taftan and Bostanabad in the following years. Further work on the natural pozzolans of Jajroud Terrace, Momghan Dam, Sahand and Sabalan pumice, Bostanabad and Taftan pumice, and Kerman pozzolan has been carried out by other Iranian researchers.

Geological studies show that rocks with pozzolanic properties in Iran can be divided into four sub-types, which are shown in *Fig. 4* for the distribution of these rocks in Iran.

I. Green tuffs of the Karaj Formation related to the Lower Eocene with a dacite composition.

II. Green tuffs of the Oligo-Miocene sections with a rhyodacite to rhyolite composition.

III. Neogene pumice-bearing sections with a dacite and dacite-andesite composition.

IV. Quaternary ash and pumice flow with a dacite composition.

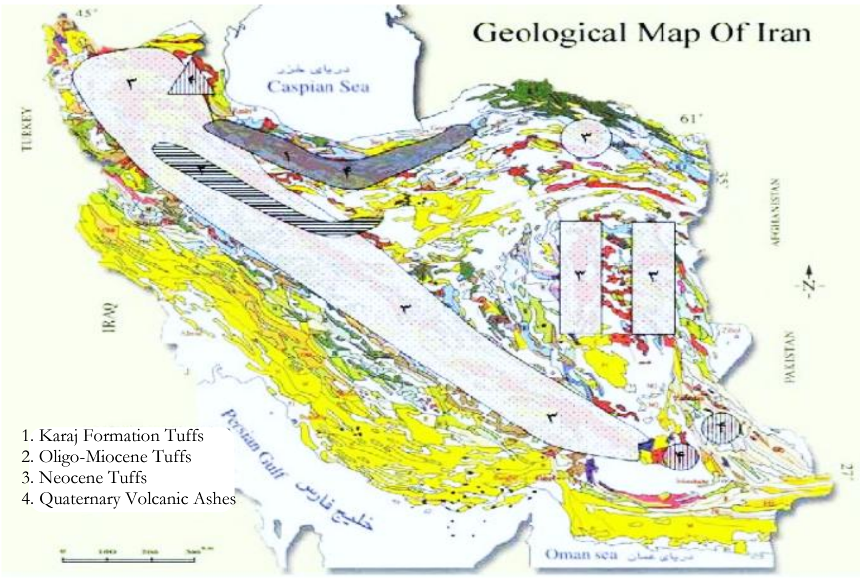


Fig. 4. Distribution of rocks with pozzolanic properties in Iran [4].

2.1.2 | GGBFS blast furnace slag

It has been produced in Europe since 1863. In the United States and Canada, its production and consumption have been high since 1978-1972. In some European countries, slag cement production reaches 60% of the total cement. Major projects include the Saudi-Bahrain road, which is about 40 km long, and the Conventional Bridge in Canada. Imported slag was used in the Shahid Rajaee Port dock projects and the Bushehr Nuclear Power Plant in the 1970s.

2.1.3 | Silica fume

The first test was carried out in 1950 at the Norwegian Institute of Technology. In the same years, it was used in tunnel lining in Oslo. It was first used in reinforced concrete structures in Norway in 1971. In 1976, the first standard was written in Norway. Then, it was used in ready-mixed concrete in Gothenburg, Sweden, and in Denmark and Norway, and was produced with cement in a factory in Iceland. It has been used in Canada since 1981. Malhotra and Meta have carried out extensive work since this year. Research work began in England in 1982. In Iran, the Iran Ferroalloy Factory and the Iran Ferrosilicon Factory have produced about 7,000 tons of micro silica each since 1993, but its use in concrete has actually boomed since 1997. Microsilica has been used in large projects such as Shahid Bahonar Pier, Chabahar Pier, Shahid Rajaee Port Complex, several fishing ports, Karkheh Dam spillway, Kowsar Dam, repairs to the Folad Pier, and large projects in the South Pars region.

2.1.4 | Rice husk ash

Rice husk ash was first used in Germany in 1924. Later, in 1956, America used it to make cement blocks. A few years later, in 1960, it was used in Pakistan. From 1972 onwards, extensive research began on this subject. In fact, the use of pozzolan was carried out by MENA from these issues onwards. Years later, more extensive work was carried out in Malaysia in 1979, India in 1981, and then Japan. In Iran, extensive research has been carried out on the properties and application of rice husk in concrete at the Building and Housing Research Center, the University of Science and Technology, and Amir Kabir University.

2.1.5 | Glassified clay

The use of lime has been noticeable since 3600 years ago. The Romans and Greeks have been familiar with its use since then. Pieces of brick and lime were used in India under the name of red. The use of this pozzolan with lime in Europe began in the 17th century. In countries such as Brazil, Denmark, France, England, America, and India, it dates back more than a hundred years to build dams and use them. One of the dams that used a core of lime and clay mixture was the Aswan Dam in Egypt in 1902. The production of metakaolin from heated kaolin has practically started since 1990 [7].

2.1.6 | Economic effects

By using these materials to produce cement, fuel and energy consumption can be saved. The low-cost factor of pozzolan itself and low production costs can lead to the introduction of an economical product to the market. Other advantages of these materials include increased durability and reduced maintenance costs in concrete structures.

2.1.7 | Environmental effects

During the cement production stages, each ton of clinker releases one ton of carbon dioxide gas into the air. Cement factory pollution is reduced by reducing cement production and replacing cement additives. Synthetic cement additives are products and wastes of various factories that can cause environmental pollution. The use of these materials in concrete, which is essentially a form of burial of these materials, can significantly reduce environmental pollution. Disturbance of the ecosystem is reduced by using cement additives and not using primary raw materials such as limestone and clay. The findings indicate that the use of cement additives increases the durability and useful life of concrete structures, and on the other hand, the lack of placement of construction waste reduces environmental pollution [8].

2.1.8 | Properties in concrete

Among the materials that reduce the efficiency of concrete are pozzolans (except fly ash). Using these materials reduces the heat generation of concrete and a relative improvement in water absorption and particle separation in concrete occurs. The mechanical properties of hardened concrete improve. These properties include strength and modulus of elasticity. In the long term, there is a reduction in permeability and an increase in the durability of concrete. In corrosive environments such as sulfate, chloride, and reinforcement corrosion, the phenomenon of alkaline reaction is more noticeable.

3 | Resins

Polymer resins are used to make the material that holds the fibers in the FRP layer and also to stick the layers on the concrete. If the adhesion between concrete and FRP layers is weak, there is a possibility of unexpected failure of the composite system and separation of different parts, so resin plays a very important role in connecting different parts [9]. It is common to use epoxy resin to connect FRP parts in important and sensitive void points, such as increasing the bending and shear strength of beams. Because the strength of epoxy resins is very high, in many cases, due to high pressure, the failures that occur are caused by the tearing of the concrete, which shows the weakness of the concrete. Because of this, the strength of concrete, which indicates the determining strength of the resin and the strength of the adhesive, does not have much effect, and as a result, fractures occur in the concrete part or in the concrete that is next to the contact surface of the adhesive and concrete [8].

3.1 | History of Development and Formation of FRP

Since one of the disadvantages of steel plates is corrosion and, as a result, the adhesion between steel and concrete is reduced, and their installation is difficult and requires heavy equipment, researchers have proposed the FRP system as a suitable alternative to steel. Some countries have accepted the FRP system as a replacement for steel plates, and therefore, this system has grown and developed significantly. For the first time in 1978, a report based on the results of laboratory work carried out on FRP materials was presented in Germany. After this research, the FRP system was used for the first time in Switzerland for the flexural strengthening of reinforced concrete bridges. The earthquake accidents that occurred in Japan in 1955 caused them to use the FRP system for the first time in 1980 to enclose and limit reinforced concrete columns.

The history of studies and research on the use of fiber reinforcements to increase the strength of concrete structures in the United States dates back to the 1930s, but this research did not grow much for many years. Over time, and in the 1980s, the American organizations FHWA and NSF continued their research in this field, starting the real growth and development of the reinforcement of concrete structures. The results of this research were used in many projects in this city and under various environmental conditions. The development of regulations and FRP is growing in Europe, Japan, Canada and the United States of America. Since about 20 years ago, the Japanese Society of Civil Engineers has also published guidelines on the use of FRP materials in concrete structures [10].

3.2 | Methods of Manufacturing FRP Composites

Carbon, glass and aramid fibers are commonly used in the manufacture of these materials. FRP is formed by placing fibers together in a resin. The resin continuously binds these separate fibers together and connects them. There are also different types of resins used, the most common of which are polyester, vinyl ester and epoxy. FRP is divided into three different types depending on the type of fibers used: GFRP (glass fiber reinforced polymer sheets), CFRP (carbon fiber reinforced polymer sheets) and AFRP (aramid fiber reinforced polymer sheets) [11]. To increase the strength of reinforced concrete structures with the FRP system, two methods are used: the first method is wet bonding, and the second method is the use of prefabricated FRP materials (*Fig. 6*). In the first method, which is wet bonding, resin is used at the site to impregnate non-woven fibers with fibers held in one direction (*Fig. 5*). In the second method, depending on the type of use, prefabricated FRP materials can be produced in various forms that are suitable for reinforcing beams against bending or in the form of plates that can be used to wrap around columns. During the execution of work at non-level intersections and with curves and edges of the section, the first method, namely wet bonding, is more convenient, but if prefabricated FRP is used in this case, the result of the work will be of higher quality. There is another method that is not so common. This method is very similar to the wet bonding method, which is called resin impregnation. All types of FRP materials are packaged and come with instructions, which should be followed carefully. If the wet bonding method is used, this instruction should be followed more closely [12].

Fig. 5. Wet gluing method [13].

Fig. 6. Prefabricated FRP materials [13].

4 | Advantages of FRP

One of the important advantages of this system is its very high resistance to corrosion and high resistance to weight ratio. Other features of the FRP system include its lightness, despite its very high resistance, which leads to ease of transportation and reduction in the cost of its use and labor. The high resistance of this system against corrosion makes its performance durable. The weight of FRP plates is only 20% of the weight of steel plates, although their resistance is more than twice that of steel plates, and this resistance can be increased up to ten times. FRP composite materials have other uses, such as their use in the aviation industry, which has been using composite materials for years. Its only limitation for use in construction engineering is due to the high cost of these materials, which is decreasing over time, which will result in increasing use. Despite the high cost of FRP in the field of strengthening structures, due to the ease of implementation, the low cost of the implementation stage, as well as other advantages of this system, it can be called one of the most effective ways of strengthening concrete structures.

5 | Components of FRP

Usually, the composite is formed by mixing two or more different microscopic materials. The important feature of this mixture is that after mixing, it creates a clear boundary and retains all its physical and chemical properties. In general, this mixture, based on a series of criteria, together has better properties than its components.

In composites, there are the following two distinct areas:

I. Continuous phase (matrix).

II. Discontinuous phase (amplifier).

Each of the materials in the composite has a specific task. For example, fibers in this system are the main load-bearing member of the structure. The function of the matrix in this system is to keep them in place and their desired arrangement. Also, matrices act as a load transfer medium between fibers and protect them from environmental damage due to increased temperature or humidity.

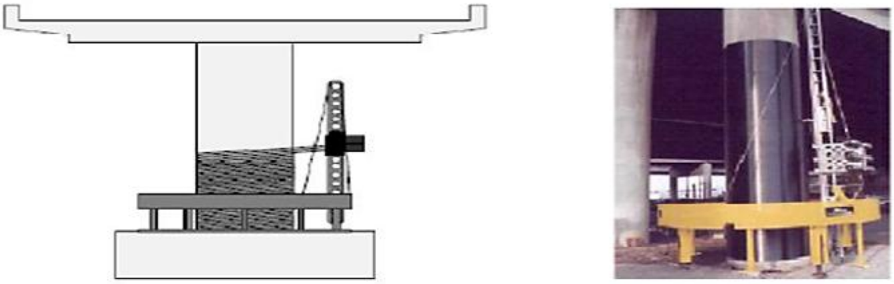


Fig. 7. Automatic column winding system.

6 | Gluing FRP Fibers

To attach FRPs, first, these fibers are cut into sheets, and then they are uniformly covered on the surface using a brush and glue, and then they are moved on the attached FRPs using roller brushes until they are completely covered on the surface. Paste the comment. Also, this will make the bubbles that exist at the FRP connection to the surface be taken and the FRP will stick to the surface completely.

Fig. 8. Installation of FRP fibers on resin.

7 | Conclusion

Considering the role of lightweight concrete in various structures and the end of the resistance properties of concrete in the case of lightning, screwing can be used to compensate for this reduction in strength. Especially since lap screws are very useful in columns, and FRP laps can help a lot in strengthening the columns, and in the case that lightening causes a sharp decrease in the resistance properties of concrete, it is suggested to use 2 laps for strengthening. It is suggested to use 10% pozzolan along with 2 rounds of FRP in the construction of important structures such as the columns of bridges and towers. This will result in an increase in compressive and tensile strength over time at high ages of concrete.

Authors' Contributions

S. A. R.: Research Design, Data Curation, Software, Investigation, Writing-Original Draft, Methodology, Conceptualization, and Visualization. S. J. L.: Validation, Formal Analysis, Writing-Review & Editing, and Validation. The authors have read and agreed to the published version of the manuscript.

Data Availability

All data supporting the reported findings in this research paper are provided within the manuscript.

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Conflict of Interest

The authors declare that in this paper, there is no conflict of interests.

Consent for Publication

All authors have provided their consent for the publication of this manuscript.

Ethics Approval and Consent to Participate

No studies involving human participants or animals were performed in this research.

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