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Physical and Mechanical Properties Investigation of Concrete with Rice Husk Ash and Recycled Aggregate

Soodabeh Mehri[1,*], Seyyed Hamzeh Taghavi[2]

[1] Department of Architecture and Ubran Planning, Savadkooh Branch, Islamic Azad University, Iran; Mehri@iausk.com.
[2] Department of Civil engineering, Mohammad Baqer University of Sari, Mazandaran, Iran; hamzeh.taghavi94@gmail.com.

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Abstract

Over the past years, extensive studies have been conducted on concretes containing rice husk ash and recycled aggregate, which have shown the advantages of those concretes. Today, in most parts of the world, there has been a huge evolution in concrete technology to achieve concrete with high strength. Considering that the compressive strength of concrete is one of the most important mechanical characteristics of concrete and also one of the main parameters of concrete design, extensive research has been done by researchers to investigate the factors influencing the compressive strength of concrete. In this thesis, the physical and mechanical properties of concrete with rice husk ash and recycled aggregate have been studied. The results of this laboratory study show that the compressive strength of concrete containing 30% recycled aggregate and rice husk ash is higher than that of 40%. Also, the average 7-day compressive strength of concrete containing 30% recycled aggregate and rice husk ash is 288, and the average of 40% is 218.5, which indicates that the sample is more than 30%. The average 28-day compressive strength of concrete containing 30 The percentage of recycled aggregate and rice husk ash is 289. The average of 40% is 314, which shows that the 40% sample is more. Also, the 28-day tensile strength of concrete containing 30% recycled aggregate and rice husk ash with a water-to-cement ratio of 0.377 is equal to 39. The average of 40% is 42, which indicates that the tensile strength of the 40% sample is higher.

Keywords: Mechanical performance, Rice husk ash, Recycled aggregate, Compressive strength, Tensile strength.

1 | Introduction

In recent years, the use of concrete has grown significantly all over the world, and the use of concrete in the construction industry is increasing day by day. With this increasing trend, in the not-too-distant future, we will definitely face a shortage of mineral resources used for the preparation of natural aggregates, and we must look for a suitable alternative for natural aggregates [1]. Due to the limited life of concrete structures and the destruction of concrete structures due to natural factors such as earthquakes, floods, storms, etc., we are

Corresponding Author: Mehri@iausk.com
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always faced with a large volume of waste and destructive concrete that accumulates in landfills. It has caused many problems for the environment. The reuse of old waste concrete in new concrete as recycled concrete aggregates reduces the use of natural aggregates, preserves the environment, reduces energy consumption, and reduces construction costs [2].

The use of recycled concrete aggregates in new concrete in the form of fine and coarse grains as a substitute for natural sand due to the lack of stone materials in certain places, eliminating the purchase of ordinary concrete aggregates and the cost of Its transportation, especially in the place of destruction of old buildings, seems to be economical and reasonable. Although the use of this method is not yet common in our country and it is currently in the research phase, but has become legal in many advanced countries of the world, and now concrete contains waste concrete aggregates [3].

A study in the European Union shows that an average of about 28% of construction demolition waste was recycled in the late 1990s. Many of the European Union member countries follow the recycling of about 50 to 90 percent of construction demolition waste as a substitute for natural resources such as concrete, steel, wood, and mining materials. Recycling materials is usually cheaper than natural materials. For example, in Germany, the Netherlands, and Denmark, the recycling of waste materials has been reported to have a lower cost than emptying and disposing of waste materials [4].

For the first time, the recycling of waste concrete caused by the destruction of construction after World War II was done in Germany by Khalaf and Doni. Since then, extensive research work has been done in developed countries on the possibility of reusing recycled concrete in new concrete.

The waste resulting from the destruction of buildings can include broken pieces of destructive concrete, bricks used in buildings, or street tables and sidewalks. Therefore, recycled aggregates can be obtained from the demolition of buildings, bridge foundations, runways, and road subgrade concrete. The concrete that is made of these materials is called concrete containing waste aggregates [5].

Regarding the recycling technology of turning concrete blocks into concrete aggregates, much research has been done, and the obtained results have been available for a long time. Based on the comprehensive research and development of projects carried out by the Ministry of Construction of Japan, the experimental quality standard of recycled materials for the use of this type of concrete in buildings was published in 1996. According to this plan, the recycling rate of materials in this country has improved from 48% in 1990 to 96% in 2000. Most of these recycled materials were used as sub-base materials in road construction [6].

In Japan, the transformation from a normal society to a sustainable society was felt as a necessary need due to the pollution of the natural environment, the depletion of natural resources, and the reduction of the capacity of final waste disposal facilities. In 2005, the construction industry accounted for 19% of the total volume of industrial waste (75 million tons per year), which is a reason for the reuse of construction waste materials in order to preserve the environment. In particular, the recycling of concrete parts, which constitutes 37% of construction waste, is a very important issue that should be promoted [7].

In 1989, about 330 million tons of aggregate materials were used in Ukraine, of which only 10% included recycled materials. About 220 million tons of aggregates were used in England in 2001, a quarter of which included recycled materials. In 2005, the amount of recycling in England and Scotland was about 67% and 50% of the use of waste materials related to construction. In Taiwan, after the severe earthquake that occurred in the center of Taiwan in 1990 and caused the destruction of 100,000 homes, a comprehensive plan was prepared for the management of waste and debris related to the destruction of structures. It has been reported that about 30 million tons of these wastes have been used in the reconstruction of destroyed structures, and about 80% of these wastes were used in new structures [8].

2 | Concrete Containing Waste Concrete Aggregates

In recent years, the global use of concrete has significantly increased, and its application in the construction sector continues to rise daily. With this upward trend, it is likely that we will soon encounter a shortage of the mineral resources needed to produce natural aggregates, compelling us to seek appropriate alternatives. Considering the finite lifespan of concrete structures and their vulnerability to natural disasters like earthquakes, floods, and storms, we frequently confront substantial amounts of waste and damaged concrete. The growing accumulation of this waste in landfills has led to several environmental issues. Utilizing old concrete waste as recycled concrete aggregates for new concrete minimizes the need for natural aggregates, safeguards the environment, lessens energy consumption, and cuts down on construction expenses [2], [3].

Utilizing recycled concrete aggregates as replacements for natural sand and gravel—both fine and coarse aggregates—in new concrete offers a sensible and cost-effective solution, especially given the limited availability of stone materials in certain areas. This approach eliminates the need to purchase traditional concrete aggregates and reduces transportation costs, particularly during the demolition of older structures. Although this technique remains relatively uncommon in our country and is still being researched, it has already become a legal requirement in numerous developed nations, where concrete now incorporates waste concrete aggregates [4].

According to a study conducted in the European Union, approximately 28% of demolition waste from construction was recycled on average in the late 1990s. Numerous EU member countries aim to recycle between 50% and 90% of construction demolition waste as a substitute for natural resources like concrete, steel, wood, and mined materials. The cost of recycling materials is typically lower than that of natural resources. For instance, in Germany, the Netherlands, and Denmark, recycling waste materials has been noted to be more economical than disposing of waste through landfilling [2].

Recycling waste concrete generated from construction demolitions was first conducted in Germany by Khalaf and Doni after World War II. Since that time, extensive research has been undertaken in developed nations regarding the feasibility of reusing recycled concrete in the creation of new concrete. Demolition waste may consist of: shattered concrete pieces, bricks from structures, or paving from streets and sidewalks. As a result, recycled aggregates can be sourced from the dismantling of buildings, bridge supports, airport taxiways, and concrete from roadbeds. Concrete produced from these materials is referred to as waste aggregate concrete [4].

In relation to the technology for recycling concrete blocks into concrete aggregates, extensive research has been conducted, and the findings have been accessible for a considerable time. Following thorough research and development initiatives undertaken by Japan's Ministry of Construction, the Experimental Quality Standard for Recycled Materials intended for use in this type of concrete within buildings was issued in 1996. As a result of this initiative, the recycling rate of materials in Japan rose from 48% in 1990 to 96% in 2000. A significant portion of these recycled materials was utilized as sub-base materials in road construction [5].

In Japan, the shift from a conventional society to a sustainable one was seen as an urgent necessity due to issues like environmental pollution, depletion of natural resources, and the diminishing capacity of final waste disposal facilities. In 2005, the construction sector was responsible for 19% of the overall industrial waste produced (75 million tons annually), highlighting the need to recycle construction waste materials to safeguard the environment. Notably, the recycling of concrete components, which make up 37% of construction waste, is a critical issue that needs to be advanced [5].

In 1989, Ukraine consumed approximately 330 million tons of aggregates, with only 10% of that being recycled. In 2001, the United Kingdom utilized roughly 220 million tons of aggregates, with about a quarter recycled. By 2005, the recycling rates for construction waste were approximately 67% in England and around 50% in Scotland. Following a devastating earthquake in central Taiwan in 1990 that led to the destruction of 100,000 homes, a detailed plan was established for handling demolition waste. Reports indicate that around 30 million tons of this waste were repurposed in the rebuilding of demolished properties, with about 80% used in new constructions [5].

Hong Kong, home to approximately 6.8 million residents and around 1.2 million households, is characterized by its mountainous terrain, making it necessary to demolish older buildings and replace them with skyscrapers to add new floors. Since local landfills reached capacity in 2002 after operating for eight years, it became crucial to find methods for reusing demolition waste for ongoing development. To tackle this issue and encourage the use of recycled concrete aggregate in the region, the Hong Kong government established a temporary recycling facility to process various sizes of recycled concrete aggregate from construction debris. In the production of low-grade concrete C20, entirely recycled coarse aggregate is utilized, whereas for the creation of high-strength concrete (C35-C25), only 20% of the coarse aggregate is recycled.

Fig. 1. A picture of a concrete recycling center in Hong Kong.

3 | Rice Husk Ash in Concrete

In recent years, there has been a notable rise in the support for utilizing alternatives to cement. A key factor contributing to this trend is the reduction in cement usage, as the process of manufacturing cement is both costly and environmentally damaging, while its demand continues to grow annually. Rice husk, a byproduct of the production process, is utilized as fuel in various countries; however, its incineration, which serves to dispose of it, results in environmental contamination. Since the late 1960s, considerable investigations into the pozzolanic characteristics of rice husk ash in concrete have been conducted, and this research persists today, notwithstanding the existence of appropriate furnaces for controlled burning and methods for removing impurities from rice husk ash through chemical processes. Of all agricultural byproducts, rice husk ash is known to have the highest silica content. Rice husk comprises approximately 20% hydrated amorphous silica, which, when burned under controlled conditions, yields highly reactive amorphous silica. Incorporating rice husk ash as a partial substitute for cement not only reduces costs in the construction sector but also, when processed correctly and used optimally, greatly enhances the strength characteristics of concrete.

According to the standard referenced in ASTMC618, rice husk ash can be classified as an artificial pozzolan. By combining rice husk and lime in equal amounts and subjecting the mixture to heating in a suitable oven at 600 °C for 4 hours, a hydraulic adhesive material can be produced that resembles cement, which is itself a type of pozzolanic material. Under specific burning and grinding conditions, the chemical makeup of rice husk ash consists of 85-95% silica. The generation of high-quality rice husk ash with respect to its pozzolanic properties is influenced by the burning conditions, including the regulation of temperature and duration, which are essential for producing ash of the desired quality. The active silica found in rice husk ash contributes to the concrete matrix, enhancing both the strength and durability of the concrete. The extent of this strength increase is influenced by the processes used to prepare rice husk ash, such as the method and temperature of combustion.

A key factor that influences the pozzolanic effectiveness of rice husk ash is the extent of its grinding. This factor is crucial because the microstructure of the ash from combustion, which consists of a silica framework, is entirely porous and fragile, and as grinding increases, the particle size will diminish. This decrease in particle size will result in a greater volume of water needed to saturate the surfaces of the ash particles.

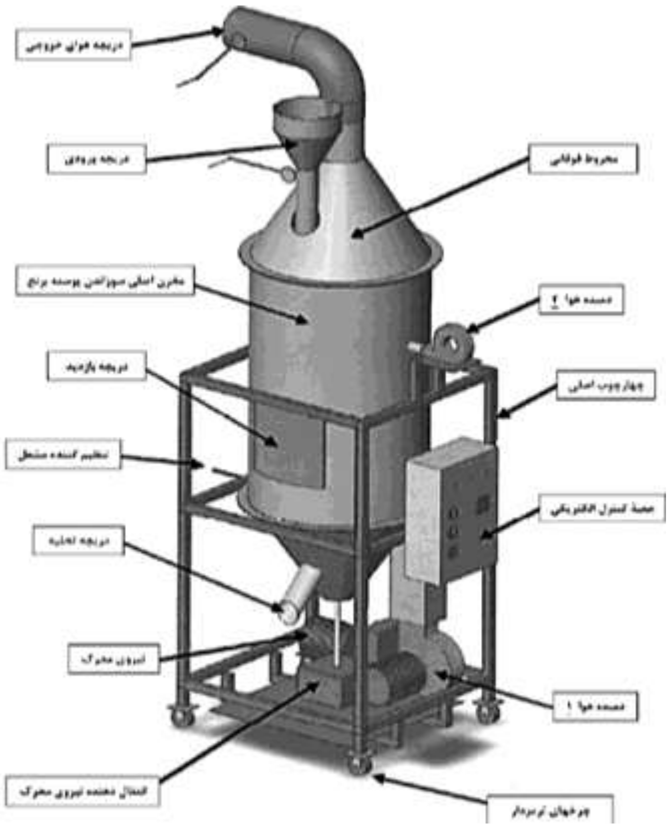

Fig. 2. Schematic view of the rice husk ash kiln built at Amirkabir University of Technology.

4 | The Effect of the Method of Burning on the Appearance of Rice Husk Ash

Fig. 3 shows some samples of rice husk ash that were burnt at 110 degrees Celsius for different periods. As the burning time increases, the white ash becomes more colored. This means that its carbon content has decreased. On the other hand, it can be seen that with the increase in burning temperature (in case of constant burning), the color of the ash became darker, and its carbon content increased [9].

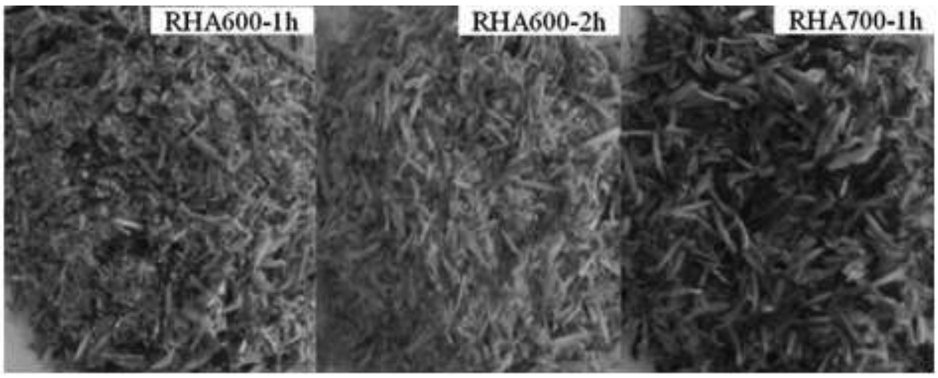

Fig. 3. Appearance of rice husk ash.

5 | The Effect of Rice Husk on Mechanical Properties and Continuous Durability

5.1 | Compressive Resistance

The compressive strength of concrete can reflect the process of cement and pozzolanic activity of concrete and the cohesion of cement paste and aggregates. By adding rice husk ash to concrete, the compressive strength of concrete decreased in the early days, but with the passage of time and the performance of pozzolanic reactions, this decrease in compressive strength improved. Found [10]. *Fig. 4* shows the effect of rice husk ash on the compressive strength of concrete.

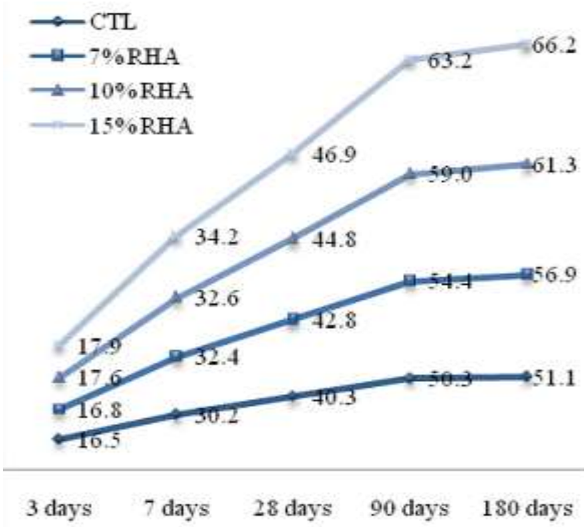

Fig. 4. Compression test results of a cubic concrete sample containing rice husk ash.

5.2 | Tensile Strength and Modulus of Elasticity

The tensile strength of concrete increases with its age; in addition, rice husk ash has a significant effect in increasing the tensile strength of concrete. Also, with the increase of strength, the modulus of elasticity has increased, and it shows a good effect of rice husk ash on the mechanical properties of concrete. *Fig. 5* and *Fig. 6* show the effect of rice husk ash on tensile strength and modulus of elasticity [11].

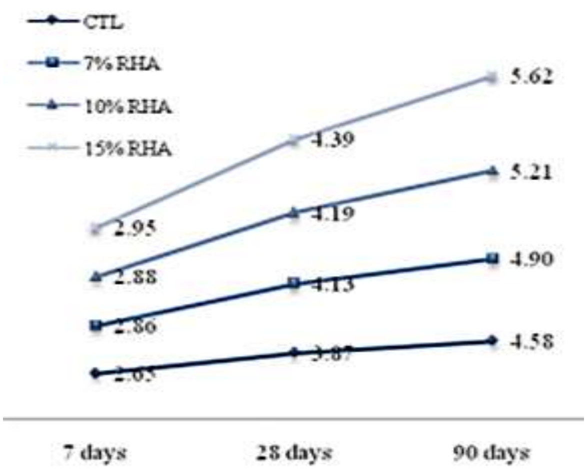

Fig. 5. Results of the tensile strength test of concrete containing rice husk ash.

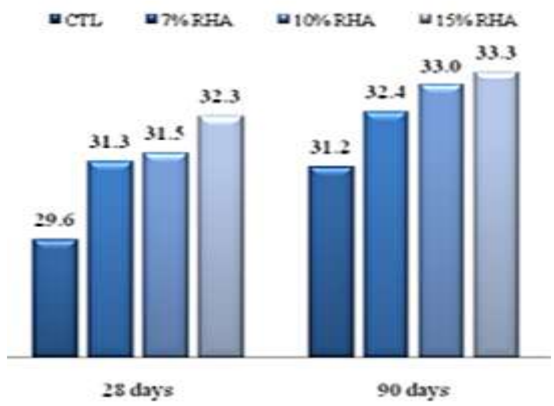

Fig. 6. Test results of the elasticity modulus of concrete containing rice husk ash [12].

6 | Slump Test

According to ACI 116-R90 regulations, workability is a property of freshly mixed concrete or mortar that determines the ease and uniformity of mixing, pouring in place, compacting, or polishing its surface [13].

According to ASTM C125, workability is the property that determines the work required to move freshly mixed concrete with minimal loss in uniformity. It is worth mentioning that the slump test does not measure the performance of concrete but describes its flow. By definition, fluidity is the relative mobility or the ability of concrete to flow, which is determined by the slump test and based on the ASTM C143 standard. To perform the slump test, fresh concrete is poured into the slump cone in three layers. Each layer is pounded 25 times using a hammer so that the height of each layer after compaction is approximately one-third of the height of the mold, and if after compacting the upper layer of the concrete surface lower than the edges of the mold, pour some concrete on it again and smooth its surface with a rod using roller movements. The act of lifting the mold should be done in approximately five seconds and with a continuous upward movement without applying lateral or rotational movement to the mold or concrete [14].

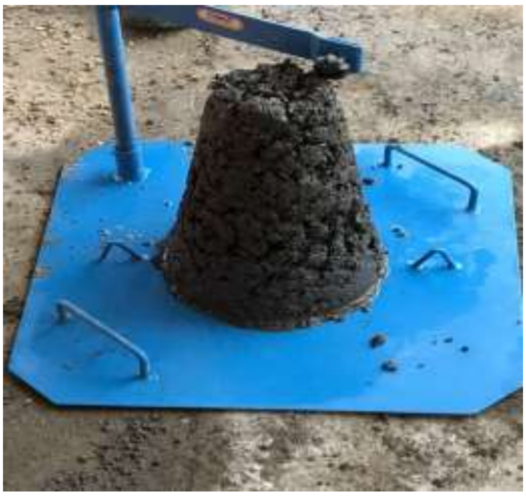

Fig. 7. Slump test [15].

7 | Conclusion

I. The results of the slump test are in the range of 7 to 10 cm, which is acceptable according to the quality of cement and the ratio of water to cement used. Meanwhile, the slump is 30% concrete containing recycled aggregate and more than 40% rice husk ash.

II. The compressive strength of concrete containing 30% recycled aggregate and rice husk ash is higher than that of 40%.

III. The average 7-day compressive strength of concrete containing 30% of recycled aggregate and rice husk ash is 288, and the average of 40% is 218.5, which indicates that the sample is more than 30%.

IV. The average 28-day compressive strength of concrete containing 30% recycled aggregate and rice husk ash is 289, and the average of 40% is 314, which indicates that the 40% sample is more.

V. The 28-day tensile strength of concrete containing 30% recycled aggregate and rice husk ash with a water-to-cement ratio of 0.377 is equal to 39, and the average of 40% is 42, which indicates that the tensile strength of the 40% sample is higher.

VI. The average elastic modulus of concrete containing 30% recycled aggregate and rice husk ash is 28.955, and the average elastic modulus of concrete containing 40% recycled aggregate and rice husk ash is 36.645, which indicates that the elastic modulus of the sample is 40% higher.

VII. Recycled aggregate with low quality does not affect the tensile strength of concrete.

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Author Contribution

All authors made equal contributions to the conception, design, and execution of this study. Soodabeh Mehri was responsible for the research design, data collection, and initial drafting of the manuscript, while Seyyed Hamzeh Taghavi focused on data analysis, manuscript revision, and granting final approval for the version to be published. Both authors reviewed and consented to the final manuscript.

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Data Availability

The data that support the findings of this study can be obtained from the corresponding author upon reasonable request.

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