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MECHANICAL PROPERTIES OF RECYCLED AGGREGATE CONCRETE WITH STEEL FIBER: A REVIEW

Ashtar S. Al-Luhybi*

Civil Department, Engineering College, Mosul University
Mosul, Iraq

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A B S T R A C T

In the building process, the recycling of aggregates arising from building and demolition debris is one of the best alternatives to maintain the environment and the areas needed to bury these debris. It also helps to preserve natural concrete sources from depletion efficiently. The use of recycled aggregates in new concrete manufacturing, however, leads to a decrease in concrete's strength characteristics. This reduction rises with the rise in the percentage of recycled aggregates used in concrete, which has caused many researchers to undertake many researches on how to enhance the characteristics of recycled aggregate-containing concrete. This paper presents several studies that examined the effect of adding steel fiber to improve the properties of concrete containing a coarse recycled aggregate.

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الخواص الميكانيكية للخرسانة الحاوية على ركام معاد مع الألياف الفولاذية: مراجعة

عشتار صالح اللهيبي/ قسم الهندسة المدنية، كلية هندسة ، جامعة الموصل

الخلاصة

ان إعادة استخدام الركام الناتج من مخلفات البناء والهدم في عملية البناء مرة ثانية هي من افضل الحلول التي تم اتباعها للحفاظ على البيئة والمساحات المطلوبة لدفن هذه النفايات كما انها تساعد بشكل فعال في الحفاظ على المصادر الاولية الطبيعية المكونة للخرسانة من الاستنزاف. الا ان استخدام الركام المعاد في انتاج خرسانة جديدة يؤدي الى انخفاض في تحمل الخرسانة ويزداد هذا الانخفاض مع زيادة نسبة الركام المعاد المستخدم في الخرسانة، الامر الذي قاد الكثير من الباحثين الى اجراء العديد من البحوث والتحريات التي تبحث في كيفية تحسين خواص الخرسانة الحاوية على ركام معاد. يعرض البحث الحالي العديد من الدراسات التي تناولت تأثير اضافة الالياف الفولاذية لتحسين خواص الخرسانة الحاوية على ركام خشن معاد.

الكلمات الدالة: حماية البيئة، ركام خشن معاد، ركام كونكريت معاد، خصائص ميكانيكية.

* Corresponding Author: E-mail: aziztaher@uomosul.edu.iq

1. Introduction

Because of its low cost and material accessibility, concrete is presently one of the most commonly used construction products in all over the world [1]. There are more reasons why concrete is a very commonly used material in construction. In case it has been designed and produced in an appropriate manner, it will have great mechanical properties and durability. Concrete is characterized by its ability to take any form or mold, adaptable, relatively fire resistant, available at reasonable prices [2]. Its maintenance costs are low, easy to handle, good at carrying compression. For these purposes, in the building industry, concrete is the most appropriate material [3]. Around the world, concrete is produced at more than 10 billion tons per year, to prepare 10 billion tons of concrete, 10 billion tons of concrete materials are needed [4]. This means that the concrete industry

consumes and drains large amounts of natural resources and therefore causes environmental, economic and energy losses [5].It was also found that the total quantities of construction and demolition debris around the world is estimated to be (2-3) billion per year [6].Singh and Sharma [7] mentioned some of the reasons that increase the volume of construction debris:

- Many of the old buildings, concrete pavements and bridges are over-old; their use has become limited as a result of the deterioration it has suffered, which cannot be repaired and need to be demolished.
- Demolition of concrete structures that do not serve the current need.
- The need for new facilities for better economic growth.
- The constructions collapse and turn into debris when exposed to some natural disasters such as earthquakes, hurricanes and floods.
- Sometimes the debrisis produced by man-made wars.

These debris and their large quantities are either collected in the collection site of waste and accumulate annually and since they are durable, not biodegradable or decomposable, they occupy large areas of the earth [8, 9], or may be disposed of by burying them in landfills [10-12]. In both cases, it is another environmental problem.

Therefore, on the one side, natural resources are depleted and on the other, big amounts of building and demolition waste. Therefore, it was necessary to find a solution that reduces the depletion of natural resources and the exploitation of these wastes and reduce the amounts spent on burying and preserving the environment. One of the techniques used for recycling is the partial or total substitute of the ordinary aggregate in the manufacturing of fresh concrete. Where the concrete blocks that do not contain pieces of wood, reinforcement steel bars or gypsum products are broken into sizes similar to the size of the natural gravel and then washed and separated into certain sizes after sifting with sieves. Reusing debris is a cheap source of aggregate for non-gravel countries [13], this is in addition to solving the two previous environmental problems.

2. Recycled aggregate concrete

Recycled aggregate concrete can be defined as concrete containing the recycled (coarse or fine) aggregate arising from demolition and building debris as a complete or partial substitute of the natural aggregate [5]. Although the use of recycled aggregate from construction and demolition debris has solved two environmental problems, its use in the formation of new concrete negatively affects its mechanical properties. This is due to a major reason, which is the presence of the old cement mortar attached to the recycled aggregate, this mortar causes increased water absorption of the new concrete[14,15].The bulk density of the concrete, which contains a coarse recycled aggregate, is less than the normal concrete. This is also due to the cement paste on the surface of the recycled aggregates [16, 17]. The modulus of elasticity of the concrete containing the recycled aggregate is reduced in value compared to the conventional concrete [18, 19].

Several studies have been conducted on the effect of the addition of recycled aggregates on the compressive strength of the concrete. The results varied, it was found that the compressive strength of the concrete containing the recycled aggregate from the construction and demolition debris is less than normal concrete [20-26]. Many researchers have demonstrated that the recycled aggregates from well-known and good-quality concrete give concrete with an equivalent compressive strength and sometimes higher than the compressive strength of natural concrete [27-29]. Although the findings differ, it is not always known whether the recycled aggregate is from good quality concrete or not. The effect of the use of recycled aggregates in concrete on tensile and flexural strength has been studied and investigated in numerous researches. It has been concluded that the use of recycled aggregates reduces tensile and flexural strength [30-33]. Since in the recycled aggregate concrete, the content of the cement paste is high, this results in dry shrinkage and creep values higher than normal concrete [34].

Based on the above, a lot of studies is being performed to enhance the characteristics of concrete containing recycled aggregate, one of these methods is what researchers did by treating the recycled aggregate before using it either by immersing it with special solutions [35], or through processing using polymer materials [36], or by making the recycled aggregate saturated by immersing it with water before adding it to the concrete mixture and this is to reduce the water absorption of the old cement paste [37]. Some researchers have improved the characteristics of concrete containing recycled aggregate using plasticizers, which reduce the amount of water added to the mixer to get good workability for the concrete [9]. There are also researchers who have worked to improve the properties of this type of concrete through the addition of pozzolan materials [38-40]. There are other studies that investigated the effect of adding pozzolan materials and steel fibers on the behavior of concrete containing recycled aggregates [41-42].

3. Research importance

Several studies have been conducted to determine the extent, to which construction and demolition debris can be used as a recycled aggregate in concrete, the results showed that they could be used. The effect of many variables and additives for this type of concrete was also studied to improve its properties. The current research aims to present the results of some studies that investigated the effect of adding steel fibers to the concrete containing a coarse recycled aggregate. The research was limited to the selection of researches that study the effect of adding steel fiber without the addition of any other materials and without the presence of steel reinforcement, in order to determine the effect of the addition of steel fiber on the mechanical properties of the concrete containing the

recycled aggregate and to make the picture clear to the rest of the researchers.

4. The influence of using steel fiber on the mechanical characteristics of the recycled aggregate concrete

Bhikshma and Manipal (2012) [43] investigated the effect of the addition of steel fibers on mechanical characteristics compressive, tensile and flexural strength and the modulus of elasticity of the recycled aggregate concrete. The two researchers conducted a practical study in which two concrete mixtures were prepared with two different compressive strength (20 and 30MPa), and for both mixtures steel fibers were added with two different aspect ratios (40 and 60). For each aspect ratio, the steel fibers were added with variable ratios (0,0.5,1,1.5%). The results showed that the addition of steel fiber improved the mechanical properties of recycled aggregate concrete. Where they found that when adding the steel fibers by (1.5%) there is an increase in compressive, tensile and flexural strength of the recycled aggregate concrete with grade 20 and for two aspect ratios (40 and 60) reached to (25-31%), (28-30%) and (23-25%) respectively. The increase in compressive, tensile and flexural strength when adding the same percentage of fiber to the recycled aggregate concrete with grade30 and for two aspect ratios (40and60) reached to (28-22%), (39-36%) and (29-26%) respectively. The results showed that there was an increase in the values of the modulus of elasticity and for both mixings.

Hameed (2013) [44] also studied the effect of adding steel fiber on the properties of the concrete containing recycled aggregate, the diameter of this fiber was (0.3mm) and length (2.3mm) where the researcher casted mixtures without recycled aggregate and without steel fibers and mixtures containing recycled aggregate and without steel fibers. Other mixtures containing recycled aggregate with different ratios ranging from (0%) to (100%) were also casted and with the increment of (25%) as an alternative to the normal aggregate with the presence of steel fiber with ratio (6%) of the total weight of concrete. The results showed that the steel fiber improved the mechanical properties of the recycled aggregate concrete compared to the recycled aggregate concrete and without using of steel fiber in terms of compressive strength, tensile strength and modulus of elasticity.

Sryh and Forth (2015) [45] conducted a practical study aimed at determining the effect of addition of steel fibers on compressive, tensile, flexural strength and the modulus of elasticity of the recycled aggregate concrete. Where the researchers casted 12 concrete mixtures .These were divided into three groups, the first group used only normal aggregates with a change in the ratio of steel fiber where four ratios were used (0, 0.5, 1, 1.5%), in the second and third group of mixtures, the recycled aggregates were used with (50and 100%) as an alternative to the normal aggregate with the addition of steel fibers by four ratios (0, 0.5, 1, 1.5%). Based on the results of the tests, the researchers concluded that the use of recycled aggregates with (50%) in the concrete resulted in a decrease in compressive, tensile, flexural strength and a decrease in the modulus of elasticity by (5, 15, 10 and 20%) respectively. The use of recycled aggregates with (100%) in concrete caused a decrease in compressive, tensile, flexural strength and modulus of elasticity values with percentage that reached to (10, 30, 22, 30%) respectively. This is due to the presence of mortar attached to aggregates and the cutting of bricks and mud. As for the effect of adding fiber to the mixtures, they found that the use of fiber has improved the mechanical characteristics of all mixtures, the addition of steel fibers increased the compressive, tensile, flexural strength and increased the modulus of elasticity. The researchers also observed that the compressive strength of the standard cylinders was higher than that of the cubes. The reason for this is the direction of the fiber is relative to the load. In cylindrical specimens, the direction of the fibers is perpendicular to the direction of the loading, unlike that in the cubes which is parallel.

Krishna (2015) [46] investigated the effect of the addition of steel fibers on compressive and flexural strength of the recycled aggregate concrete where the researcher prepared concrete mixtures containing different percentages of recycled aggregates (0, 25, 50, 75, 100%) as alternative to the normal aggregate. The researcher also added different percentages of steel fiber for each mixture (0, 1, 1.5, 2%). The results showed that the use of steel fibers increased the compressive and flexural strength of the recycled aggregate concrete for all the ratios of replacement and for all added fiber ratios. The researcher also noted that the relationship of (load-deflection) of the beams were not affected when recycled aggregates are used with steel fiber when compared to beams containing natural aggregate.

Pradeep and Gowda (2016) [47] studied the effect of the use of steel fibers of the mesh type on the compressive and flexural strength of the recycled aggregate concrete. Where the researchers prepared concrete mixtures with variable content of recycled aggregates as an alternative to natural aggregates (0, 10, 20, 30%). For each content three variable ratios of fiber were added (0, 5, and 10%) of the total volume of the mixture. The results showed that the addition of steel fibers improved the compressive strength where the increase was from (11 to 24%) with the presence of recycled aggregates. They also noted that the absorption capacity of the beams prepared from recycled aggregate concrete and steel fibers which is calculated from the measurement of the area under the (load-deflection) curves of the beams is about 10-40 times higher than the normal mixtures.

Chandar et al. (2017) [48] investigated the effect of adding steel fibers to concrete with the presence of recycled aggregates, where they casted specimens of mixtures containing neither recycled aggregate nor steel fiber as control specimens and they also casted other mixtures containing recycled aggregate with ratio(100%) as an alternative to the normal aggregate with the addition of steel fibers by five ratios (0, 0.5, 1,

1.5, 2%). The results showed that the compressive strength of the recycled aggregate concrete was decreased by (2.36%) but it is increased with the addition of steel fiber, the increase in compressive strength when adding steel fibers by (1%) reached to (10%). The addition of steel fibers improved the tensile strength of the recycled aggregate concrete and the increase is evident at the addition ratios (1 and 1.5%).

Bhan and Kaur (2018) [49] investigated the effect of the addition of steel fibers on the mechanical properties of concrete containing recycled aggregate, which include compressive, tensile and flexural strength. Where the researchers studied the effect of changing the ratio of replacement of normal aggregates with recycled aggregates and the effect of changing the ratio of steel fibers on mechanical properties. Nine concrete mixtures were caste, three of which had the percentage of recycled aggregate (0%), the variable was the ratio of steel fiber, three ratios were adopted in this study (0, 0.5, and 1%), and the rest of the mixtures were divided into two groups. The variables in these two groups were the percentage of recycled aggregates where two ratios (50 and 100%) were added as an alternative to normal aggregates and the content of steel fibers where three different ratios were used (0, 0.5, 1%), after testing the specimens, the researchers noted that there is a decrease in compressive, tensile and flexural strength of the concrete with increased percentage of recycled aggregates. They also found that the use of steel fiber enhanced the compressive, tensile and flexural strength and it increased by increasing the proportion of steel fiber.

Sryh and Forth (2016) [50] investigated the effect of adding steel fibers on dry shrinkage and creep of the recycled aggregate concrete. Where the researchers prepared nine concrete mixtures divided into groups where the variables in the mixtures were the percentage of recycled aggregates, for which they used three ratios (0, 50 and 100%) as substitutes for normal aggregates. They also used three ratios of steel fiber (0, 0.5, and 1%). The results showed that by increasing the proportion of recycled aggregates, dry shrinkage increases and the values of compressive creep and tensile creep increase, but they found that the addition of steel fibers to the recycled aggregate concrete reduced the percentage of increase in the values of dry shrinkage, compressive and tensile creep by ratio reaching to (15, 5 and 20%) respectively, with the addition of (1%) of steel fiber. They also noticed that the effect of steel fiber is evident on the tensile creep rather than the compressive creep.

Ghorpade (2013) [51] studied the effect of adding steel fibers on shear strength of high strength concrete containing recycled aggregate where the researcher prepared concrete mixtures containing recycled aggregate with different ratios (0,20,40,60,80,100%) and for each mix of these mixtures added two ratios of steel fiber (0.1%). The results showed that when the percentage of recycled aggregate was increased, shear strength was reduced but the addition of steel fiber improved and increased the shear strength. The researcher recommended that it is desirable for considerations of shear strength that the replacement of natural aggregates with recycled aggregates should be up to 20%.

Heeralal et al. (2009) [52] studied the effect of fatigue behavior of concrete beams containing recycled aggregate and steel fibers. The researchers carried out their study on standard beams of dimensions (100 × 100 × 450 mm), which were examined under static load and fatigue load. Variables in this study were the percentage of recycled aggregates, where the recycled aggregates were used (0, 50, 100%), the ratio of steel fibers was 1% by volume. The results showed that with the increase in the percentage of recycled aggregate, the flexural strength of the beams decreased but increased by (15%) when adding the steel fiber. The researchers also noted that the number of loading cycles decreases with the increase of the percentage of recycled aggregate but it increases with the addition of steel fiber and failure is slow. The results showed that the absorption capacity of the beams containing recycled aggregate and steel fiber is higher than the beams without fiber. The results also showed that the maximum deflection at ultimate static load and maximum deflection at fatigue test of the beams were close for the same type of beam.

5. Conclusion

Based on the results of the studies, the following can be concluded:

1- Increasing the proportion of coarse recycled aggregate in the concrete mix negatively impacts the concrete's mechanical characteristics.

2- The use of steel fibers in the recycled aggregate concrete increases the compressive, tensile, flexural and shear strength, and works to increase the modulus of elasticity.

3- The use of steel fibers reduces the dry shrinkage and creep of the recycled aggregate concrete.

4- Steel fiber use increases the absorption ability of the beams containing a recycled aggregate.

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