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Reuse the Concrete Waste to Replace Coarse Aggregate: A Systematic Review

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Abstract: The construction demolition wastes (CDW) are often costly and hazardous to the environment. Recycling this disposal will push the way towards sustainability and environmental conservation. The most suitable component of CDW for recycling purposes is the concrete. This study reviews the previous founds in the utilization of waste concrete as coarse aggregates, often called recycle coarse aggregates (RCA), to be replaced with the natural course in several applications including concrete produces. Concrete that consists of recycled aggregate is often termed as recycled aggregate concrete (RAC). It is essential to go through the common properties of recycled concrete, fresh and hardened, to promote and escalate its application in the local construction industry. This research aims to review the significant factors that influence those properties including the replacement ratio and recent enhancing treatment methods to come up with greener recommendations for further improvements. Moreover, to highlight the most efficient uses regarding the recycled aggregate properties. Selected previously published founds in the Scopus database are reviewed and the results have been compared and analyzed for further discussion. High-level research techniques are used such as narrow-to-narrow limitations and systematic compartments to ensure the study outcomes quality. This study supports that the quality of recycled concrete is reduced with increasing RCA replacement ratio, but their overall performance is comparable to natural aggregate concrete (NAC). In addition, the recycled aggregate with the replacement ratio up to 30% of RCA is similar to the control concrete in compressive strength quality. This research will encourage local studies for heading towards developing and to facilitate this promised material.

Keywords: Construction Demolition Wests, Recycled Coarse Aggregate, Recycled Concrete, Compressive Strength Replacement Ratio.

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1. Introduction

Nowadays, growth in population and economy has influenced the construction industry leading to a necessity for infrastructural development, causing an enormous renewal of the built facilities which produce massive quantities of construction demolition waste (CDW). This has adversely affected the environment on one hand and contributed to the threat of depleting natural resources on the other hand. Recycling construction waste into useful building materials will help to overcome both problems at the same time. One such construction waste that is recyclable is concrete. While the world today is working towards sustainability, the necessity for recycling this material is increased as it produces a massive quantity of waste in form of construction demolition waste (CDW). Moreover, 50–95% of CDW can be recycled [1].

The most common outcome of recycling construction and demolition waste (CDW) is recycled aggregates that can be replaced with natural aggregates in various applications while offering economic and environmental benefits [2]. Because of the mortar adhering to its surface, RCA has some disadvantages versus NA. It is more porosity than NA, owing to a greater proportion of pore spaces and microstructure on the interface (and sometimes in the interfacial transition zone (ITZ)) [3].

Although the characteristics of recycled coarse aggregate (RCA) differ from natural coarse aggregate, it can be used for various construction purposes including as a replacement to the natural aggregate [4]. According to many experimental studies, the compressive strength of recycled aggregate concrete is highly related to several factors including original concrete properties, aggregate recycling process, treatment methods, and coarse aggregate replacement level. The study found that RCA and natural aggregates if mixed in a proportionate ratio can be used in both pavement and building construction [5].

In this study, selected published resources have been comprehensively reviewed and analyzed. Therefore, the database that is used to assist in forming this study scope is (Scopus Index), with effective limitation techniques such as the Narrow-to-Narrow search method. This study reviews the last two decades published founds on the significantly influenced properties of replacing natural coarse aggregates (NCA) with recycled coarse aggregate (RCA). Several compressive strength tests with 0, 25, 50, 75, and 100% RCA replacement are reviewed from previous experimental published documents, and the results have been compared and analyzed for further discussion.

2. Data Collection

For this research, the previous studies have been filtered, highlighted, and analyzed to form the study outcomes. Therefore, a comprehensive comparison was conducted about certain significant properties of the recycled aggregate concrete and its enhancement by different replacement ratios. As this review research relies on an enormous database, it is very significant to produce a suitable and effective search methodology. One more important thing to be considered is the narrow-to-narrow method of inputting the keywords to ensure the quality of the resources without any exception.

2.1 Methodology

This study contains very popular concepts, which made the research scope very large and more ramified. The first keyword that was used in this research is (Concrete) whereas the number of available documents was (419,090). By continuing the search process using the next keywords which are (Recycled Aggregate, and Coarse Aggregate) the number of documents to (17,690 and 7,894) respectively. This step of limitation has excluded about 96% of the scope to be ready for further limitation tools. It is impossible to go through all the RCA published resources, even only their titles, due to the huge number of resources (7,894 documents in this study). Limitation of the searching database is very necessary. However, the unsound limitation will impact the study background adversely leading to fewer quality data collection. On the other hand, some documents will be used out of the limitation, which depends on the important information that may be found from other sources to support this research. The following Figures (1) and (2) illustrate the methodology and limitation tools that have been used.

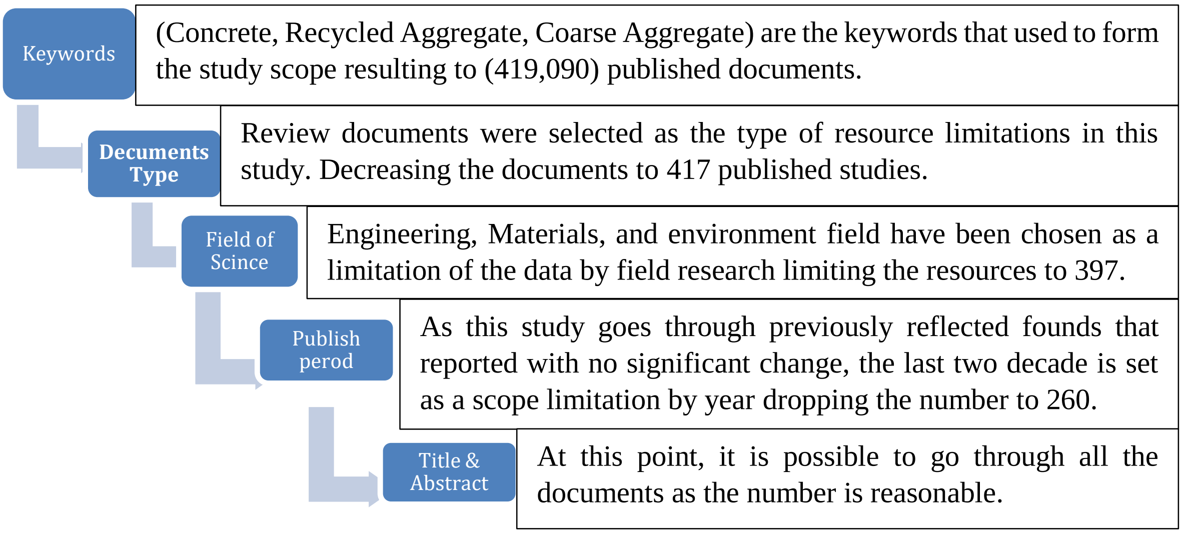

Figure 1: The workflow of the methodology.

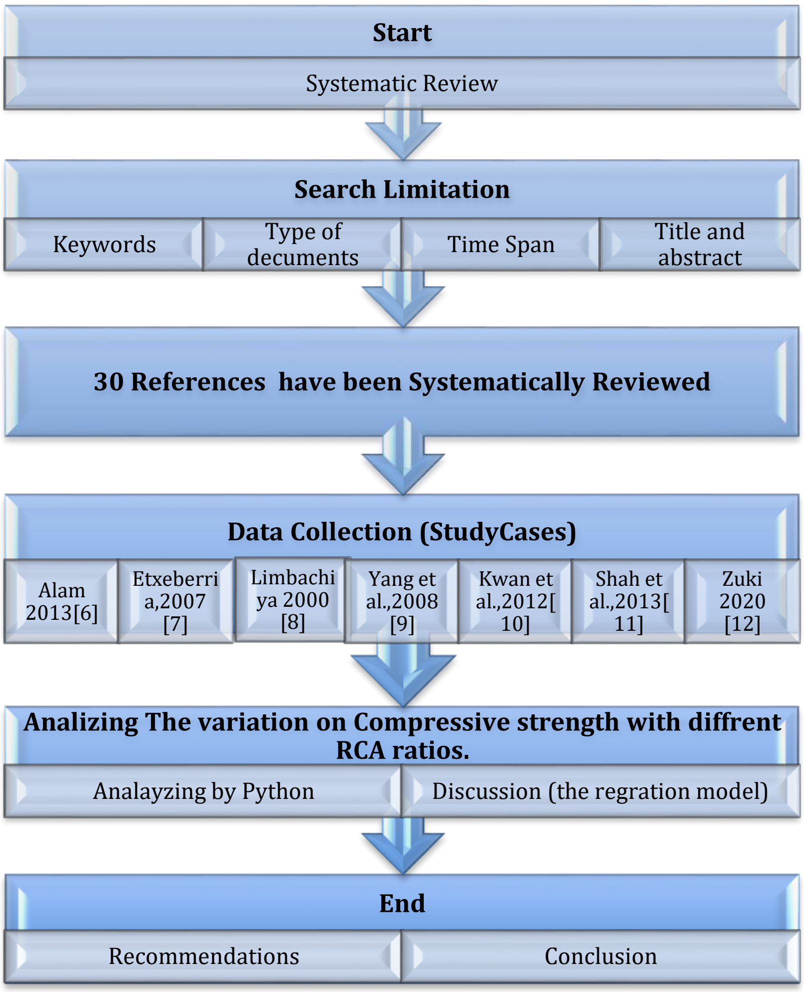

Figure 2: The workflow of the methodology.

2.2 Data Comparison

For this research, the previous studies have been filtered, highlighted, and analyzed to form the study outcomes. Therefore, A comprehensive comparison was conducted about certain significant properties of the recycled coarse aggregate and its influences on the produced concrete in order to limit the study scope for high-quality founds.

i. Recycled Coarse Aggregate (RCA)

RCA is highly variable in terms of its properties due to the variety of concrete from which extracted. However, a general range may be established as several researchers have studied and reported the RCA characteristics as shown in Table 1.

Table 1: The properties variations of RCA to the NCA.

Characteristic	NCA	RCA	Reference	The Contrast
Specific Gravity	2.11	2.03	Alam, [6]	Recycled aggregate has a lower density and specific gravity than the natural aggregate. NCA's specific gravity is around 2.7 while RCA's specific gravity ranges between 2.2 and 2.6 under saturated, dry surface conditions.
	2.7	2.55	Katz [13]	
	2.6	2.4	Limbachiya[8]	
Bulk Density kg/m3	2109	2026	Alam, [6]	
	2400	1433	Katz [13]	
	2600	2410	Limbachiya,[8]	
Water Absorption	2.28	4.35	Nassar [14]	Because of the connected mortar, RCA absorbs significantly more water than NCA. This higher water absorption refers to that the water droplets are absorbed instead of collected on the surface of the aggregate for the hydration process. Researchers propose that 30% of RA has been used to maintain the normal need of 5% of absorption capacity for construction materials [22].
	1.28	4.94	Pepe [15]	
	2.5	5.5	Katz [13]	
	2.17	5.23	Alam et al. [6]	
	2.5	4.9	Limbachiya [8]	
	0.4	5.5	Leite et al. [16]	
	0.3	4.7	Salem et al [17]	
	4.35	6.28-7.56	Poon et al. [18]	
loss abrasion	0.29	0.32	Dimitriou [19]	The abrasion resistance of RA is 20% to 45% and can be high as 50% as shown.
	-	(20-50) %	ACPA [20]	
	0.228	0.316	Zuki [12]	
	-	0.243	Katz [13]	

ii. Improving the Performance of RCA

Enhancing the recycled aggregate concrete is achieved by improving the recycled aggregate [3]. The same study reported that the enhancement of recycled aggregate properties can be done fundamentally by three main methods which are: Treatment of the recycled aggregate for better performance, improvement of the binder by Strengthening the attached mortar, and the combination of these two treatments methods.

iii. Recycled Aggregate Concrete (RAC)

As the aggregate forms a large portion of the concrete body, it plays an important role in identifying the concrete's properties. Indeed, most of the concrete engineering properties are influenced by aggregate characteristics. Table (2) review the impacts of using RCA in the fresh stage of the concrete.

Table 2: The influences of RA on fresh concrete.

RAC Characteristic	Review Founds
Workability	Recycled aggregate concrete's workability is less compared to natural aggregate concrete due to the higher absorption capacity [17]. According to Hasan, 1992[24] and Leite et al., 2013[16], RAC required (5 to 10) % more water to have the same workability as in NAC though it is highly affected by the properties of RA. However, Yang et al., (2008) [9] found that as the percentage of RA increased, the slump value slightly decreased in a very small ratio, which may be offset with the use of admixtures.
Slump Value	According to Topcu and Sengel, 2004 [26], the recycled aggregate concrete's slump value is reduced with the increases of the recycled aggregate amount replaced at a fixed water-cement ratio.
Air Content	Salem et al., 2003 [17] found that recycled aggregate concrete has higher air content than natural aggregate concrete. This indicates that recycled aggregate concrete contains much more entrapped air than natural aggregate concrete. A similar found was observed by Katz, 2003[13].
Initial and Final Setting Time	According to Alam, 2013[6], RAC showed a greater initial strength development than NAC. However, the level of strong growth was much slower than that of the NAC. The initial compressive strength enhancement of RAC is largely due to the rough texture of RCA, which facilitates bonding and fitting between the adhesive and RA [3,17].

iv. Improving the Performance of RAC (Modification of the mixing process)

Tam, 2008 [28] reported that some of the drawbacks of RAC properties can be improved by different mixing techniques. Several techniques have been described in the literature for optimizing the efficiency of RAC during the mixing process. Table (3) shows the common mixing techniques.

Table 3: Modification of the mixing process

Mixing technique	Review Founds
Double Mixing Method	The double mixing method will improve the long-term properties of the recycled aggregate concrete such as chloride penetration, carbonation depth, and will significantly increase the compression strength compared to the traditional mix concrete [30].
Two-Stage Mixing Approach (TSMA)	The two-stage mixing process is consisting of two steps that relied on the adding of water with time. First, around half of the needed water is mixed with the aggregate and then binder substances are added for denser artificial transition zoon (ITZ), remaining water is then applied at altered times [29]. It was found that this method has improved the interface of the aggregate surface leading to improvement in durability and compression strength up to 21% [28].
Air Content	Luo et al., 2018 [23] reported that the triple mixing method has a significant improvement on both fresh and hardened engineering characteristics of concrete compared to the double mixing method. This mixing method improves the RAC surface and the interfacial transition zone (ITZ) by a surface coating of pozzolanic materials.

v. Compressive Strength of Recycled Aggregate Concrete

Ulloa, 2013 [27] reported that the compression strength of recycled concrete is significantly affected by the level percentage of RA replacement and the water-cement ratio of the source concrete. According to Etxeberria et al ,.2007 [7] experiment results that conducted on varying amounts of recycled aggregate substitution (30%, 50%, and 100%), concrete composed entirely of recycled coarse aggregates has a compressive strength of 20–25 percent less than ordinary concrete (CC) at 28 days when the effective w/c ratio is the same (w/c = 0.50) and the cement amount is the same (325 kg of cement/m3). They concluded that 8.3 percent extra cement was required in RC100 concrete to meet the compressive of the CC at a 0.5 effective w/c ratio. While the RC50 mix required 6% more cement quantity than the CC, the effective w/c ratio was lowered to 0.52 with the RC50 mix. And concrete made with 25% of recycled coarse aggregates achieved the same properties as the CC concrete mix maintaining the mix proportions and its production order the same. Another experiment with the same level of RA percentages (30%, 50%, and 100%) for Yang et al.,2008 [9], produce 40 MPa concrete, has reported that any replacement levels of RCA will have the same compressive strength as for NAC. According to Etxeberria et al,.2007 [7], RC with low–medium compression strength (20– 45 MPa) are possible to be achieved even with a level of 100% RCA replacement. Moreover, high-strength RC requires not more than 30% RCA replacement. RCA. Limbachiya, 2000 [8] produced high strength concrete (80 MPa) on 28th day by 30% of RCA. If more than 30% of RCA replacement levels are used, the strength of RAC will be decreased as they noticed.

3. Data Analysis and Discussion

The variation of compressive strength of different RCA at similar (c/w) ratio, but several replacement ratios have been compared and analyzed as shown in Table (4) and Figure (3) respectively.

Table 4: The variations of compressive strength of RAC with different RCA replacement levels.

Reference	0%	30% and less	50%	75% and above
Limbachiya, [8]	76	76	71	69
Etxeberria et al [7]	29	28	29	28
Alam [6]	50	42.6	37.8	-
Yang et al [9]	40	36	38	35
Kwan et al [10]	40	36	38	25
Zuki [12]	43.4	38.8	35.8	25.7
Shah et al [11]	20.27	12.91	14.81	17.06

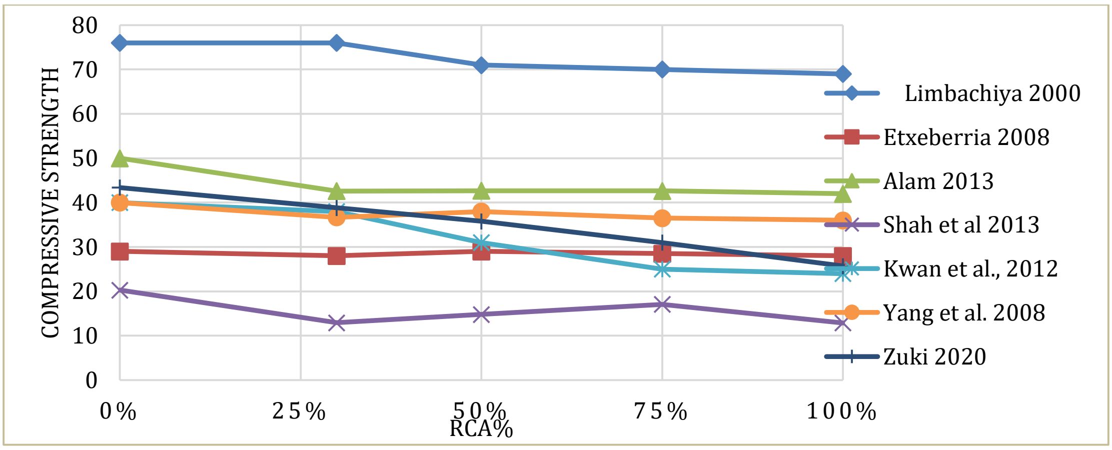

Figure 3: The variations of compressive strength of RAC with different RCA replacement levels.

The collected data, once been organized, has given an obvious inference about the relationship between the ratio of recycled aggregate with the comparison strength. However, in order to select the most efficient replacement ratio of RCA, a machine learning tool which is Python-Jupyter is used to identify the correlation coefficients for each replacement amount as shown in table (5). In which the closest correlation to 1 is a leaner relationship in terms of compressive strength quality.

Table 5: Steps to identify the best replacement ratio using Python.

N	Data Input	Software Output

1

Data Input:

```python
#import Packages
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
```

```python
 #Import Dataset
df= pd.read_csv('FYP2.csv')
                  # Veiw the data:
                     # df   "All data"
                     # df.head (20) "20from up"
                     # df.tail (20) "20from below"

df

```

Software Output:

	Reference	0%	30% and less	50%	75% and above	Unnamed: 5
0	Limbachiya 2000	76.00	76.00	71.00	69	NaN
1	Etxeberria 2008	29.00	28.00	29.00	28	NaN
2	Alam 2013	50.00	42.60	37.80	-	NaN
3	Yang et al. 2008	40.00	36.00	38.00	35	NaN
4	Kwan et al., 2012	40.00	36.00	38.00	25	NaN
5	S.Zuki 2020	43.40	38.80	35.80	25.7	NaN
6	Shah et al 2013	20.27	12.91	14.81	17.06	NaN

2

Data Input:

```python
 #Replace missing value

df['75% and above'] = df['75% and above'].replace(['-'],'35.5')

# correlation coefficient
df.corr()
```

Software Output:

	0%	30% and less	50%
0%	1.000000	$\boxed{0.991474}$	0.972506
30% and less	0.991474	1.000000	0.991221
50%	0.972506	0.991221	1.000000
Unnamed: 5	NaN	NaN	NaN

The analysis of the impact of different recycled aggregate ratios on comparison strength had been done. Based on the relationship correlation value of the published comparison tests on recycled aggregate concrete to the control concrete for each experiment.

The output of data analysis illustrates that up to 30% of the RCA ratio is the optimum replacement percentage in terms of comparative strength as it gives a correlation of (0.991474). Considering that, there is an obvious inverse relationship between the replacement ratio of recycled coarse aggregate and the resulted compression strength. Moreover, the variation in the characteristics of the recycled aggregate has precluded establishing a formal guideline for the mix design of the recycled aggregate concrete. Although, the influence of recycled coarse aggregate on the compression strength, it is still accepted for construction purposes. However, several considerations may be taken to improve the RAC performance starting from RA manufacturing until the concrete curing.

4. Conclusion and Recommendations

The study reviewed the published experimental founds on the implementation of recycled coarse aggregate RCA for concrete productions in order to investigate the utilization of concrete waste to replace the coarse aggregate. The compressive strength of recycled aggregate concrete decreased with the percentage increment of recycled coarse aggregates replacement to the nature aggregate at a similar water-cement ratio, mix stages, and age of tested results. And that because of the porosity contents at the recycled aggregate on one hand, and the old interfacial transition zone (ITZ) on the other hand leading to an inverse relationship between the replacement ratio of recycled coarse aggregate and the resulted compressive strength. However, according to the published data analysis, it can be claimed that the most efficient ratio for RCA replacement with the NCA in concreting work is identified as no more than 30% in which the normal quality will remain. In addition, the application of RCA in construction will save natural resources and decrease landfill construction waste in Malaysia, ways to economically achieve that is by extending its uses further than concreting works in construction such as retaining and property separation walls, as ballast at railways, landfill overlayers, drainage system and more other applications.

While the findings of this study enabled significant conclusions to be formed about the promotion of sustainable concrete, further research is necessary to scale up manufacturing and implementation of this sustainable concrete in actual life. Furthermore, and as an extension of this study, it is recommended that the influence of pre-wetting recycled aggregates on water needs and the consequent effect on compressive strength may be investigated deeper. Moreover, and due to the porous nature of recycled aggregates, very high water-cement content was required. High Range Water Reducers (Superplasticizers) to decrease the water content and achieve high workability and strength of concrete mixes may be a worthy experiment in this search field.

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