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A STATE OF THE ART REVIEW ON RECYCLED AGGREGATE CONCRETE

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ABSTRACT

Numerous experimental and theoretical studies on recycled aggregate concrete have been carried out in the past 10 years. This paper presents several reviews of RAC. The review presented in this report clearly indicates an increasing trend and incentive for the greater use of manufactured and recycled aggregates in construction. There are, however, limitations to the use of such materials. This report focuses on the known benefits and limitations of a range of manufactured and recycled aggregates. A successful strategy must be based on both cost and performance. In terms of performance, many countries are focusing on recycled concrete aggregates (RCA) which is proven to be practical for non-structural concretes and to a limited extent for some structural-grade concrete. However, the processing and quality control cost associated with their use plus the premium paid for mix design adjustment to achieve the same strength grade as concrete with natural aggregates can vary considerably.In Iraq, there are a number of manufactured and recycled aggregates readily available in certain localities which have the potential to be used in construction.

Keywords: reinforced concrete, review, recycled, aggregate.

1. INTRODUCTION

Concrete is the most common material used in Constructions. Conventional concrete typically contains about 12% cement and 80% aggregate by mass. Although the concrete is the most extensively used construction material in the world due to it's low cost, high availability, and simple constructability. However, the use of cement is a main contributor to high-energy usage, CO2 and dust emissions, natural resources depletion, air pollution, global warming, and continuous environmental deterioration [1]. The world's annual cement production of 1.6 billion tons accounts to about 7% of the global loading of carbon dioxide into the atmosphere. Producing one ton of Portland cement requires about four giga-joules of energy. Taking out huge quantities of raw materials for the production of cement such as, limestone and clay, and fuel such as coal, often results in extensive deforestation or denudation and top-soil loss. Therefore, many technologically advanced countries such as the United States and Japan are trying to reduce the use of cement and concrete and searching for alternative structural materials for housing construction [1&2].

The amount of construction and demolition (C&D) waste has increased considerably over the last few years. The increasing cost of landfill, the scarcity of natural resources coupled with the increase in aggregate requirement for construction, has attracted increasing interests, from the construction industry, concerning the use of recycled aggregate (RA) to partially replace the virgin aggregate. Indeed, in some European countries, a large proportion of aggregate comes from secondary sources and recommendations for the use of recycled aggregate have been set out by RILEM [3]. While the environmental and economical benefits of using recycled aggregates are well accepted, some hypothetical problems related to durability aspects resulted in recycled aggregates being employed practically only as base filler for road construction. Concrete, however, is one of the high-grade applications where recycled aggregates can be used. Their use in concrete opens a whole new range of possibilities in the reuse of materials in the building industry. The utilization of recycled aggregates is a good solution to the problem of an excess of waste material, provided that the desired final product quality is reached. Accordingly, the performance characteristics of concrete incorporating commercially produced recycled aggregates, hereafter, referred to as recycled concrete, requirere assessment in relation to natural aggregate concrete [4].

Recently, a wide range of wastes has been successfully reused in the construction industry, e.g. old asphalt pavements, recyclable Portland cement concrete, brick, plastic, steel, tires, glass and many others.

2. PAST STUDIES ON RECYCLED AGGREGATE

Ravindrarajah and Tom (1985) studied the effect of utilizing recycled concrete of various qualities as coarse aggregate upon the strength and deformation of concrete. Tests on aggregates displayed that the recycled concrete aggregates (RAC) have higher absorption capacity and lower specific gravity than the original aggregate. The resistance to mechanical actions like crushing, impact, and abrasion for RCA is additionally lower. The consequences of utilizing RCA rather than natural aggregates (NA) in concrete caused lowering in compressive strength up to 25.0% and in modulus of elasticity up to 30.0% increase in damping capacity up to 30%; and better of creep and drying shrinkage [5].

Ravindrarajah *et al.* (1987) studied the consequences of utilizing recycled old concrete on the deformation and strength concrete. The features of (RA) defer from those of (NA) due to the existence of a considerable percentage of mortar affixed to NA and loose mortar. For concrete with medium strength, the incomes display that strength and modulus of elasticity are reduced by 10.1% and 35.4%, respectively, while drying shrinkage approximately was doubled when RA were utilized in lieu

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of NA in similar mixes. The coarse aggregate effect on deformational characteristics was more than that of fine aggregate. Fresh concrete featured were only marginally affected by the utilization of RA [6].

Eldin and Senouci (1993) carried out an experimental study to examine the potential of utilizing crumb rubber and tire chips as aggregate in Portland-cement concrete. The authors tested some properties of concrete (such as the strength and toughness) within which completely varies amounts of rubber-tire pieces of many sizes utilized as aggregate. The concrete mixes showed lower compressive and tensile strength than natural aggregate (NA) concrete. Although, these mixes didn't show brittle failure, but a ductile, plastic failure, and can absorb a big amount of energy of plastic under two lodes tensile and compressive. An accurate model is employed to explain the consequences of rubber as aggregate on the compressive and tensile strength reduction of concrete. The compressive and tensile strengths of a 35 MPa Portland-cement concrete were determined after replacing the coarse aggregate and sand with rubber particles. Reductions of up to 85% of the compressive strength and up to 50% of the tensile strength were observed when the coarse aggregate was replaced by rubber. A smaller reduction in compressive strength of 65% was observed when sand was replaced by crumb rubber [7].

Al-Negheimish *et al.* (1997) studied experimentally & theoretically the use of locally produced electrical arc furnace steel slag in concrete manufacturing. The slag was used as coarse aggregate since it proved to be quite hard and did not contain any appreciable free chemical compounds of potentially adverse effects such as lime. For comparison, crushed gravel was used in parallel to the slag. Mechanical properties, as well as the drying shrinkage of both slag and gravel concrete, were measured. The results showed that the compressive and flexural strength for slag concrete are similar compared to gravel concrete but higher splitting tensile strength and modulus of elasticity was obtained. The drying shrinkage of recycled aggregate (RA) is less than that of gravel concrete. The results of this investigation are encouraging since they show that using slag material as coarse aggregate has no negative effects on short-term characteristics of hardened concrete. The utilizing of slag resulted in a significant increase in the density of concrete by about (2775 kg/m^3). The increase is because of the higher specific gravity of the slag as compared to gravel. The slag concrete may be used for certain applications where its extra weight (about 20% more than gravel concrete) is advantageous [8].

Al-Manaseer and Dalal (1997) investigated the feasibility of using post-consumer shredded plastics as a substitute for conventional coarse aggregates in concrete. The plastic aggregates were shredded scrap from bumpers manufactured for cars. The volume replacement of plastic aggregates for coarse aggregates in concrete samples was 10, 30, and 50 percent. The results of tests showed that the compressive strength of the concrete samples ranged from 48.3 to 19.3 MPa. The compressive and tensile failures of concrete specimens containing plastic as aggregates were found to be more ductile in behavior than similar types of concrete made with conventional aggregates [9].

Marmash and Elliott (2000) used the waste of concrete from hollow cored floor units(of prestressed precast) as a replacement of aggregate (RCA).Block concrete waste were crushed to 14 millimeter cone, jaw and impact crushers can be used. About three to four times the water absorption of the RCA was bigger than river gravel and natural limestone utilized for control targets. The fine RCA was approximately at the coarse end of the British Standard limit (BSL). The workability had increased at about 20.0% replacement if Concrete made utilizing zero, 20.5% and 50.2% substitution of fine and coarse RCA, but at about 50.0% replacement, this would be reduced considerably. The strength of compressive of concrete created with RCA was within +5.0Mpa of the control result of about 62.2MPa. RCA from the cone crusher made the best strengths. The major conclusion is that concrete made with up to about 50.0% substitution of eachcoarse and fine RCA seems to be comparable with normal concrete in terms of workability &compressive strength [10].

Chen *et al.* (2002) studied the using of rubble of building collected from demolished and damaged structures as an aggregate. This material might function a recycled aggregate (RA) in concrete, after crushing and screening. Several experiments utilizing RA of assorted compositions from this martials was made. The check results displayed that the rubble of buildings could be turned into helpfulRA through the correct process. Its strength will be affected when unwashed RA in concrete is used. This is going to be additional obvious at lower w/c ratio of about (0.37), the strength of compressive of RA concrete stays most effective 61.0% that of ordinary concrete. When the RA was washed, these negative effects were greatly enhanced to be over 75.0% when the (w/c) ratio is larger than 0.60. This is often very true for strength of flexural of the RA concrete. A recycled coarse aggregate was a weakest phase (at a low (w/c) ratio). This effect will take control the strength of RA concrete. This mechanism doesn'toccur during a recycled mortar. The amount of recycled fine aggregate will rule the mortar strength [11].

Elzafraney *et al.* (2005) used recycled plastics (polyvinyl chloride (PVC), polypropylene (PE), and high-density polyethylene (HDPE)) as a partial replacement for coarse aggregates to change and modify the properties of thermal for buildings. 2-comparable structures had been constructed and designed, the first was with natural aggregate (NA) (control) and the second with an excessive content of recycled plastics (RP). The energy and thermal behavior of the two structures were studied and investigated. The experimental results displayed that the RP concrete structure showed higher levels of comfort and energy efficiency as compared by structures casted with NA. RP concrete in combination with energy-efficient building design techniques proved to be of large value in lowering heating loads and the cooling of the structures and also in improving the comfort level of the buildings. High-recycled-content concrete also favors the

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development of cheap concrete walls and slabs of improved resistance to heat loss. [12].

Jasim (2009) proposed converting the waste plastic to plastic hollow aggregate (PHA) of a certain shape. This plastic hollow aggregate can be used in nonstructural Concrete Masonry Units (CMU) mix to produce plastic hollow aggregate concrete masonry units (PHACMU). The PHACMU mix designed to be composed of plastic hollow aggregate, sand, cement, and water(without any additive). Zero-slump concrete mixes of cement: sand volume proportions of 1:2, 1:2.5, and 1:3 and plastic hollow aggregate content of 10, 20, and 30% by volume of the hardened concrete had been moulded in 15 cm cube specimens, cured, and tested to obtain density and compressive strength. The obtained density of the test specimens ranged from 1892 to 1550 kg/m^3 and the compressive strength ranged from 16.37 to 3.73 MPa (non-structural). The concrete specimens density classified as lightweight and medium-weight CMU according to the standard specifications of CMU (IQD 1129 [13], ASTM C90 [14], and ASTM C129 [15]). The compressive strength of some specimens had met the requirements of compressive strength of the standard specifications of CMU of both load-bearing and non-load-bearing CMU (IQS 1077 [16], IQD 1129, ASTM C90, and ASTM C129). The plastic hollow aggregate produced by a set of devices specially designed and fabricated by the researcher for the purpose of this research. The zero-slump concrete mixes which investigated molded by an apparatus specially designed and constructed by the researcher utilizing the compaction effort by a drop hammer [17].

Kallak (2009) studied the feasibility of using crushed bricks to replace the coarse aggregate (gravel) in concrete. Two types of the concrete mixture were cast. One was with a mixture of 1:2:4 (without crushed bricks) and is used as a reference. And the other was prepared with different percentage of crushed bricks (byweight). Totally, thirty concrete specimens (cubes and cylinder) are molded with and without crushed bricks (without additive) and tested under compression and split tension according to British standard (BS) specifications. Test results showed that using crushed bricks as coarse aggregate cause reduction in the strength of concrete by about (11-87) % at age of 28 days according to the ratio of crushed bricks replacement. The splitting tensile strength of crushed brick concretes is lower than that of natural aggregate concrete. The crushed brick replacement ratio ranged from (0.2-1.4) in concrete and increases the water to cement ratio as it increases the water absorption. The workability of the crushed bricks concrete is founded to be lower than that of NA concrete. Also, the percentage of W/C increases for constant slump when the amount of crushed bricks was increased [18].

Mirza and Saif (2010) proposed a study about the effect of utilizing silica fume on recycled aggregate concrete mechanical properties. The percentages of used recycled aggregate replacements of NA by weight were zero, 50.0, and 100%, while the percentages of used silica fume replacements of cement by weight were 5, 10, and 15%. The results indicated that the compressive and tensile strength values (of the recycled concrete aggregate) had increased when the RA and the silica fume contents increased. The study also indicated that in order to an allowance 50% of recycled aggregate in structural concrete, the mix must blend 5% of silica fume [19].

Mirjana *et al*. (2010) carried out a study on the partial replacement of river aggregate by recycled aggregate (RA) with percentages 0,50,100%.Concrete with recycled aggregate was gained by crushing cubes of old concrete used for strength of compressive test. The strength class of old cubes was C30/37, nomenclature according to Eurocode 2. The properties of the bulk density of hardened concrete, the bulk density of fresh concrete, workability (slump test), air content, water absorption, wear resistance were investigated. The compressive, flexural strength, splitting tensile strength, drying shrinkage, modulus of elasticity, the bond between ribbed and mild reinforcement and concrete are also investigated. To obtain the properties of hardened concrete 99 specimens were made and tested. It has been found that the natural aggregate (NA) concrete and RA concrete has similar workability if the dried recycled aggregate is used. Also if water-saturated surface dry RA was utilized, additional water must be added during mixing, the same workability can be gained after a prescribed time. If the quantity of RA had increased, the bulk density of fresh concrete is slightly decreased. The study also showed that for concrete, the compressive strength mainly depended on the quality of RA. The recycled aggregate has no influence on the compressive strength if the good quality aggregate is used for the production of new concrete. The same result founded for concrete tensile strength (splitting and flexural). With increasing RA content the modulus of elasticity is also decreased. A lower modulus of elasticity of RA was obtained compared to NA. Concrete compressive strength of RA was shown in Table-1 [20].

Table-1. Concrete compressive strength and relative compressive strength at different ages [20].

Concrete type	**Concrete age** (days)			**Standard deviation** (MPa)
	2	**7**	**28**	
R0 (MPa)	27.55	35.23	43.44	1.5769
R50 (MPa)	25.74	37.14	45.22	1.2089
R100 (MPa)	25.48	37.05	45.66	3.5016

*Where R is Recycled aggregate.

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Mohammed *et al*. (2011) accomplished a study on the effect of utilizing waste fibers on the some properties of concrete. Waste of steel lathe fibers were added by a proportion of (four, six and eight percent) by weight of concrete and a proportion of gravel were substituted by waste of rubber tires fibers in a percentages of (five, ten, and fifteen percent) by volume. Also, the combined fibers were utilized, such as waste of steel lathe fibers by adding (four, six, and eight percent) with constant replacement of wastes of rubber tires fibers of (ten percent). The outcomes displayed that when waste of steel lathe waste fibers were added in plain concrete mixture cause improvement in its strength under compression by about (fifteen percent) and its tension strength by about (21%). While rubber tires waste cause a reduction in both compressions by about (81 %) and tension about by (50%) strengths. Also, the compression and tension strengths are reduced by (88% and 31%) respectively when combinedfibers were employd. The dry concrete density of lathe waste fibers concrete was about (2343-2363kN/m^3), the rubberized concrete density is (2129-2239kN/m^3) and for combined fibers concrete density (2024-218kN/m^3). The compression strength is shown in the following Table-2 [21].

Table-2. Summary of compressive strength of concrete mixes [21].

Concrete type	Specimen number		
	1	2	3
	Compressive strength (MPa)		
Plain (PC)	20.48	22.07	21.46
Steel Lathe (LC) 4%	22.50	23.70	22.34
Steel Lathe (LC) 6%	22.95	24.72	24.26
Steel Lathe (LC) 8%	24.72	25.83	23.35
Timer rubber aggregate (RC) 5%	6.20	9.10	10.20
Timer rubber aggregate (RC) 10%	5.10	6.20	6.20
Timer rubber aggregate (RC) 15%	4.50	4.00	4.00
Combine (CC) (4%+10%)	3.40	2.80	4.00
Combine (CC) (4%+10%)	4.53	4.53	2.83
Combine (CC) (4%+10%)	2.83	2.83	2.26

*(PC) = plain concrete, (LC) = Steel lathe aggregate concrete,
(RC) = Timer rubber aggregate concrete and (CC) Combine concrete.

Bolden *et al*. (2013) proved an economical valuable solution for the utilizing waste materials. Waste construction materials when recycling, saves energy, reduces waste of solids, natural resources were saved, and greenhouse gases were reduced. Investigations were done for many studies for using acceptable waste, reusable and recycled materials and methods. The use of swine manure, silica fume, citrus peels, animal fat, fly ash, roofing shingles, cement kiln dust, plastic, tire scraps, foundry carpet, glass, sand, slag, and concrete aggregate in construction is becoming increasingly popular because of shortage and increasing cost of raw materials. The authors made a survey targeting experts from the construction industry to investigate the current practices of the uses of recycled materials in the construction industry. That study presented an initial understanding of the current strengths and weaknesses of the practice intended to support construction industry in developing effective policies regarding using waste and recycled materials as construction materials as shown in Table 3 and 4 [22].

Table-3. Percentage use of recycled aggregate in concrete [22].

Material	%	Material	%
Recycled concrete	15.0	Recycled asphalt	12.0
Wood	8.0	Shingles	7.0
Metal	6.0	Fly ash	5.8
Gypsum	5.8	Brick	5.0
Slag	3.0	Steel	3.0
Aluminum	3.0	Glass	1.0
Silica fume	2.0	Tire	1.0
Klink dust	2.0	Rubber	1.0
Carpet	2.0	Foundry Sand	2.0
Swine manure	0.0	Animal fat	0.0
Citrus peal	0.0	Sewage sludge	1.0

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Table-4. Reasons for not using recycled materials [22].

Reason	%	Reason	%
Cost	22	Marketing	7
Lack of education	13	Equipment	4
Hazards	11	Storage	4
Quality of end product	11	Availability	2
Contamination	8	Personal	10
Permits	7		

Mathew *et al* (2013) studied the ability to use recycled plastics (RP) as coarse aggregate in concrete. The preliminary questions appear of the heat of hydration and the bond strength regarding plastic aggregate were solved. Tests had been carried out to find the properties of plastic aggregate such as density, specific gravity, and aggregate crushing value. As a hundredpercentsubstitute of natural coarse aggregate (NCA) with plastic coarse aggregate (PCA) is not possible, partial replacement at varied proportions was examined by the researchers [23], [24]. The percentage of replacement that gave higher strength of compressive was employed by the authors to know the other properties such as modulus of elasticity split tensile and flexural strength. The higher strength of compressive was gained with about 20.0% NCA substituted concrete as shown in figure (1). With restricted test on bond strength of PCA concrete, an admixture was added to the water of mixing @ 0.41% from weight of cement to enhance bonding between plastic aggregate and the mixture. Heat resisting behavior of the PCA concrete was investigated by the authors. At a temperature of 400^{O}C, the NCA concrete has shown about 33% loss in strength but PCA concrete show 75% reduction. [25].

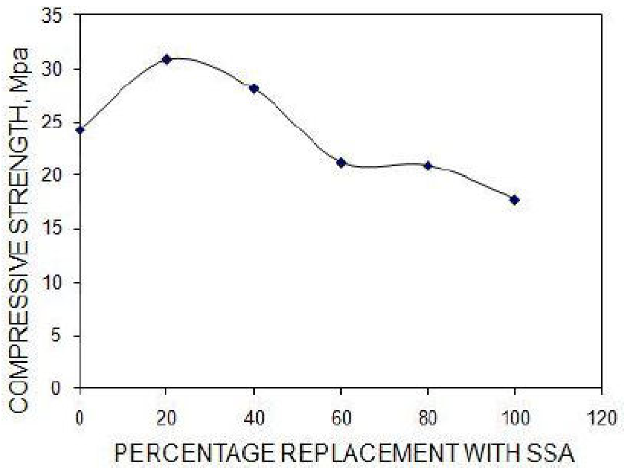

Figure-1. Compressive strength curve [25].

Osei (2013) presented an experimental investigation on studying the effect of complete replacement of natural aggregate by recycled concrete aggregate on the compressive strength of concrete. 2 -sets of concrete mixtures of ratios 1:3:6, 1:2:4, 1:1.5:3, 1:1:2 by mass were molded using natural aggregates and recycled aggregates concrete. The compressive strengths of 1:3:6, 1:2:4, 1:1.5:3, 1:1:2 concrete using recycled concrete aggregates were 12.2MPa, 17.2MPa, 21.7MPa and 25.9MPa respectively corresponding to about 32%, 21%, 12% and 21% reduction in strength compared to concrete casting with natural aggregate. A natural aggregate concrete mix of ratio 1:1:2 had the highest 28-days density (2465) kg/m^3, while the density of the same mix with recycled aggregate at 28-days (2340) kg/m^3. The densities and compressive strengths of natural aggregate concrete were higher than that of the corresponding RAC. From this study the result indicates that RCA can potentially substituted completely NA in the production of both non-structural and structural concrete [26].

Seyyedalipour *et al* (2014) investigated the utilizing of (the paper industry and pulp) wastes in various concrete mixes containing different contents of the waste to minimize environmental outcomes of these wastes disposal. The author's discussion covered paper industry and pulp waste management which have obtained sizableinterest and considers ash dregs, grit, and fiber. The concrete mixes prepared with water, cement, aggregate, and with an adequate amount of these wastes compared in terms of some tests especially strength with the normal concrete. In the end, the benefits and disadvantages of the use of (paper industry and pulp) wastes in concrete formulations as an alternative to landfill disposal were studied. Generally, the compressive, splitting tensile and flexural strengths increased up to 10% addition percentage of waste paper pulp. The further increased percentage in waste paper pulp addition reduced the strengths gradually. So the most suitable mix proportion is the 5 to 10% replacement of waste paper pulp to cement as shown in Figures 2 and 3 [27].

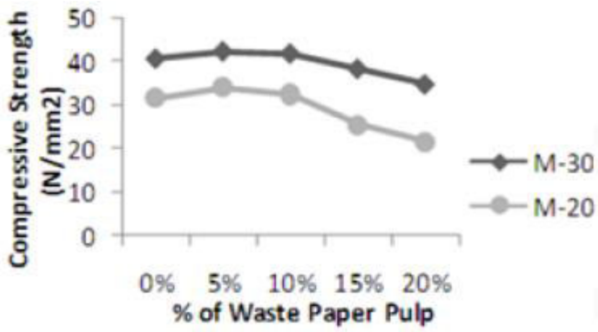

Figure-2. Compressive strength [27].

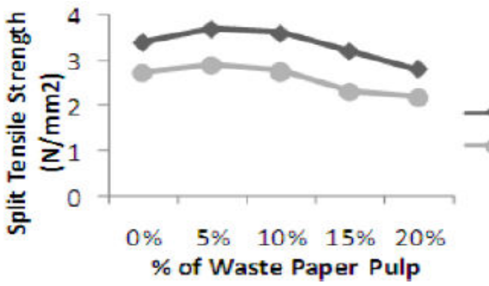

Figure-3. Split tensile strength [27].

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Keryou and Ibrahim (2014) used in their experimental study, waste glass (WG) collected from Turkey-made window glasses as a partial replacement of coarse aggregates with 0, 20, 25, and 30% percentages of replacement by weight with densities 2400, 2388, 2380, 2372 kg/m^3 respectively. The proportions of control mix by weight were (1: 1.96: 2.73: 0.5) (cement: sand: gravel: W/C). Some mechanical and other properties of the concrete, made with these percentages have been studied at both fresh and hardened stages. The experimental results obtained from testing the samples prepared from concrete mixes with w/c ratio equal to 0.5, showed that using WG cause decrease in fresh density and slump due to angular grain shape, while, splitting, flexural, and compressive strengths where enhanced. Tests revealed that with increasing the WG percentage the strengths gradually increase up to a given limit beyond which they decreased. The high effect was reached at 25.0% proportion of replacement. At this percentage, the increases in the splitting tensile and flexural compressive strengths at the 28-day age were 38, 31, and 30%, respectively. The results of this study showed a considerable economic effect from using the optimum proportion of WG 25% as partial replacement of coarse aggregate [28].

Balaji andKumar (2014) carried out an experimental investigation by using M20mixture and tests have been conducted as per recommended methods by applicable codes. When 100 percent substitute of natural coarse aggregate (NCA) by plastic coarse aggregate (PCA) is no longer feasible, the partial substitute was employed. And additionally, hair was utilized as fiber reinforcement in concrete and as partial substitute from cement. The hair has an excessive strength of tensile which is equal according to as regarding a copper cable with a same diameter. Tests were carried out to finding the properties of (PA) and human hair. Experiments had been performed on concrete cubes along with a number of percentages of human hair (0%, 0.5%, 1%, 1.5%, 2%, and 3%) from cement wight and with the same proportion of PA as 20%. Tensile strength was enhanced with human hair. The strength has improved as compared to that of the normal concrete. When M-20 concrete 28- day strength with (2%) hair is compared with the normal concrete, it is found must increase of7MPa in compressive strength, as shown in Table-5 [29].

Table-5. Compressive strength result obtained from by adding human hair and plastic aggregate to concrete [29].

S. No.	No. of days	% hair	% plastic	Compressive strength in MPa
1	7	0%	0%	24.67
2	14	0%		28.36
3	28	0%		32.43
4	7	0.5%	20%	26.03
5	14	0.5%		30.22
6	28	0.5%		33.57
7	7	1.0%	20%	28.56
8	14	1.0%		33.78
9	28	1.0%		38.22
10	7	1.5%	20%	29.34
11	14	1.5%		33.89
12	28	1.5%		38.45
13	7	2.0%	20%	30.34
14	14	2.0%		34.89
15	28	2.0%		39.45
16	7	3.0%	20%	28.26
17	14	3.0%		32.89
18	28	3.0%		39.12

Bhanbhro *et al* (2014) used bricks as coarse aggregate. Cubes of concrete made with recycled bricks were molded and tested for all weight of concrete, moisture content, compressive strength, and dynamic modulus of elasticity. The results displayed that the concrete containing recycled aggregates (RA) has lower strength than normal concrete. Reducing the density up to 16% as compared to normal concrete. The compressive strength of concrete made with RA was found to be 23%, 34.1% and 37.2% (without using super-plasticizer) less

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as compared to concrete made with natural aggregates for 7, 14 and 28 days of curing period respectively. The average bulk density of concrete made with RA was 1910 kg/m3 and same for the normal concrete was found as 2281 kg/m3 [30].

Tsoumani *et al.* (2014) presented an experimental study on the properties of concrete prepared with recycled aggregates (RA) collected from construction and demolition waste. Concrete mixtures with target strength of compressive (25MPa) were prepared using RA at the levels from zero to 100% of the coarse aggregate and a superplasticizer. Their influence on concrete's compressive strength was investigated as shown in Table 6. As a result, the effect of their use on compressive strength was found to depend on the percentage of coarse aggregate substituted. For low proportion of substitution (less than 25%), it can be said that this influence was negligible [31].

Table-6. Effect of recycled aggregates content on 7-day and 28-day compressive strength of concrete [31].

Mix	Replacement percentage %	7-day compressive strength (MPa)	Percentage of effect (compared to M1-0%)	28-day compressive strength (MPa)	Percentage of effect (compared to M1-0%)
M1	0.0	23.86	-	32.83	-
M2	15.0	27.98	17.27	35.52	8.19
M3	25.0	26.30	10.23	34.31	4.51
M4	35.0	22.17	-7.08	28.63	-12.79
M5	50.0	20.74	-13.08	24.33	-25.89
M6	100.0	17.93	-24.85	21.67	-33.99

Hawi (2014) studied the effect of using recycled coarse aggregate from wasted concrete as a substitute for natural coarse aggregate with different ratios 0%, 20 %, 40 %, 60 %, 80% and 100%, all mixes was with the ratio (1, 2, 4). The author studied the fresh and hard concrete properties and the effect of adding superplasticizer with 2.0% and 3.0% by weight of cement mixtures properties. The obtained results showed the negative effect on concrete properties when substituting natural coarse aggregate with recycled coarse aggregate. That effect was little when used 20% percentage substituting and increasing when percent substituting increased. The results also showed the enhancement on recycled coarse aggregate concrete with an addition 2.0% and 3.0% superplasticizer in the mixture and manufacturing new concrete with 80% recycled coarse aggregate and 3% superplasticizer with same properties of natural coarse aggregate concrete [32].

Sarawak (2014) examined the use of recycled industrial timber aggregate (RITA) as an aggregate replacement in producing concrete slab. There are two types of concrete slabs specimens namely RCS1 (Fiber Glass-Reinforced) and RCS2 (Polyvinyl Chloride Pipe-Reinforced) were tested. The strength development of RITA aggregate concrete slab was investigated. The serviceability limit state of the specimens was also studied. Superplasticizer was added to achieve the concrete workability. The test results were recorded at the age of (7, 14 and 28) days respectively. The result showed that the use of higher percentage of RITA aggregate tends to reduce the concrete strength. The replacement of 30% RITA aggregate reinforced with polyvinyl chloride pipe and E-Class glass fiber performs low strength development compared with normal concrete slabs. The deflection of the concrete slabs performed a linear relationship with the applied load. The preliminary findings demonstrated that 30% RITA aggregate had good potentials as a partial aggregate replacement in concrete slab construction combined with E-Class glass fiber or polyvinyl chloride pipe (PVC) [33].

Borhan (2015) carried out an experimental work to produce a recycled lightweight concrete. Crushed cellular concrete (traditionally known as Thermostone) was employed as partial substituting for both the coarse and fine aggregates in various proportion (without using superplasticizer).With (1:2:4) (cement: sand: gravel) mixing ratio was designed for a control mix with a 0.44 w/c, this ratio was constant for all mixes. The samples were tested for compressive strength by utilizing 2-different methods: one involved testing the samples at room temperature in saturated surface dry conditions, while the other method consisted of testing the samples rapidly after heating them to 55C^{o}. The outcomes revealed that the compressive strength can be reduced with increasing the recycled lightweight aggregate. The outcomes additionally revealed that the compressive strength of the heated samples was lower than that for the samples tested in saturated dry surface conditions for overall mixtures. The compressive strength reduced to about 33% for the mix with 20.0 % lightweight aggregate content. And this increased by up to about 71% for the 100% coarse aggregate substitution in comparison with the control mix (see Figure-4). Using thermostone as a coarse and fine aggregate in the total substitution of natural aggregate showed a concrete mix with a compressive strength 75% lower than that noted in standard concrete. However, that difference would be decreased by increasing the RA content. The dry density of the concrete containing thermostone decreased gradually, eventually reaching to about 1501 kg/m^3 with 100% substitution of

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the NA. It was additionally observed that the density of the samples and the coefficient of thermal conductivity can be decreased with increasing the ratio of substitution, which makes that type of concrete useful in places where better thermal insulation is required [34].

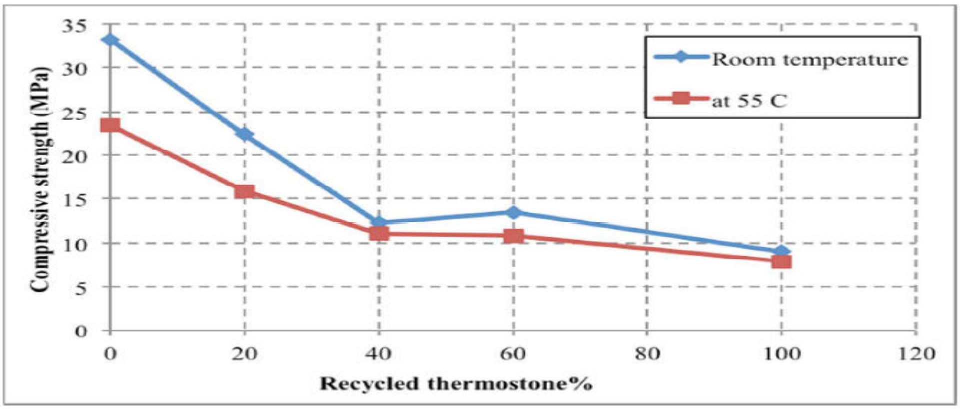

Figure-4. Compressive strength verses. Thermostone content as a coarse aggregate [34].

Khalaf (2015) used (PVC) waste plastic and polyethylene terephthalate (PET) as a volumetric substitution by original aggregates in order to prepare sustainable concrete. The mixture percentage were (1:1.19:1.81) (cement: sand: gravel) by weight with cement amount 525 kg/m3, water to cement ratio of 0.41 and slump value of 90±5 mm. Four different percentages (25, 50 75 and 100%) of coarse PVC plastic waste, while two percentages (25 and 50%) of fine PVC plastic waste aggregate were used as a volumetric substitution to (NA). Concrete mixtures have different proportions of (10.0, 20.0, 30.0, 40.0 and 50.0%) of coarse PET plastic waste aggregate as a volumetric substitution to NA were also prepared. SBR was used by about10% from cement weight for the three selected concrete mixes, one containing only natural aggregate, with 100% coarse PVC aggregate, and one with 40% coarse PET aggregate. The properties of these concrete mixes were investigated. 2-concrete masonry units were carried out from 3-selected mixes. The first has 75% coarse PVC plastic waste aggregate, and the second 30% coarse PET plastic waste aggregate and third 40% coarse PET plastic waste aggregate. All mixes contained waste aggregate as a volumetric replacement to natural coarse aggregate. The studied properties of these units were, water absorption, density and compressive strength. Generally, the obtained results illustrate that all concrete mixes prepared in this investigation can be classified as high strength concrete with compressive strength in the range of 44.9 MPa to 110.4 MPa (reference mix). The obtained results showed that using plastic waste aggregate caused a reduction in compressive, flexural, splitting tensile strength, static modulus of elasticity, thermal conductivity, and density. The percentage reduction in compressive strength for concrete containing 25, 50, 75 and 100% coarse PVC plastic waste aggregate were 44.4%, 54.25%, 57.15% and 59.3 respectively. Meanwhile, for concrete containing 25 and 50% fine PVC plastic waste aggregate the percentage reduction in compressive strength were 35.8% and 47.2. While for concrete containing 10, 20, 30, 40 and 50% coarse PET plastic waste aggregate the percentage reduction in compressive strength were 33.06%, 41.39%, 68.47%, 79.61% and 84.4% respectively compared to reference mix. Despite of some drawbacks like decrease in compressive, splitting tensile and flexural strength, the use of PA presented several advantages. One was that the use of PA leads to produce lightweight concrete according to the percentage of plastic waste utilized. For concrete containing higher percentage of PET plastic waste of 40% and 50% as a volumetric replacement to natural coarse aggregate, the dry density was 1910 and 1850 kg/m^3 respectively. While for concrete with high percentage of PVC plastic waste of 100% as a volumetric replacement to natural coarse aggregate the dry density was 1900 kg/m^3. The obtained concrete was structural lightweight concrete except the concrete mix containing 40% PET which is nonstructural. The result showed that the mechanical properties of concrete containing SBR have improved especially for concrete mixes containing plastic waste aggregate. The inclusion of SBR increased the compressive, splitting tensile and flexural strength by about 16.9%, 33.33% and 36.9% for concrete containing 100% coarse PVC plastic waste aggregate and 44.3%, 43.47% and 23.9% for concrete with 40% coarse PET aggregate respectively, in comparison with mixes without SBR. The experimental tests showed that the concrete masonry units containing plastic waste aggregate conform to the Iraqi standard No.1077/1987 [16] for load-bearing concrete masonry units with moderate weight to lightweight units according to its density [35].

Khalid (2017) used a percentages 25.0%, 35.0%, and 45.0% recycled concrete aggregate (RCA) and ceramic (CER) waste as coarse aggregate in the production of concrete. The control (normal) concrete has a 2300 kg/m^3 density. The density was reduced to 2100 kg/m^3 when the first batch of concrete was used. The second and third batches had an average density of 2200 kg/m^3, which was between the first batch control concrete. Some tests, such as compression and splitting tensile strength, were conducted to determine and compare the

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mechanical properties of the produced concrete with those of the natural aggregate concrete. The concrete containing 34.0% RCA and 34.0% ceramic waste displayed the favorable properties as compared to the natural aggregate concrete as shown in Figure-5 [36].

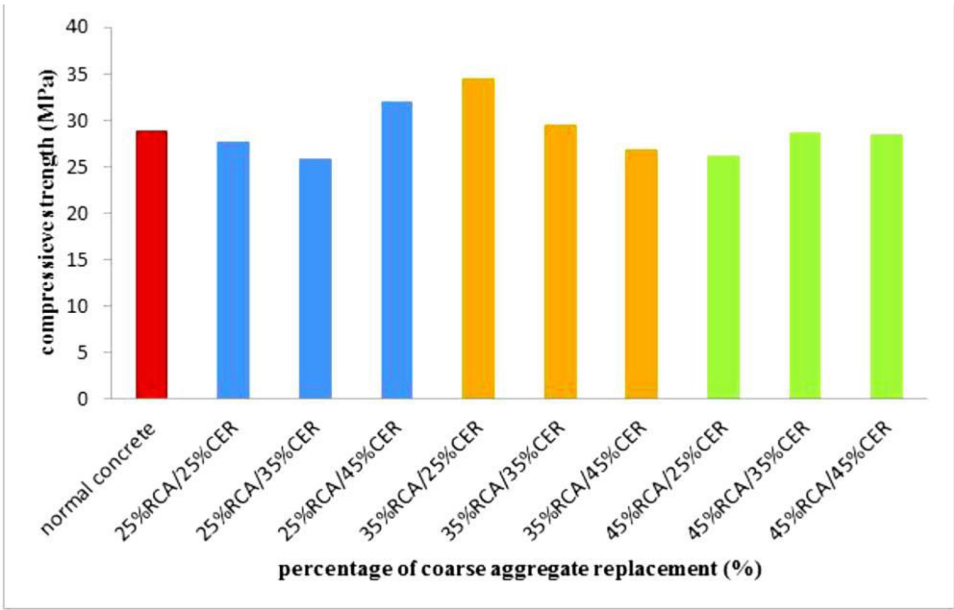

Figure-5. Compressive strength for concrete containing RCA and ceramic waste for 28 days [40].

Lafta (2017) used plastics as a partial replacement of coarse aggregate for the production of lightweight plastic concrete with varying percentages 25%, 50% and 75% for four mixtures (A, B, C, D) and by utilizing plasticizer (SBR) with 2%. This mixture of lightweight plastic concrete which compared with the reference mixture (A). 12 cubic (10 * 10 * 10 cm) are taken and tested in three ages (7, 14, 28) days, and four cylinders (10 cm * 30 cm) tested at 28 days. Also, twelve tiles are produced with dimension (40 * 40 * 5 cm) tested at ages (7, 14, 28) days. Cubic specimens of the mixture (B) gave the highest compressive strength 45 MPa compared to the specimen with reference mixture (A) 48.1 MPa with 28 days. Where the mixtures achieved increased strength for delayed age and better curing. Cylindrical samples give for the mix (B) tensile strength 3.60 MPa which compared with reference mixture (A) that give tensile strength 3.65 MPa at age 28 days then curing with water. The tiles specimens (40 * 40 * 5) cm gave modulus of rupture for the mixture (B) with (4.05) MPa while reference mixture gave modulus rupture (4.15MPa). Note that mixture(B) gave the optimum replacement of plastic, which showed better properties of concrete products [37].

3. CONCLUSIONS

The previous studies showed that:

a) The compressive and tensile strength are decreased with replacing natural aggregate by recycled aggregate.

b) The use of slag resulted in a significant increase in the density of concrete (2775 kg/m^3). The increase is because of the higher specific gravity of the slag as compared to gravel.

c) The compressive and splitting tensile failures of concrete specimens containing plastic aggregates were found to be more ductile in behavior than similar types of concrete made with conventional aggregates.

d) The check results displayed that the rubble of buildings could be turned into helpful RA through the correct process. Its strength will be affected when unwashed RA in concrete is used.

e) Using crushed bricks as coarse aggregate cause reduction in the strength of concrete by about (11- 87) % at age of 28 days according to the ratio of crushed bricks replacement. The splitting tensile strength of crushed brick concretes is lower than that of natural aggregate concrete.

f) Using silica fume and super-plasticizer causing increases in compressive and tensile strength of recycled aggregate concrete.

g) When waste of steel lathe waste fibers were added in plain concrete mixture cause improvement in its strength under compression by about (fifteen percent) and its tension strength by about (21%). The dry concrete density of lathe waste fibers concrete was about (2343-2363kN/m^3).

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h) Using Waste Glass cause decrease in fresh density and slump due to angular grain shape, while, splitting, flexural, and compressive strengths where enhanced. The results of this study showed a considerable economic effect from using the optimum proportion of WG 25% as partial replacement of coarse aggregate.

i) Some of recycled material improves splitting tensile strength such as hair of human.

j) Using recycled aggregate help to solve environmental issues.

k) Using thermostone as a coarse and fine aggregate in the total substitution of natural aggregate showed a concrete mix with a compressive strength 75% lower than that noted in standard concrete. The dry density of the concrete containing thermostone decreased gradually, eventually reaching to about 1501 kg/m^3 with 100% substitution of the NA.

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