Effects of Recycled Coarse Aggregates on Properties of Normal Concrete

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Abstract:
Large area in Libya is witnessed accumulation of huge amounts of concrete debris, a result of demolition works, especially in recent years. these wastes can cause many environmental problems and took forms of normal concrete, bricks and tile as well as waste reinforced concrete. This study was capable of achieving the research objectives of the work plan, which included the effect of the strength of recycled coarse aggregate on the strength and workability of RAC. The recycled coarse aggregate was produced by the crushing of old concrete from old construction works (demolition wastes) in the laboratory. In this research, one series of concrete mixtures were prepared, in which the coarse recycled aggregate was used as 0%, 05%, 10%, 15%, 20%, 25%, 30% and 50% replacements of coarse natural aggregate. The results indicated that the brief analysis of properties of coarse recycled aggregates and judged its effectiveness in use of concrete. This has been confirmed by the results of the aggregates tests. The concrete mixes were designed using absolute volume method, concrete mixes were designed with 28-day compressive strength as 30 MPa. From here, a new relationship between the percentage of recycled aggregates and the new concrete properties. The results of test show that it could recycled aggregate contents have improved of the compressive strength and workability to reach the more level of natural aggregate concrete for using (5~15) % of recycled aggregate

replacement. The indirect tensile strength of concrete increases at all percentage of recycled aggregate for natural aggregates.

Keywords: demolition works, recycled coarse aggregate, compressive strength, workability.

الملخص

تشهد مساحات كبيرة من ليبيا تكدس كميات كبيرة من مخلفات الخرسانة نتيجة أعمال الهدم وخاصةً في السنوات الاخيرة، يمكن أن تتسبب هذه المخلفات في العديد من المشاكل البيئية، وتكون هذه المخلفات على شكل خرسانة عادية وطوب وبلاط وخرسانة مسلحة. استطاعت هذه الدراسة تحقيق أهداف العمل البحثي، والذي تضمن تأثير قوة مقاومة الركام المعاد التدوير على مقاومة الخرسانة التشغلية، حيث تم أنتاج ركام خشن معاد التدوير وذلك بتكسير خرسانة قديمة من مخلفات الهدم في المعمل.

في هذا البحث تم تجهيز مجموعة واحدة من الخلطات الخرسانية حيث تم أستخدام الركام الخشن المعاد التدوير بنسبة (0، 5، 10، 15، 20، 25، 30 و50)% كنسبة بديلة من الركام الطبيعي الخشن، حيث أشارت نتائج الاختبارات المعملية على الركام المعاد التدوير الى إمكانية استخدام هذا النوع من الركام في صناعة الخرسانة وتم تأكيد ذلك من خلال نتائج أختبارات الركام الفيزيائية والميكانيكية، تم تصميم الخلطات الخرسانية باستخدام طريقة الحجم المطلق، وتم تصميم الخلطات بناءاً على مقاومة ضغط تصل الى 30 ميجا باسكال بعد 28 يوم، من هنا تم الحصول على نتائج جيدة بين نسبة الركام المعاد التدوير وخصائص الخرسانة الجديدة حيث تظهر نتائج على الخرسانة المحسنة بالركام المعاد التدوير، ويمكن تحسين مقاومة الخرسانة وقابلية التشغيل بأضافة الركام المدور بنسبة أستبدال تتراوح من 5 إلى 15% كنسبة من الركام الطبيعي، كما تزداد مقاومة الشد الغير مباشر للخرسانة عند جميع النسب من الركام المعاد التدوير المستخدمة في هذه الدراسة.

الكلمات المفتاحية: أعمال الهدم، الركام الخشن معاد التدوي، مقاومة الضغط، التشغيلية

Introduction:

Concrete waste is the solid waste resulting from the demolition of structures. This waste is also produced from ready-mix concrete production factories. On the other hand, it may be a result of wars or natural disasters such as earthquakes and floods. Most buildings in Libya were constructed of reinforced concrete accompanied with brick and tile materials. These wastes are thrown in open places for collection or landfills. Because of the amount of concrete debris accumulates annually in huge quantities, this solid waste has a high durability, which is naturally accruing non-biodegradable or non-biodegradable naturally, and therefore it has become a problem of environmental pollution, and it is increasing annually in all parts of the world, especially in Libya. Recycling and reusing this concrete waste are the most important solutions for this environmental hazard that started in 1945 in different countries of the world, especially after the second world war, its use being already accounted for in the regulations of many countries. Many researchers demonstrate the feasibility of the use of fragmented concrete as coarse aggregates, also suggested some treatment methods for improved performance of properties of recycled concrete when to using recycled aggregate. The use of these wastes was not limited to the cost of cleaning up the damaged sites, but it also contributed significantly to the need for new building materials [1].

Recycled concrete is Used primarily for paving and backfilling as well as in many engineering fields varying from country to another. However, with increasing efforts to develop them, they began to be used in the construction of foundations, block concrete and building bricks for non-high strength concrete. One of the most important problems concerning by concrete recycling projects and the production of aggregates at recycle aggregate in Libya is primarily the provision of natural aggregates locally and huge quantities. This leads to the lack of a search for a new source, in addition to the existence of large areas where waste can be disposed of and insufficient awareness of such issues. The main reasons for not producing recycled concrete is the unavailability of factories and machines that are used to crush concrete waste and remove impurities such as steel, organic materials, and others [1].

Research Significance:
The main objective of this study is to provide information on the fresh and hardened properties of recycled concrete produced using recycled aggregate concrete (RAC) to support the practical work in assessing the practicability of actually building with recycled aggregate concrete. Furthermore, this study aims to spreading of parameters like environmental consciousness, protection of natural recourses, and development.

Materials and Experimental:
The recycled aggregate used in this experimental program was collected from the Intelligence Service in the Tajoura region. The max. nominal size of recycled aggregate and natural aggregate is 14 and 20 mm. The first part is to produce the recycled coarse aggregate by the crushing of demolished building structure mainly the columns and foundation which was free from any reinforcement or other contaminants in the laboratory. The second part is to produce the recycled coarse aggregate by the crushing and sieving of wasted concrete, the main source of recycled concrete aggregate was demolished building structure mainly the columns and walls which was free from any reinforcement or other contaminants.

Materials:

1- Cement
The cement used in this study is Ordinary Portland Cement, produced from Arab Union Cement Factory with surface area of 300.25 m^2/kg. The Portland cement used conform to Libyan specification (م.ق.ل) No.340/1997. Its chemical and physical properties are shows in Table 1.

Table 1: Physical properties of the used Ordinary Portland cement [م.ق.ل 340: 1997].

Physical properties	Test results	Quality requirement
Standard W/C	30%	---
Setting time Initial Final	 140 min 3:40 hr.	 00:45 (Min.) 10:00 (Max.)
Soundness of cement	0.3 mm	10.0 mm (Max.)

Compressive strength (50.0mm cube), MPa 3-day 28-day	25 MPa 46 MPa	more than 21.0 (MPa) more than 39.0 (MPa)

2- Fine Aggregate (Sand):

Natural sand from Zlatan area was used throughout this study. Table 2 shows the grading of the fine aggregate (Sand) and the limits of the BS specification No.882/1992 [2]. Figure 1 presents the particle size distribution of fine aggregates used for the preparation of all mixtures concrete of study.

Table 2: Grain size test of fine aggregates [BS 882–1992 F-Sand].

Sieve Size (mm)	Passing (%)	Limit of specification	Pass? (X=Fall)
5.00	100.00	---	
2.36	100.00	80-100	
1.18	100.00	70-100	
0.600	99.66	55-100	
0.300	55.34	5-70	
0.150	6.75	---	
Fineness modulus, FM (%) =1.38			

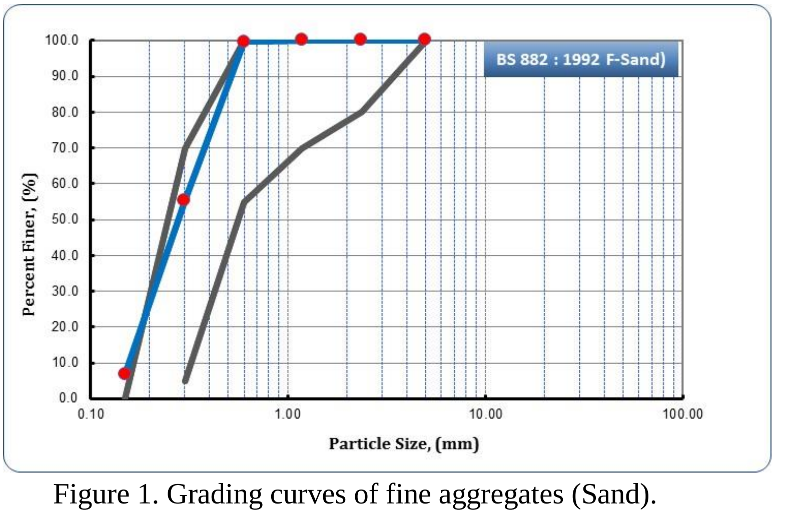

Figure 1. Grading curves of fine aggregates (Sand).

3- Coarse Aggregate:

The two aggregate sizes are combined, sub-angular aggregates of maximum size 20 mm from Abu Arshada quarry in (Garian region, Libya) area. That is used in this study as shown in Figure 2. Table 3 and Figure 3 shows the grading of natural aggregates, which conforms to British Specification BS: 822-1992 [2]. Table 4 shows physical and mechanical properties of natural coarse aggregate.

Figure 2: Grading curves of coarse aggregates (Crushed phonolite).

Table 3: Grain size test of coarse aggregate [BS 882–1992].

Sieve Size (mm)	Passing (%)	Limit of specification	Pass? (X=Fall)
37.5	100.00	100	
20	90.51	85-100	
14.0	52.43	0-70	
10.0	26.83	0-25	x
5.0	0.48	0-5	
2.36	---	---	
Fineness modulus (%), FM=3.88			

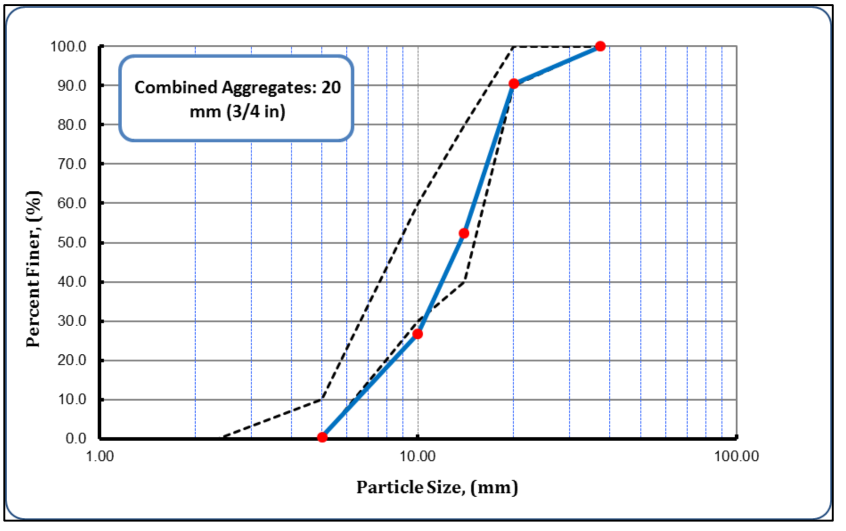

Figure 3: Grading curve of combined coarse aggregate.

Table 4: Physical and mechanical properties of natural coarse aggregate.

Property of aggregate	Test result		Quality requirement	Test specification
	The D_{max} 14 mm	**The D_{max} 20 mm**		
Specific Gravity	2.552	2.548	2.7 – 2.5	ASTM C127
Bulk density	1405.0 kg/m3		1800- 1400kg / m3	ASTM C29
Water absorption	%0.46	%0.64	3% (min.)	ASTM C128
Impact Value	4.27%		30% (min.)	
Crushing Values	21.90%		40% (min.)	BS 812-110:1990
L.A. Abrasion (Fragmentation)	%13.37		40% (min.)	ASTM C 131/ASTM C 535
Material finer than 75µ	0.10%	0.17%	4% (min.)	ASTM C117
Fineness Modulus	3.93	2.33	----	----

4- Water:

Water was used throughout this research work from ground water well that was used for the same water was used for both mixing and curing of concrete.

5- Admixtures (Recycled coarse aggregate):

In this research, crushed coarse aggregate used as a result of breaking big concrete masses as shown in Figure 4 into different – sized pieces, by a drill-hammer. Then these broken concrete pieces were taken into construction materials laboratory at Express Train Company to get small pieces with maximum size (14 mm) of recycled aggregate. After that the powder was separated from (14 mm) pieces by using 2.36 mm sieve.

Figure 4: Grading curves of coarse aggregates (Crushed rock).

These (14 mm) pieces were washed by tab water and left to dry for nearly (24 hrs.) at the oven. Then, these pieces were put in bags ready for working. Table 5 and Figure 5 show the sieve analysis of this type of coarse aggregate according to BS specification No.882/1992 [2]. The Table 4 shows summary results of physical, mechanical and the specifications limits for recycled aggregates-14mm.

Table 4: Physical and mechanical properties of recycled coarse aggregate.

Property of aggregate	Test result The D_{max} 14 mm	Quality requirement	Test specification
Specific gravity	2.438	2.5 – 2.7	ASTM C127
Specific gravity on an oven-dry basis	2.326		
Bulk Density	1277.9 kg/m^3	1400 -1800 kg/m^3	ASTM C29 C29M
Water absorption	4.81%	3% (min.)	ASTM C128
Impact Value	12.69%	30% (min.)	م ق ل 257، 258
Crushing Value	30.80%	40% (min.)	BS 812 Part 110
L.A. Abrasion (Fragmentation)	29.93%	40% (min.)	ASTM C131
Material finer than 75µ	---	04% (min.)	ASTM C117
Fineness Modulus	2.47	----	----

Table 5: Grain size test of recycled coarse aggregate [BS 882–1992].

Sieve size (mm)	Passing (%)	Limit of specification	Pass? (X=Fall)
37.5	100.00	---	
20	100.00	100	
14	96.09	85-100	
10	54.73	0-50	x
5	1.78	0-10	
2.36	0.56	---	

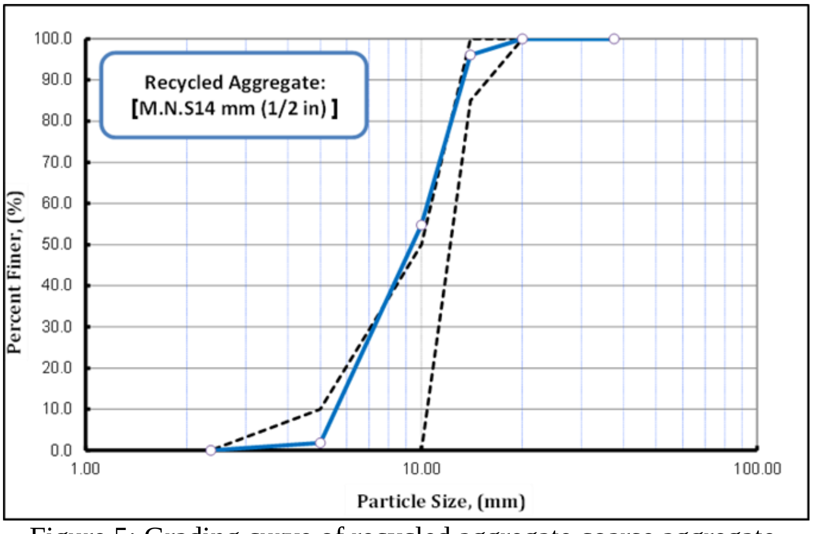

Figure 5: Grading curve of recycled aggregate coarse aggregate.

Concrete Mix design:

Concrete mix proportions were calculated according to absolute volume method and are shown in Table 6. Wetted recycled aggregate, basic water content and additional water quantity were used to achieve the required workability of concrete mixes.

Concrete Mix Design by absolute Volume Method: This method assumes that the absolute size of the concrete is the sum of the absolute volumes of concrete constituents of cement, sand and aggregates is as follows:

$$Absolute\ Volume = \frac{W_{Cament}}{\rho_{cement}} + \frac{W_{water}}{\rho_{water}} + \frac{W_{aggregate}}{\rho_{aggregate}} + \frac{W_{sand}}{\rho_{sand}} + \frac{W_{adddixmture}}{\rho_{addixmture}} + volome\%(air) = 1 \text{------------------------} (1)$$

Where:

W_{Cement} = Wight of cement (kg)

W_{W} = Wight of mixing water (kg)

W_{FA} = Wight of fine aggregate (kg)

W_{CA} = Wight of coarse aggregate (kg)

ρ_{CA} = specific gravity of cement (kg/m^3)

ρ_{CA} = specific gravity of coarse aggregate (kg/m^3)

ρ_{S} = specific gravity of fine aggregate (kg/m^3)

ρ_W = specific gravity of water (kg/m^3)

Table 6: Design amounts of concrete constituents by (Absolute volume method).

Concrete mixture No.	Replacement of natural coarse agg.	Effective water cement ratio (W/C)	Effective aggregate cement ratio (A/C)	Cement (kg/m³)	Coarse agg. (D_{max}=14mm), kg/m³	Fine agg. (Sand), kg/m³	Total water (kg/m³)
Mix (1) reference	0%	0.425	4.10	300	737.46	737.44	201.10
Mix (2)	5%	0.425	4.10	300	700.59	737.44	213.08
Mix (3)	10%	0.425	4.10	300	663.71	737.44	214.62
Mix (4)	15%	0.425	4.10	300	626.84	737.44	216.16
Mix (5)	20%	0.425	4.10	300	589.97	737.44	217.7
Mix (6)	25%	0.425	4.10	300	553.10	737.44	219.24
Mix (7)	30%	0.425	4.10	300	516.2	737.44	220.8
Mix (8)	50%	0.425	4.10	300	368.7	737.44	227.0

Preparation, Casting, Compaction and Curing of the Specimens:

In this study, the recycled aggregate was used in making recycled aggregate concrete, in addition to the reference concrete mix. The concrete was molded into cubes of the size 150mm x 150mm x 150mm. The mixing of the concrete was done according to the (BS 1881-108) method for the targeted compressive strength of 30 MPa at 28 days. Eight (**8**) mixes were cast using the recycled aggregates and normal aggregates with different sizes of 10 mm and 14 mm. The 5%, 10%, 15%, 20%, 25%, 30% and 50% of recycled aggregate was used in the mix as a coarse aggregate for the recycled aggregate concrete. Additionally, concrete made of natural aggregate (Ref. Mix) with the same water/cement ratio served as the control batch. Based on mix design by absolute volume method, the target slump in this studied is between 50-120 mm. Concrete casting was carried out in three layer each layer of 50 mm. Each layer was compacted by using a tamping rod for (25) tamped until air bubbles emerged from the sample of the concrete, and the concrete is level off smoothly to the top of the molds. After that, the specimens remolded carefully, marked and immersed in water until the age of test.

Results of Fresh Concrete Testing:

Workability of concrete defined as physical properties of concrete alone without referring to the circumstances of a particular type of construction. Workability is a property of fresh concrete and this is measured by slump test and describes as a measure consistency [**3**].

Workability of recycled concrete and normal concrete:

Many different test methods have been developed in attempts to characterize the properties of fresh concrete. In this study, slump tests are used to determine workability of fresh concrete. Figure 6 clearly shows the slump is clearly seen the slump obtained by recycled aggregate concrete between 80-120 mm and for natural aggregate concrete. It shows the slump values that is lower than recycled aggregate concrete of 75 mm. The test results of workability for all eight concrete types are presented in Table 7.

Figure 6: The slump test according to [BS 1881 part 116].

Table 7: Results of workability concrete testing according to [ACI 211.1-81].

Concrete mixture	Replacement of natural coarse agg.	Target slump, cm	Slump value[1], cm	Degree of workability	Consistency
Mix (1) reference	0%	75-100	75	medium	Plastic
Mix (2)	5%	75-100	105	high	Plastic
Mix (3)	10%	75-100	120	high	Plastic
Mix (4)	15%	75-100	95	medium	Plastic
Mix (5)	20%	75-100	75	medium	Plastic
Mix (6)	25%	75-100	80	medium	Plastic
Continued (Table 7): Results of workability concrete testing according to [ACI 211.1-81].					
Mix (7)	30%	75-100	95	medium	Plastic
Mix (8)	50%	75-100	80	medium	Plastic
[1] measured slump test immediately after mixing of all 8 concrete mixtures.					

Results of Hardened Concrete Testing:

Since the recycled aggregate has different properties than natural aggregates, it behaves differently in concrete mixes and causes the finished concrete to perform unlike normal concrete. This section describes the variation between the properties of recycled concrete and conventional normal concrete. This section describes the variation between the mechanical properties of recycled concrete compared to conventional normal concrete.

1- Compressive strength:

Uniaxial compressive strength for hardened concrete was determined by using (ELE) compression machine. Measured compressive strengths of all **Eight** (8) concrete types at age of 7 and 28 days. The results of compressive strength at 7 and 28 days for recycled aggregate concrete and Ref. concrete (mixture of natural aggregate) mixes are shown in Table 8.

Table 8: Results of compressive strength of cubes at 7 and 28 days.

Concrete No.	Replacement of natural coarse aggregate	Compressive strength	
		at **7** days, MPa	at **28** days, MPa
Mix (1) reference	0%	36.57	49.51
Mix (2)	5%	37.58	49.99
Mix (3)	10%	43.01	49.34
Mix (4)	15%	42.26	52.74
Mix (5)	20%	39.38	48.67
Mix (6)	25%	38.77	51.61
Mix (7)	30%	38.07	48.77
Mix (8)	50%	41.20	44.65
Cubes made, Cured and tested in accordance with BS 1881-116 and EN 12390-3.			

Table 8 above and Figure 7 shows the results of the 7 days and 28-days compressive strength of concrete. Generally, the compressive strength seems to increase slightly with the addition of recycled concrete. Therefore, the compressive strength of concrete was increase from 49.51MPa (Ref. mix) to 52.74MPa. The replacement of natural aggregate with 15% of recycled aggregate increased the compressive strength to accepted extent. The relationship between compressive strength of concrete and recycled aggregate percentage is shown in Figure 7. Application is usually limited to the max size (14mm) of recycled aggregate.

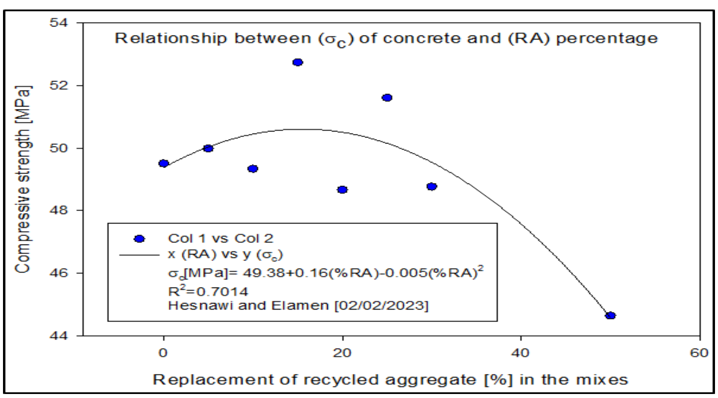

Figure 7: Relationship between compressive strength of concrete and recycled aggregate percentage.

2- Splitting tensile strength:

Indirect tensile strength was measured using a diameter of 10 cm and long of 20 cm cylindrical specimens and following the testing procedure outlined in BS EN 12390-6. Three specimens of each the concrete mix all types of concert were casted and were tested after 7 and 28 days. The results of indirect tensile strength at 28 and 7 days for normal and recycled concrete mixes are shown in Table 9. The test results are shown in Figure 8.

Table 9: Results of tensile strength of cubes at 7 and 28 days.

Concrete No.	Replacement of natural coarse aggregate	Indirect tensile strength	
		at **7** days, MPa	at **28** days, MPa
Mix (1) reference	0%	1.835	2.495
Mix (2)	5%	2.135	3.381
Mix (3)	10%	2.732	3.249
Mix (4)	15%	2.959	2.799
Mix (5)	20%	2.346	2.506
Mix (6)	25%	2.935	3.056
Mix (7)	30%	3.048	2.730
Mix (8)	50%	2.890	2.660
Cylinders made, cured and tested in accordance with BS EN 12390-6.			

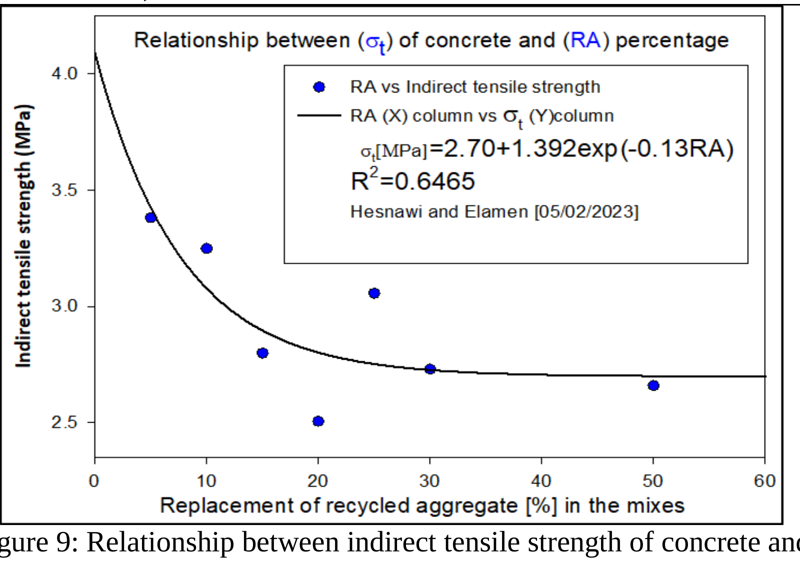

Figure 9: Relationship between indirect tensile strength of concrete and recycled aggregate percentage.

The indirect tensile strength of recycled concrete was obviously decreased at all percentage of replacement of recycled aggregate. Therefore, the highest reduction was recorded by the using of recycled aggregate at 21.3%. Thus, the tensile strength of concrete was decreased from 3.381 MPa (Mix No.2) to 2.66 MPa due to such use. However, the preference remains for recycled concrete in relation to this mechanical property.

Conclusions:

From the results and discussion, the conclusions are drawn as follows:

1. Test of workability results show that it could decreased the workability of recycled aggregate concrete to reach the same level with natural aggregate concrete. This behavior can be attributed to the incremental pores in the recycled aggregate concrete mix which are the spaces for the absorbed water.

2. The compressive strength of recycled aggregate concrete increased by the inclusion of recycled aggregate beads in the mix. The use of 15% of recycled aggregate concrete increase the compressive strength of the concrete by about 15.56%.

3. Using of 15% recycled aggregate concrete with 85% natural aggregate (max size=14mm) as partial replacement of coarse aggregates were suitable for the production of recycled concrete.

4. The tensile strengths of recycled aggregate concrete was influenced due to coarse recycled aggregate grains. The addition of 15% recycled aggregate concrete increased the tensile strengths from 1.835 MPa to 2.959 MPa.

5. Therefore, that the optimum replacing amount and rate of recycled aggregate for produce the recycled aggregate concrete is about 15%.

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