Recycling Building Demolition Waste as An Asphalt Binder Course in Road Pavements: A Case Study in Benghazi

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***Abstract*-At the recent years in Libya especially in Benghazi, building demolition increase because of wars and the processes of destruction that lead to increase concrete waste, causing extreme pressure on the available land-filled sites that's becomes a new challenge to local environment. Due to environmental reasons and the shortage of natural resources, it is greatly valuable to recycle construction and demolition waste as much as possible. This paper investigates the feasibility of using recycled concrete aggregate (RCA) as a replacement to the natural aggregates (NAs) in the Asphalt Binder Course (ABC). So this study make as first evaluation to return use concrete aggregate for old and demolition building in concrete asphalt mix In Benghazi, the recycled concrete aggregate (RCA) obtained from building to live long more than 20 years after crash reinforcement concrete and sieving to get requirement granular particle to make asphalt mixture depends on International Specification (ASTM) American Society for Testing and Materials. In this research a number of aggregate tests is conducted which are sieve analysis, specific gravity, absorption, abrasion, impact value and crushing value. These tests are to investigate the applicability of using the recycled aggregates of demolition building debris as an asphalt binder in road pavements .Also, for comparison, the same tests were applied on the natural aggregates. Furthermore, number of bitumen tests is conducted. They are penetration test, softening point and ductility. The aim was to investigate its applicability to be used as a binder material. Marshal samples are prepared using both natural blending aggregates and recycled blending aggregate to investigate the properties of the asphalt mix; flow, stability and density and comparing the results with the specifications. The results showed that it is possible to use the recycled aggregates in preparing the Asphalt Binder Course taking into account the need to increase the bitumen content, the optimum bitumen content using recycled aggregates and for natural aggregates is 7%.**

***Keywords; Demolition waste, Recycled concrete aggregate (RCA), Asphalt Binder Course (ABC), Road Pavements*.**

I. INTRODUCTION

Benghazi is the second largest city in terms of population, with an area of 43,535 km². It has a population of 544,688 inhabitants. In any country in the world, the demolition debris is considered as an environmental problem as well as it could have economic benefits based on local factors. So, a lot of studies and researches have been done all over the world on the recycling of that debris and their usage in aggregate production. This research aims to explore the possibility of identifying opportunities for reusing the recycled aggregates in the Asphalt Binder Course. After a review of previous studies and researches about asphalt mixtures made with RCA and their performance comparing with natural aggregates mixtures, we observed that there was a great difference in opinions. Some researchers concluded that RCA mixtures present a reasonable water resistance performance [3–6]. On the other hand, there were authors concluded the opposite. Moreover, they saw that RCA in RCA mixtures should be limited with percentage of 5–10% of the total aggregates in the mixture [8] or the RCA should be treated by coating them with slag cement paste [9] or a liquid silicon resin to improve the water resistance of hot mix asphalt mixtures made with RCA. In addition to water resistance performance of RCA mixtures, some authors have stated that asphalt mixtures made with RCA are stiffer than traditional mixtures [10, 11, 12] made with natural aggregates, while others concluded the opposite [13, 14].

II. MATERIALS

1. Aggregates

To achieve the main objective, (RCA) and (NAs) were used; Table I, shows the main and local sources of the required materials for asphalt mix.

Table I.The main and local sources of the required materials for asphalt mix.

Material	**Source**	
	Main	**Local**
Recycled aggregates	Demolished buildings. See Figure (1,2)	Main postal building
Natural aggregates	Crushed rocks (Imported from outside locations)	ALABIAR

Table II. Sieve analysis (ASTM C 136) results of natural and recycled coarse aggregate

SIEVE SIZE (mm)	SIEVE #	CUMULATIVE RETAINED (g)		% CUMULATIVE RETAINED		% SAMPLE PASSING	
		NAs	RCA	NAs	RCA	NAs	RCA
31	11/2"	0	377	0	5.38	100	94.62
20	3/4"	95	3860	4.75	55.14	95.25	39.48
14	1/2"	1268	1509	63.4	21.55	31.85	17.93
10	3/8"	584	466	29.2	6.65	2.65	11.28
4.75	#4	42	409	2.1	5.84	---	5.44
2.363	#8	0	132	0	1.88	--	3.56
-	pas	0	238	0	3.4	--	--
		1989	6991				

The Fig. 1, shows the main postal building in Benghazi, from which samples were taken.

Figure 1. Main postal building.

Recycle concrete and use it as a new course and fine aggregate, and this necessarily requires breaking it with crushers according to the concrete condition and then used again. The knowledge of the aggregate gradient of aggregates aims to ensure that the aggregate gradient conforms to the specifications, and Fig. 2, shows screening of the recycled aggregate samples before using them.

Figure 2. Recycled aggregate

Granular gradient means the distribution of different sizes of aggregate particles. The gradient limits and the maximum size of the coarse aggregate are very important because they affect the amount of aggregates to be used in addition to the need for cement, water, operability, pumpability and durability of concrete, so we should palm trees to see the sizes as in the Fig. 3.

Figure 3. Classified crushed aggregates grading and recycled aggregate

2. Bitumen

AC 60/70 bitumen was used as asphalt binder in this study. Its properties are shown in Table III.

Table III. Properties of asphalt binder.

Test	Standards	AC 60/70
Penetration	ASTM D5	62.3
Ductility	ASTM D113	>100
Softening point	ASTMD36, 2002	52

III. RESEARCH METHODOLOGY AND EXPERIMENTAL WORK

Fig.4, outlines the conducted research methodology and experimental work. The methodology was divided into three phases as follows.

Phase I included the preparation of the investigated materials for the ABCs mixtures. ABC mixtures were prepared from

NAs and/or RCA obtained from building to live long more than 20 years after crash reinforcement concrete the second phase was the routine tests that were performed on bitumen, NA and RCA materials. The virgin asphalt (bitumen) was characterized by penetration, Ductility, and softening point tests. Phase III included the design and testing of the four different ABC mixes by Marshall Design method and characterization of them by stability, Flow, Density. All tests were conducted according to the current requirements of the ASTM.

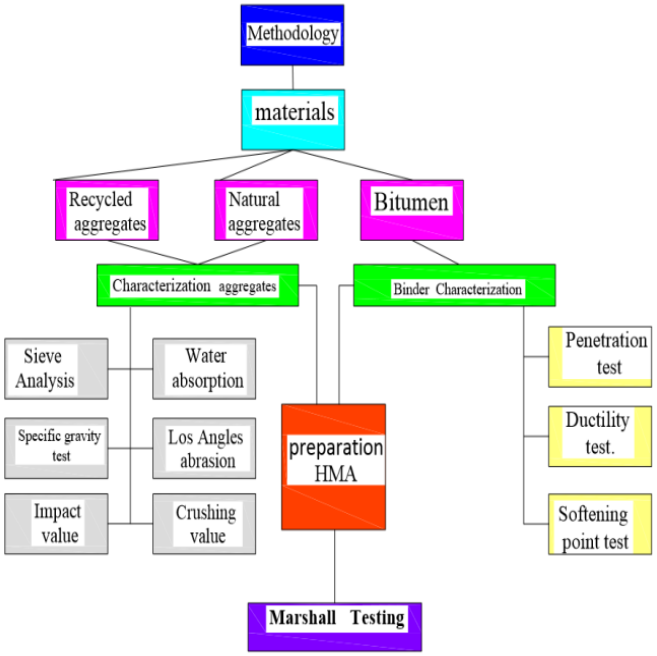

Figure 4. Research Methodology

IV. RESULTS AND DISCUSSION

-Testing of Aggregate

Table IV summarizes the general engineering properties of the investigated RCA and NAs. It can be seen from the table that the new RCA showed lower bulk specific gravity, higher absorption, and higher Abrasion value.

Percentage of Impact value, % and Crushing value, % for the RCA surpassed the requirements specified by ASTM.

Table IV. The test results of natural and recycled coarse aggregate.

Property	Designation No.	Symbols and Results	
		NAs	RCA
Bulk dry S.G	ASTM : C127	2.38	2.22
Bulk SSD S.G		2.44	2.36
Apparent S.G		2.54	2.58
Effective S.G		2.46	2.47
Absorption (% Abs.)	ASTM : C128	2.69	6.18
Abrasion value(%A.V)	ASTM : C131	48.90%	52.30%
Impact value, %	BS812:PART 3:1975	25.80%	32.20%
Crushing value,%	BS812:PART 3:1975	32%	33%

-Preparation and Testing of Asphalt Mixes

After selecting the suitable aggregate gradation for recycled aggregates; several asphalt mixes were prepared by using various percentages of bitumen (from 4% to 7% at0.5% incremental) with the recycled aggregates compared with a control mix (Asphalt mix with natural aggregate). Figures (5) and (6) show the Marshall Specimens using the recycled aggregate and natural aggregate respectively. To prepare the best mix for the asphalt binder course with the best mechanical properties and the optimum bitumen content, the researcher made the following steps:

1. Two gradations (curves) were selected within the two types of aggregates (Recycled and natural).
2. Trail mixes for the two gradations were carried out in the laboratory with using several percentages of bitumen (4%, 5%, 6% and 7%) for each gradation. Marshall Method was adopted.
3. The samples were tested and their mechanical properties were determined. The results of the mechanical properties were compared with the international specifications.
4. Propose the gradation or the range which achieves the best mechanical properties with least bitumen content.

The purpose of Marshall Test is to determine the stability and flow of a compact sample of the asphalt mixture and to determine the optimal asphalt ratio, Fig. 5 and Fig. 6 shows the Marshall Specimens using Recycled aggregate and Marshall Specimens using natural aggregate.

Figure 5.Marshall Specimens using Recycled aggregate.

Figure 6.Marshall Specimens using natural aggregate.

- *Trial A: Control Mix*

In this section, the curve, the outputs of job mix with different bitumen contents for the natural mix will be illustrated. Table V, shows the mechanical properties of asphalt mix using natural aggregate with different bitumen contents.

Table V. The Outputs of job Mix for natural aggregates blending with different bitumen contents.

TEST DESCRIPTION	**Natural aggregate**			
Bitumen%	4.5%	5%	6.3%	7%
Weight of sample in Air (g)	1208	1210	1265	1263
Weight of sample SSD (g)	1212	1214	1267	1265
Wight of sample in water(g)	625.6	614	667.6	672.2
Density of compacted mix ρA (g/cm3)	2.07	2.03	2.12	2.14
Max. theoretical density ρbit (g/cm3)	2.31	2.3	2.26	2.24
Corrected stability	1459	1240	1648	1925
Flow (mm)	3.18	3.72	3.42	3.42
Percent bitumen volume Vb (%)	8.87	9.66	12.72	14.26
Air voids contents in total mix Va (%)	10.38	11.73	6.19	4.46
Voids in mineral Agg. (V.M.A) (%)	19.25	21.39	18.91	18.72
Voids fill with bitumen (V.F.B) (%	46.07	45.16	67.26	76.17

Va% = Air voids.
Vb% = bitumen volume.
VMA% = Voids mineral Aggregates.
VFB% = Voids Filled Bitumen.

In general, as in Fig. 7, we find that the ratio of bitumen is less than 4%, the density decreases, but after 4%, the increase in Bitumen % increases in density to reach the limits of 2.14 this is in the case of using the natural aggregate. As for stability against bitumen% using natural aggregate, it appears in Fig. 8, and we notice that it increases from the percentage of bitumen 5% and takes an ascending curve, In addition, We also note that the ratio of trapped air decreases with an increase in the percentage of bitumen in the mixture Fig. 9, shows Air voids Bitumen % using natural aggregate.

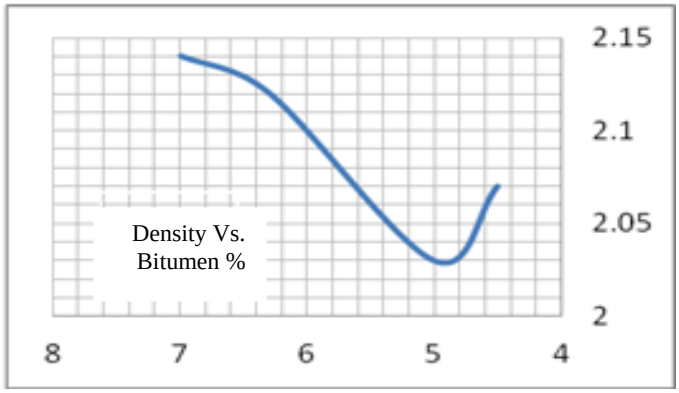

Figure 7. Density Vs. Bitumen % natural aggregate.

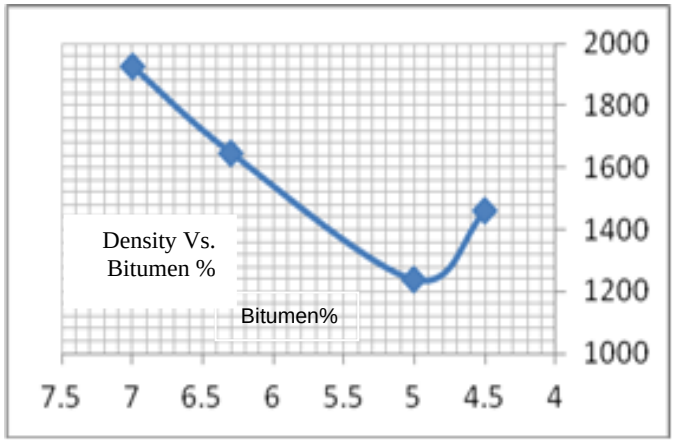

Figure 8. Stability Vs. Bitumen % using natural aggregate.

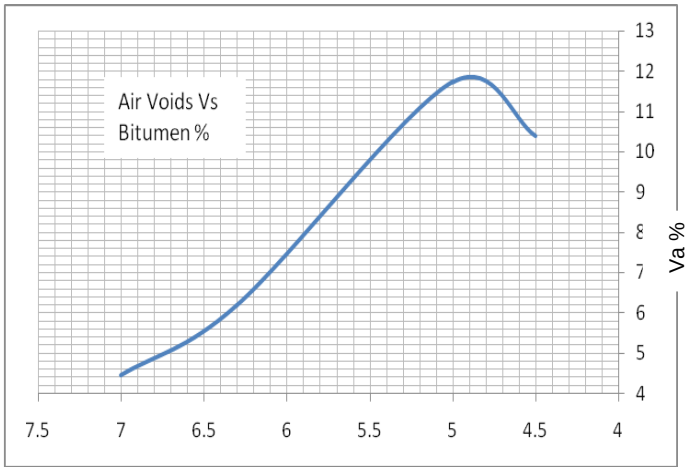

Figure 9. Air voids Vs. Bitumen % using natural aggregate.

- *Trial B: Asphalt mix with recycled aggregate*

In this section, the curve, the outputs of job mix with different bitumen contents for the natural mix will be illustrated. The Outputs of Job Mix for Recycled Gradation with Different Bitumen Contents: Table VI, shows the mechanical properties of asphalt mix using recycled aggregate with different bitumen contents.

Table VI. The Outputs of job Mix for recycled aggregates blending with different bitumen contents.

TEST DESCRIPTION	**Recycled aggregate**			
Bitumen%	4%	5%	6%	7%
Weight of sample in Air (g)	1188	1190	1150	1238
Weight of sample SSD (g)	1194	1193	1152	1241
Wight of sample in water(g)	562	566.4	553.2	608.1
Density of compacted mix ρA (g/cm3)	1.90	1.91	1.93	1.97
Max.theoritical density ρbit (g/cm3)	2.34	2.31	2.28	2.25
Corrected sabiltiy	760	992.3	1081	1159
Flow (mm)	3.3	2.4	3.4	3.8
Percent bitumen volume Vb (%)	7.23	9.09	11.02	13.13
Air voids contents in total mix Va (%)	18.8	17.31	15.35	12.44
Voids in mineral Agg. (V.M.A) (%)	26.03	26.4	26.35	25.57
Voids fill with bitumen (V.F.B) (%	27.77	34.43	41.82	51.34

As for the mixture made from recycled concrete, we find that Fig. 10, shows the relationship between the density and the percentage of bitumen% using recycled aggregates, and that the density increases by increasing the bitumen ratios no matter how small. As for the relationship of the ratio of stability to bitumen% using recycled aggregates, it is illustrated in Fig. 11. We find it an ascending relationship. In addition, Fig. 12 shows the air spaces of bitumen% using recycled aggregates. For example, the air intake ratio was 12.4% at the ratio of bitumen 7% while when using the natural aggregate, as in Fig.9, we find at the ratio of bitumen 7%, the proportion of air trapped is 4.4%.

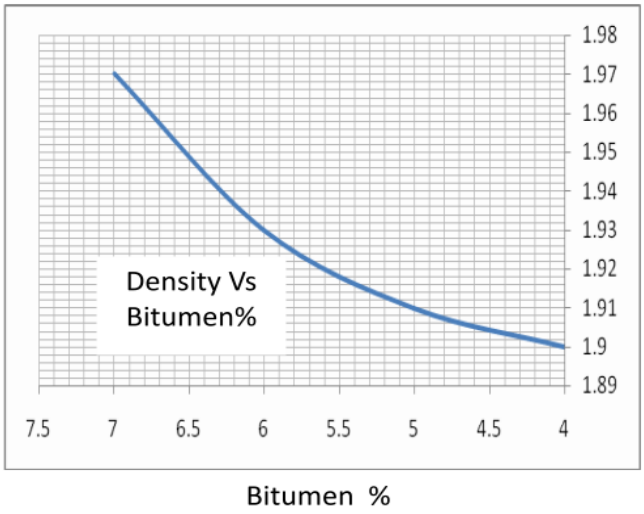

Figure 10. Density Vs. Bitumen % using recycled aggregate.

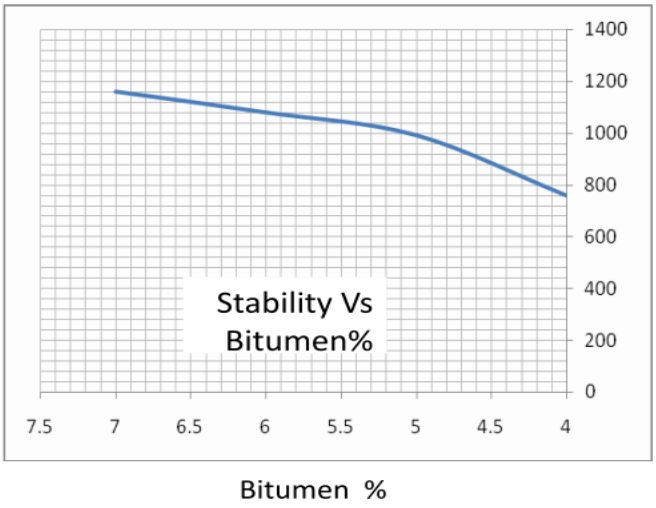

Figure 11. Stability Vs. Bitumen % using recycled aggregate.

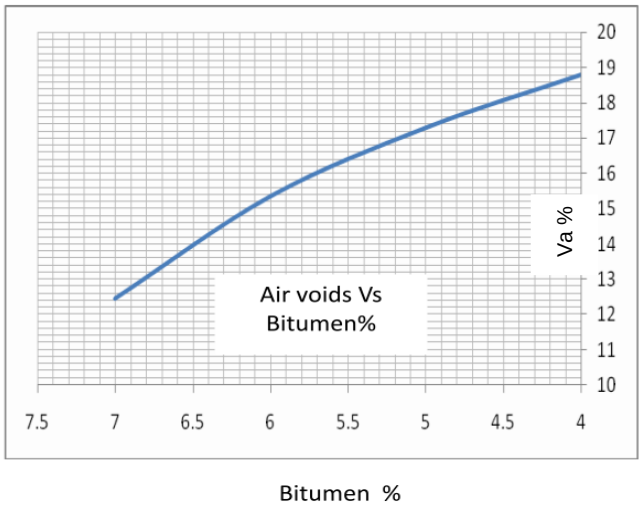

Figure 12. Air voids Vs. Bitumen % using recycled aggregate.

V. CALCULATION OF THE OPTIMUM BITUMEN PERCENTAGE

In order to calculate the optimum bitumen content, we should obtain three values for the bitumen content, which are:

- The bitumen content Vs the highest stability of the asphalt mix. (%mb) Stability.
- The bitumen content Vs the highest value of the density of the asphalt mix. (%mb) pa.
- The bitumen content Vs the allowed percent of air voids in the asphalt mix. (%mb) va

Therefore, the optimum bitumen content is calculated as the average of the above-mentioned bitumen contents**.**

$$\text{Optimum}\%m_b = \frac{(\%m_b)_{va} + (\%m_b)_{sastabilty} + (\%m_b)_{pa}}{3}$$

Table VII.The properties of the asphalt mix using the optimum bitumen content with both aggregates.

Optimum Bitumen % due to	Type of Aggregate	
	natural	Recycled
% Va	7%	7%
Stability	7%	7%
Density (ρ a)	7%	7%
% mb	(7%+7%+7%)/3=7 %	(7%+7%+7%)/3=7%

VI. RESULTS DISCUSSION

With reference to the previous results for the asphalt mixes using two types of aggregate blending (Recycled–Natural) and with various percentages of bitumen, the following table shows comments on the results and summarizing it.

Table VIII. Comments on the results.

Property	**Comment**	**Value at optimum bitumen content**	
		Natural aggregate	**Recycled aggregate**
Density of compacted Asphalt (gm/cm3)	The value of asphalt mix density using recycled aggregate is lower because the recycled aggregates contains suspended materials (Calcareous materials) also it has high porosity which led to reduce the weight of aggregate in unit volume.	**2.14**	**1.97**
Air voids (Va)%	At optimum bitumen content with recycled aggregate, the air voids percentage =12.44% However, the value of (Va %) for asphalt mix using the recycled aggregates is more than the value using natural aggregates and exceeds the ASTM specifications.	**4.46**	**12.44**
Stability (kg)	The stability of asphalt mix using recycled aggregates is less than the stability using the natural one. However, it exceeds the criteria in the ASTM specifications. Therefore, the asphalt mix using the recycled aggregates has high strength.	**1925**	**1159**
Flow (mm)	The flow of the asphalt mix using natural aggregates is within the ASTM specifications and less than the flow in asphalt mix using recycled aggregates.	**3.42**	**3.8**
VFB %	This property is independent of the aggregate type.	**76.17**	**51.34**
Void in Mineral aggregate (VMA)%	The value of VMA for asphalt mix using the recycled aggregates is more than the value using natural aggregates	**18.72**	**25.57**

VII. CONCLUSION

In this research, a lot of experimental tests were conducted for the asphalt mixes using two types of aggregates (Recycled and conventional) and the results were compared with the regional specification. Therefore, the following point can be concluded: It is possible to use the aggregates from demolition debris in preparing the asphalt layers particularly in the asphalt Binder course, knowing that the bitumen content when using recycling aggregate and natural aggregate is (7%)

VIII. RECOMMENDATIONS

1. It is possible to use multi sources of the aggregate for the asphalt mix, such as (construction debris, pavement stone "Interlock" – Asphalt mixes – curb stone).
2. It is recommended to conduct similar tests on other layers of the asphalt mix using different aggregate percentages.
3. It is recommended to conduct researches on using the destroyed asphalt pavements to produce new asphalt layers (Reclaimed Asphalt pavements).
4. It is recommended for further studies to use the asphalt materials in preparing the aggregate layers (Cold mix recycling).
5. Further research is recommended in the future to evaluate the performance of the investigated asphalt mixtures containing RCA either in the laboratory using advanced performance testing such as the ABC dynamic modulus and fatigue, or by constructing a trial field section and monitoring performance over time.

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