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The Application of Recycled Aggregates of Construction Debris in Asphalt Concrete Mix Design

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ABSTRACT: The purpose of this research was to evaluate the application of recycled aggregates of construction debris such as concrete, cement block and rubbles from Pars-Kangan site in *asphalt* concrete *mix design*. To evaluate the performance of aggregates different *mix designs with recycled* aggregate percentages of 0, 10, 30, 50 and bitumen percentages of 4, 4.5, 5, 5.5, 6, and 6.5 were provided and two Marshall specimens (Totally 48 specimens) prepared for each mix design. Marshall test was conducted on the specimens to evaluate their physical and mechanical *properties. The test results indicated that the increase of recycled aggregates percentage in asphalt* concrete *mix design leads to lower strength in* Marshall specimens. Hence, in the next round of research the *same asphalt* concrete *mix designs with bitumen-sulfur proportion of 60-40 were provided in order to increase the strength of aggregates. The* Marshall physical and mechanical *test results specified that sulfur has a significant role in increasing the* strength of specimens. But increasing the recycled aggregates resulted in decrease of strength. By comparing the test results, *it was inferable* that sulfur doesn't have a significant role in increasing the technical specifications of aggregates, and it only increases the strength of specimens.

Key words: *Asphalt* concrete *mix design*, *Aggregate durability,* Fracture, *Asphalt* Concrete, *Recycled* aggregate, Marshall properties, *Sulfur asphalt* concrete

INTRODUCTION

Although construction wastes have less threat to the environment than other types of wastes (such as industrial, chemical, medical and electronic wastes) and it is easier to manage, but are not aesthetically acceptable and should be disposed with proper methods. For this purpose some researches have already done on application of construction wastes such as concrete and cement blocks in *asphalt* concrete *mix design.* Mills-Beale J. and You Z. (2010) investigated the viability of using recycled concrete aggregate for a typical light duty asphalt highway and concluded that the use of recycled concrete aggregate would save some amount of compaction energy. Arabani M. and Azarhoosh A. R. (2012) concluded that the use of recycled concrete aggregate as fine aggregate in asphalt mixtures and steel slag as fine or course aggregate produced Marshall stability increased and flow decreased. There are many other researchers who investigated the use of recycled waste solid materials as filler in asphalt concrete, and found that such alternative filler may improve the engineering characteristics of asphalt concrete to some extent. Chen M. and et al. (2011) investigated the potential of use recycled fine aggregate powder (RFAP) as filler in asphalt mixture. The results from this investigation indicate that the use of RFAP can improve the properties of asphalt mixture, such as including water sensitivity and fatigue resistance. Wu S. and et al. (2011) performed an experimental study to investigate some properties of asphalt mastic with recycled red brick powder (RBP). The results from this experimental study indicate that RBP may have some positive effect on high-temperature properties but some negative effect on low-temperature properties of asphalt mastic. Do H.S. and et al. (2007) conducted laboratory tests to study the possibility of using recycled waste lime (RWL) as filler in asphalt concrete. They concluded from various test results that a waste lime can be used as mineral filler and can greatly improve the resistance of asphalt concrete to permanent deformation at high temperatures. Zhang et al. (1999) investigated the potential use of municipal solid waste combustion

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bottom ash as a paving material. Laboratory results suggested that the properties of ash are typical of a lightweight aggregate, and the 50% ash–asphalt mixture design meets the New Hampshire DOT specifications. An ash demonstration project at 50% substitution was constructed and the 5 year period of field performance evaluation indicated that the ash section performs as well as the control section. Lawton et al. (1999) studied the feasibility of stabilizing zinc clinker and road millings to produce low-permeability pavement materials. Laboratory results indicated that mixtures could be stabilized either by Portland cement or a combination of three additives (a binder, a stabilizer, and a sealant). Sobhan and Mashnad (2001) evaluated the performance of a moderate-strength roller-compacted concrete (RCC) made from reclaimed crushed concrete used as aggregate, Class C fly ash, and waste-plastic fibers reinforcement. It was found that new cement- bound composite made from recycled products could be used as a pavement construction material. In addition, the plastic fibers could improve the toughness characteristics significantly in split tension and moderately in flexure. Swami et al. (2007) investigated the potential use of kimberlite tailings, a waste material left after the recovery of diamond, in road works. The laboratory studies indicated that kimberlite tailings can be used in sub base and base course layers. They may also be used in bituminous macadam as the base course and in premix carpet as a wearing course. A one kilometer long roadway was constructed and the observed performance was found to be satisfactory after 1 year service.

This research investigated the application of recycled aggregates of construction debris such as concrete, cement block and rubbles from Pars-Kangan site in *asphalt* concrete *mix design*. The main purposes of research were to evaluate:

- The possibility of using construction debris as primer layer of hot asphalt concrete pavements.
- Approaches for local applications of sulfur in asphalt concrete due to it's high production volume in the region.
- The role of recycled aggregates percentage on water absorption increase of aggregates.
- The influence of sulfur on increasing the strength and hardness of the Marshall specimens and determination of its parameters.

MATERIALS & METHODS

Recycled aggregates employed in this research were provided by collecting concrete and cement blocks from construction debris of Kangan port, transferring them to the crushing and breaking them into the size of natural aggregates. Firstly the characteristics of the aggregates were evaluated. Kangan port is located at south of Iran as displayed in Fig. 1.

The aggregates characteristics were determined through experiments such as aggregation, Los Angeles abrasion test, sand equivalent value test, determining percentage of fractured particles in coarse aggregates, density and water absorption test. After breaking the construction residues in the crusher, aggregates were transferred to the dryer and were heated at 145 ° C. After cooling materials (24 hours later), samples were prepared for the tests mentioned earlier.

The widely applied bitumen in asphalt concretes are pure bitumen with penetration grades of 40-50, 60-70, 85-100 and 120-150. Appropriate penetration

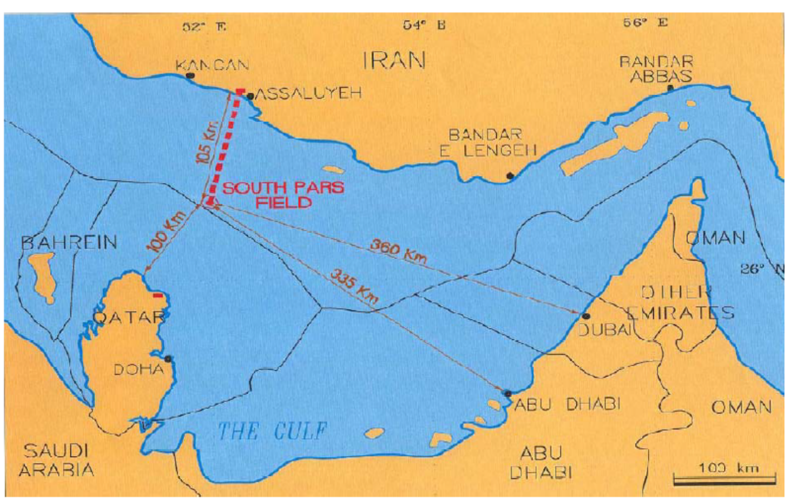


Fig. 1. Location of Kangan port

grade should be selected based on local weather conditions and the traffic of heavy vehicles. According to Kangan's weather condition 60-70 bitumen was selected for the research. Characteristics of the bitumen and sulfur utilized in this research are in Tables 1 and 2.

Natural aggregates used in this study are of limestone with 94% of fracture which were provided from river of old Tombak village in the area.

To evaluate the performance of aggregates from constructional debris in asphalt mixtures four different designs with recycled aggregate percentage of 0, 10, 30 and 50 were prepared and the tests mentioned earlier were conducted on them. Naming each of designs is associated with the amount of construction debris in it, for example RA30 is a mix design with 30% of aggregates from construction debris.

Aggregates grading is one of the most important factors that affects the strength and bearing capacity of asphalt concrete. Grading is usually performed by using sieves No. 4, 8, 16, 30, 50, 100 and 200 (ASTM D448-12). Suitable asphalt aggregate gradation is selected due to several factors such as pavement type, type and location of the desired layer in the pavement, asphalt layer thickness and the grain size (ASTM D1073-11). Aggregates used in asphalt concrete must have sufficient strength to withstand the weight of heavy vehicles and rollers. Using the Los Angeles abrasion test, a sign of aggregates resistance against tension is obtained. The method was adapted from ASTM C131.

Six other tests were also conducted on the aggregates:
- Sand equivalent (ASTM D2419)
- Percentage of fractured particles (ASTM D5821)
- Durability (ASTM D4644)
- Specific gravity and absorption of coarse aggregates (AASHTO T85)
- Specific gravity and absorption of fine aggregates (AASHTO T84)
- Specific gravity (AASHTO T100)

The purpose of bitumen asphalt mixture design is to choose the best and most cost-effective aggregates and bitumen mixture which should provide the following features for asphalt concrete:
- Enough strength to withstand the loads caused by traffic without deformation.
- Limit the void space to a maximum amount in order to prevent air and water penetrate in the asphalt.
- Efficient enough to be easily spread and compacted.

Considering the aggregation and facilities ASTM D 1559 method was adapted for preparing bitumen asphalt samples in this research. Sample preparation consists of three following phases, heating the aggregates and bitumen separately, mixing them, and then compressing the mixture. Firstly aggregates and bitumen were heated separately. Coarse and fine aggregates mixed according to the ratios obtained from gradation test and heated at 180° C for 24 hours. Bitumen was also heated at 125° C for about 30 minutes. Bitumen must not be heated directly, so hot sand was used to heat the bitumen indirectly. After heating the aggregates and bitumen, they need to be mixed well in order to have the entire surface of the aggregates coated with bitumen, considering that temperature must not be below 107° C. As the purpose of marshal strength test is to determine the best

Table 1. Properties of bitumen used in mix designs

Property	Unit	Limit	Method	Result
Density at 25°C	gr/cm³	1.010 – 1.060	ASTM D71 ASTM D3289	-
Penetration at 25°C	mm/10	60 - 70	ASTM D5	64
Softening point	°C	49-56	ASTM D36	51
Ductility at 25°C	cm/s	>100	ASTM D113	-
Flash point	°C	>250	ASTM D92	320

Table 2. Properties of sulfur used in the mix designs

Property	Unit	Value
Solid density at room temperature	gr/cm³	2.07
Density of liquid at 130-150 °C	gr/cm³	1.788
Viscosity at 130-150 °C	cp	10
The amount of H2S in the liquid state	ppm	<10
The amount of organic material	ppm	<500
Solid state color	-	Yellow

bitumen percentage, two samples with 4, 4.5, 5, 5.5, 6 and 6.5 percentages of bitumen were prepared for each RA0, RA10, RA30 and RA50 asphalt mixture designs, totally 48 Marshall samples. After mixing bitumen and aggregates about 1200 g of each mixture collected separately in a cylinder with 10cm diameter and 7.5 cm height and compacted using a 4.5 kilograms rod falling from 45cm height, 75 times for each sample according to AASHTO T245 and ASTM D1559 standards. After that the samples remained in 60° C warm water for 30 minutes (Fig. 2).

Fig. 2. Samples in the Marshall water bath

After that Marshall test was conducted on the samples and the maximum required force to break the sample or deform them was measured which is called Marshall strength. Deformation of the samples was measured in millimeters which is called flow value of bitumen concrete. Unit weight test, stability test, flow value test, air voids, voids filled with asphalt and voids in mineral aggregates tests were also conducted on the samples.

The sulfur asphalt mix design is exactly the same as common asphalt mix designs but a mixture of sulfur and bitumen is used. In this research applied ratio of bitumen- sulfur was 60-40, which means 60% bitumen and 40% sulfur. And the procedure was all the same as described earlier. So two samples for each four mix designs RA0-S, RA10-S, RA30-S and RA50-S with bitumen-sulfur percentages of 4.5, 5, 5.5, 6, 6.5 and 7 (totally 48 samples) were prepared with the same procedure for Marshall test.

RESULTS & DISCUSSION

Aggregate weight loss percentage of RA0, RA10, RA30 and RA50 using Los Angeles abrasion test method of ASTM and AASHTO (500 rpm) was determined. The results of this experiment are shown in Table 3. Los Angeles abrasion test was performed on coarse aggregates (sieve No. 4). The results show that by increasing the percentage of recycled aggregates in the composition of the mixture has lead to the increase of materials abrasion percentage. This is due to the mortar adhered to recycled aggregates. Sand equivalent values of aggregates finer than sieve No. 4 using ASTM D2419 and AASHTO T176 are also shown in Table 3.

The results show that increasing the percentage of recycled aggregates in the composition of the mixture increases the sand equivalent value, which determines the high quality of fine recycled aggregates. The reason is that washed sand is used in construction cement which has higher sand equivalent value. Lower percentage of fractured particles of natural aggregates in comparison of recycled aggregates is due to rounded corners of natural aggregates.

Results of Marshall test (ASTM D6927-06) determining the physical and mechanical properties of different mix designs are shown in Fig. 3.

With comparison of different asphalt concrete mix designs it is concluded that the major impact of increasing the percentage of recycled aggregates in asphalt concrete mixture design is on reducing the strength of the Marshall specimens. But increasing the recycled aggregates reduces the other parameters which can be recovered by increasing the bitumen which is not economical. So it is wise to use sulfur-bitumen concrete mix design in order to reduce the price.

Marshall test results of sulfur-bitumen concrete mix designs (determining the physical and mechanical properties of different mix designs) are in figure 4-B (Ratio of bitumen- sulfur is 60-40). According to

Table 3. Abrasion, Sand equivalent value and Percentage of fractured particles of RA0 to RA50

Mix design	Abrasion test result	Result of sand equivalent test	Percentage of fractured particles
RA0	29	68	87
RA10	35	70	88
RA30	38	75	93
RA50	42	79	94

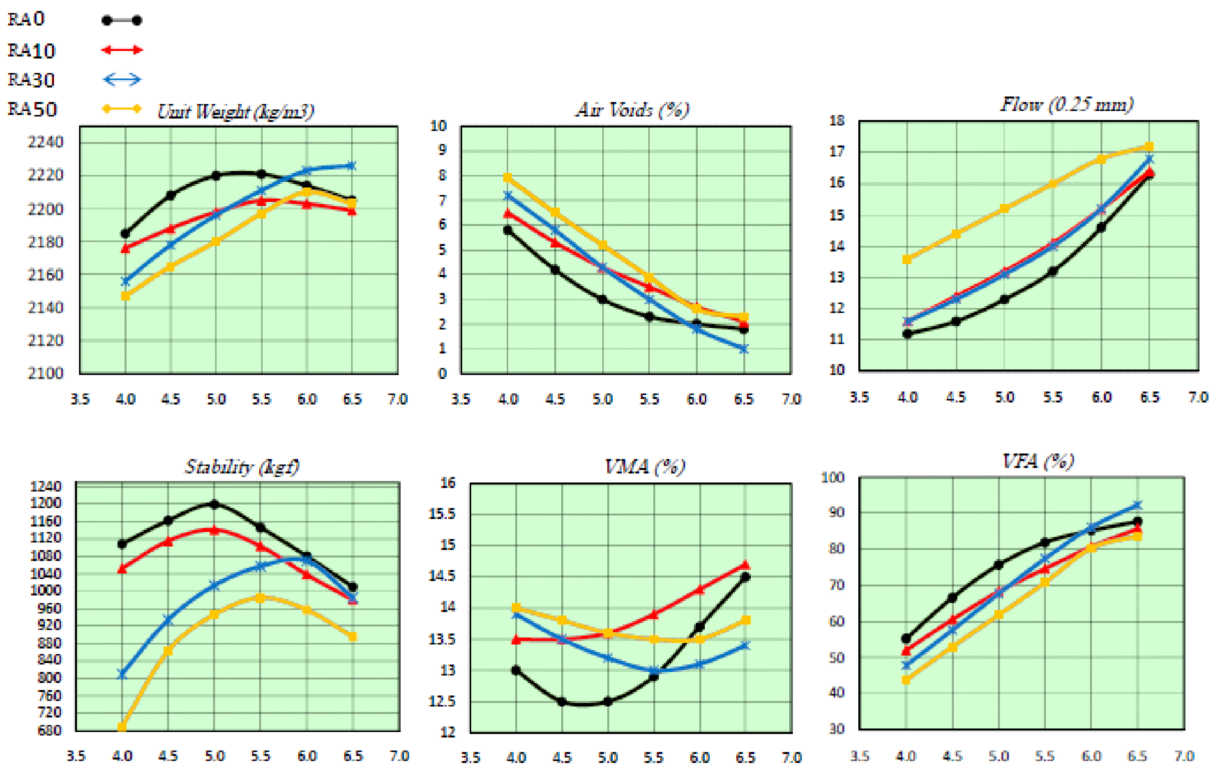
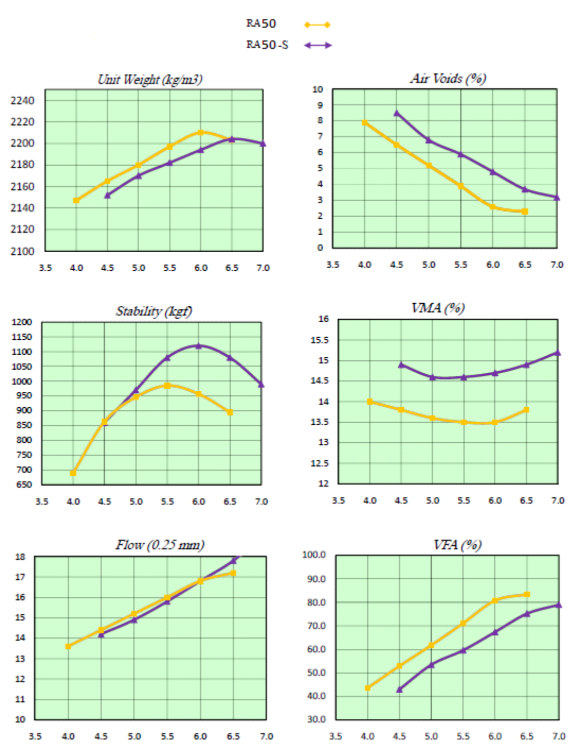


Fig. 3. Comparison of different asphalt concrete mix designs parameters obtained from Marshall test



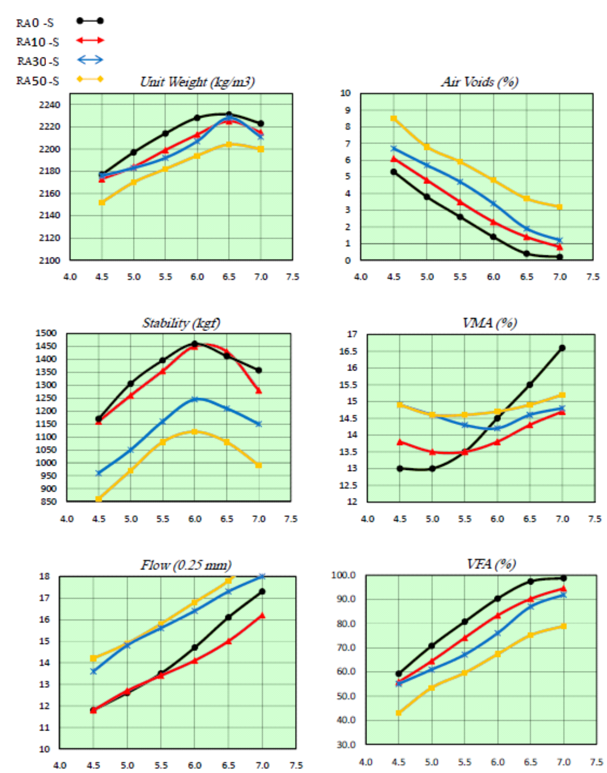


Fig. 4-A. Comparison of the physical and mechanical properties of RA50 and RA50-S mix designs
Fig. 4-B. Marshall test results of bitumen-sulfur concrete mix designs and other parameters

the results replacing 40% of bitumen by sulfur, increases the strength of the Marshall specimens and pore space filled with bitumen (VFA), and it also decreases void space (Va). Comparing sulfur asphalt mix designs shows that the true specific gravity of the sample (depending on the quality of the aggregate), reduces by increasing percentage of recycled aggregates. But like conventional asphalt mix designs with increasing percentage of recycled aggregates strength of samples are greatly reduced in sulfur asphalt mix designs.

In order to evaluate the effect of sulfur in improvement of technical specifications of Marshall specimens containing recycled aggregates, a comparison of physical and mechanical properties of mixings RA50 and RA50-S has been done (see Figure 4-A). Since the major portion of samples are aggregates, increasing sulfur did not have a significant impact on density. The maximum strength of the sample RA50 is 985 kilograms per cubic meter, while maximum strength of the RA50-S sample is 1120 kilograms per cubic meter. Due to the higher density of sulfur in comparison of bitumen (approximately twice), percentages of Va and VFA were almost the same in two samples. However, the flow rate and the percentage of free space between aggregates (VMA) of RA50-S have increased in comparison with RA50.

CONCLUSION

The test results show that the hardness of aggregates reduces by increasing percentage of recycled aggregates in the composition of asphalt concrete mixture due to the mortar adhered to recycled aggregates. The increase in sand value is due to the presence of washed sand in the composition of concrete debris. Recycled aggregates are more fractured than natural aggregate, thus the density is increased due to the lower internal friction angle and as a result better interlock. Recycled aggregates had the greatest effect on strength among the physical and mechanical properties of Marshall samples, which means increasing the percentages of recycled aggregates resulted in decrease of strength.

Results of tests to determine the technical characteristics of sulfur-bitumen mix design Marshall samples indicated that sulfur had a significant impact on increasing samples strength. According to the comparison of samples with and without sulfur, it was obvious that sulfur did only have major impact on strength of samples.

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