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LOW-COST PAVEMENT BY USING SOLID WASTE, RECYCLED AGGREGATES, CRUMB RUBBER, AND WASTE PLASTIC FOR RURAL ROAD

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ABSTRACT: In this paper, a practical idea is presented for the possibility of producing low-cost pavement for paving rural streets with light traffic loads by using asphalt mixtures of recycled aggregates (RA), fine used rubber (FR), and waste plastic (WP). The mechanical properties of the asphalt mixtures with the RA were determined. In addition to the determination of these characteristics when adding the WP to the hot RA before mixing them with asphalt at a temperature of 180 °C according to the dry method. Also, the results of tested mixtures were compared with asphalt mixtures that use FR as an alternative to fine aggregate, where the substituted ratio of WP were 0, 2, 4, 6, and 8%: FR were 0, 0, 1.5, 3, 4.5, and 6% of the percentage of fine RA. The outcome of the total tests that have been carried out on modified asphalt mixtures with both FR and WP, it can be advised that adding them leads to a clear increase in Marshall's stability. The percentage of FR that can be added to asphalt mixes is 3% and the WP is 4% of the total weight of fine aggregates. As a result, asphalt mixtures can be produced using RA, FR, and WP that can work within permissible conditions in rural areas, thus making a product of low-cost compared to others.

Keywords: Fine Rubber, Recycled Aggregate, Waste Plastic, Modified asphalt.

1. INTRODUCTION

Generally, recycling of waste materials is based on the principle of reducing the creation of large amounts of waste and reducing the areas of landfills and lowering the cost of the disposal process, thus preserving a healthy environment in addition to its low cost by preserving the energy consumption and natural resources of the aggregates. [1]. As known, construction materials especially concrete which are an essential material in construction processes, and need for concrete continues to increase dramatically. Simultaneously, the depletion of natural resources materials was accompanied by increasing demand for concrete, which imposed an environmental distortion of natural areas. Also, transporting raw materials from quarries far from construction areas is considered expensive. All these problems created a need to adopt a new strategy to reconsider the consumption of raw materials and replace them with other materials with satisfactory specifications [2].

Road pavements generally undergo two types of failure. The first type is directly related to the loading which in turn weakens the material capacity (fatigue of the pavement), which is called structural failure. As for the second type, it is a functional failure, as indicated by its name. It is directly related to the service provided by the surface layer of the road, comfort, maintenance, and low operational costs for road users [3]. Also, the excessive moisture content in the various structural layers of the pavement or inadequate compaction has a disruptive effect on the pavement strength in general [4-5]. Considering that the quality of the materials entered into the pavement design is a direct reason for the success of the roads and its infrastructure from the viewpoint of the road user, and these materials must maintain adequate toughness and durability throughout their operational life, without causing fatigue, cracks or damage to traffic [6]. Concrete is one of the most important margins in the consumption of natural aggregates (NA), as the addition of RA reduces the consumption of NA to 20%, and reduces the production of CO2 between 15 to 20% [7]. Several researches and investigations were able to estimate the quantities of the RA resulting from the demolition of residential buildings and old infrastructures, the amount of concrete destroyed in European Union countries is estimated at 850 million tons yearly [8]. The decrease in resources the NA will rise to 2500 x 109 tons yearly in the US at the end of the year 2020 [9]. Several studies have shown that the properties of the recycled collectors are less than the natural ones, the proportion of greater wear, and greater absorption of water [10]. As for the amounts and volume of waste produced annually, US statistics show that total solid waste is 200×10^6 tons yearly, an approximately 53% of which is thrown into the landfill, about 13% of which is WP [11]. As for the amount of produced from WP in Jordan, it is estimated at thousands of tons annually, which are discarded in landfills [12-13]. Several researchers have been able to prove that the addition of some plastic products classified as solid waste and some polymers to the asphalt can develop asphalt concrete performance [14-15]. Polyethylene (PET) with high or low density and its residues is considered as a good modified binder material that improves the physical and mechanical properties of asphalt and also contributes to the recycling of waste, as well as protecting the natural environment from the effects of pollution [16-17].

Another solid waste that gives rise to environmental concerns of human societies is used tires. It is estimated that 1.5 billion tires are manufactured annually worldwide, and nearly a quarter of this number are manufactured in the European Union. And as a first approximation, it can be said that for every new tire that is put on the market, a tire that has expired will be thrown instead [18]. Mixing rubber with asphalt mixtures will modify the original structure in addition to a change in the contact state of the materials with each other so that the asphalt mixture is loosened more easily than a conventional asphalt pavement [19]. The addition of used rubber improves many properties and performance of the asphalt mixtures. It improves the physical properties of the rubber-modified mixture, reducing the ductility and the degree of penetration [20-21]. But, the rubber-treated mixture suffers from poor durability, which is due to the weak cohesion and adhesion between the rubber and asphalt, which can be lost due to the action of freezing and melting, leading to the separation of the aggregates from the highway surface, and later on, the water can permeate within these gaps and when the traffic is repeated, forms a pressure that leads to weakness and loose Asphalt mixture [19]. Adou and others in 2018 used the dry method for mixing WP and asphalt with increasing proportions regularly 1, 2, 3, and 4% of the weight of the asphalt. The overall results confirmed the improvement of the performance of the asphalt mixtures when adding WP, where the stability increased by approximately 15%, and that 4% was the preferred percentage that gives higher stability. Added to these features is greater resistance to water action, the addition of WP has also led to a significant increase in the properties of aggregates, increase the abrasion resistance, and decreases the water absorption and increased hardness [22]. Also, Paul and Bhattacharya in 2015 conducted a study similar to the previous study, where the aggregates were mixed with WP according to the dry method, and the results were close to Adou and others' study [23]. F. Onyango and others, 2015 studied the modification of the characteristics of asphalt mixtures with FR and WP, and the fine aggregates were replaced, according to the following percentages for WP of 0, 2, 4, 6, 8, and 10%, as they were added to asphalt according to the wet method (i.e. mixing it with asphalt). As for adding FR, it was added to the aggregates according to the dry method at a replaced ratio of 1, 2, 3, 4, and 5% by volume of fine aggregates. Their study concluded that the optimum FR content is 2% as a volume percentage of fine aggregates and 4% of low-density polyethylene as a weight percentage of fine aggregates, and it also showed that there is a higher percentage increase in stability value by 30% over conventional asphalt. It also showed that the stability decreases with the increase in WP, after a ratio of 6%, as for the FR, the stability decreases after 2%. And as for the flow, it increases with the increase of the FR and the WP [24].

2. METHODOLOGY

The research stages were divided into five parts. The first stage is the stage of preparing the RA, and it included verifying the suitability of these materials to be added to asphalt mixtures, where the aggregate gradation, the L. A. Abrasion, the specific gravity were tested. Table 1, 2, and 3 illustrate the results of the tests, Table 3 shows that the value of both the specific gravity and the water absorption are much higher than the acceptable limits for asphalt mixtures which are, 15-30% and 08-3.7% respectively [25-26]. The second stage is the preparation of FR, which was brought from the free zone of one of the waste tires recycling plants, Al Zarqa free zone, Jordan. The size of these materials ranged from 0.3 to 4.75 mm, table 4 shows FR gradation. The third stage is the cutting of the WP into pieces ranging from 1 to 3 mm. The fourth stage is testing of asphalt and its properties, shown in Table 3. The fifth stage is the mixing of the mixture. The RA was mixed with small WP pieces at a temperature of 180 °C, after which the asphalt was added to the hot RA and mixed at 155 °C. As for the rubber, it was mixed at 155 °C with asphalt and RA. Marshall test has been implemented to achieve this study (ASTM, D: 1559-89). WP is a used bottle got from suburban areas. These bottles were chopped into small parts from 0.8 to 3 mm, where WP has a 0.95 of specific gravity value. The substituted ratio of WP were 0, 2, 4, 6, and 8%: The substituted ratio of FR were 0, 1.5, 3, and 4.5, and 6% of the percentage of fine RA. As for asphalt, its specifications were as follows, the penetration grade is 60-70, the Softening point is 53 ^{O}C, the fire point is 312 ^{O}C, the flashpoint is 278 ^{O}C, the ductility is 84 cm and the specific gravity is 1.03.

Table 1: Gradation for coarse aggregate (ASTM, C131)

# Sieve	25 mm	19 mm	12.5 mm	9.5 mm	#4	#8
Passing (%)	100	97.2	60.6	33.6	2.8	0.57

Table 2: Gradation for fine aggregate (ASTM, C131)

# Sieve	9.5 mm	# 4	# 8	# 16	# 30	# 50	# 200
Passing (%)	100	90	86	50	30	16	7

Table 3: Properties of RA

Examination	RA
L. A. Abrasion, ASTM, C131–81	44.87%
Specific Gravity value, ASTM C127	2.26
Absorption value of water, ASTM C127	6.93%

Table 4: Gradation for FR

# Sieve	Passing %	Remaining%
NO. 4	100	0
NO. 8	52	48
NO. 16	44	56
NO. 30	4	96
NO. 50	1	99

3. RESULTS

3.1 Determine the Optimum Asphalt Ratio

The mechanical properties of RA produce low values for stability (higher value is 670 Kg) as shown in Figure 1. These values are below the permissible limits for designing asphalt mixtures (the minimum values are 806 Kg for heavy traffic). But, these values are satisfied with typical values for medium traffic, the minimum stability for medium traffic is 534 kg [27]. It is for this reason that these mixtures can be considered suitable for roads in rural areas. The same result can be observed in the specific gravity chart, Figure 2. The values of the specific gravity of asphalt mixtures from RA is low (higher value is 2.07) compared with mixtures made with normal limestone aggregate. This is attributed to the presence of large voids within the old cement mortar surrounding the RA. Figure 3 shows the increase in the flow with the increase in the asphalt ratio, this is because asphalt increases the sliding of the aggregates together, which gives more density and thus greater flow. Generally, flow is the maximum change in the sample at the moment of collapse, and it is an important indication of the hardness of the sample. The larger the flow, the weaker the hardness, and vice versa [28-29]. There is an inverse relationship with respect to the percentage of air voids and the asphalt content as shown in Figure 4, as the asphalt content increased, the percentage of air voids decreased. It can be noted that for 4% of air voids, the asphalt content is 7.5% of the total sample weight, which is considered a lot compared to limestone aggregate and this increase in the asphalt content which is due to the high permeability of the RA. Figure 5 shows the relationship between the void mineral aggregate (VMA) and asphalt content. The VMA is considered as one of the most important indicators for better durability of asphalt mix if the VMA percentage is as low as possible [30]. The optimum asphalt is 7.5% of the mixture weight according to the maximum stability, specific gravity as well as a percentage of 4% air voids.

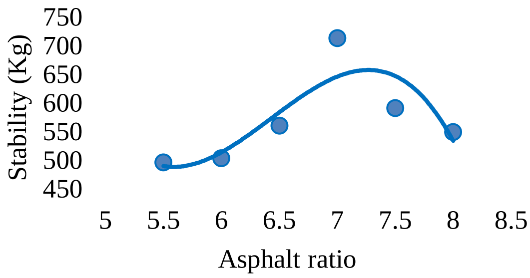

Fig. 1. Stability with asphalt ratio%

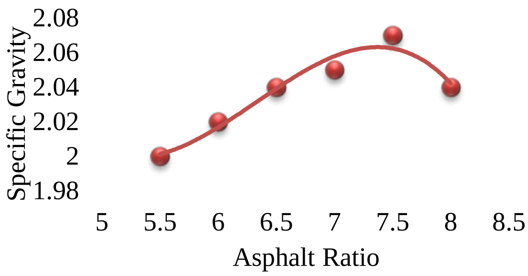

Fig. 2. Specific gravity with asphalt ratio %

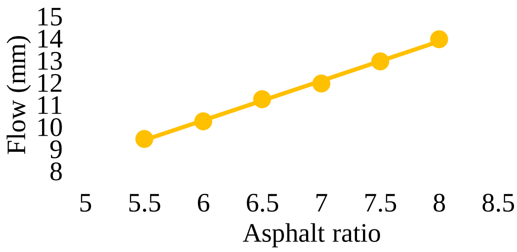

Fig. 3. Flow with asphalt ratio %

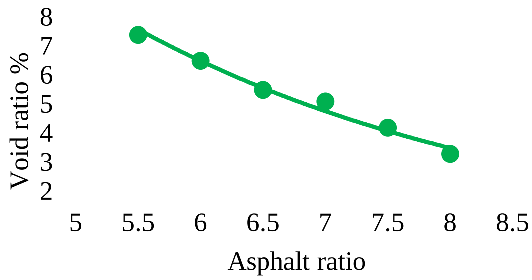

Fig. 4. Air voids with asphalt ratio %

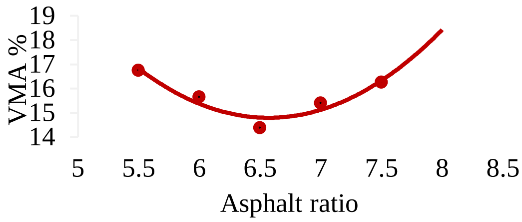

Fig. 5. VMA with asphalt ratio %

3.2 Determination of Optimum FR and WP Ratio in Modified Asphalt Mixtures

In this part of the study, modified asphalt mixtures are produced with two types of additives, which are FR and WP. Each increase in the percentage of WP leads to an increase in stability until reaching a maximum value, without considering the influence of FR. After that, the effect of the WP becomes inverse, as shown in Figure 6. This is due to the formation of new small particles from the WP that lead to an increase in the hardness of the asphalt. Hence, the density decreases as a result of an increase in the volume of voids and thus it leads to less stability. By observing the rest of the curves of FR, the optimum ratio is 3% by weight of fine materials, which corresponds to 4% of the WP, without considering the influence of WP. These results closely approximate the findings of F. Onyango and others [24], 2015, and Adou and others in 2018 [22]. It is also evident that increasing the percentage of FR at 6% or 4.5% leads to a significant decrease in stability and it is much less than 0% of FR. It is also noticed that 1.5% of the FR has stability more than 0%, but it decreases greatly with the increase of the WP. Figure 7 shows the decrease in the specific gravity of modified asphalt mixtures as a result of an increase in both FR and WP which is a natural result because the specific gravity of WP and FR is less than the weight of aggregates. It is also clear that the curve 3% of FR is the nearly to be constant for various ratios of WP, and there is a clear increase in the specific gravity of the modified strands at 6% or 4.5% of FR with the increase WP. Returning to the definition of the flow that was referred to previously, the highest flow obtained through examinations is at a rate of 6% of the FR, which corresponds to the lowest value of stability, as shown in Figure 8. The lowest flow is at 3% of the FR that agreed with the highest stability. It is also noticed that the flow values decrease with increasing the percentage of WP. As for the flow values, they came in contrast to what F. Onyango and others, 2015 [24] have found in the Reference studies presented in the previous paragraph. From the previous three figures, 1, 2, and 3, it is clear that the percentage of FR that can be added to asphalt is 3% and the WP is 4% of the total weight of fine materials of the same size as the substituted materials.

It is well-known that whenever the asphalt has a capable of protecting of an aggregates, the durability is better. The smaller the air voids within the asphalt mixture, the more durable will be. Therefore, adding FR and WP helps increasing the durability of asphalt mixtures and improving their performance under different weather conditions and during service, thus protecting the aggregates from being frost - thawing and the water action and also protect it from the oxidation of the asphalt itself, and as a result, it is more durable for the cohesion of the asphalt and the aggregates. Consequently, asphalt mixtures can be produced using RA, FR, and WP that have capability of work within permissible conditions in rural areas, thus it can be easy to produce a product with low-cost compared to other additives.

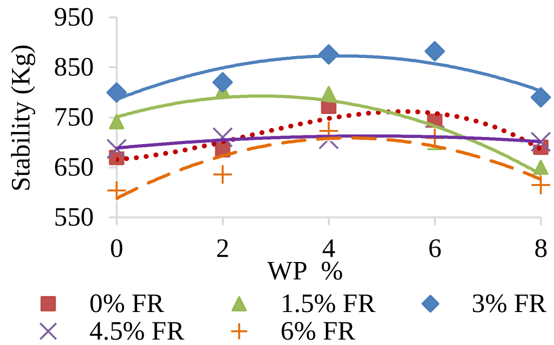

Fig. 6. Stability with FR and WP ratio %

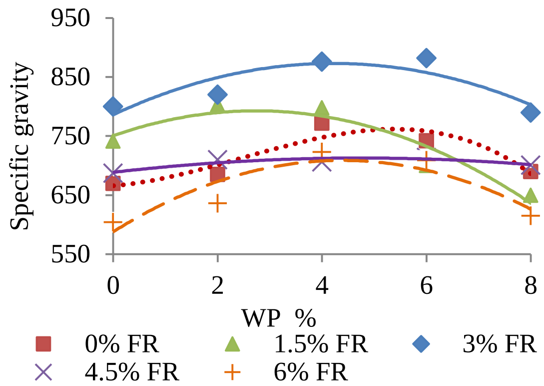

Fig. 7. Specific gravity with FR and WP ratio

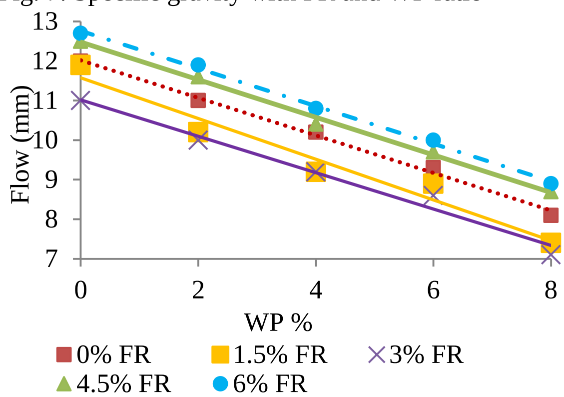

Fig. 8. Flow with FR and WP ratio

4. CONCLUSION

Asphalt mixtures can be produced using RA, FR, and WP that can work within acceptable conditions in rural areas, thus making a product that is low-cost compared to others. The percentage of FR that can be added to asphalt is 3% and the WP is 4% of the total weight of fine materials. It is also evident that increasing the percentage of FR at 6% or 4.5% leads to a significant decrease in stability and is much less than 0% of FR. It is also noticed that 1.5% of the FR has stability more than 0%, but it decreases greatly with the increase of the WP. As for the flow values, the highest flow obtained through examinations is at the percent of 6% of the FR, which corresponds to the lowest value of stability, The lowest flow is at 3% of the FR that agreed with the highest stability. It is also stated that the flow values decrease with increasing the percentage of WP.

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