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ECO-FRIENDLY HOT MIX ASPHALT BY USING RECYCLED CONCRETE AGGREGATE AND WASTE PLASTIC

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ABSTRACT

Irregular and unexpected increase of waste materials and depletion of raw materials alike are one of the interesting future challenges facing civil engineers today. As a result of conditions with Arab region of the destruction of infrastructures and buildings, large quantities of recycled concrete aggregate (RCA) are produced. In this study, the basic engineering properties of hot mix asphalt (HMA) that use RCA and waste plastic bags (WPB) as additives is calculated. Four types of mixes have prepared. The first mix is the control mix consisting of 100% the natural aggregate (NA) and the asphalt cement, the second mix comprise 100% of RCA and the asphalt cement, the third mix is a compound mix containing of natural coarse aggregate (NCA) which represent 53% of the total weight of aggregate with recycled concrete fine-aggregate (RCFA) which represent 47% of the total weight of aggregate and the asphalt cement, the fourth mix involves the third mix but asphalt modified by the waste plastic (2, 4, 6, 8 and 10 % by weight of asphalt). All mixtures were tested by Marshall Tests. As a conclusion of this study, it is detected that use 100% RCA in HMA is not useful for heavy traffic. Replacement of RCA with NCA has a considerable effect on the performance of HMA, where the increase of stability about 50% related to the second mix (100% RCA), this improvement allow the use such mixtures in HMA for heavy traffic. The appropriate increase in Marshall stability reach to 75% compare with second mix by adding 3.3% WPB to third mix (53% NCA plus 47% RCFA), it can encourage the use of RCA and WPB in industry of HMA as environmentally friendly and economical alternative.

Key words: Recycled Concrete Aggregate, Natural Aggregate, Waste Plastic, Asphalt Cement, Modified Asphalt.

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1. INTRODUCTION

The major function of the surfaces course (HMA) is to carry a load transmitted from traffic and spread them to the base course, sub-base course and subgrade within the acceptance strength to those layers. Aggregate establishes the main structural element of HMA, it is selected carefully to ensure the ideal performance of pavement during its service-life [**Pourtahmasb, 2016**]. Especially with the increasing of traffic volume that require a corresponding augmentation in the resistance of volume changes and load bearing capacities of the entire pavement. [**Appiah et al. 2017**]. In the past, selection of the pavement type based on cost and performance. Currently, a new influenced factor can be considered, this is the sustainable development. [**Brian Prowell, 2008**]. Sustainability involve three elements are society, economy, and environment. A modern systems are often required to assess construction projects against the economic, environmental, and social requirements of sustainable development [**Haifang Wen et al. 2014**]. A sustainable pavement defined as "a pavement that minimizes environmental impacts through the reduction of energy consumption, natural resources and associated emissions while meeting all performance conditions and standards" (According to Modified Asphalt Research Center) [**Haopeng Wang et al. 2018**].

Pavement construction, maintenance and rehabilitation required a great amounts of raw natural aggregates that lead to the depletion of those resources. In the United States above 320 million tons of raw construction materials are consumed annually in the several construction phases of the road network of country at a high cost exceeds $150 billion. [**Kenneth and Yaw, 2016**]. This ensure the increasing need to look for in sustainable construction alternative. Limited natural resources such as aggregates suffer from depletion causing of industrial and modern urban development. The demolition of old structures such as residential buildings, concrete bridges, highways, dams, and even from a natural catastrophes or wars may be suitable raw materials for construction of many civil project. One of effective solutions for growth environmental problems is use of recycle concrete aggregates (**RCA**) in the construction of pavement structure. Using of the RCA may be solve several problems as follows [**Qasrawi and I. Asi, 2016**]:

- It decrease areas required for disposal by removing the increase of waste concrete.
- It results in decreasing of the consumption of energy from aggregate production and transportation it (possibility of use it in the same municipal area).
- It lead to conserve of NA especially in zones which suffer from depletion of natural materials.
- It reduces effects on the environment and landscape by eliminating demolished concrete debris. As well as reduce harmful gas emissions.
- Minimizing the transport costs of disposal concrete.

Physical properties of the RCA is different from NA because of high porosity and low density of the RCA resulting by coated cement around the aggregates. In general, RCA has poor engineering properties, for these considerable reasons that make RCA is not suggested as aggregate for HMA [**Yoon-Ho Cho et al. 2011**]. Construction demolition waste consists of 40% concrete, 30% ceramic, 10% wood, 5% plastics, 5%metal, and 10% other combinations [**Sonawane and Pimplikar**, **2012**]. Rapid urbanization and huge population increases are creating high request for new highway networks, where these developments need to lots of highways. Surface course comprise up to 45% of an urban network in the US [**Kaloush et al. 2010**]. The quantities of demolished constructions in Europe countries amount to about 180 million tons per year [**Qasrawi and I. Asi, 2016**]. Environmental impacts related to the manufacture of **HMA** in terms both the increase of consumption of natural resource (aggregates, asphalt) and **CO2** emission are motivating the exploration for effective solutions, sustainable alternatives are considered one of the promising solutions. As it is known plastic is non-decayed in nature, it remains unchanged for thousand years may be reach 4500 years on earth, where waste plastic at landfill is very dangerous, they may be leaked out toxic chemicals into the soil medium, and ground water table and pollute the water[**Miss Apurva J Chavan, 2013**]. The large quantities of municipal solid-plastic waste are disposed either land filled or burned, and in two disposal procedures are not considered the most appropriate methods to dispose the solid waste and it causes environmental pollution of soil, water and air [**Rajasekaran et al. 2013**]. The statistics of the U.S. Environmental Protection Agency indicate that the municipal solid-waste (MSW) created in the USA is about 200 x 10^6 tons per year. 8%wt waste plastic, 38%wt of them is a paper products, and about 3% wt textiles and carpets [**Sulyman et al. 2016**]. Many types of modifiers such as crumb rubber, polymers, and waste plastic can be added HMA to develop bituminous mixtures performance. Choosing of modifier for particular civil project based on various influences including availability, ability of construction, expected performance and cost. Plastic waste is a byproduct of all bottles (soft drinks, water, and yoghurt), household-plastic appliances and bags (food packaging) which have been used before. Plastic appliances are made of **PET** (Polyethylene Terepthalate) and **HDPE** (High-density Polyethylene) [**Prowell, 2008**]. The re-use of plastic wastes is essential option from different viewpoints. It benefits to save the natural resources which consider non-compensable, it decreases the environmental pollution and aids to save and recycle of processes of energy production [**Ismail and AL-Hashmi, 2007**].

2. LITERATURE REVIEW

Qasrawi and Asi in 2016 stated that the use of RCA decrease Marshall stability, specific gravity and increase air void. In their study, the natural coarse aggregate (NCA) was replaced with 0%, 25%, 50%, 75 and 100% by RCA. The investigations tests stat that the replacements percentage 25% and more should not be added to HMA for heavy-traffic pavements. **Pourtahmasb in 2016** used the RCA in preparing HMA and stone mastic asphalt (SMA), where fine-RCA and coarse-RCA are replaced with the different percentage of NA (0%, 20%, 40%, 60% and 80% by the weight of RCA). The results shown that use RCA in both HMA and SMA mixtures increases the optimum asphalt content (OAC), as stated that the use 40% coarse-RCA, 80% fine-RCA in SMA, and 60% coarse-RCA, 50% fine-RCA in HMA can be satisfactory due to meet within the standard requirements. **Yoon-Ho Cho and others in 2010** prepared four categories of aggregate mixtures, 100% NA for mix (1), coarse-NA greater than seive #4 and the rest (passing from sieve #4) is fine-RCA for mix (2), coarse-RCA greater than sieve #4 and the rest is fine-NA for mix (3), 100% RCA for mix (4). This research presented that the Marshall test can be applied for design of HMA that use RCA, it is also specified that mixtures of HMA with RCA (Mix 2 and 3) have a good performance related to mixture HMA with NA (Mix 1), while Mix 4, does not display a good performance. **Rodríguez Pasandín and others in 2014,** they prepared mixtures of HMA by adding of the different percentages of RCA (5%, 10%, 20% and 30%) instead of NA, the NA-RCA mixture left in oven to four hours at temperature 170 ^{0}C. the study approved that the HMA contained RCA and preheated to 4 hours offered a very good water-resistance, an acceptable resistance to permanent deformation, and higher stiffer than that of HMA made of aggregate without heated in the oven. **Bhusal and others in 2011** blended RCA with NA at percentages (0 %, 20 %, 40 %, 60 %, 80 %, and 100 % by weight of NA), the study displayed that increases the asphalt content as RCA increase, and also indicated that use of RCA as aggregate in HMA is not suggested, even though the volumetric requirements for the RCA mixes are satisfied standard requirements. **El‑Tahan and others in 2018** in their investigation revealed that use 100% new-RCA (obtained from laboratory cubes) increase the stability and flow compare with old-RCA mixes (from the demolished building). Abrasion characteristic, indirect tensile strength, and stability loss were within the requirement limits. Another studies were achieved by **J. Mills-Beale and Z. You**

(2010); Pourtahmasb and Karim (2014). The test results of mix design indicated that RCA is absorptive, the optimum asphalt content increase as the percentage of RCA increased, and RCA had important effects on the volumetric requirements of the mix. It is consider a suitable for low-volume roads if RCA replace by a certain quantity of NA in HMA. **Radevića and others in 2017** stated that OPC increase as RCA content increase, and also they indicate to possibility of utilizing RCA in HMA. **Al-Humeidawi in 2014** investigated the possibility of using waste plastic bags and RCA in preparing of asphalt mixture. It was found that coat the RCA with asphalt modified by waste Plastic lead to increase Marshall stability to value up to 10% and 9% in indirect tensile strength in comparable with control mixtures.

3. OBJECTIVES

Unexpected increasing of population in Jordan resulting from the conditions in this region is created a considerable growth in activities of peoples such as transportation sector in general and especially in transportation infrastructure which increase depletion of raw materials. Therefore, it is necessary to look for a sustainable solution in construction of highway infrastructures compatible with an increasing developments. Therefore, the main objective of this research was to study a possibility of using recycled aggregates that have poor specifications in HMA for heavy traffic, as well as adding of the various replacement percentage of WPB to coating RCA. Consequently, reduce WPB generation in the environment.

4. METHODOLOGY

In order to obtain properly investigation data, all of the specimens were prepared using the same method (dense gradation for natural and recycled aggregates and the asphalt according to Jordan specifications of ministry of public works and housing). The methodology can be summarized in several steps:

First Step: The properties of natural and recycled aggregates were defined. Los Angeles abrasion value (ASTM C131 – 81) for NA was 27.14% smaller than allowable limit 30% according to MORTH (IV Revision) specifications [**Yadav Santosh et al. 2013**], and 41.24% for RA greater than 30% relative to high porosity to RA. Specific gravity of the coarse, fine and fillers for **NA** was 2.57, 2.64, and 2.72 respectively, and for RA of 2.23, 2.41, and 2.69. A water absorption of the RCA was 7.1%, it is larger than the WSDOT specification (3.7 % max) [**Salehlamein et al. 2015**], higher water absorption can be due to old mortar cement which coated coarse aggregate where the old mortar involve high porosity. Water absorption for natural NCA was 2%.

Second Step: several tests were achieved to examine the asphalt properties, penetration value of 64 mm (ASTM D-5), softening point of 51.45 ºC (ASTM D-36), ductility value of 77 cm (ASTM D113), flash point and fire point were 286 ºC, 314 ºC respectively (AASHTO T48), specific gravity of 1.03. This Asphalt was brought from one of a local highway contractor in Amman city.

Third Step: Waste plastics bags (WPB) obtained from several residential zone in Amman city cut into a small size from 2.36 mm to 4.75mm, these bags are vegetables-packaging bags that use in most markets.

Fourth Step: Marshall test (ASTM D1559-82), a 1200 gr of NA and RCA aggregates (include coarse, fine and filler aggregates) is heated with a temperature of 170 ^{0}C. Asphalt is also heated with a temperature of 120 ^{0}C and then increasing percentage of asphalt ((5, 5.5, 6, 6.5, 7, 7.5, 8% by weight of the aggregates) is added into heated aggregates and then carefully mixed at a temperature of 150 ^{0}C – 160 ^{0}C. finally these mixtures put in the mould and compacted by 75 blows on each side of specimen at temperature of 140ºC. The total number of specimens were

42, 21 each of them, three specimens for each the asphalt percentage were prepared. From this procedure the optimum asphalt content is determined for NA and RCA aggregates.

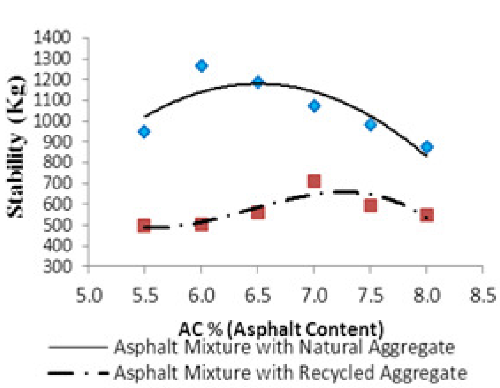
Fifth Step: in this step, a various amounts of aggregates of RCA ranging between sieve #4 (4.75 mm) to 3/4’’ (19 mm) were replaced with natural coarse aggregate (NCA) to make a 18 specimens. The replacement percentage (0%, 15%, 30, 45%, 60%, and 75%) of the weight of RCA, a 0% represent the mixtures that contain 100% RCA without NA, these mixtures was a conventional mix. The optimum of replacement percentage of RCA has been determined.

Finally step: Modified asphalt were prepared in the wet process, a 2000 gr of asphalt which has been tested in second step heated to 110 ºC in oven until fluid situation and WPB was gradually added into asphalt mixer with temperature from 160 ºC to 170 ºC. Mixing of WPB was sustained for 15-30 minutes to achieve homogenous blends. Replacement percentage of WPB was 1, 2, 4, 6, 8 and 10% by weight of asphalt. Finally, WPB was added to coat the aggregate, which has been already heated to ensure uniformly distribution over aggregates. The temperature was monitored well because of their very important effect on the asphalt properties. The specimen numbers were 54 (18 for each of NA, NCA-RCFA and RCA mixtures), the optimum WPB content is determined.

4. RESULTS & DISCUSSIONS

4.1. Performance of asphalt mixtures with NA and RCA

Comparative study between the asphalt mixtures that use the natural and the recycled aggregate:



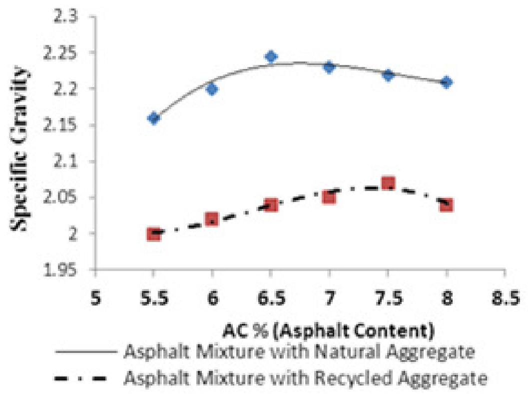
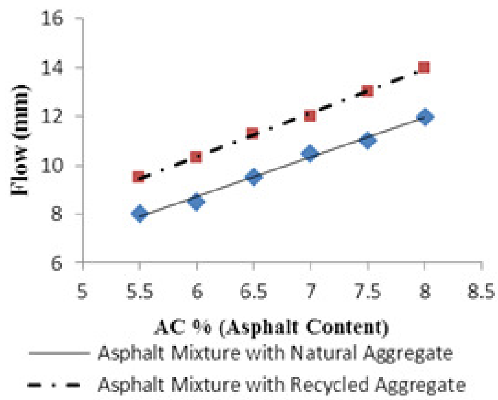


Fig 1 Marshall Stability VS Asphalt Content% **Fig 2** Specific Gravity VS Asphalt Content%



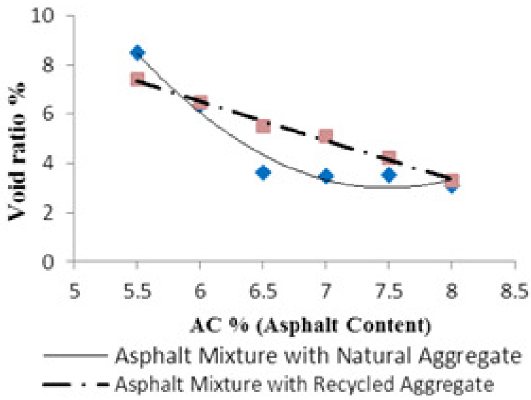


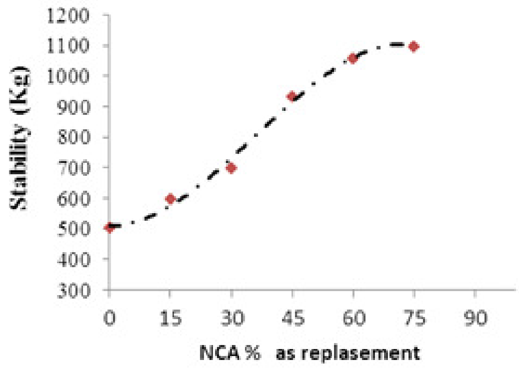
Figure 3 Flow VS Asphalt Content% **Figure 4** Void Ratio% VS Asphalt Content%

As of Fig. 1, it can be noted a big difference between stability values for asphalt mixtures with NA and RCA mixtures. This can be related to poor properties of RCA (the higher value of Los Angeles abrasion), where the value of the highest stability of the RCA mixtures didn't exceed 714 kg, it is not satisfy for standard requirements, the lowest value for heavy traffic is 816 kg according to Federal Highway Administration, U.S. Department of Transportation [**Garber and Hoel, 2009**]. Fig. 2, also shows significant variations in the specific gravity, this reduction in specific gravity of RCA mixtures may be attributed to properties of RCA aggregates (high porosity). The same results were also testified by [**Bhusal and others in 2011].**

As demonstrated in Fig.3, the flow value for NA mixtures lower than RCA mixtures. Generally, flow value can consider as an indicator how much mix stiffness is, high flow for mixtures mean that they are relatively weak. The flow-stability relationship is adverse the smaller flow higher stability and vice versa. Fig. 4, illustrations the relationship between the air void and the asphalt content for two types of mixtures, it can be seen that at 5.5% asphalt content was air void for NA mixtures greater than RCA mixtures, and then starts decreasing gradually as asphalt content increase after interception point 5.75% until it reach to a lower value than RCA mixtures, this can be explained to the fact that the RCA has more porosity than NA, it leads to increase asphalt content, Test results are compatible with many investigates, **[J. Mills-Beale and Z. You (2010); Pourtahmasb and Karim (2014)**]. From Figs. 1, 2 and 4 can determine the optimum asphalt content (**OAC**) for NA and RCA mixtures, where was **OAC** 6.4 % for NA and 7.5 % for RCA by the total weight of mixtures.

4.2. Performance of RCA mixtures that use the NCA as an additives

After the failure of the preceding attempts to produce HMA by using RCA for heavy traffic, the different percentages of NCA have been added to RCA mixtures at **OAC** of 7.5%, the results shown in following figures.



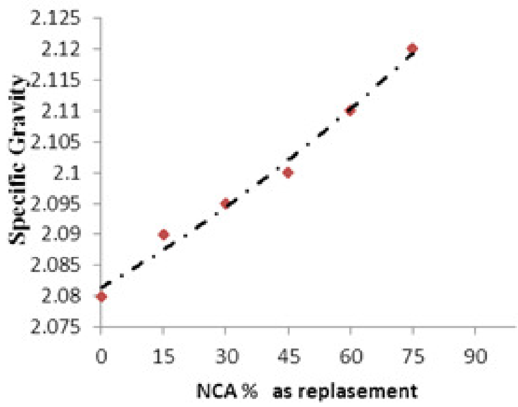
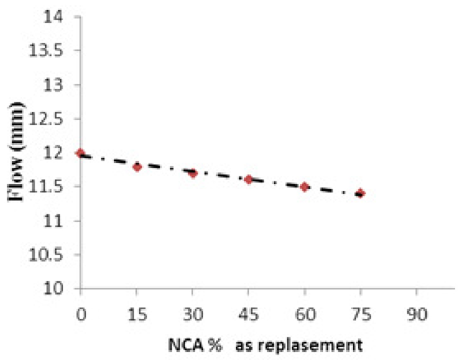


Fig 5 Marshall Stability VS natural aggregate content% **Fig. 6.** Specific Gravity VS natural aggregate content%



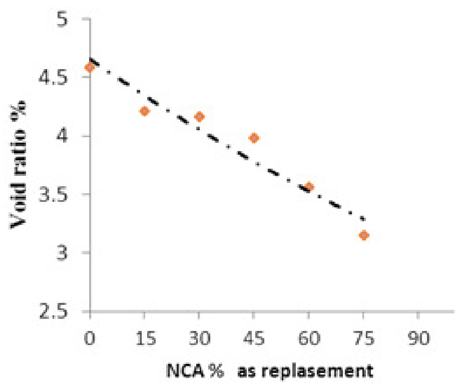
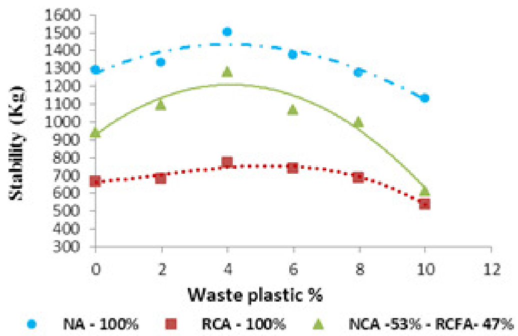


Fig 7 Flow VS natural aggregate content% **Fig 8** Void ratio % VS natural aggregate content%

As displayed in the Fig. 5, the addition of NCA with increasing percentages lead to a gradual increase in the Marshall Stability and specific gravity of RCA mixtures. On the other hand, the using of NCA lead to decrease in air void and flow values. These findings are consistent with [**Qasrawi and Asi in 2016].** Based on the acceptable air void (3-5%) and minimum stability (816 kg) the all of recycled coarse aggregates in asphalt mixtures can be substituted with NCA that represent 53% of total aggregate weight at OAC of 7.5% (53% of natural coarse aggregate (NCA) and 47% of recycled concrete fine-aggregate). The new compound mixes are NCA (53%)–RCFA (47%).

4.3. The effect of using of waste plastic (WPB) on properties of asphalt mixtures

Comparative study for NA-100%, RCA-100% and NCA (53%) – RCFA (47%) mixtures that use waste plastic as additives at OAC of 7.5% by the total mix weight have achieved, where replacement percentage of WPB was 1, 2, 4, 6, 8 and 10% by the asphalt weight. From this procedure the standard specifications of the HMA at OAC can be determined.



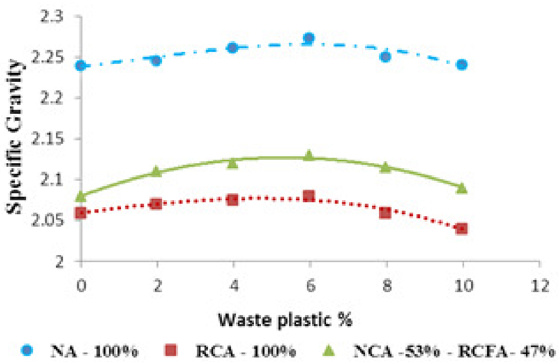


Fig 9 Marshall Stability VS Waste Plastic% **Fig 10** Specific Gravity VS Waste Plastic%

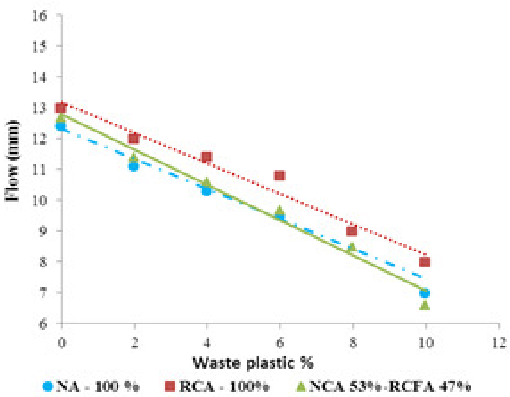


Fig 11 Flow VS Waste Plastic%

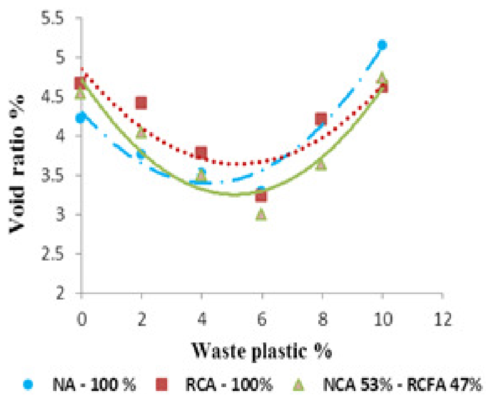


Fig 12 Void Ratio VS Waste Plastic%

The relationship between Marshall stability values and WPB content are shown in Fig. 9. From this figure can be concluded that add waste plastic to RCA-100% mixtures has no important effect on the required stability where it is still smaller than the standard stability (816 Kg). But, there is consider effect on the NCA (53%) – RCFA (47%) mixtures, where Marshall stability value exceeded the standards value and reach to 1281 kg at 4% of waste plastic, this result indicate to the possibility RCA and waste plastic in HMA for heavy traffic. Such results have been obtained by several researchers [**Al-Humeidawi, in 2014**; **Radević et al., in 2017**]. In term to NCA-100% and NCA (53%) – RCFA (47%) mixtures have higher stability at also 4% of waste plastic. It is obvious from Fig.9 any addition of waste plastic content after (4%) decrease the mixtures stability. The resulting reduction in the stability value may be due to the hardness of asphalt cement (more stiff and brittle). For RCA-100% the maximum stability was at 6% waste plastic by the asphalt weight.

The specific gravity increase as waste plastic content increase up to 4% for NCA-100% and NCA (53%) – RCFA (47%) mixtures as shown in fig.10, after this value the specific gravity gradual decline. As an explained in the preceding section, this result can be contributed to the production of a stiffer modified asphalt. RCA-100% has maximum value of specific gravity at 6% waste plastic by the asphalt weight.

The use of waste plastic reduced the flow value in all mixtures as presented in Fig.11. The formation of a stiffer modified asphalt can result in a lower flow as waste plastic content increase. On the other hand, higher flow corresponding with lower stability as demonstrated in fig.8.

From Fig. 12, it is seen that the air voids decrees as waste plastic content increase until the minimum value after that value the air voids in the mix gradual increase for all mixtures. Also, 2% of waste plastic content is satisfied to standard requirements in NCA (53%) – RCA (47%) mixtures, 1% of waste plastic content for NCA-100% mixtures and 4% of waste plastic content for RCA-100% mixtures.

Depending on the fig. 10, 11 and 12 the optimum asphalt-waste plastic for NCA (53%) – RCA (47%) mixtures is 3.3 % of asphalt content in the mix.

5. CONCLUSIONS

The results of laboratory investigations proved that the use of the RCA without any additives does not satisfy the standard limits for heavy traffic. Also stated that add 53% of NCA as replacement percentage instead in recycled coarse concrete aggregate (RCCA) has significant effect on the Marshall Stability reach to 50%. In addition, it reduces of optimum asphalt content (OAC), as the percentage of NCA in the RCA mixture increases the OAC decreases. And related to an air void, the replacement percentage up to 53% satisfactory the standard limit.

Furthermore, the optimum asphalt-waste plastic was 3.3% of asphalt content, where coating of the aggregate surface (NCA-RCFA mixtures) by modified asphalt cement has resulted in development of Marshall Stability 25% comparable with NCA-RCFA mixtures without waste plastic. Utilizing waste plastic in HMA will discount bitumen content by around 3.3% as well as it is been a good option as anti-stripping agent of aggregates and eco-friendly (avoid removal of plastic waste by land fill).

Although the use of RCA has some of adverse result on the mechanical and physical properties of HMA. But, the addition of selected percentage of NCA and waste plastic shows that it is suitable for heavy traffic, and it is one of a sustainable construction solutions for highway pavement.

6. RECOMMENDATIONS

More laboratory tests are suggested to coat the RCA in the dry method, in this process the RCA heated to 160 ^{o}C -170 ^{o}C and then mixing with plastic waste before addition of asphalt into the hot RCA. Using another plastic types such as low density polypropylene. Development a new researches by using different aggregate types instead in limestone (NCA) are suitable for production of new asphalt pavements mixes.

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