Evaluation of the effect of recycled asphalt pavement on the behaviour of plastic cracking in concrete pavements

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Abstract
The use of recycled asphalt materials in the construction of concrete pavements is important in terms of preserving the environment and building a sustainable pavement. However, it is necessary to investigate the effect of these materials on the change of pavement behaviour. Paste cracking is one of the most common types of failure in concrete pavements and needs a deeper study. The present research examines. The average width, length and area of cracking caused by paste shrinkage in control concrete mixtures containing 25, 50, 75 and 100% recycled materials were evaluated using ASTM C1579 standard method. The results indicated that by replacing recycled asphalt crumb materials, the severity of cracking increased significantly. The average width, length and area of cracking increased up to 43, 33 and 99%, respectively. It was observed that the replacement amount of recycled asphalt crumb material has a significant effect on the change of paste cracking behaviour. Also, the results showed that the recycled asphalt crumb material caused a greater change in the average cracking width than its length.

Keywords: “Recycled Asphalt Pavement (RAP) ”, “Concrete pavement”, “Plastic shrinkage cracking”, “Geometric characteristics”, “Cracking severity”,.

Introduction

Recycled Asphalt Pavement (RAP) is the extraction of existing asphalt in asphalt pavement, which is created for reasons such as the destruction of the current asphalt and the implementation of a new asphalt layer. Recycled or reclaimed asphalt pavement is, in fact, asphalt removed from the pavement, which includes aggregates and bitumen. Recycled asphalt pavement material is one of the recycled materials that accounts for a large amount of refuse produced in the construction industry[1,2]. Disposing of construction wastes has a high cost and also causes destruction of the environment. On the other hand, the use of natural materials in the construction industry causes the reduction of natural resources and leaves environmental effects in addition to economic consequences in any project[3,4]. These cases have made the use of recycled materials as a substitute for part or all of the natural materials to the attention of researchers and managers of the construction industry. This is also true in the road construction and paving industry, and the efforts of researchers in this industry have always been to use fewer natural materials and use more recycled materials. As a result, the use of recycled asphalt materials in the construction of concrete mixtures used in concrete pavements has received more attention.

The use of new materials, especially recycled ones, requires consideration of the effects of them on changing the behavior of concrete pavements, so that the performance and durability of these structures can be investigated by replacing recycled materials with natural materials. One of the most important cases in this field is the investigation of the change in plastic shrinkage cracking in concrete pavements, which is considered as one of the common failures in the early hours after the construction of the pavement[5,6]. Plastic shrinkage in concrete mixtures occurs after the concrete has been placed in the early hours after construction. The rapid drying of the concrete surface due to the environmental evaporation rate and the excess of this rate over the concrete bleeding rate leads to shrinkage in the concrete, which, if the concrete structure is restraint, tensile stresses occur on the concrete surface[7,8]. Due to the low tensile strength of fresh concrete in the early hours after implementation, the tensile stresses caused by the plastic shrinkage exceed the tensile strength of fresh concrete and lead to cracks in the concrete surface[9,10]. Plastic shrinkage cracking occurs more often in concrete structures with high surface-to-thickness ratio (flat concrete structures) and threatens the performance and durability of these structures[11–13]. For this reason, this type of failure and cracking is more important in concrete pavements.

Investigating the effect of adding recycled materials in concrete and replacing these materials with natural materials on plastic shrinkage cracking has been the focus of some researchers. For example, Bandimrad et al. investigated the effect of replacing the sand obtained from recycled concrete chips with natural sand in the concrete mixture on plastic shrinkage cracking concrete. In this research, 4 different values of degree of saturation in recycled aggregates were considered. The results of their work showed that the degree of initial saturation in recycled aggregates has a significant effect on the formation of the plastic shrinkage. Also, they stated that the replacement of sand in the concrete mixture with the sand obtained from the recycling of concrete chips, in a high replacement amount, has a significant effect on the change of the shrinkage behavior and the sensitivity of the plastic cracking in concrete. This shows that by replacing natural aggregates in the concrete with recycled aggregates obtained from concrete chips, it can have a noticeable effect in changing the early behavior of concrete[14]. In another study, Bandimrad et al. analyzed the change in cracking behavior due to premature shrinkage of concrete in free and restraint shrinkage conditions, under the influence of replacing natural sand with sand obtained from recycled concrete. The results showed that cracking severity decreased with the amount of recycled concrete. Also, it was stated that recycled sand had a different effect on the early shrinkage behavior of concrete[15]. Liu et al. evaluated the plastic shrinkage of cement mortars containing recycled powders from masonry bricks and aerated blocks. In this research, digital image analysis technique was used to evaluate the plastic shrinkage cracking behavior. The results of their study showed that mortars containing recycled powder from the recycling of ventilated blocks showed a higher risk of cracking. In contrast, mortars containing recycled brick powder had a lower risk of cracking[10].

The summary of researches background shows that using materials obtained from the recycling of different materials (such as concrete chips and bricks) affects the behavior of plastic shrinkage in concrete mixtures. This issue changes the behavior of plastic shrinkage cracking in concrete mixtures. From this point of view, according to the reviewed results, it can be said that replacing natural materials in concrete with recycled materials has an effect on the plastic shrinkage cracking in concrete and this effect can be remarkable. On the other hand. However, investigating the effect of using materials obtained from the recycling of asphalt pavement in concrete mixtures and replacing this material with natural materials in concrete, on the change of plastic shrinkage cracking in concrete mixtures used in concrete pavement, has been studied less. Also, investigating the effect of the content of this material on the intensity of plastic shrinkage cracking in concrete pavement is another important point which needs to be studied in order to determine the appropriate content in the concrete mixture so as to cause a minimum increase in plastic shrinkage cracking severity in concrete pavement. Considering the importance of using recycled materials in concrete pavements in order to preserve the environment and also the importance of plastic shrinkage cracking in these concrete structures, the present research examines the effect of recycled asphalt pavement on the behavior of plastic shrinkage cracking in concrete pavements.

Materials & Methodology

The cement used in this research was type 1-425 Portland cement with a specific weight of 3150 kg/m^3. The chemical analysis specifications of this cement, provided by the manufacturer, are given in Table 1.

Table 1: Chemical characteristics of type 1-425 Portland cement used in this research

Chemical characteristics	K_2O	Na_2O	IR	SO_3	L.O.I	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2
Content (%)	0.45	0.50	0.3	2.0	1.4	2.9	62.5	3.9	4.6	21.0
Standard value according to ISIRI 389	-	-	0.75<	3<	3<	5<	-	6<	6<	20.0>

The aggregates used in the concrete mixtures were limestone stone aggregates with a maximum size of 19 mm. These materials were divided into three grading groups, including fine-grained aggregates with a size of 0-5 mm, coarse-grained aggregates with a size of 5-12 mm, and coarse-grained aggregates with a stone size of 12-19 mm. Fineness modulus, water absorption and relative density of 0-5 mm fine-grained aggregates were 3.46%, 2.58% and 2.63% respectively. 5-12 mm coarse-grained aggregates had water absorption and relative density of 1.07% and 2.63, respectively, and 12-19 mm coarse-grained aggregates materials had water absorption and relative density of 0.98 and 2.62, respectively.

Recycled Asphalt Pavement (RAP) material was the result of the crushed asphalt pavement in an asphalt pavement project. Figure 1 shows the recycled asphalt pavement used in this research. Recycled asphalt pavement has a maximum size of 19 mm and are available in coarse-grained and fine-grained dimensions.

Figure 1: the recycled asphalt pavement (RAP) used in the current research

The concrete mixtures proportions of concrete pavement were determined in such a way that the criteria mentioned by Rule 731 for concrete mixtures used in concrete pavement are met. For this purpose, the ratio of water to cement was considered to be 0.50. The selection of this ratio of water to cement aggregates is higher than the considered values in real conditions, but with this purpose, it was chosen so that the number of cracks formed in the concrete would be noticeable. The proportions of aggregates 0-5 mm, 5-12 mm and 12-19 mm were chosen by 55, 25 and 20 percent, respectively. The amount of cement considered in the concrete mixtures was 425 kg/m^3. This amount of cement was chosen in order to create the workability required in concrete pavement mixtures. Recycled asphalt pavement, without bitumen separation operation, was used in making concrete mixtures. The combination of recycled asphalt pavement in amounts of 25, 50, 75 and 100% replaced the combination of natural materials. In this way, the number of 5 concrete mixtures was examined in the research. In Table 2, The proportions of reference concrete mixture can be seen.

Table 2: Concrete mixtures proportions considered in this study

Concrete Mixtures	**Cement (Kg/m^3)**	**Fine Aggregates (0-5 mm) (Kg/m^3)**	**Coarse Aggregates (5-12 mm) (Kg/m^3)**	**Coarse Aggregates (5-12 mm) (Kg/m^3)**	**Water (5-12 mm) (Kg/m^3)**
Reference	425	923	419	334	212

Plastic shrinkage cracking in concrete mixtures was evaluated using the ASTM C1579 standard method. In this method, a concrete slab mould with dimensions of 100 x 355 x 560 mm according to the standard was used. Inside the mould, in order to increase cracking, a steel tool with specific dimensions was used. This steel tool had a stress riser in the middle and two restraints on the sides. Figure 2 shows the specifications of the steel mould and tools.

Figure 2: ASTM C1579 concrete slab mould used in the research

In this test, concrete slab samples were tested under specific environmental conditions including temperature of 40 degrees Celsius, air relative humidity of 20% and wind speed of 30 km/h. The considered conditions were chosen in order to create harsh environmental conditions in terms of plastic shrinkage and to achieve the maximum amount of plastic shrinkage cracking in concrete samples. In order to create the mentioned environmental conditions, an atmospheric simulating chamber was used. This chamber has the ability to create and maintain the ambient temperature from 20 to 50 degrees Celsius with an accuracy of 0.1 degrees Celsius, the relative humidity of the air from 20 to 100 percent with an accuracy of 1 percent, and the wind speed from 0 to 30 km/h with an accuracy of It was 0.1 km/h. Figure 3 shows the atmospheric factors simulation chamber used in this research.

Figure 3: The atmospheric simulating chamber used in research

After making the concrete mixtures, concrete was poured inside the mould in one layer and then compacted using a hammer. After that, the atmospheric factor was set in the desired environmental conditions and then the concrete slab mould was placed inside the chamber. The duration of the experiment was chosen as 6 hours. During the test, the sample was subjected to atmospheric loading. The choice of this amount of test duration was made because in most of the observed researches, the maximum amount of plastic shrinkage cracking occurs in the first 6 hours after the concrete is made. In Figure 4, the concrete samples under test can be seen.

Figure 4: Concrete samples under testing in the atmospheric simulating chamber

At the end of the test, microscopic images of the crack line in the middle of the sample were taken using an optical microscope connected to a computer. The captured images were entered into the Digimizer image analysis software and analyzed. Image analysis was done in such a way that at first, each microscopic image was calibrated using the actual size inside the image, then it was analyzed using the image analysis tool inside the software. The geometric characteristics of cracking including the average width of cracking, length of cracking and area of cracking of each concrete slab sample were determined. In Figure 5, the analysis of digital images can be seen in the digital image analysis software.

Figure 5: Digital image under analysing in the software

Results & Discussion

In this part, the effect of recycled asphalt aggregates in different contents on the geometric characteristics of plastic shrinkage cracking is investigated. Figures 6, 7, and 8 show the average crack width, crack length, and crack area in mixtures containing recycled asphalt aggregates with different content compared. Examining the results, it can be seen that the replacement of recycled asphalt pavement increases the severity of plastic shrinkage cracking in concrete mixtures. By replacing the recycled asphalt pavement by 25%, the average width, length and area of cracking of the RAP25 mixture increases by 7, 10 and 20%, respectively, compared to the RE mixture. By replacing recycled asphalt pavement with natural materials in concrete mixtures, the strength characteristics of concrete are changed and reduced. The reason for reducing the strength properties of concrete by replacing asphalt pavement is the presence of a layer of bitumen and aggregates bond together. The bitumen layer that surrounds the aggregates reduces its adhesion with the cement paste. Also, the aggregates stuck together in the concrete mixtures have low strength and reduce the strength of concrete. Tensile strength of concrete is also one of the strength characteristics of concrete mixture, which is reduced by replacing recycled asphalt pavement with natural aggregates. By reducing the tensile strength of concrete in early age, the strength against forces caused by the plastic shrinkage is reduced, as a result, the severity of cracking increases. As can be seen from the results, the effect of recycled asphalt pavement on cracking changes occurs in both longitudinal and transverse directions. In other words, the recycled asphalt pavement has caused an increase in cracking in both directions, which leads to a significant increase in the cracking area, because the change in the cracking area is affected by the change in its length and width.

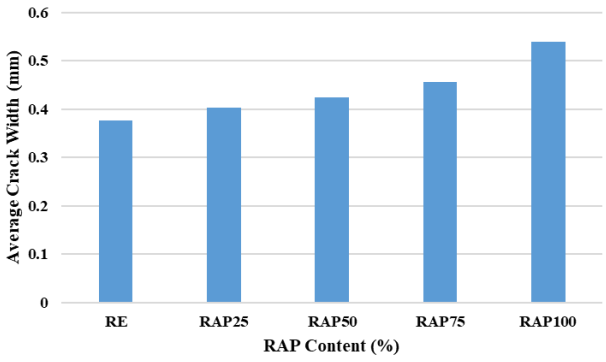

Figure 6: Average Crack width in reference and recycled asphalt pavement (RAP) in different content

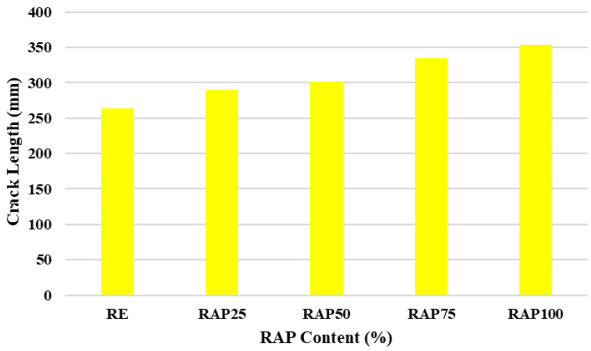

Figure 7: Crack length in reference and recycled asphalt pavement (RAP) in different content

With further investigation, it indicates that with the increase in the amount of replacement of recycled asphalt pavement with natural materials, the increasing trend of the severity of plastic shrinkage cracking in concrete mixtures continues. By replacing recycled asphalt pavement in amounts of 50, 75, and 100% in RAP50, RAP75, and RAP100 concrete mixtures, the average crack width was 13, 21, and 43%, respectively, and the crack length was 14, 26, and 33% and the cracking area increases by 32%, 52% and 99% respectively. This issue indicates that the amount of recycled asphalt pavement replacement has a significant effect on the changes in the severity of plastic shrinkage cracking in concrete mixtures. By increasing the amount of replacement of asphalt materials, the amount of bitumen and bonded aggregates in the concrete mixture increases. This causes the strength of cement paste and aggregates in concrete to decrease and the strength properties of concrete, especially the tensile strength of fresh concrete, are further reduced. As a result, by increasing the replacement rate of recycled asphalt pavement, the severity of plastic shrinkage cracking in concrete will increase. At 100% replacement content, the severity of plastic shrinkage cracking increased in such a way that the area of cracking in concrete mixes increases to nearly 100%. This issue shows that the amount of replacement of recycled asphalt pavement may have a noticeable effect on one of the geometric characteristics of cracking so that it doubles its intensity. For this reason, the amount of replacement of recycled asphalt pavement in concrete mixtures becomes very important. Also, the results indicate that the amount of replacement of recycled asphalt pavement causes a significant change in cracking in both directions.

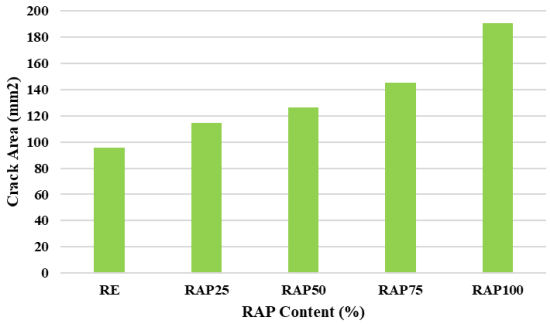

Figure 11: Crack area in reference and recycled asphalt pavement (RAP) in different content

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Conclusions

The present research evaluated the effect of recycled asphalt pavement on the behaviour of plastic cracking in concrete pavements. The most important results obtained from this research are as follows:

- By replacing natural materials with recycled asphalt pavement, the geometric properties of cracking increase significantly.
- The average width, length, and area of cracking increases by 43, 33, and 99 percent, respectively, by replacing recycled asphalt pavement.
- The amount of replacement of recycled asphalt pavement has a significant effect on the changes in the behavior of plastic shrinkage cracking in concrete mixtures.

- By replacing the recycled asphalt pavement, the average width of the crack changes more than the length of the crack.

References

[1] H.K. Sepuri, N. Hossiney, S. Chandra, Y. Chen, P.A. Bekoe, V.S. Nagavelly, Effect of Recycled Asphalt Pavement (RAP) Aggregates on Strength of Fly Ash-GGBS-Based Alkali-Activated Concrete (AAC), Adv. Sustain. Dev. (2022) 221–230. https://doi.org/10.1007/978-981-16-9744-9_15.

[2] S. Debbarma, G.D. Ransinchung, Using artificial neural networks to predict the 28-day compressive strength of roller-compacted concrete pavements containing RAP aggregates, Road Mater. Pavement Des. 23 (2022) 149–167. https://doi.org/10.1080/14680629.2020.1822202.

[3] K.K.S. Adithya Tantri *, Gopinatha Nayak *, Muralidhar Kamath , Adithya Shenoy, Utilization of cashew nut-shell ash as a cementitious material for the development of reclaimed asphalt pavement incorporated self compacting concrete, Constr. Build. Mater. (2021).

[4] E. Athika Wongkvanklom a, Patcharapol Posi b,*, Apichit Kampala b, Traitot Kaewngao c, Prinya Chindaprasirt d, Beneficial utilization of recycled asphaltic concrete aggregate in high calcium fly ash geopolymer concrete, Case Stud. Constr. Mater. (2021).

[5] H. Ziari, H. Fazaeli, S.J. Vaziri Kang Olyaei, M.A. Ziari, Evaluation of effects of temperature, relative humidity, and wind speed on practical characteristics of plastic shrinkage cracking distress in concrete pavement using a digital monitoring approach, Int. J. Pavement Res. Technol. 15 (2022) 138–158.

[6] F. Sayahi, M. Emborg, H. Hedlund, A. Cwirzen, Effect of steel fibres extracted from recycled tyres on plastic shrinkage cracking in self-compacting concrete, Mag. Concr. Res. 73 (2021) 1270–1282. https://doi.org/10.1680/jmacr.20.00116.

[7] H. Zhang, J. Xiao, Plastic shrinkage and cracking of 3D printed mortar with recycled sand, Constr. Build. Mater. 302 (2021) 124405. https://doi.org/10.1016/j.conbuildmat.2021.124405.

[8] F. Sayahi, M. Emborg, H. Hedlund, A. Cwirzen, M. Stelmarczyk, The severity of plastic shrinkage cracking in concrete: A new model, Mag. Concr. Res. 73 (2021) 315–324. https://doi.org/10.1680/jmacr.19.00279.

[9] H. Rong, W. Dong, W. Yuan, X. Zhou, An improved ring test to assess cracking resistance of concrete under restrained shrinkage, Theor. Appl. Fract. Mech. 113 (2021) 102976. https://doi.org/10.1016/j.tafmec.2021.102976.

[10] Q. Liu, J. Xiao, A. Singh, Quantification of plastic shrinkage and cracking in mortars containing different recycled powders using digital image correlation technique, Constr. Build. Mater. 293 (2021) 123509. https://doi.org/10.1016/j.conbuildmat.2021.123509.

[11] M. Wyrzykowski, S. Ghourchian, B. Münch, M. Griffa, A. Kaestner, P. Lura, Plastic shrinkage of mortars cured with a paraffin-based compound – Bimodal neutron/X-ray tomography study, Cem. Concr. Res. 140 (2021) 106289. https://doi.org/10.1016/j.cemconres.2020.106289.

[12] G.M. Moelich, J. Kruger, R. Combrinck, Plastic shrinkage cracking in 3D printed concrete, Compos. Part B Eng. 200 (2020) 108313. https://doi.org/10.1016/j.compositesb.2020.108313.

[13] W. Boshoff, V. Mechtcherine, D. Snoeck, C. Schröfl, N. De Belie, A.B. Ribeiro, D. Cusson, M. Wyrzykowski, N. Toropovs, P. Lura, The effect of superabsorbent polymers on the mitigation of plastic shrinkage cracking of conventional concrete, results of an inter-laboratory test by RILEM TC 260-RSC, Mater. Struct. Constr. 53 (2020). https://doi.org/10.1617/s11527-020-01516-6.

[14] A.Z. Bendimerad, E. Rozière, A. Loukili, Plastic shrinkage and cracking risk of recycled aggregates concrete, Constr. Build. Mater. 121 (2016) 733–745. https://doi.org/10.1016/j.conbuildmat.2016.06.056.

[15] A.Z. Bendimerad, B. Delsaute, E. Rozière, S. Staquet, A. Loukili, Advanced techniques for the study of shrinkage-induced cracking of concrete with recycled aggregates at early age, Constr. Build. Mater. 233 (2020) 117340. https://doi.org/10.1016/j.conbuildmat.2019.117340.