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Durability effect of reclaimed asphalt aggregate on concrete road pavement

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ABSTRACT: The use of recycled aggregates instead of natural aggregates used in concrete reduces environmental pollution and concrete costs. Recycled Asphalt Pavement (RAP) aggregate used as recycled aggregate has a lower water absorption than natural aggregate due to its bituminous structure, which reduces the water requirement of fresh concrete. In this study, it was aimed to determine the optimum use of RAP particles as aggregate in concrete for read pavements and to determine their durability properties. For this purpose, RAP was used instead of crushed stone aggregate used in concrete road construction. RAP was used by replaced aggregate 0%, 25%, 50% and 100% of the crushed stone aggregate used on the concrete road. The dose of the produced concrete was 350 kg/m^3 and the water/cement ratio was kept constant as 0.45. The fresh workability and air content of concretes containing RAP were determined. Compressive strength, splitting tensile strength, electrical resistivity value, accelerated corrosion test of hardened concretes were subjected to corrosion resistance, water absorption and porosity percentage, acid resistance, ultrasonic pulse rate and Scanning Electron Microscope (SEM) and X-ray Diffractometer (XRD) analyzes were determined. In the experimental results, it has been observed that the use of RAP ratio of 25% and 50% remains within the limit values for concrete pavement. It is recommended to be used on reinforced concrete roads that will be exposed to adverse environmental conditions with its high corrosion resistance, thanks to its anti-corrosion feature.

KEY WORDS: Recycled asphalt pavement; Concrete road; Durability; Corrosion; Acid attack.

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RESUMEN: *Efecto del árido asfáltico reciclado sobre la durabilidad de un pavimento de hormigón*. El uso de áridos reciclados en lugar de áridos naturales en el hormigón reduce la contaminación ambiental y los costes del hormigón. El árido de Pavimento Asfáltico Reciclado (RAP) utilizado como árido reciclado tiene una menor absorción de agua que el árido natural debido a su estructura bituminosa, lo que reduce el requerimiento de agua del hormigón fresco. En este estudio el objetivo fue determinar el uso óptimo de partículas de RAP como árido en hormigón para pavimentos lisos y determinar sus propiedades durables. Para ello se utilizó RAP en lugar de los áridos de piedra triturada utilizados en la construcción de carreteras con hormigón. Se utilizó RAP reemplazando el 0%, 25%, 50% y 100% del árido de piedra triturada. El hormigón producido tenía un contenido en cemento 350 kg/m^3 y la relación agua/cemento se mantuvo constante en 0,45. Se determinó la trabajabilidad en fresco y el contenido de aire de los hormigones que contienen RAP. También se determinaron la resistencia a la compresión, la resistencia a la tracción, el valor de resistividad eléctrica y la prueba de corrosión acelerada de hormigones endurecidos. Igualmente, se evaluó la absorción de agua y porcentaje de porosidad, la resistencia al ataque ácido, la frecuencia de pulso ultrasónico y la microestrucutra mediante microscopio electrónico de barrido (MEB) y difractómetro de rayos X (DRX). En los resultados experimentales se ha observado que el uso de una relación RAP del 25% y 50% se mantiene dentro de los valores límite para pavimentos de hormigón. Se recomienda su uso en carreteras de hormigón armado que estarán expuestas a condiciones ambientales adversas por su alta resistencia a la corrosión, gracias a su característica anticorrosión.

PALABRAS CLAVE: Pavimento asfáltico reciclado; Carretera de hormigón; Durabilidad; Corrosión; Ataque ácido.

1. INTRODUCTION

During renovation and maintenance works on highways, old road pavements are scraped from the road surface with machines called milling cutters, and they are broken into certain sizes with the help of these machines and stored as waste material in municipal construction sites or empty lands (1). Due to the high amount of these waste materials, they cause environmental pollution (2). The availability of waste generated during production means not only an industrial gain but also an environmental problem (3). For this reason, alternatives that can be found in the evaluation of asphalt wastes will not only provide resources for the country's economy, but also will eliminate the environmental polluting feature of these wastes to a large extent (4). As a result of using waste asphalt cracks in concrete instead of natural aggregate, environmental pollution can be prevented and a great contribution can be made to the national economy (5, 6). Considering that road construction and widening works are increasing day by day in almost all countries of the world, it is inevitable that the aggregate requirement will increase accordingly (7). The cost of concrete will decrease, as the use of waste asphalt fractures in concrete as aggregate has the effect of reducing natural aggregate consumption and transportation costs. The fact that the water absorption capacity of waste asphalt fractures, which is a bituminous material, is lower than that of natural aggregate, reduces the water requirement in fresh concrete and increases the workability. Moreover, when various studies are examined, it is seen that the toughness of the hardened concrete increases and the formation of cracks decreases (8-10). Erdem et al. (11) In their study, they investigated the use of 100% recycled aggregates in concrete and its effect on mechanical strength. They used concrete waste aggregate and RAP obtained from precast elements as waste aggregate. They stated that the use of 100% is not suitable for concrete, causing structural problems. According to İbrahim et al. (12) using RAP in self-compacting concrete, they investigated fresh, mechanical and durability properties. After examining all experimental results, they suggested that RAP should not be used more than 25% in self-compacting concrete. Zaumanis et al. (13) analyzed rutting resistance and fatigue performance of high modulus asphalt concrete with 100% RAP dosage. It was stated that high modulus asphalt concrete prepared with 100% RAP content could not fully meet the performance index requirements and it behaved inferior resistance to crack propagation compared with the traditional high modulus asphalt concrete. Yang et al. (14) Recycled asphalt mixtures containing RAP 50%, 60% and 70% RAP and steel slag were prepared and their road performances were characterized. Their results indicate that incorporating steel slag in recycled asphalt mixtures with 70% RAP content reveals a desirable performances index in contrast to basalt. Asphalt fractures are waste materials that occur during the renovation and maintenance of roads, it has been seen from the studies in the literature that it is possible to reuse these materials on flexible and rigid pavements. Cracks can be seen in the concrete slab under the stresses caused by the temperature and humidity difference and traffic loads on concrete roads, which are a rigid pavement. In order to prevent these cracks, the joints that make the concrete road into free slabs should be made at certain and appropriate intervals. In addition, these cracks can be minimized and concrete tensile strength can be increased by placing steel wires close to the surface or by placing mesh reinforcements close to the surface. It is seen as a great advantage that the concrete road is the only pavement type that accepts steel reinforcement among the road types. Another method to prevent crack formation in concrete roads is to increase concrete toughness by using various materials with higher deformation capacity instead of aggregate. This situation was examined in detail in the study, and the effects of using waste asphalt fractures instead of aggregate on the formation of cracks in concrete were investigated (15, 16). It is stated in the specifications that the amount of cement in concrete road construction should be at least 350 kg/m^3. In addition, the amount of alkali in the cement and the reactivity of the aggregate to be used should be considered against the possibility of alkali-silica reaction, and the necessary standard tests should be done beforehand. For Concrete Pavement, the concrete must be of at least C 30/37 class and its flexural strength must be at least 4.0 MPa. It is recommended that the water/cement ratio should not exceed 0.45 (15-17).

From the literature review, it was seen that most of the research is focused on the evaluation of RAP in concrete as a recycling material in terms of physical or mechanical properties. However, durability properties were not taken into consideration. Therefore, the novelty of this study is to investigate in detail whether recycled asphalt aggregate (RAP) obtained by scraping old asphalt can be used in concrete road construction. For this purpose, RAP was used instead of crushed stone aggregate used in concrete road construction. In all concrete mixes, the dose was kept constant as 350 kg/m^3 and the water/cement ratio of 0.45. Recycled asphalt pavement aggregates (RAP) supplied from Afyonkarahisar asphalt construction site were added to the concrete mixtures by replacing the total of crushed sand and crushed stone-I used in the concrete at the rates of 25%, 50% and 100%. The fresh slump and air contents of the concrete samples were determined. The mechanical properties of compressive and splitting strength, physical properties of water absorption, porosity, ultrasonic pulse velocity and electrical resistivity were determined. Reinforced corrosion and acid effect were examined as durability properties, and finally, microstructure properties were examined with SEM and XRD analyzes.

2. MATERIALS USED

As cement, CEM I 42.5 cement in accordance with TS EN 197-I (18) standard was used. Three different sizes of limestone-based aggregate were used as aggregate: 0-6 crushed sand, 6-12 mm crushed stone-I and 12-22 mm crushed stone-II. The specific gravity of the aggregates was determined as 2.65 gr/cm^3 for crushed sand, 2.70 for crushed stone-I and 2.72 for crushed stone-II Recycled asphalt pavement aggregates (RAP), supplied from Afyonkarahisar asphalt construction site, were added to the concrete mixtures by changing the weight of the total crushed sand and crushed stone-I used in the concrete at the rates of 25%, 50% and 100%. RAP view is given in Figure 1. The specific gravity of RAP was determined as 2.6 gr/cm^3. Concrete mixtures prepared in the concrete mixer in the laboratory were produced with 350 doses and a water/cement ratio of 0.45. A hyperplasticizer additive was used at the rate of 1% by weight of cement.

Figure 1. Recycled Asphalt Pavement (RAP).

3. APPLIED EXPERIMENTS

Following the concrete production, the fresh workability and air content of concretes containing RAP were determined. Compressive strength, splitting tensile strength, electrical resistivity value, accelerated corrosion test of hardened concretes were subjected to corrosion resistance, water absorption and porosity percentage, acid resistance, ultrasonic pulse rate and SEM analyzes were determined. All experiments were carried out at laboratory ambient temperature. Each experiment is applied to 3 samples and the average is given in the results section. As a result of these comprehensive tests, if the RAP ratio exceeds 25%, it has been observed that concrete roads are risky in terms of both mechanical and durability properties.

The slump value of fresh concrete in accordance with the TS EN 12350-2 (19) standard, and the percentages of air contents according to the TS EN 12350-7 (20) standard were determined for workability. The concrete placed in the molds was removed from the mold after 24 hours and cured in water for up to 3, 7 and 28 days under standard conditions. After the curing process, the compressive strengths of 150x150x150 mm concretes for 3, 7 and 28 days were determined according to TS EN 12390-3 (21), and the split tensile strengths were determined according to TS EN 12390-6 (22). Instead of tensile test and flexural test, the tensile strength of the produced concrete was determined by splitting tensile strength.

Concretes reaching final strength after completing the 28-day curing period were subjected to physical property and durability tests. Porosity and water absorption, which are the basic physical properties of concrete, were determined using standard TS EN 12390-7 (23) test methods.

Electrical resistivity values were measured according to ASTM C 1760 (24) with the help of resistivity meter using the two-plate method on 100x100x100 mm. The resistance meter measures 0.1, 0.12, 1, 10 and 100 kHz in alternating current. The purpose of determining the electrical resistivity at different frequencies is to determine the resistivity value that can be obtained depending on the measurement frequency. In other words, the frequency value chosen during the determination of the resistivity values of the materials directly affects the results. The electrical resistivity values of the mortars whose resistance values (δ) were measured were also determined by the Equation [1]:

$$\delta = R\,\frac{A}{L} \qquad [1]$$

Where:
δ: Electrical resistive (kΩ·m)
R: resistance (kΩ)
A: Sample area (cm^2)
L: Sample length (m)

The Ultrasonic pulse velocity (UPV) test was carried out with the linear method in accordance with TS EN 12504-4 (25) on 100x100x100 mm. The probes of the device that sends ultrasonic sound waves are placed on the concrete surface and time is given for the sound wave to pass from one surface to the other in the concrete. The measure of the concrete sample between the probes is the path length of this sound wave, using the distance and duration of the sound, the speed of sound was determined. UPV gives information about the strength of concrete and the number of voids in it. The fuller the concrete, the higher the speed of sound.

In order to determine the acid resistance of concretes, 3 different solutions with 0.5, 1M and 1.5M concentrations were prepared by using H_2SO_4 (sulfuric acid). Concretes reaching final strength were weighed and placed in acid solutions and exposed to acid for 14 days. At the end of 14 days, the weights of the concretes removed from the acid solution were measured and their weight losses were determined. The detected weight losses were calculated as a percentage. The samples were in size of 100x100x100 mm.

The accelerated corrosion test was used to examine the corrosion performance of the reinforcement bar in the concrete. In order to apply the accelerated corrosion test, Ø12 mm diameter reinforcement was placed in the mold center of the Ø100/200 mm cylindrical concretes, leaving equal rust in all directions. This experimental setup consists of a power source with direct current capacity, a plastic container with 4% concentrated NaCl solution and two stainless steel plates, and a test sample. The reinforced concrete sample was placed in a container with 4% NaCl solution. A reinforcement bar (working electrode) is connected to the positive pole of the direct current (DC) source, which applies a constant 50 volts voltage to the system, and plates (counter electrode) are connected to the negative pole. In this circuit, the reinforcement bar is the anode, the plates the cathode, and the NaCl solution is the electrolyte (Figure 2). The current values of the samples under voltage, the corrosion initiation times, the temperature of the brine solution and the weight losses in the reinforcement after the test were determined.

Figure 2. Accelerated corrosion test setup.

4. RESULTS AND DISCUSSIONS

In terms of durability of road concretes, they should contain as little hydrated water as possible. Therefore, this situation has a direct impact on machinability. Workability can also be increased with the use of some chemical additives. The slump values of concretes containing RAP at certain rates are presented in Figure 3. While the slump values of the control series were 60 mm, the workability of the concretes increased with the use of RAP and 75 mm slump was obtained in the concretes using 100% RAP. As the surfaces of RAP aggregates are covered with bitumen, frictions between the other components in the concrete and among themselves are relatively reduced, which increases the workability by enabling the concrete to move more easily. The percentages of air content of concrete samples containing RAP are given in Figure 4. It is seen that the air content decreases with the increase in the rap rate. The air content decreased to 2% in the reference concrete and 1.8% in the concrete where the RAP ratio was 100%. The decrease in compressive strength and apparent density have the same trend with increasing air content in concrete mixes (26).

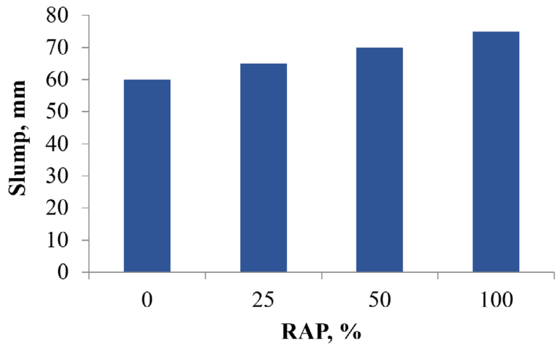


Figure 3. Fresh concrete slump values according to rap rates.

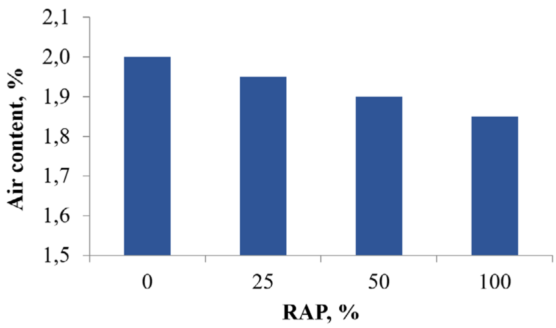


Figure 4. Fresh concrete air content according to rap rates.

The compressive strengths of concretes containing RAP in certain proportions are presented in Figure 5. When the 7 and 28-day strengths of the concretes are examined, the strength development in all series is approximately the same. However, the compressive strengths of 7- and 28-day-old concretes started to decrease as the RAP ratio increased. The adhesive cement matrix and RAP in the concrete was relatively weak due to asphalt residue, thus, the effect of the crushing age was more moderate (27, 28). Compared to the 28-day control concrete, the strength loss in concretes with 25, 50 and 100 percent RAP is 26%, 36% and 59%, respectively. It is recommended that the concrete to be used in road construction should have a cube compressive strength of at least 37 MPa for 28 days. Accordingly, the 28-day concrete strength of the series containing 25% RAP is 41.6 MPa, while the compressive strength of the concretes containing 50% RAP is 35.7 MPa. Therefore, RAP ratio of 25%-50% can be used in road concrete in terms of compressive strength. In terms of splitting strength, concretes containing RAP showed similar properties to compressive strength (Figure 6). The split tensile strength of concretes using fully RAP is 1.85 MPa, while the split tensile strength of control concretes is 3.7 MPa. This criterion is also met with the use of RAP between 25% and 50% in road concrete, which is recommended to be at least 2 MPa in terms of splitting tensile strength.

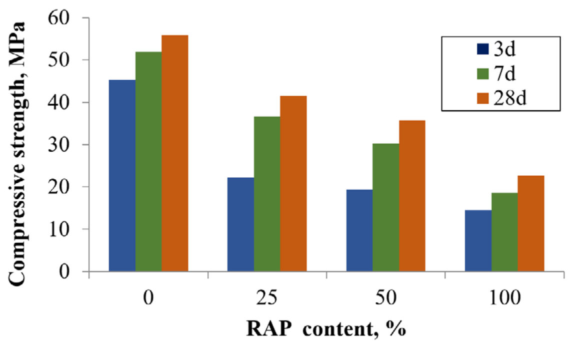


Figure 5. Compressive strength of concretes according to RAP ratios.

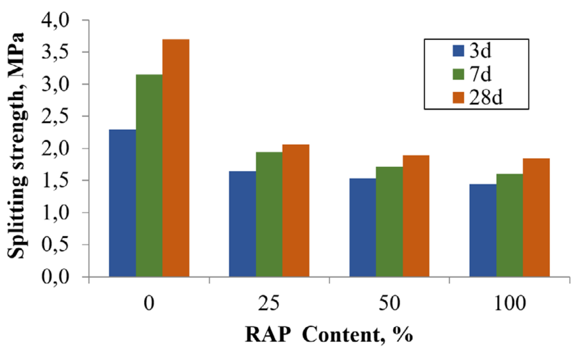


Figure 6. Splitting strength of concretes according to RAP ratios.

The electrical resistivity values of concretes containing certain proportions of RAP are given in Figure 7. With the increase of the frequency value, the electrical resistivity values decreased. As is known, frequency is the number of revolutions per second of an alternating current (AC) signal (29). In cement-based systems, electrical conductivity occurs due to ion transfer in porous solutions and ion transfer accelerates with increasing frequency. Therefore, the resistance decreases with increasing frequency. The electrical resistivity value was determined as 0.43 kΩ.m at a frequency of 0.1 kHz and 0.30 kΩ.m at a frequency of 100 kHz in concrete with a RAP ratio of 0%. In concrete where 100% RAP is used, it is determined as 19.65 kΩ.m at 0.1 kHz frequency and 0.70 kΩ.m at 100 kHz frequency. The electrical resistivity values decreased with the increase of RAP content.

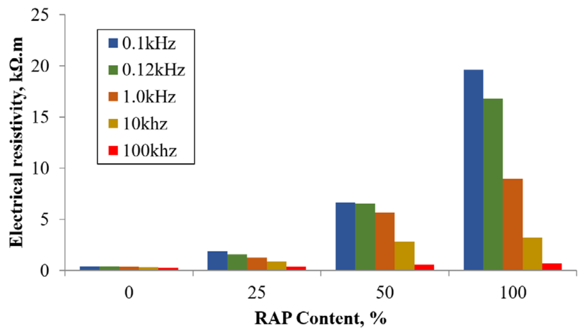


Figure 7. Electrical resistivity change of concretes according to rap rates and frequency.

Current data obtained from accelerated corrosion test are given in Figure 8, solution temperatures in Figure 9 and corrosion initiation times in Figure 10. When we examine the flow data, the highest current value was observed in the concrete where 25% of RAP was used, and the lowest current value was observed in the concrete where RAP was used 100%. In this type of test methods, the high current drawn during the test shows that the corrosion event will be faster (30). When we examined the solution temperatures, it was seen that it was directly proportional to the current data. The solution temperature increases with the increase in the current drawn by the sample. Starting from the current values, the points where the temperature started to increase were determined as the corrosion initiation times. When the corrosion initiation times were examined, it was determined as 6320, 7160, 8960 and 10280 minutes, respectively, in cases where 0, 25, 50 and 100% RAP ratios were used. It is the concrete sample in which corrosion first started, 0% of RAP was used, while 100% of RAP was used last. It has been observed that with the increase of the RAP ratio, the corrosion initiation times increased, and the use of RAP increased the corrosion resistance of the concrete. Corrosion initiation times were found to be inversely proportional to current densities (31). Corrosion initiation times increased with decreasing current density. Concrete appearances after corrosion given in Figure 8 also show that RAP reduces corrosion resistance. While there was a high rate of rust stains in the sample with 0% RAP ratio, it was observed that the concrete containing 100% RAP had less rust stains.

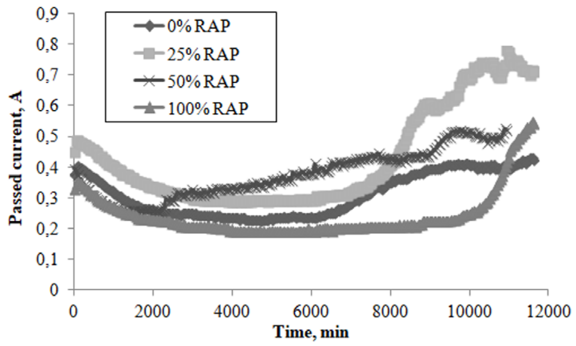


Figure 8. Current values of concretes containing RAP at certain ratios in accelerated corrosion test.

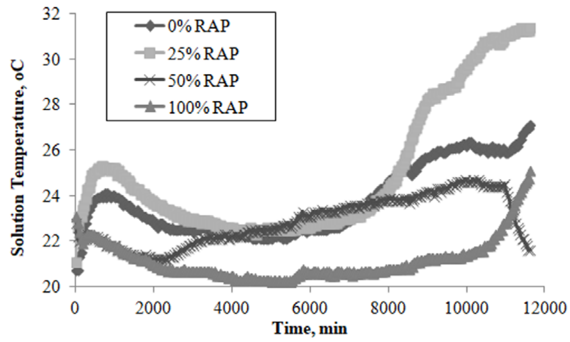


Figure 9. Solution temperatures in accelerated corrosion test of concretes containing certain ratios of RAP.

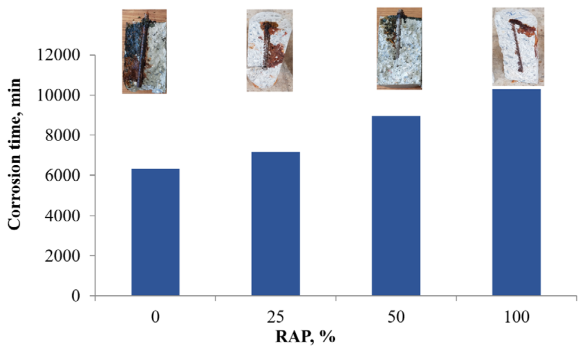


Figure 10. Corrosion times of reinforcements in accelerated corrosion test of concretes containing RAP at certain ratios.

The correlation between corrosion times and electrical resistivity values of concretes containing RAP is given in Figure 11. Correlation R^2 value between corrosion time and electrical resistivity was determined as 0.9973. This shows that there is a strong correlation. Since reinforcement corrosion is an electrochemical process, there are studies that electrical resistance is used as a parameter that provides information about this process, and it is used in the development of service life models (32, 33). The electrical resistivity values and the accelerated corrosion test results showed parallelism. The higher the electrical resistivity, the less ion mobility that will occur in the concrete, which reduces the corrosion rate.

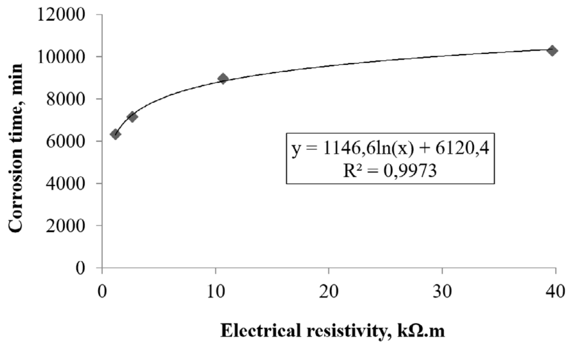


Figure 11. Correlation between corrosion initiation times and electrical resistivity in concretes containing certain ratios of RAP.

The weight losses in the reinforcements as a result of the accelerated corrosion test are given in Figure 12. While the weight loss is 8.03% in concrete with a RAP ratio of 0%, it was determined as 6.71%, 4.45% and 2.46%, respectively, in the case of 25%, 50% and 100% use of RAP ratio. A 5.56% reduction in weight loss occurred with the use of 100% RAP ratio. It was observed that with the increase of RAP ratio, concretes showed higher protection against reinforcement corrosion. The polymer-based bitumen layer decreased the ion mobility and increased the electrical resistivity of the concretes, as well as increased the corrosion resistance.

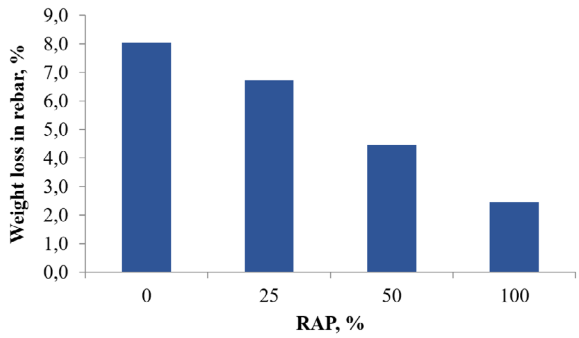


Figure 12. Weight losses of reinforcements in accelerated corrosion test of concretes containing certain ratios of RAP.

The water absorption and porosity values of concretes containing RAP are given in Figure 13. It was observed that the water absorption and porosity percentages increased with the increase in the RAP ratio. In the case of using 0%, 25%, 50% and 100% RAP ratio, the porosity values were determined as 5.40%, 5.94%, 6.0% and 6.17%, respectively. In the case of using 0%, 25%, 50% and 100% RAP ratio, the water absorption values were determined as 2.20%, 2.49%, 2.52% and 2.68%, respectively. In the study conducted by Abraham and Ransinchung (34) they observed that when the RAP ratio is 25%, the porosity and water absorption value are close to the reference concrete, while it increases too much when the RAP ratio rises to 50% and 100%. The increase in void content of RAP mixtures was attributed to the increase in porosity in the interfacial transition zone of RAP mixtures compared to mixtures with natural aggregates (35).

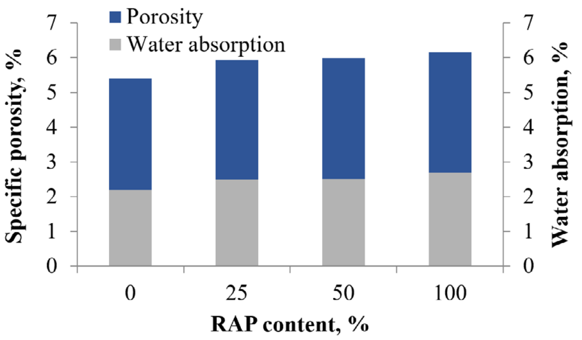


Figure 13. Water absorption and porosity values of concretes containing RAP at certain ratios.

Weight losses of concretes containing RAP under the effect of acid are given in Figure 14. With the increase in the RAP ratio, the weight losses due to the acid effect decreased. During the contact of the concrete with the acidic environment, calcium ions are separated from the calcium-containing phases in the hardened cement paste, that is, the calcium silicates that emerge as a result of hydration to form the calcium salt, resulting in a significant decrease in mechanical strength and durability performance (36). As the use of RAP increases the void ratio, the void ratio in the concrete increases and the penetration of acid into the concrete accelerates. This increased the damage caused by the acid with the increase of the RAP ratio, causing an increase in weight losses (37). An increase in weight loss was observed as the molarity of the acid increased. With the acid molarity, the aggressiveness of the acid also increases and the concretes are damaged more. Although increases in acid damage were observed with the increase of RAP ratio, it was observed that when 25% was used, it gave results close to the sample without RAP. While the weight loss in 0.5 M sulfuric acid is 3% in concretes with 0% RAP content, the weight loss reaches 17% with an increase in acid molarity of 1.5M. While the weight loss in 0.5M sulfuric acid is 18% in concretes with 100% RAP content, the weight loss reaches 42% with an increase in acid molarity of 1.5M. In concretes where 0% RAP was used, if the acid molarity increased from 0.5 to 1.5, there was an average of 6 times increase in weight losses. On the other hand, if the acid molarity increased from 0.5 to 1.5 in concretes where 100% RAP was used, there was an average of 2 times increase in weight losses.

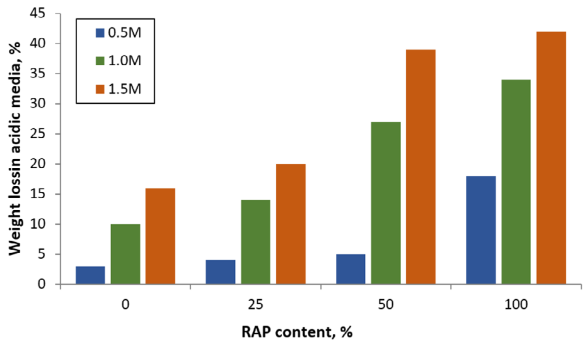


Figure 14. Weight loss of concretes containing RAP in certain proportions under the influence of acid.

Ultrasound transmission velocity (UPV) is one of the measurement methods used to estimate the void structure of materials such as concrete, and it is thought that with an increase in this value, it becomes a fuller and denser material, and as a result, its strength will be higher (38, 39). UPV measurements of concretes containing different ratios of RAP were made at 3, 7 and 28 days and the results are given in Figure 15. With the advancement of concrete age, hydration products increase and fill the voids. For this reason, an increase in UPV values was observed as the age of concrete increased. It can be thought that the voids in the concrete increase slightly with the RAP ratio. The speed of sound decreased with the increase of the void ratio. Using the RAP rate of 0%, 25%, 50% and 100%, the UPV values were measured as 4.52, 4.40, 4.34 and 4.22 km/h, respectively. In addition, it was concluded that the bitumen-coated aggregates prevent the transmission of sound, therefore the sound transmission speed decreases (40). Because polymeric materials such as bitumen are in the group of materials that reduce the transmission of sound.

SEM images and XRD analyzes of concretes containing RAP are given in Figure 16. When the SEM image is examined, bitumen coated asphalt surfaces are seen. It is clearly seen that the bitumen coated parts have a smooth surface on the aggregate surface (41, 42). The asphalt coating of the aggregate surface provides the concrete with more workable but weaker adhesion with the cement matrix compared to the reference concrete. As a result of XRD, elemental analysis in the form of surface scanning was obtained. In element analysis, it was observed that all components, especially CaO, decreased between 150-300 nm. Since there is a bitumen layer on the aggregate surface in the mentioned range, the components occurring in the concrete have decreased. The polymeric bitumen on the aggregate surface reduces the conductivity in the concrete, thus significantly reducing corrosion.

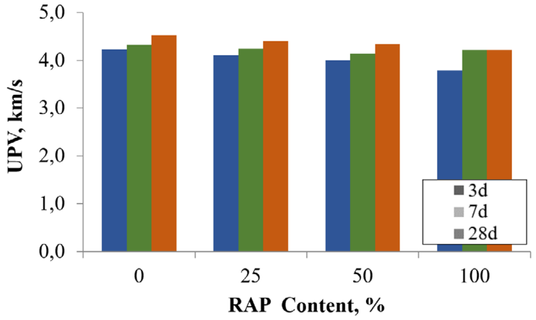
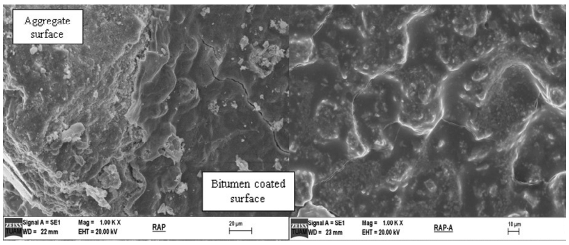
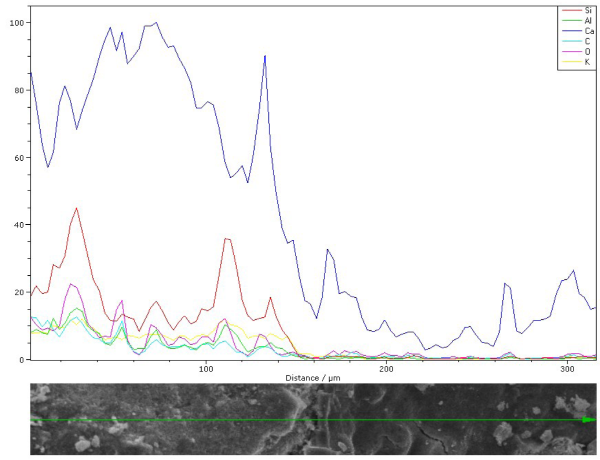


Figure 15. Ultrasonic pulse velocities of concretes containing certain ratios of RAP.



(a)



(b)

Figure 16. SEM and XRD analysis of concretes containing certain ratios of RAP, (a): SEM, (b): XRD.

5. CONCLUSIONS

In this study, the use of waste asphalt fractures in concrete road construction, instead of crushed stone in certain proportions, was investigated, especially in terms of strength. As a result of the findings, the following conclusions were drawn:

- Thanks to the bitumen coated aggregate surfaces, it has been observed that they increase the workability compared to the crushed stone concrete with the same low water/cement ratio. It was observed that there was a decrease in air.
- The fact that the aggregate surfaces are covered with bitumen weakens the aggregate-cement adherence, resulting in a decrease in compressive and splitting strengths.
- It has been observed that the electrical resistivity values increase with the increase in frequency. A high increase in electrical resistivity values was observed with the increase of RAP ratio.
- In all the results obtained from the accelerated corrosion test, it was observed that the increase in the RAP ratio increased the corrosion resistance.
- Since corrosion is an electro-chemical reaction, it has been observed that it is directly related to the electrical resistivity value in the concrete. The correlation coefficient R2 value was determined as 0.9973 and showed a strong relationship.
- An increase was observed in RAP content, water absorption and porosity values. It has been stated that the polymeric bitumen layer on the aggregate surface reduces the adherence in concrete. The high porous structure formed by the RAP content has reduced the acid resistance of the concrete.
- Polymeric materials such as bitumen are in the material group that reduces the transmission of sound, and since the aggregates are covered with this material, they cause a decrease in the ultrasound transmission rate in the concrete.
- In SEM analysis, the bitumen layer on the aggregate surface is clearly visible. The asphalt coating of the aggregate surface provides the concrete with more workable but weaker adhesion with the cement matrix compared to the reference concrete.
- As a result of XRD, when the bitumen coated aggregate surface was examined, a decrease in concrete components was observed. The polymeric bitumen on the aggregate surface reduces the conductivity in the concrete, thus significantly reducing corrosion.

The transportation of materials on the renewed roads is among the important factors in increasing the cost. From a financial point of view, one of the most important factors increasing road construction costs is the transportation of aggregate to the construction site. The distances between the material source and the construction site impose an additional burden on construction costs. After RAP is crushed to the desired dimensions, it can be utilized in mobile concrete batching plants located close to the construction site and can reduce the transportation cost required for natural aggregates. As a result, it was concluded that it provides up to 50% of the limit values recommended in the specifications in terms of pressure and splitting strength, and therefore it can be used in concrete road construction. While obtaining RAP, it should be kept in mind that the behavior may change depending on the bitumen content and the aggregate origin in the RAP, and it is recommended to determine the optimum ratios with preliminary experiments before using them. It is recommended to be used on reinforced concrete roads that will be exposed to adverse environmental conditions with its high corrosion resistance, thanks to its anti-corrosion feature.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authorship contribution statement

Tayfun Uygunoğlu: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing.

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