Tikrit Journal of Engineering Sciences (2024); 31(3): 60-71
DOI: http://doi.org/10.25130/tjes.31.3.6

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Evaluating Some Mechanical Characteristics of Asphalt Mixtures Containing Recycled Concrete Aggregate and Modified by Polyphosphoric Acid

Marwa J. Badr *, **Mohammed Q. Ismael**
Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq.

Keywords:
Index of Retained Strength (IRS); Polyphosphoric Acid (PPA); Recycled Concrete Aggregate; Treated RCA; Tensile Strength Ratio (TSR).

Highlights:

- *The use of recycled concrete aggregate in flexible paving resulting from crushed protection formwork that has become visually and environmentally disruptive.*
- *Improving the properties of recycled aggregates by treating them with HCL.*
- *Using polyphosphoric acid reduces the percentage of asphalt consumed in asphalt mixtures containing recycled aggregate, and this has a positive role from an economic standpoint.*

ARTICLE INFO
Article history:

Received	23 June	2023
Received in revised form	29 July	2023
Accepted	17 Sep.	2023
Final Proofreading	25 Feb.	2024
Available online	10 July	2024

© THIS IS AN OPEN ACCESS ARTICLE UNDER THE CC BY LICENSE. http://creativecommons.org/licenses/by/4.0/

Citation: Badr MJ, Ismael MQ. **Evaluating Some Mechanical Characteristics of Asphalt Mixtures Containing Recycled Concrete Aggregate and Modified by Polyphosphoric Acid**. *Tikrit Journal of Engineering Sciences* 2024; **31**(3): 60-71.
http://doi.org/10.25130/tjes.31.3.6

*Corresponding author:

Marwa J. Badr
Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq.

Abstract: Sustainable waste management aims to reduce the consumption of raw materials by reusing as many RCA materials as possible. This research aims to evaluate the influence treated and untreated recycling coarse aggregate on the hot asphalt mixture's properties using asphalt grade (40-50) modified with 3% Polyphosphoric Acid (PPA). RCA was used in different proportions (25%, 50%, 75%, and 100%) as a substitute for raw coarse aggregate; the effect of treatment on improving the RCA's quality was tested. Volumetric properties associated with the Marshall test for asphalt concrete were tested. Tensile strength ratio (TSR) and index of retained strength (IRS) measurements were used to assess the moisture effect. The study findings indicated that 25% RCA is the maximum amount of RCA from concrete that should be added to asphalt mixtures. This percentage recorded the highest values for TSR and IRS, with the ideal modified asphalt content of 4.86%. Based on the results of this study, asphalt concrete's durability will generally grow with RCA use, while its susceptibility to moisture will increase. However, treated RCA improved the results compared to untreated RCA. Using asphalt modified with polyphosphoric acid remarkably improved the asphalt mixtures' performance and reduced the asphalt consumption rate.

تقييم بعض الخصائص الميكانيكية للخلطات الاسفلتية المحتوية على ركام الخرسانة المعاد تدويرها والمعدلة بحامض البولي الفوسفريك

مروة جواد بدر، محمد قادر اسماعيل
قسم الهندسة المدنية/ كلية الهندسة/ جامعة بغداد/ بغداد - العراق.

الخلاصة

تهدف الادارة المستدامة للنفايات الى تقليل استهلاك المواد الخام من خلال اعادة استخدام أكبر قدر ممكن من النفايات، يهدف هذا البحث الى تقييم تاثير استخدام ركام الخرسانة الخشن المعاد تدويرها (RCA) المعالج وغير المعالج على خواص الخلطات الاسفلتية الساخنة باستخدام اسفلت درجة (٤٠-٥٠) المعدل بنسبة ٣٪ من حامض البولي فوسفورك (PPA). تم استخدام RCA بنسب مختلفة (٢٥٪,٥٠٪,٧٥٪,١٠٠٪) كبديل للركام الخشن الخام، وتم اختبار تاثير المعالجة على تحسين جودة RCA وتم اختبارالخصائص الحجمية المرتبطة باختبار مارشال للخرسانة الاسفلتية كما تم تقييم تاثير الرطوبة من خلال فحص نسبة مقاومة الشد غير المباشر (TSR) ومؤشر القوة المتبقية (IRS). اظهرت نتائج هذه الدراسة ان الكمية المثلى من ركام الخرسانة المعاد تدويرها التي يمكن دمجها في الخلائط الاسفلتية هي ٢٥٪ حيث سجلت هذه النسبة اعلى قيم ل TSRوIRS عند محتوى الاسفلت المعدل الامثل ٤,٨٦٪. حيث ان استخدام RCAيزيد من ديمومة الاسفلت الا أنه يزيد من تحسس الرطوبة في الخلطات الاسفلتية الحارة، الا ان الخلطات الاسفلتية التي استخدام فيها RCA المعالج اعطت نتائج أفضل من الخلطات التي استخدم فيها RCAالغير معالج وكذلك استخدام الاسفلت المعدل ادى الى تحسين اداء الخلطات الاسفلتية وتقليل نسبة استهلاك الاسفلت.

الكلمات الدالة: مؤشر القوة المتبقية (IRS)، حامض البولي فوسفورك,ركام الخرسانة المعاد تدويرها, معالجة ركام الخرسانة المعاد تدويرها,نسبة مقاومة الشد (TSR).

1.INTRODUCTION

Using recycled asphalt mixes is a practical engineering solution for addressing the difficulties associated with sustainable development and climate change. The recent surge in material prices and heightened public concern for the environment strongly moved toward adopting technology for eco-friendly buildings in the asphalt concrete industry [1,2]. Additional improvement ingredients are necessary as long as using recycled aggregate produces poor-performing asphalt mixtures [3]. There has been a lot of interest and several studies evaluating using crushed concrete as a replacement for coarse aggregates in hot-mix asphalt [4]. Moisture damage in asphalt mixtures refers to the strength and durability loss due to the presence of water. This distress, which causes damage to asphalt concrete, has received significant interest over the past decades, as its negative consequences extend to the deterioration of other stresses, such as fatigue and rutting [4,5]. RCA contains voids due to the cement mortar. Other RCA characteristics are “higher permeability and a lower density” than the original natural aggregate [6]. Several treatments are being conducted to improve the low quality of the recycled physical and chemical properties. Hydrochloric is among these treatments acid (HCL), which removes the cement slurry, adhering to the aggregates; it works well for cleaning cement slurry, according to Abass and Albayati [7]. Improving asphalt significantly improved the hot asphalt mixes’ performance, especially those containing recycled aggregates. Among those improvers is polyphosphoric acid, considered one of the best improvers that improve the Iraqi asphalt pavement [8]. According to Ismael [3], the sustainable approach to replacing natural aggregates with recycled aggregates showed low levels of volumetric properties and increased the optimum content of asphalt from 4.1% in natural aggregate mixtures to 4.5% in recycled mixtures. The RCA is more absorbent than natural aggregates, as RCA consists of natural entireties and a layer of adhering mortar or cement paste, as water absorption depends on the natural cement matrix porosity [3, 9]. According to Kavussi et al. [10], the treatment of recycled aggregates reduced the sensitivity of asphalt mixtures to moisture, which is attributed to the lower water absorption by the recycled aggregates. The treatment succeeded in improving the recycled aggregates’ quality and allowing for increased use of this waste in construction projects, which positively impacted the environment. Nazal and Ismael [4] concluded that the volumetric properties of asphalt mixtures containing RCA, such as “VMA and AV, in addition to stability and flow, meet the requirements of the Iraqi specifications SCRB (2003).” Also, asphalt mixtures containing recycled aggregate consume more asphalt percentages than asphalt mixtures with natural asphalt, as the increase was 15.4% in the optimum asphalt content when the RCA ratio increased from 0% to 100% due to the absorption property and proved that using RCA reduced the moisture susceptibility of asphalt mixtures, as the results showed that the indirect tensile strength ratio for all mixtures that contain RCA was higher than the control mixtures except for the “tensile strength ratios” for mixtures that have 100% RCA and the “index of the retained strength” values for all mixtures RCA was higher than typical aggregate mixtures. Xu et al. [11] concluded that it is possible to reach the total replacement of coarse aggregates in hot asphalt mixes as long as the engineering properties, especially moisture susceptibility, are satisfactorily dealt with, where RCA is considered a promising candidate to replace the excessive using natural aggregates, as high-quality and sustainable pavements can be built at the same time. Giri et al. [12] found that the RCA blend satisfied the Marshall test standards and moisture requirements. Refs. [13-16] also showed that using RCA made HMA with less damage from water. Ossa et al. [17] stated that up to 20% of RCA was acceptable for use in wear courses of urban road pavements; percentages up to 40% of RCA was proper only when anti-stripping additives were included. Qasrawi and Asi [18] demonstrated that substituting RCA up to 50% led the mixtures to meet water resistance requirements. However, The authors also reported that RCA yielded mixtures with lower stripping resistance. The binder's properties are among the factors that may affect the bituminous mixtures' resistance to water. Some investigations have shown that high-viscosity asphalt improved moisture damage to HMA [19], whereas increasing the viscosity of asphalt improved resistance to moisture damage [20-22]. In this regard, it is interesting that polyphosphoric acid has been used since the 1970s in road paving and that one of the main effects of adding PPA to asphalt is to increase its viscosity [23, 24]. Hilal [8] stated that when PPA was added to the binder, the asphaltene content increased, the resin concentration decreased, and the asphalt became more solid and viscous. Increasing the PPA content, the softening point increased and improved, as well as increased Marshall stability and enhanced the asphalt pavement's performance.

2.MATERIALS AND TESTING

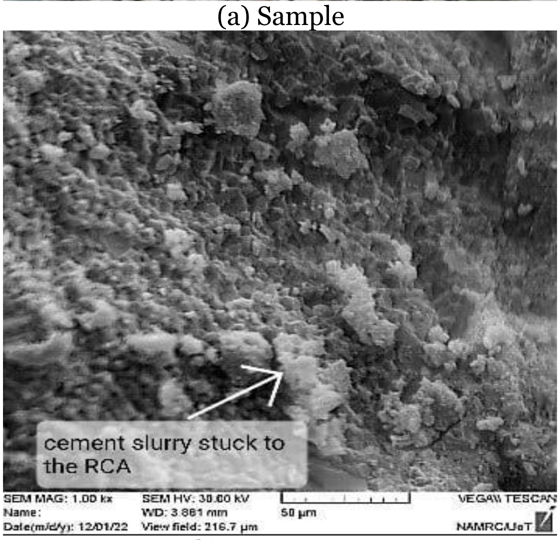
2.1.Materials

The raw materials used in this study were the treated and untreated recycled coarse aggregate as a substitute for the natural aggregate in the hot asphalt mixes at rates of (25%, 50%, 75%, and 100%). Before processing, the RCA was "rinsed and dried in an oven at 105.5 °C for 24 hours." Then, it was treated by immersing it in an acidic solution consisting of 37% hydrochloric acid (HCL) at a low concentration of 0.1 mol/L for 24 hours at room temperature at 25 °C and then immersed in distilled water and drained to remove the acid solution [5]. Followed by a drying and sieving operation to determine the actual gradation and appropriately combine it with natural aggregate (NA). Table 1 combines the physical properties of NA and types of RCA treated (TRCA) and untreated (UTRCA). For a closer view, Figs. 1 and 2 show a masterpiece of the used aggregates combined with corresponding SEM images. Two figures show that a large percentage of the cement slurry stuck to the RCA particles was removed after acid treatment. The coarse aggregates are replaced by the RCA ratios of 25, 50%, 75%, and 100% except for control mixtures. Limestone was employed as a "filler." The aggregates were combined with asphalt grade (40–50) that had been treated with polyphosphoric acid at a rate of 3% by the asphalt weight. Polyphosphoric acid is an inorganic chemical, i.e., pure and viscous. Polyphosphoric acid is a short-chain polymer, as shown in Fig. 3. Due to its interactions with specific asphalt components, it is regarded as a chemical improver. Its characteristics are shown in Table 2, and the physical attributes of virgin and treated asphalt are shown in Table 3.

Table 1 The Physical Characteristics of the Used Aggregate.

Property	ASTM Des. No	Natural Aggregate		Coarse RCA	
		Coarse	Fine	Treated	Untreated
Bulk Sp. Gr.	C127 & C128	2.633	2.559	2.451	2.332
% of water absorption	C127 & C128	0.28	0.81	2.66	2.89
% of abrasion	C131	17	----	21	27
Flat and elongated (5:1) (%)	D4791	4	----	7	7
Soundness loss by magnesium sulfate solution, %	C88	0.1	----	0.2	1.07

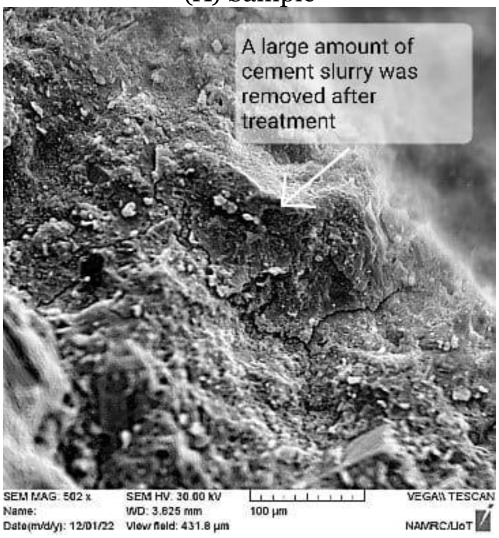
(a) Sample



(b) SEM Images

Fig. 1 Masterpiece and SEM Images of Untreated RCA.

(A) Sample



(B) SEM Images

Fig. 2 Masterpiece and SEM Images of Treated RCA.

The basis of this conclusion has been covered with an additional discussion of physical tests for modified asphalt, which is evident from the physical tests of asphalt modified with polyphosphoric acid, reducing penetration when adding 3% PPA from 46 to 37. Since the penetration test evaluated the asphalt viscosity, it was concluded that it had become more viscous. The softening point of asphalt indicated its tendency to flow at high temperatures. Test results showed that when 3% PPA was added to virgin asphalt, the asphalt softening point increased from 54 to 59, indicating that the PPA has a hardening effect on the asphalt, associated with a significant change in the asphalt structure from liquid to gel. The decrease in the penetration test is another factor that supports this conclusion. Adding PPA increased the asphalt stability at high temperatures, dramatically fitting Iraq's road paving. Due to its hot weather, the ductility substantially fell from 151 to 123 cm when 3% wt. PPA was added, demonstrating that PPA improved asphalt performance in high-temperature conditions; however, adding more PPA is anticipated to result in a lower low-temperature deformation capacity.

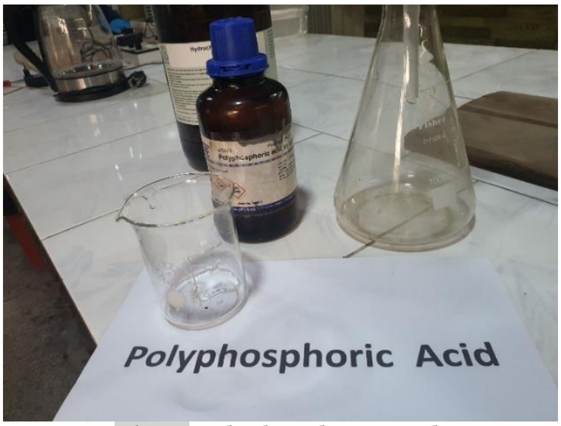


Fig. 3 Polyphosphoric Acid.

2.2. *Mix Design*

To determine the optimum asphalt content (OAC), the Marshall method was used according to ASTM D6927, as shown in Fi g.4. The mixtures designed in Marshall molds were compacted on both sides 75 times. Four asphalt contents were added to each of the aggregate mixtures, starting from 4.5% by the total mix weight, with an increased rate of 0.5%. Three replicate samples were made for each content. 4% of all air voids were used as the primary criterion for selecting OAC. At the same time, all other characteristics, such as stability, flow, density, and mineral voids, were checked to ascertain the desired requirements for control mixtures, (UTRCA) mixtures with modified asphalt by 3% PPA and TRCA mixtures with modified asphalt by 3% PPA.

Table 2 Physical and Chemical Properties of PPA.

Appearance	Color	Odor	Solubility	Assay P_2O_5 basis	Assay H_3PO_4 basis	Density (g/ml) @ 20℃	Boiling
Viscous liquid	Colorless, Clear	Odorless	Soluble in ethanol and water	85%	115%	2.05	~550℃

Table 3 Physical Properties of Virgin and Modified Asphalt Binder.

Test	Unit	ASTM	Result	
			Virgin Asphalt	Modified Asphalt with 3%PPA
Penetration @ 25 °C	0.1 mm	D5	46	37
Softening Point	°C	D36	54	59
Ductility @ 25 °C	cm	D113	151	125

Fig. 4 Mix Design Procedure.

2.3.Moisture Susceptibility

2.3.1.Indirect Tensile Strength Test (ITS)

Tensile strength is important to the mixture's performance under moisture susceptibility, fatigue, and rutting [25]. The moisture susceptibility of all mixtures was evaluated according to ASTMD-4867. Six samples were prepared using the Marshall method for each mix of the designed RCA. The desired air void content in the prepared samples was in the range of (6-8)%, attained by compacting "cylindrical samples (101.6 mm×63 mm) using 51 to 64 blows per side "compacting the models less than 75 times to achieve a void percentage of 7% to weaken the model and be able to determine the effect of moisture on it, according to specification D4867." The six samples were divided equally into two groups. The first unconditioned samples were tested at room temperature of 25 °C, and the other group, called conditioned samples, were placed in a beaker filled with water at a temperature of 25 °C; a 70 kPa vacuum was applied for 5 minutes to the flask to achieve 55-80% saturation after it was subjected to a cycle of freeze-thaw at -18 ± 2 °C for 16 hours immediately followed by 24 hours at 60 ± 1°C before testing at 25 °C. Fig. 5 shows the test procedure.

Fig. 5 Indirect Tensile Strength Test.

2.3.2. Compressive Strength Test

This method measures the cohesion loss caused by the water influence on compressed asphalt mixtures. "Six prototypes with a diameter of 101.6 mm and a height of 101.6 mm were created for this purpose. Three samples were evaluated after four hours of storage in 25 °C air immersion. Before the compressive strength test, the remaining three samples were deposited in a water bath at 60 °C for 24 hours and then transferred to a water bath at 25 °C for two hours." Calculating retained strength index according to ASTM D-1075, which must be a minimum value of 70% as approved in SCRB (R9), as shown in Fig. 6.

Fig. 6 Compressive Strength.

3. RESULTS AND DISCUSSION

3.1. Mix Design

The volumetric analysis and the results of the "Marshall design method" for mixtures containing NA and RCA of both types, i.e., UTRCA and TRCA, showed that the optimum content of asphalt, i.e., when using virgin asphalt, was 4.9%, 5.0٩%, and 5.01%. In comparison, the optimum content of asphalt when using modified asphalt with 3% PPA was 4.8%,4.91%, and 4.86, i.e., the mixture optimum values according to the recommendations of the Asphalt Institute. Observations revealed that the RCA mixtures required approximately (2-4) % more asphalt binder than the NA mixtures to attain the peak of Marshall feature and volumetric properties. These results concur with numerous previous research [26, 27]. This increased need is likely related to the adhesive cement slurry and the increase in the porosity of the aggregate texture, which led to the absorption of more asphalt cement. The results also showed that the mixtures containing TRCA were less consuming asphalt cement than the mixtures containing UTRCA, as the treatment reduced the sticky cement slurry while using modified asphalt reduced consuming asphalt cement compared to the mixtures in which virgin asphalt was used because the modified asphalt was more viscous than virgin asphalt and adding polyphosphoric acid was a percentage of the asphalt weight. Hence, the O.A.C decreased, as shown in Fig. 7. Fig. 8 shows the test results for the laboratory density of asphalt concrete, in which the coarse aggregate was replaced with treated and untreated recycled aggregate and the control mixtures, where the recycled mixtures resulted in a much lower density than the control mixtures. Based on the stability requirements of 8kN as specified in SCRB, the recycled mixtures resulted in higher stability than the control mixtures "because the recycled aggregate was created by crushing large parts of concrete, and this process increased the particles angularity, increasing the stability value in the mixtures in which the recycled aggregate was used," as shown in Fig. 9. The results agree with [5], maybe because the pieces of broken concrete aggregate were stuck together, causing friction between the pieces stronger. The flow also increased with the rise of asphalt content. It was observed that TRCA mixtures had a lower flow than TURCA; however, all mixtures met the standard range of 2-4 mm specified in SCRB, as shown in Fig. 10. The results indicated that the VMA of UTRCA was higher than that of TRCA, attributed to the adhesion of cement mortar decreased after treatment, as shown in Fig. 11.

3.2. Effect of PPA on Marshall Result and Volumetric Properties

Figures 12 to 15 show the volumetric properties and Marshall results for the control mixtures, in addition to the two recycled mixtures with asphalt modified with 3% polyphosphoric acid. The results of Marshall proved that the mixtures containing modified asphalt had a higher stability value than the control mixtures and the recycled mixtures in which virgin asphalt was used; such material behavior complies with the finding of [28-30]. The results showed that using asphalt modified with polyphosphoric acid reduced the flow values in the recycled mixtures. The mixtures' density decreased with increasing RCA using virgin asphalt, while the mixtures in which modified asphalt was used gave a higher density. The results agree with previous studies [8, 24]. The VMA % decreased using modified asphalt compared to mixtures in which virgin asphalt was used. The results are consistent with [28] and These tests were done in accordance with [31-33].

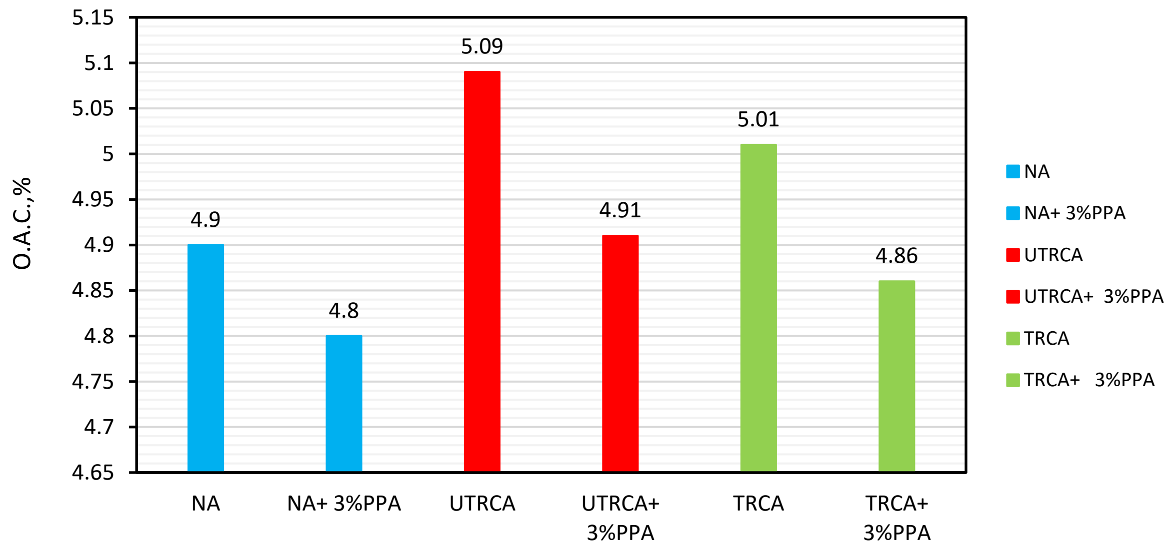


Fig. 7 The Effect of PPA on O.A.C of RCA- Mixtures.

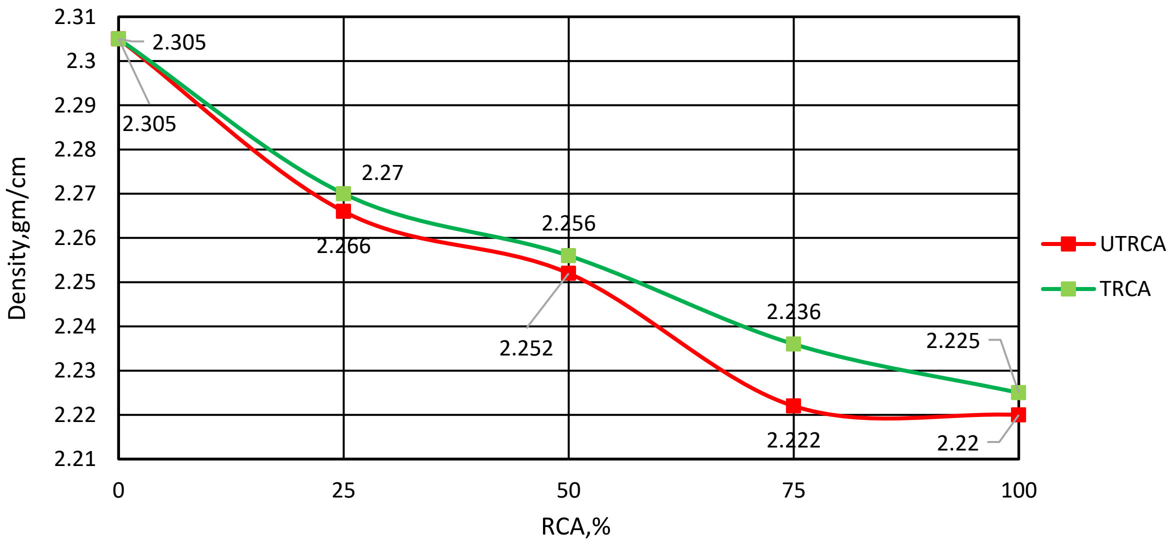


Fig. 8 The Effect of RCA Content on Density.

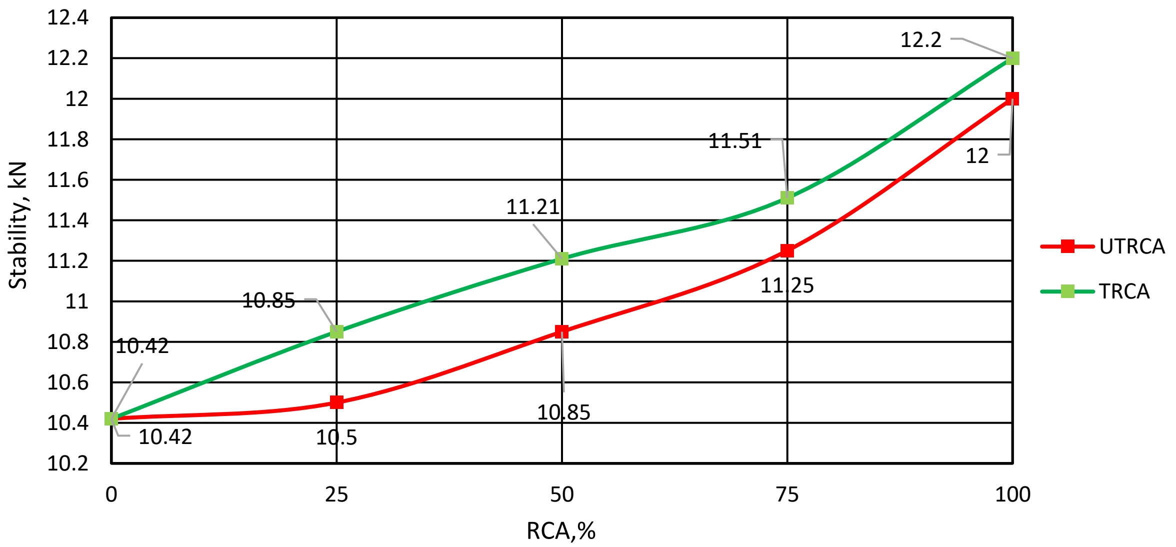


Fig. 9 The Effect of RCA on Stability.

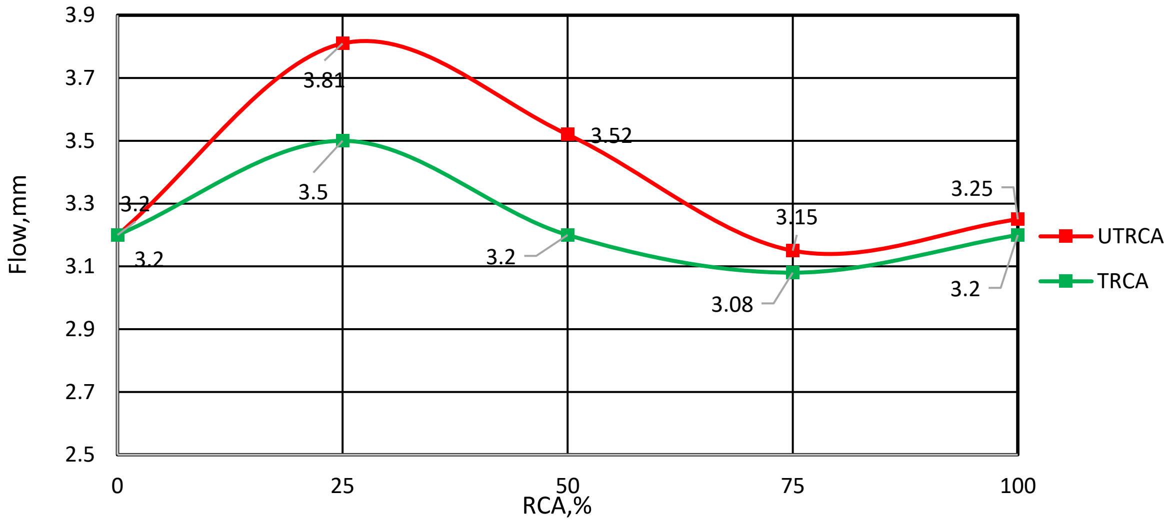


Fig. 10. The Effect of RCA on Flow.

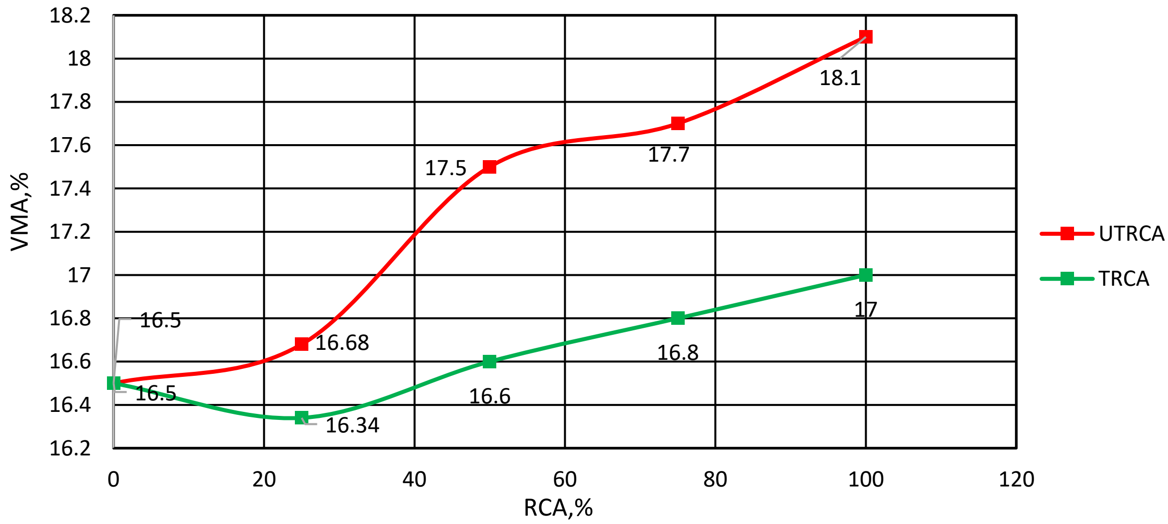


Fig. 11 The Effect of Asphalt Content on VMA.

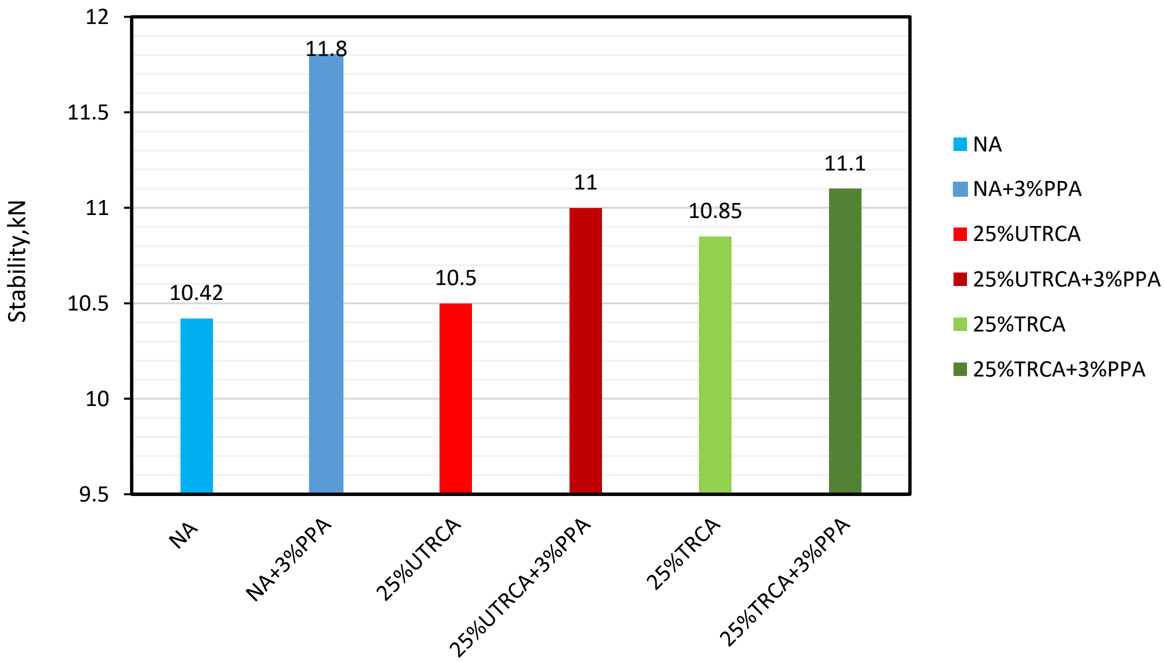


Fig. 12 Effect of PPA on Stability.

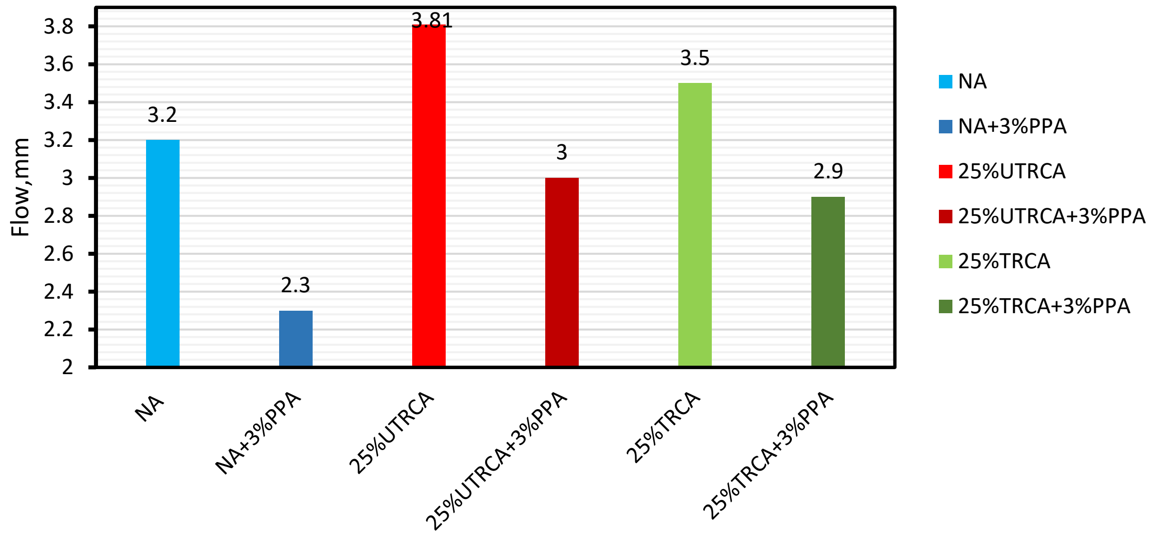


Fig. 13 Effect of PPA on Flow.

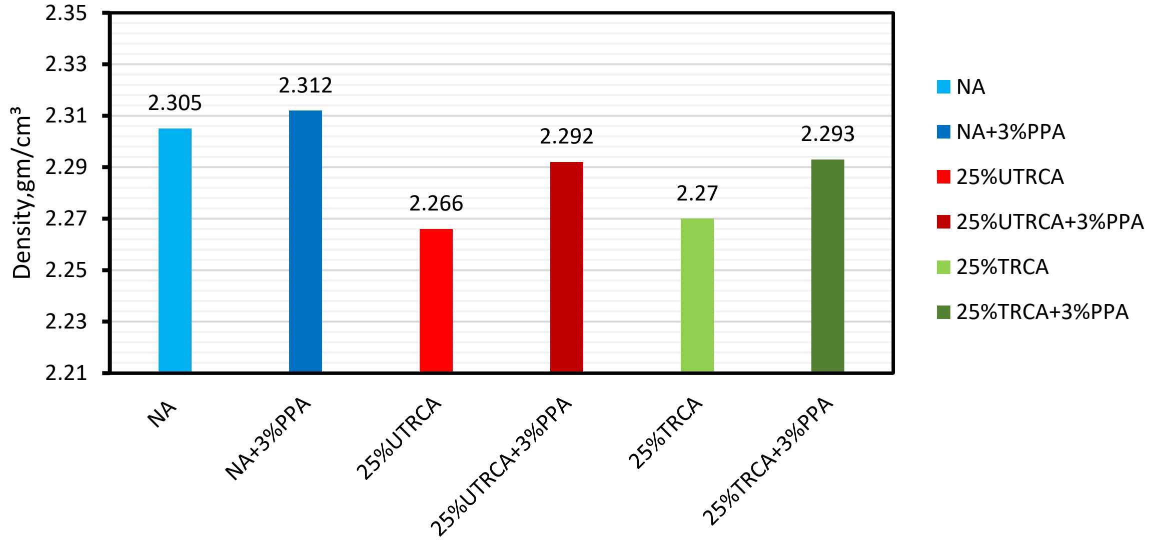


Fig. 14 Effect of PPA on Density.

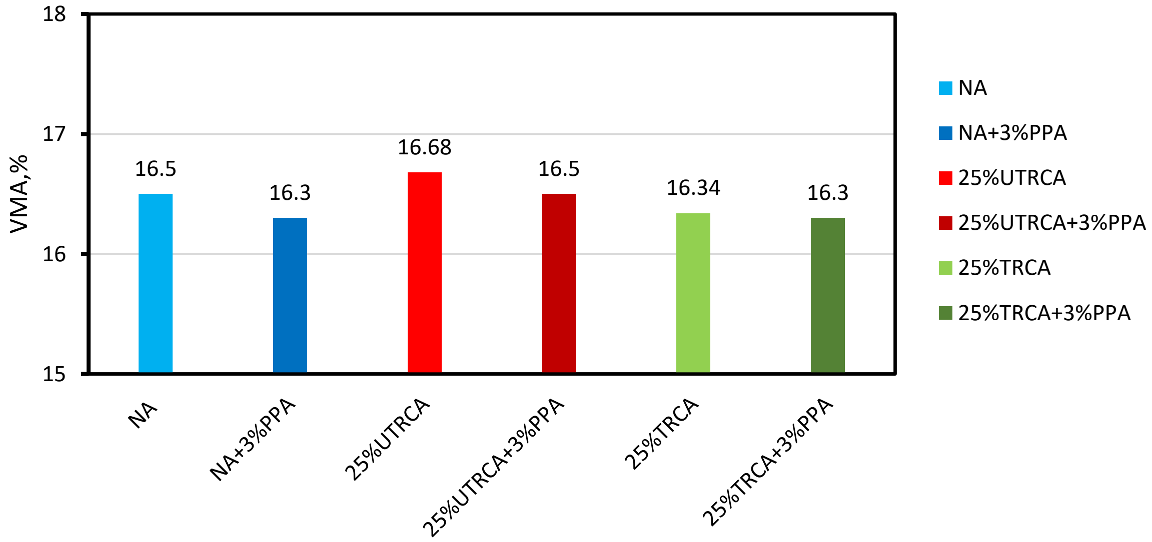


Fig. 15 Effect of PPA on VMA.

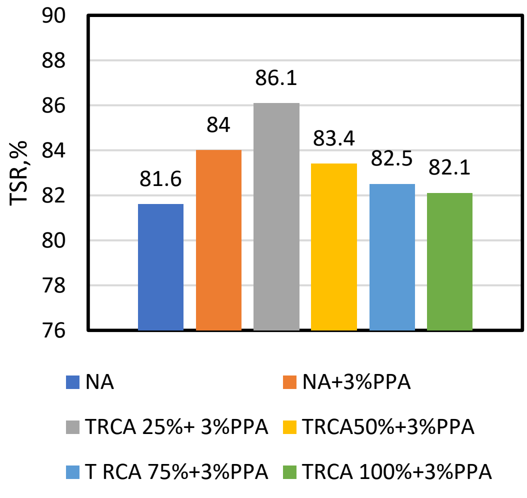
3.3. Moisture Susceptibility

3.3.1. Tensile Strength Ratio (TSR)

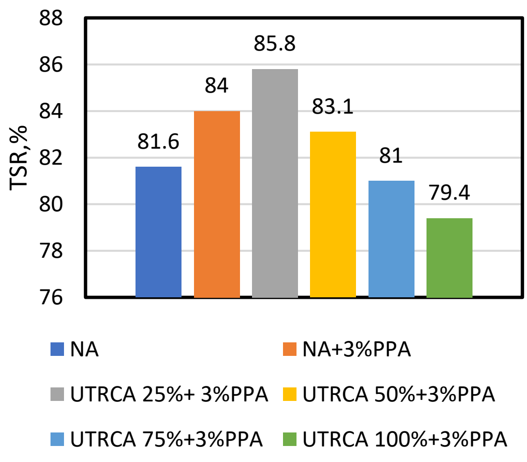
As shown in Fig. 16 (a), the mixtures TSR made of TRCA were more resistant to moisture damage than the mixtures made of NA and the mixtures modified with PPA. The mixtures, in which the natural aggregate was replaced by 25% of TRCA, are most suited to guarantee the long-term durability of the RCA HMA's water resistance over its service life. The mixtures made of UTRCA were less water resistant than those made of TRCA and more than those made of natural aggregates, as shown in Fig. 16 (b). The results agree [12-15].

3.3.2. Index of Retained Strength (IRS)

The retained strength index (IRS) values for the control mixtures were remarkably lower than those for both RCA mixtures, i.e., UTRCA and TRCA, except those containing 100% RCA, as shown in Fig. 17. Also, the IRS values for the mixtures containing 25% RCA were higher than the mixtures containing 50%, 75%, and 100%. The results of the mixtures in which modified asphalt was used were higher than those in which virgin asphalt was used. The results agree with [4, 24].

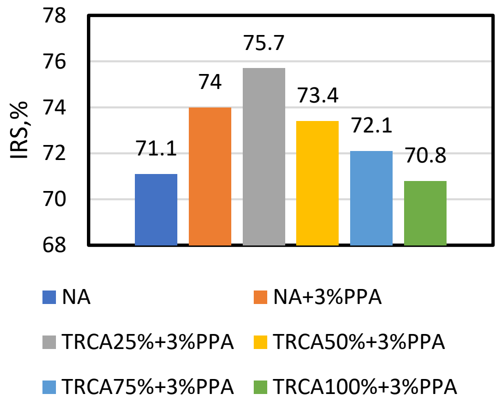


(a)

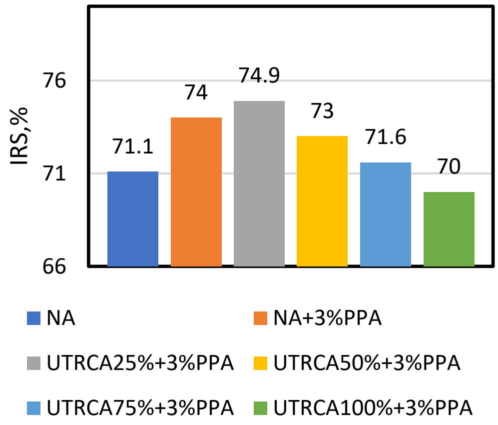


(b)

Fig. 16 Tensile Strength Ratio Result (TSR).



(a)



(b)

Fig. 17 Index of Retained Strength Results (IRS).

4. CONCLUSIONS

Several conclusions can be made from this work, as follows:

1- Maximum values of "the Tensile Strength Ratio and the Index of retained strength" were achieved with an RCA content of 25%.

2- Using RCA in high proportions of more than 25% produced asphalt mixtures of low density. When replacing the TRCA by 25%, the density decreased by 1.54%, and mixtures of higher density were produced when using asphalt modified with polyphosphoric acid.

3- The results showed that the stability value improved with increasing RCA ratios, resulting in a 4.1% rise in stability strength for NA mixtures when TRCA was replaced by 25%. Also, using polyphosphoric acid-modified asphalt increased stability for the same mixtures.

4- Due to the high porosity, RCA mixtures consumed more asphalt binder than control mixtures. The optimum asphalt percentage increased by 3.9% in 25% UTRCA mixtures and 2.24% in 25% TRCA mixtures. The asphalt rate increased as the RCA ratio increased.

Using asphalt modified with polyphosphoric acid reduced consuming asphalt binder in recycled mixtures, and using modified asphalt reduced the optimum asphalt percentage increase in the UTRCA mixtures, where the increase compared to the NA mixtures was 0.2%. Using modified asphalt in TRCA mixtures reduced the optimum rate by 0.8% compared to NA mixtures.

5- All TSR results exceeded the minimum specification limits of 80% in TRCA mixtures. In comparison, when UTRCA was used in asphalt mixtures, it also exceeded the minimum specifications limits of 80% in the TSR test, except for the RCA replacement rate of 100%, and using asphalt modified with polyphosphoric acid gave better results than using virgin asphalt.

6- This work determined that using RCA improved the asphalt concrete durability and increased susceptibility to moisture. However, treated RCA led to better results than untreated RCA, and using asphalt modified with polyphosphoric acid gave better results than using virgin asphalt in asphalt concrete containing RCA.

7- The asphalt modified with Polyphosphoric acid significantly affected the asphalt binder rheology, which allowed the modified asphalt to resist high temperatures and stress level conditions more than the unmodified asphalt.

NOMENCLATURE

A.V	Air Voids
AASHTO	American Association of State Highway and Transportation Officials
O.A.C	*Optimum Asphalt Content*
PPA	*Polyphosphoric Acid*
SCRB	*State Corporation for Roads and Bridges*
VMA	*Void in Mineral Aggregate*
H_3PO_4	*Phosphoric Acid*
P_2O_5	*Phosphorus Pentoxide*
TRCA	Treated Recycle
UTRCA	Untreated Recycle
NA	Natural Aggregate

REFERENCES

[1] Lei B, Li W, Luo Z, Tam VW, Dong W, Wang K. **Performance Enhancement of Permeable Asphalt Mixtures with Recycled Aggregate for Concrete Pavement Application**. *Frontiers in Materials* 2020; 7:253, (1-16).

[2] Al-Hadidy A, Hameed AT. **Minimizing the Moisture Damage and Drain Down of Iraqi SMA Mixtures Using Waste Additives**. *Tikrit Journal of Engineering Sciences* 2011; **18**(3):68-80.

[3] Ismael MQ. **Chemical and Rheological Properties of Reclaimed Asphalt Binders Modified by Waste Engine Oil.** *Innovative Infrastructure Solutions* 2022;7(2):136.

[4] Nazal HH, Ismael MQ. **Evaluation the Moisture Susceptibility of Asphalt Mixtures Containing Demolished Concrete Waste Materials**. *Civil Engineering Journal* 2019; **5**(4):845-855.

[5] Ibraheem TK, AL-TAEI AA. **Effect of Low-Density Polyethylene on the Stripping Properties under Fatigue Loading of Binder Layer of HMA Mixtures**. *Tikrit Journal of Engineering Sciences* 2021; **27**(4): 102-113.

[6] El-Tahan D, Gabr A, El-Badawy S, Shetawy M. **Evaluation of Recycled Concrete Aggregate in Asphalt Mixes.** *Innovative Infrastructure Solutions* 2018; **3**(20):1-3.

[7] Abass BJ, Albayati AH. **Influence of Recycled Concrete Aggregate Treatment Methods on Performance of Sustainable Warm Mix Asphalt**. *Cogent Engineering* 2020; **7**(1):1718822.

[8] Hilal M. **Evaluation of Modified Asphalt Binder and Mixtures with Polyphosphoric Acid**. *Al-Nahrain Journal for Engineering Sciences* 2023; **26**(1): 31-36.

[9] Martinez-Arguelles G, Coll MD, Pumarejo LGF, Cotte EHS, Rondon H, Pacheco CA, Espinoza RGL. **Characterization of Recycled Concrete Aggregate as Potential Replacement of Natural Aggregate in Asphalt Pavement**. *4th World Multidisciplinary Civil Engineering, Architecture, Urban Planning Symposium (WMCAUS 2018)*; Prague, Czech Republic. IOP Publishing: p. 1-9.

[10] Kavussi A, Hassani A, Kazemian F, Taghipoor M. **Laboratory Evaluation of Treated Recycled Concrete Aggregate in Asphalt Mixtures.** *International Journal of Pavement Research and Technology* 2019; **12**:26-32.

[11] Xu X, Luo Y, Sreeram A, Wu Q, Chen G, Cheng S, Chen Z, Chen X. **Potential use of Recycled Concrete Aggregate (RCA) for Sustainable Asphalt Pavements of the Future: A State-of-the-Art Review**. *Journal of Cleaner Production* 2022; **344**: 130893.

[12] Giri JP, Panda M, Sahoo UC. **Performance of Bituminous Mixes Containing Treated Recycled Concrete Aggregates and Modified by Waste Polyethylene**. *Journal of*

Materials in Civil Engineering 2018; **30**(8):04018184.

[13] Wu S, Zhong J, Zhu J, Wang D. **Influence of Demolition Waste Used as Recycled Aggregate on Performance of Asphalt Mixture**. *Road Materials and Pavement Design* 2013; **14**(3):679-688.

[14] Pérez I, Pasandín AR, Medina L. **Hot Mix Asphalt Using C&D Waste as Coarse Aggregates.** *Materials & Design (1980-2015)* 2012; **36**:840-846.

[15] Pérez I, Pasandín AR, Gallego J. **Stripping in Hot Mix Asphalt Produced by Aggregates from Construction and Demolition Waste.** *Waste Management & Research* 2012; **30**(1):3-11.

[16] Zhu J, Wu S, Zhong J, Wang D. **Investigation of Asphalt Mixture Containing Demolition Waste Obtained from Earthquake-Damaged Buildings**. *Construction and Building Materials* 2012; **29**:466-475.

[17] Ossa A, García JL, Botero E. **Use of Recycled Construction and Demolition Waste (CDW) Aggregates: A Sustainable Alternative for the Pavement Construction Industry.** *Journal of Cleaner Production* 2016; **135**:379-386.

[18] Qasrawi H, Asi I. **Effect of Bitumen Grade on Hot Asphalt Mixes Properties Prepared Using Recycled Coarse Concrete Aggregate**. *Construction and Building Materials* 2016; **121**:18-24.

[19] Abo-Qudais S, Mulqi MW. **New Chemical Antistripping Additives for Bituminous Mixtures.** *Journal of ASTM International* 2005; **2**(8): JAI13292.

[20] Bagampadde U. **On Investigation of Stripping Propensity of Bituminous Mixtures**. Ph.D Thesis. KTH Byggvetenskap; Brinellvägen, Stockholm:2004.

[21] Xiao F, Zhao PW, Amirkhanian SN. **Fatigue Behavior of Rubberized Asphalt Concrete Mixtures Containing Warm Asphalt Additives**. *Construction and Building Materials* 2009; **23**(10):3144-3151.

[22] Al-Hadidy AR, Al-Kazzaz ZA, Ali AA. **Deterministic Extensional Viscosity and Cracking Index of Polypropylene -Modified -Asphalt Binder**. *Tikrit Journal of Engineering Sciences* 2020; **27**(1):25-29.

[23] Baumgardner G, Hajj EY, Aschenbrener TB, Hand AJ. **Responsible Use of Polyphosphoric Acid (PPA) Modification of Asphalt Binders.** 2023.

[24] Raof HB, Ismael MQ. **Effect of PolyPhosphoric Acid on Rutting Resistance of Asphalt Concrete Mixture.** *Civil Engineering Journal* 2019; **5**(9):1929-1940.

[25] Al-Baiti HKA. **Evaluation and Study the Effect of Additives and other Factors on Tensile Strength of Asphalt Paving Mixtures**. *Tikrit Journal of Engineering Sciences* 2012; **19**(1): 80-96.

[26] Pérez I, Pasandín AR. **Moisture Damage Resistance of Hot-Mix Asphalt Made with Recycled Concrete Aggregates and Crumb Rubber**. *Journal of Cleaner Production* 2017; **165**:405-414.

[27] Motter JS, Miranda LF, Bernucci LL. **Performance of Hot Mix Asphalt Concrete Produced with Coarse Recycled Concrete Aggregate.** *Journal of Materials in Civil Engineering* 2015; **27**(11):04015030.

[28] Poorna RL, Mymoon M, Hariharan A. **Preservation and Protection of Traditional Knowledge–Diverse Documentation Initiatives Across the Globe**. *Current Science* 2014; **107**(8): 1240-1246.

[29] Khader GA, Ramesh A, Kumar M. **A Laboratory Study on Acid Modified Bituminous Mixes in Comparison for Rutting Characteristics.** *Civil Engineering and Urban Planning: An International Journal* 2015; **2**(4): 19-33.

[30] Olabemiwo OM, Esan AO, Adediran GO, Bakare HO. **The Performance of Agbabu Natural Bitumen Modified with Polyphosphoric Acid Through Fundamental and Fourier Transform Infrared Spectroscopic Investigations.** *Case Studies in Construction Materials* 2016; **5**:39-45.

[31] SCRB. Standard Specifications for Road and Bridge. Section R/9, Hot-Mix Asphalt Concrete Pavement, Revised Edition. State Corporation of Roads and Bridges, Ministry of Housing and Construction, Republic of Iraq 2003.

[32] ASTM D6927. Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures, ASTM International, West Conshohocken, PA. 2015.

[33] (ASTM) Road and Paving Materials Vehicle Pavement Systems. Annual Book of ASTM Standards. Vol. 04.03. American Society for Testing and Materials 2015.