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Use of Reclaimed Asphalt Pavement as Aggregate in Roller-Compacted Concrete Pavement: A Comprehensive Review

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Abstract

Due to increased maintenance and rehabilitation actions, significant volumes of Reclaimed Asphalt Pavement (RAP) are left in stockpiles. Replacing aggregate in Portland Cement Concrete (PCC) with additional RAP could help eliminate surplus RAP stockpiles and reduce PCC's natural aggregate consumption, positively impacting the environment and the economy. This paper is a state-of-the-art review of the literature on using RAP to Roller-compacted Concrete pavement (RCCP). The potential of RAP aggregates has been assessed based on their characteristics and the optimum moisture content (OMC), maximum dry density (MDD), compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, abrasion resistance, shrinkage, porosity, water absorption, and freeze-thaw of RCCP. The literature study illustrated how a low-density, smooth-textured hydrophobic asphalt covering surrounds RAP aggregates. potentially reducing the maximum dry density (MDD) and optimum moisture content (OMC) of RCCP mixtures. This asphalt layer could reduce RAP's ability to bind with cement paste, reducing its strength properties. In addition, the hydrophobic nature of RAP may reduce porosity and water absorption. On the other hand, agglomerates and dust can have the reverse impact. Pavement application might be done with a lower replacement of RAP (less than 50%) without affecting the pavement's strength, porosity, or water absorption. However, Increasing the replacement of RAP aggregate may not be conducive to mechanical performance, but it has the potential to enhance the toughness and energy absorption capacity of pavements.

Keywords: Roller Compacted Concrete (RCC), Reclaimed Asphalt Pavement (RAP), Compressive Strength, Shrinkage, Freeze-Thaw, Water absorption, Review.

1. Introduction:

Pavements can be generally classified into two categories: rigid and flexible. Between concrete and asphalt road surfaces, there is a major difference. Concrete pavement is a rigid structure, while asphalt is a flexible structure. However, "rigid" and "flexible" accurately describe how the pavements respond to traffic volumes and their surrounding environment. The flexible pavement is an asphalt pavement. Base and subbase courses are typically built beneath an asphalt surface. In contrast, it is just a base course between the pavement and subgrade in rigid pavements composed of Portland cement concrete [1].

Roller-compacted concrete (RCC) is used to rapidly construct pavements using less equipment and labor than conventional concrete pavements. It is a stiff mixture of aggregates, cementitious

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materials, and water. Without forms, finishing, or surface texture, it is compacted by vibratory rollers after its placement by pavers. RCC produces strengths that are higher than those of conventional concrete because of the low water content and low water-cement ratio. It does not require joints, dowels, reinforcing steel, or formwork. Compared to conventional flexible pavement, it produces stronger and more durable pavement. It will bare heavy axle loads and will not slide during braking operations or turnings. Even in high-temperature conditions, it will not be brittle or soft. It is resistant to degradation by materials like diesel fuel [2].

The field of engineering is adopting a new strategy that is focused on sustainability and aims to develop innovative ways to reduce greenhouse gas emissions. Concrete, which is the most widely used construction material, is the one that, because of the manufacturing and demolition processes, has the most impact on the environment. The significant amount of energy required in producing concrete indicates the well-known problem of "greenhouse gas emissions," especially CO2. According to (3(, 90% of the total energy embedded in concrete is consumed in the production of cement, which accounts for most of the energy used in the production process. Construction and Demolition waste (CDW), which accounts for 25–30% of all material waste on Earth, is the main source of waste overall [3]. Reusing aggregates from CDW and reducing the number of materials disposed of and unused are essential. Among the several recycled aggregates that replace natural aggregates in concrete, reclaimed or recycled asphalt pavement (RAP), which is produced by milling road surfaces, is becoming increasingly popular as a useful strategy for using recycled CDW and reducing the depletion of natural resources. Significant quantities of reclaimed asphalt continue to be disposed of in landfills, mostly remaining unutilized. Compared with conventional concrete mixes, the volume occupied by the aggregate in RCCP is 10-15% larger. As a result, it seems that RCCP is an effective choice than its alternatives when it comes to using recycled aggregates. The objective of this study is to provide a detailed review of the present use of RAP aggregates within the construction industry, with a focus on their application in roller-compacted concrete pavement (RCCP) [4].

2. Reclaimed Asphalt Pavement (RAP)

Kaur et al. [5] defined the "reclaimed asphalt pavement" (RAP) as the recycled material obtained from removing old asphalt pavements. Also, [6] stated that The RAP is bitumen-coated reclaimed aggregate taken from the failed pavement's surface. Two processes are conducted to recycle RAP from the pavement milling and crushing [7].

2.1. Reclaiming process

- Reclaiming

Asphalt that has been reclaimed is called reclaimed asphalt pavement (RAP). The main component of RAP mostly involves bituminous and aggregate components; however, it may also include other admixtures and byproducts resulting from traffic activity. The two main methods for obtaining RAP are by full depth (completely destroying) the pavement or by milling the top layer of the pavement [8].

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- Milling and Full depth

According to [9] is a technique that involves using a milling machine to remove the top layer of the pavement. This method is used to construct a new coating of the pavement or to increase and restore the friction of the pavement **Figure (1.3a)**. On the other hand, full-depth pavement demolition is a technique that involves reclaiming portions of the underlying layers and the whole pavement. Due to their lower bituminous levels, full-depth masses are often crushed and are appropriate for use as unbound layers **Figure (1.3b)**.

- Crushing

Crushing of the asphalt material is required after the reclamation process. The goal of this technique is not to crush the stone material one more time. Instead, it is intended to divide the RAP into smaller portions that are bound together by bitumen. Since warmer heat re-glues the bitumen together, crushing is simplest in cold weather. The RAP material is sieved into desired fractions after being crushed [8].

The properties of the original aggregate and the binder heavily influence RAP's properties. RAP has 3% to 7% of hardened asphalt cement and 93% to 97% by weight of mineral aggregates [9],[10]. RAP contains viscoelastic asphalt, a material whose properties are influenced by temperature and loading conditions. Viscosity plays a major part in workability as RAP binder content increases. Better mix workability is made achievable by a decrease in bitumen viscosity. Consequently, Concrete's creep and shrinkage properties are influenced when RAP is used as an aggregate [9].

(a)

(b)

Figure (1.3) Reclaimed Asphalt Pavement (RAP), **(a)** Milling or cold planning,

(b) full-depth pavement demolition.

2.2. Characterization of RAP aggregates

2.2.1. Specific gravity:

The presence of low-density asphalt coating surrounding the RAP aggregates may have contributed to the observation that the specific gravity of RAP aggregate was lower than that of natural aggregates (NA). Typically, the specific gravity of RAP ranges between 2.1-2.6 for the coarser (RAP) fraction and 1.8-2.4 for the finer (RAP) fraction [11]-[16]. Because of the combined effects of the RAP aggregates' lower specific gravity and dust contamination layers, it was also found that the compacted density of RAP aggregate was lower than that of natural aggregates [15],[17]. The type of aggregate used in the pavement and the material's moisture content determines the compacted density of RAP. Previous studies on RAP show that its unit weight ranges between 1600 and 2300 kg/m3, see **Table 1**.

Table (1): Physical and Mechanical properties of RAP

Properties	Coarse RAP	Fine RAP
Specific Gravity	2.1-2.6	1.8-2.4
Absorption%	1.8-2.9	1.8-2.8
Bulk Density (kg/m3)	1940-2300	1600-2200
Crushing Value %	16-20	-
Impact Value %	4.3-33	-
Abrasion Resistance %	18-30	-
Asphalt Content %	1.9-3.5	4.5-7.5

2.2.2. Water absorption:

The water absorption capacity of aggregate refers to the capacity of (RAP) to absorb water. This provides an indication of the overall strength of the aggregate. A significant water absorption value indicates the aggregate's high porosity, making it unsuitable for concrete. Many researchers [11],[12],[16]-[18] found that compared to natural aggregates, RAP particles have lower porosity and water absorption. The water absorption of RAP ranges between 1.8-2.9%. The hydrophobic properties of bitumen or asphalt might be the cause of this.

On the contrary, other researchers [20],[21] It has been found that RAP aggregate has a slightly higher water absorption rate than natural aggregate. It is possible that the layer of dust covering the RAP caused this. Furthermore, several studies [3],[21] found that RAP aggregates have been adversely affected by the contaminants, particularly about water absorption.

2.2.3. Asphalt cement content:

The thickness of asphalt cement coating could be between 6 to 10 microns [22], and depending on parameters such as the RAP fractions, initial asphalt content, extraction method, stockpiling, and service duration etc., the amount of asphalt cement around the aggregate's ranges between 1.9 to 7.5% by weight [4],[16],[19]. While it has been observed that the inclusion of soft asphalt film may reduce the specific gravity and unit weight of aggregates, several studies suggest that this film may provide various benefits, including a decreased impact value, a decreased abrasion value, and a decreased aggregate crushing value [4],[15],[16].

In fact, in some cases, the soft layer of asphalt has a tendency to consolidate the particles into a cohesive solid mass when subjected to confining or impact pressures, preventing the assessment of the aforementioned aggregate characteristics [23]. Nevertheless, the impact value of the RAP aggregates was found to be greater than that of the conventional aggregates [17]. There are many potential causes that might contribute to this condition, including as the segregation of tiny agglomeration particles, the presence of a stiffening asphalt layer, the reclamation process used for RAP, and changes in the original composition of the aggregates.

3. Fresh Properties of RCC containing RAP

3.1. Optimum moisture content (OMC):

The studies conducted by [17],[20] revealed that the optimum moisture content (OMC) of a typical roller-compacted concrete mixture prepared using naturally available or fresh aggregates typically lies in the range of 4 and 7%. On the other hand, using RAP often results in an 8–12% reduction in the OMC value, mostly because of its asphalt layer's capacity to resist water [24]. Nevertheless, several experts have shown that the incorporation of RAP might potentially increase the OMC value by as much as 12% [11],[18],[25]. The detrimental effect on the OMC is related to the agglomeration of RAP particles, which entrap the water into the voids.

3.2.Maximum dry density:

Because of its reduced specific gravity, the addition of RAP may result in a decrease in MDD. It has been noticed that adding low-density RAP lowers the MDD of RCCP mixtures by around 5% [4],[20],[26]. However, combining the lubricating action of the asphalt layer and the lower angularity of RAP aggregates leads to improved workability and compatibility when RAP is added [17].

4. Properties of RCC containing RAP

RCC exhibits similar characteristics to conventional concrete pavement, but with distinct mixture proportions and construction techniques. Hardened concrete characteristics were analyzed in terms of compressive strength, flexural strength, split tensile strength and elasticity modulus. The thickness design RCCP is primarily determined by the compressive strength and flexural strength, which are the primary characteristics. **Table 2** provides the limits that are recommended by various governing authorities.

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Table (2): Recommended strength criteria for RCCP after 28 days of cure

Standards	Recommended strength		Country of origin
	Compressive strength (MPa)	Flexural strength (MPa)	
ACI 327	28 to 41	3.5 to 7	USA
Portland Cement Association	27.6 to 68.9	3.4 to 6.9	USA
American Concrete Pavement Association	28 (If no freeze and thaw) 31 (If exposed to freeze and thaw)	x	USA
IRC: SP-68	Typically designed for M30 grade concrete		India
British Airport Authority	x	4	British
France	20	x	France

4.1.Compressive Strength

RCC has a compressive strength that is like conventional concrete, usually between 28 and 41 MPa. Compressive strengths greater than 48 MPa have been achieved in some projects; Nevertheless, it is probable that practical construction and economic concerns would emphasis the need for greater thickness rather than focusing on strengths of this nature [2].

Based on several studies [14]-[17],[22],[27],[28] Based on the RAP fractions utilized, using RAP may result in compressive strength reductions of 9–67%, see **Table (3)**.

According to [4] the influence of partial replacement of RAP on the compressive strength of RCC, when less-aged RAP was added to the RCC mix, it was shown that the compressive strength decreased by 26 to 67%. However, using highly-aged RAP resulted in a percentage decrease of around 9–37%. This behavior is due to the oxidization effect of the highly aged RAP aggregates.

In general, it has been found that coarse RAP-included concrete mixes have about 25% higher compressive strength than fine RAP-inclusive concrete mixes [17],[22],[27],[28]. The primary causes of the aforementioned behavior have been determined to be higher asphalt concentration in fine RAP compared to coarse RAP and a lack of finer fraction ($<600\mu m$) in fine RAP relative to natural fine.

Many researchers [14],[25] reported that it is typically suggested that, to improve pavement performance, strength, and stiffness, less than 50% of RAP should be used in place of natural aggregate while producing RCC. A further investigation indicated that there were no significant effects on the compressive strength when up to 50% of the RAP was replaced [4]. In contrast, a separate investigation showed that replacing 50% of RAP had a significant impact on the properties of the concrete [16]. Many factors may be responsible for this discrepancy, including the presence of an asphalt film around the aggregates, which results in a poor bond between cement paste and the asphalt-coated aggregate, the presence of agglomerated particles on the RAP's surface, the thickness of the asphalt film covering the aggregates, the RAP's oxidation characteristics, and the asphalt coating's loss of the RAP aggregates' surface texture [15],[25],[28],[29],[31].

The study on the bonding qualities of cementitious materials with asphalt-coated particles has shown that the strength loss in the Interfacial Transition Zone (ITZ) surrounding the RAP aggregates has resulted in high porosity. Cohesive failure in the asphalt covering over the aggregates is mostly caused by significant porosity in the ITZ surrounding the RAP start of cracks rather than the cohesive failure of the cement-asphalt interface [32].

The results of this research suggest that the impact of RAP on the properties of RCC and the importance of these impacts are still not well understood.

4.2. Flexural Strength

The tensile strength of concrete is measured indirectly by flexural strength or modulus of rupture. The pavement's flexural strength is another important factor in confirming or measuring the extent of improvement. Tensile strains are created at the bottom surface of concrete pavements by the repeated traffic loads they experience, particularly in uneven terrain. Because of this, RCC has a high flexural strength, often between (3.5-7) MPa [33].

Using RAP as a substitute for certain natural aggregates, regardless of the RAP percentage or replacement ratio, may reduce the flexural strength of RCC pavement mixtures by around 5-31% (Debbarma, Ransinchung, et al., 2019a; Debbarma, Singh, et al., 2019a; Fakhri & Amoosoltani, 2017; Modarres & Hosseini, 2014). According to [15],[16],[27],[32],[34]:

The percentage decrease in flexural strength following by the addition of RAP is less than the noticed percentage in compressive strength; this might be because:

- The asphalt coating's presence could improve the flexural strength of RAP mixtures.
- The visco-elastic property of asphalt coating increases the durability of RAP by preventing cracks from propagating through the mortar paste instead of the aggregates and making RAP tougher.
- Furthermore, loading in tests of flexural and compressive strength is different.

On the other hand, [17] demonstrated that using the coarse RAP fraction results in higher flexural strength than using the finer fractions. This behavior is influenced by a higher specific gravity relative to the fine RAP and a lower asphalt concentration on the aggregate surface area. Furthermore, it is commonly known that a finer matrix has a greater surface area than a coarser matrix. As a result, fine RAP contains a high concentration of asphalt, which reduces the flexural strength of RCC, and cracks can more easily penetrate the asphalt layer.

The failure rate of RAP concrete mixes is higher for asphalt cohesiveness than for asphalt cement adhesion [32]. However, as demonstrated by the study published by [4], using the coarser RAP, which has less asphalt concentration and agglomerated particles, may decrease asphalt cohesion failure severity. This leads to the conclusion that using RAP in RCC mixtures is a sustainable solution but that coarser, more-aged RAP gives better results in pavements than finer, less-aged RAP.

Furthermore, because RCC pavements are made based on flexural strength, the results of the literature research encouraged the increased use of RAP for pavements compared to structural concrete applications.

4.3. Tensile strength

Regardless of the curing age, the utilization of RAP lowers the splitting tensile strength of RCC Pavement mixtures [4],[18],[25]. For instance, [18] stated that using 16% coarse RAP may result in a 16% reduction in splitting tensile strength. Similarly, when 100% coarse RAP was used, [25] found a reduction of almost 26%. The asphalt layer covering the RAP prevents the cement mortar and RAP aggregates from forming a strong interfacial bond and decreases the concrete strength [25].

Adding RAP aggregates to RCC Pavement mixes reduces their split tensile strength but less impacts their flexural strength [19]. Additionally, compared with control mix specimens, the RAP-inclusive specimens did not split in half after failure, suggesting that RAP inclusions may significantly increase the durability of the RCC Pavement mixes. Cement mortar failure was identified as the primary cause in the RAP-inclusive specimens, while aggregate failure was primarily linked to the control mix specimens.

A further study by [12] revealed that the tensile strength increases by almost (23) % in (28) days when both RAP at (50) % and subsequently decrease in the days that follow. Thus, further research and attention are required to understand and illustrate the RAP's influence on the concrete's mechanical properties.

4.4. Modulus of Elasticity

Compressive strength and modulus of elasticity of RCC vary similarly. Because asphalt is considerably softer than cement paste at ambient temperature, RAP has a significant detrimental effect on the RCC modulus of elasticity. Moreover, it has been noted that using RAP can reduce the modulus of elasticity of RCC Pavement mixtures by about 80% [11],[14]. A decreased modulus of elasticity reduces the normal stress in the slab and may reduce crack width, and it generates more significant slab deflection, which increases base damage [31]. Since RAP aggregates differ from conventional aggregates in terms of material properties, it is evident that using them can have a significant effect on the modulus of elasticity of RCC Pavement mixes.

4.5. Interaction between Asphalt and Cement

To understand concrete behaviors, including RAP, it is essential to study the mechanisms by which asphalt interacts with cement hydration and influences the formation of the interfacial transition zone. However, there are few published studies in this field.

According to [16],[37] the weak and porous interfacial tension zone between the RAP and cement-mortar paste is the main factor affecting the properties of RAP concrete mixes. Because an asphalt layer surrounds the RAP, it is more difficult for a strong interfacial bond to be established, which results in a porous and weak interfacial transition zone (Fig. 2). Also, because of the visco-elastic nature of asphalt, the crack propagates through the asphalt film rather than the aggregates [22], see Fig. (3). As a result, in RAP concrete mixtures, the development of asphalt cohesion failure becomes more common than the cement-asphalt adhesion failure [32].

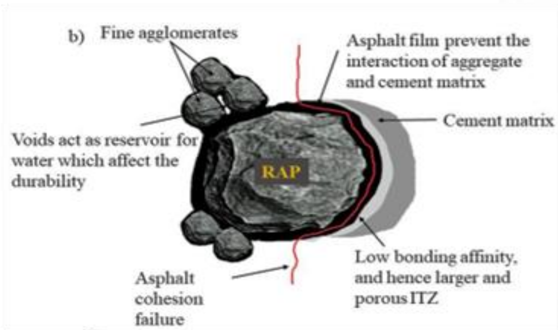

Figure 2: Schematic representation of the factors affecting the strength and durability of RAP aggregates [22]

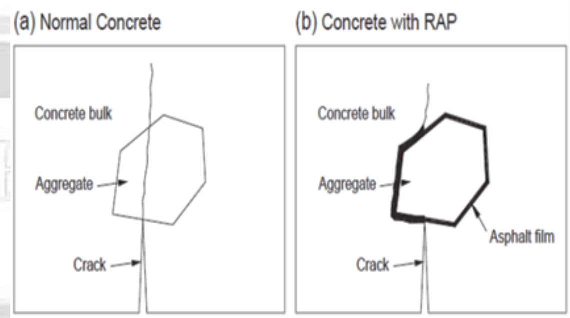

Figure 3: Crack propagation in concrete and concrete with RAP [22]

4.6.Water absorption

According to [4], regardless of the RAP percentage or replacement level, the water absorption of RCC Pavement is reduced by about (20–42) %. This could be because RAP absorbs less water. Besides that, as demonstrated positively by [4], the presence of more agglomerated particles may enhance water absorption by about (19) %. However, agglomerated RAP particles have the potential to form tiny voids that absorb water, enhancing the concrete mixture's ability to absorb water. The presence of external dust contaminants in the RAP's finer fraction may also lead to higher water absorption capacities than those shown by the coarse RAP fractions, even though it would still be less than the mix containing just natural aggregates [4],[20] .

4.7. Freeze-Thaw Durability

The construction of RCC Pavement in a cold climate can lead to various problems including internal cracking and surface scaling from freeze-thaw cycles, among other things [2]. The critical degree of saturation determines how adversely freeze-thaw cycles affect concrete (the ratio of the volume of voids total to the volume of voids that contain water). Since the overall volume of pores in the concrete significantly determines the degree of saturation, the open and porous structure of RCC Pavement may result in considerable freeze-thaw damage. To make RCC Pavement resistant to freeze-thaw damage, it is necessary to choose well-graded aggregate in addition to basic requirements (An appropriate quantity of water and cement, selection of mineral and chemical admixtures, and curing).

The results of a study by [35],[38] demonstrate that adding RAP to RCC may result in a mass loss of (0.03–1) %; nonetheless, crack propagation was seen along the edges of RAP [38],[39].

Mass loss in conventional concrete mixes usually occurs in the compaction voids; however, in mixes including reclaimed asphalt pavement (RAP), mass loss is shown to be increasing near the asphalt-to-mortar transition [38]. Besides that [40],[41], demonstrate that in samples where the cement content was up to (250–300) kg/m3 and the air was not entrained, the RCC mixes' durability factor was (65) % or higher at the end of 300 cycles.

Also, [42] studies found that the freeze-thaw resistance of RCC mixtures containing RAP up to 20% by weight does not differ significantly and that the Durability factor in all RCC mixtures was approximately 73 % (with and without RAP).

The observed heterogeneity in the findings is likely attributable to the use of different compaction processes during sample production and differences in sample size. According to reports [43], if the hardened concrete's durability factor is to be evaluated, it is "unsatisfactory" for those under 40, "doubtful" for those between 40 and 60, and "satisfactory" for those over 60.

4.8. Drying Shrinkage

RCC pavements overcome significant volume changes, which are attributed to drying shrinkage. However, because RCC has a lower water content than comparable conventional concrete compositions, the volume change due to drying shrinkage is typically less. Therefore, for RCC pavement, less cement paste means less shrinkage and less cracking. Studies have shown that, because of strong restraint, drying shrinkage in a mixture with a constant cement content reduces as rises [44]. Numerous studies on RCC mixes have demonstrated that the 28-day drying deformation occurs at the 25–300 micro strain level [44]-[46].

Additionally, [38] showed that RAP-containing RCC mixtures exhibit more drying deformation than control mixes. So, according to their study, at the end of day 112, the length changes for the RAP 15 and RAP 20 RCC mixtures was 0.06% (600 micro strains), whereas the control RCC mixtures had a length change of 0.05% (500 micro strains). This could be because the bitumen-covered surfaces in the RAP have formed a container, which has created regions where the cement paste can shrink more readily.

4.9. Abrasion resistance

Since RCC pavements have a rough texture, it's essential to evaluate the pavement's abrasion resistance to verify that it can provide a smooth riding experience. the compressive strength and the quality of the aggregates utilized are the main factors influencing the abrasion resistance of RCC Pavement mixtures. Therefore, the abrasion resistance of RCC Pavement mixes may be significantly influenced by using alternative aggregates with varying densities, and capacity for absorbing water, shapes, and textures. However, only a few studies have been done in this field. For example, [4],[20] showed that irrespective of the RAP percentage or substitution type, the incorporation of RAP has the potential to improve the reduction in mass resulting from abrasive forces. Resistance against abrasive action is mainly dependent on the surface texture of RAP. So, when using rough-textured RAP with less asphalt content, it may damage less against abrasive forces than when using smooth-textured RAP with more asphalt content, which damages more.

4.10. Porosity

Numerous investigations conducted on conventional concrete have provided evidence indicating that incorporating RAP can potentially enhance the concrete matrix's porosity due to

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agglomerated particles in RAP and porous Interfacial transition zone [28],[32]. In contrast, irrespective of RAP percentage or replacement amount, it was determined that RAP reduced the RCC Pavement porosity by about 20–48 % [20],[47]. According to [30] the primary cause of this reduction was pore blockage and asphalt softening that occurred throughout the ASTM C642 procedure's oven-drying and boiling phases. It is possible to prevent the clogging of pores and melting of asphalt during the oven drying stage by decreasing the temperature and increasing the drying time to (48±2) °C and eight days, respectively[30].

Finally, table 3 briefly shows the results of previous studies on the effect of adding RAP in different proportions on the properties of RCC.

Table (3): Published Effects of RAP on RCCP Properties

RCC Property	Effect on Property as the Amount of RAP in Concrete Increases	References
Optimum moisture content (OMC)	Decrease, 4.5 -7 % Increase, 12% 11,18,24,25	[11],[18],[24],[25]
Maximum dry density	Decrease, 5%	[4],[26]
Compressive Strength	Decrease 9-67%	[4],[14],[16],[17],[38]
Flexural strength	Decrease 5-31%	[4],[14],[16],[17],[38]
Tensile Strength	Decrease 16-26%	[18],[25]
Toughness	Increase	[4],[14]
Modulus of elasticity	Decrease 80%	[11],[14]
Abrasion resistance	Decrease	[4],[20]
Porosity	Decrease, 20-48%	[4],[47]
Water absorption	Decrease, 20-42% Increase, 19%	[4],[14]
Freeze-thaw	Mass Lose - 0.03-1%	[35],[38]
Drying Shrinkage	Increase~ 50%	[38]

5. Conclusions:

Based on the detailed literature review conducted, the following conclusions have been drawn from this task:

1) Properties of RAP aggregates: The density and specific gravity of RAP aggregates decreased as the percentage of asphalt in it increased, owing to the presence of low-density asphalt. Because of the low absorptivity of the asphalt-coated aggregates, RAP aggregates with greater asphalt content exhibited lower water absorption and vice versa.

2) A hydrophobic asphalt coating with a low-density smooth texture envelops the RAP aggregates. This coating can potentially reduce the optimum moisture content (OMC) and maximum dry density (MDD) of RCCP mixes.

3) Using long-aged and coarser RAP performs better than less-aged and finer RAP.

4) The primary determinant of the strength properties of RAP concrete mixes is the presence of a weak and porous interface (ITZ) between the RAP and cement-mortar paste. The presence of an asphalt layer around the RAP hinders the formation of strong interfacial bonding, resulting in a porous and weak interfacial transition zone (ITZ). In RAP concrete mixes, the failure of asphalt cohesion is more prevalent than the failure of cement-asphalt adhesion.

5) Pavement application may be achieved with a lower replacement of RAP (less than 50%) without affecting porosity, water absorption, and strength.

6. Recommendations:

1) Future research ought to examine the fracture property of RAP-RCC and how RAP's form affects the properties of RCC mixtures while fresh and hardened.

2) It is strongly recommended that the asphalt covering around the RAP be removed using the right techniques if RAP is used in RCCP to increase the intermolecular interaction between the RAP and the mortar.

3) Other recycled materials are more appropriate for usage as materials in (RCC) due to their superior performance compared to materials (RAP). Therefore, It is advisable to exercise caution and restrict the substitution of natural aggregates with recycled seeds to a maximum of 50% for fine and coarse grains. However, (RCC) with materials (RAPs) can be used as substrates for road asphalt or for some similar projects, low-traffic and rural roads, and extensive coverage of sidewalks.

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استخدام ركام الاسفلت المستصلح في الخرسانة المرصوصة بالحدل : مراجعة شاملة

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الخلاصة

نظرًا لزيادة أعمال الصيانة وإعادة التأهيل، فقد تم ترك كميات كبيرة من ركام الأسفلت المستصلح (RAP) في الخزن الاحتياطي. يمكن أن يساعد استبدال الركام في خرسانة الاسمنت البورتلاندي (PCC) بركام الاسفلت المستصلح RAP للتخلص من فائض مخزونات RAP وتقليل استهلاك الركام الطبيعي في PCC، مما يؤثر بشكل إيجابي على البيئة والاقتصاد. الدراسة الحالية عبارة عن مراجعة حديثة للدراسات المنشورة حول استخدام RAP في الخرسانة المرصوصة بالحدل (RCCP). تم تقييم إمكانات ركام RAP بناءً على خصائصها ومحتوى الرطوبة الأمثل (OMC)، والكثافة الجافة القصوى (MDD)، ومقاومة الانضغاط، ومقاومة الشد ، ومقاومة الانثناء، ومعامل المرونة، ومقاومة التآكل، والانكماش، والمسامية، وامتصاص الماء والتجميد والذوبان للخرسانة المرصوصة بالحدل RCCP الحاوية على RAP . أوضحت مراجعة الأدبيات أن مجاميع RAP محاطة بطبقة أسفلت ناعمة منخفضة الكثافة كارهة للماء والتي يمكن أن تقلل محتوى الرطوبة الأمثل (OMC) والكثافة الجافة القصوى (MDD) لخلطات RCCP. يمكن لهذه الطبقة الإسفلتية أن تقلل من قدرة RAP على الارتباط بعجينة الأسمنت، مما يقلل من خصائص قوتها. بالإضافة إلى ذلك، فإن طبيعة RAP الكارهة للماء قد تقلل من المسامية وامتصاص الماء. ومع ذلك، فإن وجود الغبار والتكتلات قد يسبب تأثيرًا عكسيًا. يمكن استخدام الاستبدال الأقل لـ RAP (أقل من 50٪) لتطبيقات الرصف دون التأثير كثيرًا على المسامية وامتصاص الماء والقوة. من ناحية أخرى، بما في ذلك الاستبدال العالي لركام RAP قد لا يكون مناسبًا للأداء الميكانيكي ولكنه قد يعزز امتصاص الطاقة وصلابة الأرصفة.

الكلمات الدالة: الخرسانة المرصوصة بالحدل (RCC)، ركام الاسفلت المستصلح (RAP)، مقاومة الضغط، الانكماش، التجميد والذوبان، امتصاص الماء، مراجعة.