CREATIVE SCIENCE

Journal home page: csj.snru.ac.th

Enhancing the value of reclaimed asphaltic pavement as aggregate material in concrete work

Siam Burada[a,b*] and Barames Vardhanabhuti[a]

[a] Department of Structural Engineering and Management, Faculty of Engineering, Kasetsart University, Bangkok, 10900, Thailand

[b] Integrated Engineering Consultants Co., Ltd., Bueng Kum, Bangkok, 10230, Thailand

Article history:

Received: 19-04-2025
Revised : 05-06-2025
Accepted: 10-06-2025
Published: 10-06-2025
DOI : 10.55674/cs.v17i3.261732

Keywords:

Reclaimed asphalt pavement (RAP); Replacement ratios; Compressive strength

Abstract

This study explores the use of reclaimed asphalt pavement (RAP) as a sustainable and cost-effective substitute for coarse natural aggregates in concrete. Concrete mixtures were prepared with RAP replacement levels of 0%, 15%, 30%, 50%, and 80% by weight, aiming for a minimum compressive strength of 240 ksc in 15x15x15 cm cube specimens after 28 days of curing. Key engineering properties including compressive strength, flexural strength, and modulus of elasticity were evaluated. The results show that increasing the RAP content leads to greater deviation from optimal aggregate gradation and a gradual decrease in both compressive and flexural strengths. Nevertheless, mixtures containing up to 30% RAP met the target compressive strength (exceeding 240 ksc) and achieved flexural strengths over 24.6 ksc 11% above the design specification. At a 50% RAP replacement, compressive strength remained above 180 ksc and flexural strength still exceeded 24.6 ksc. The modulus of elasticity decreased with higher RAP content, ranging from 5,000 to 25,000 MPa (53,986 to 254,930 ksc). Economically, using 30% RAP reduced the production cost by 6.89%, while a 50% RAP substitution resulted in a 12.03% cost reduction compared to conventional concrete. These findings highlight RAP's potential as a viable alternative in concrete for applications with moderate strength requirements.

*** Corresponding author** : siamburada@gmail.com

1. Introduction

The Department of Highways, under the Ministry of Transport, oversees the maintenance of highways across the country, most of which are surfaced with asphalt concrete. Each year, these pavements undergo repairs and resurfacing through milling operations to restore and enhance road quality. This maintenance process produces a substantial quantity of reclaimed asphalt pavement (RAP) waste, which has not yet been effectively utilized or adequately repurposed for added value [1]. RAP exhibits favorable physical and chemical properties for reuse in construction, with a saturated surface dry specific gravity of 2.42 and water absorption of 0.39%, both lower than those of new quarry aggregate (2.60 and 0.74%, respectively). Its fineness modulus is 3.61, and 40–75% of its particles pass through a 10 mm sieve, indicating a coarse gradation that meets standard base course requirements. These characteristics confirm the potential of RAP for effective application as a construction material [2]. Most RAP is currently used as landfill material to level waterlogged areas or fill depressions [3]. Given that asphalt roads account for approximately 94.87% of the total road network (52,254.59 km), there is substantial potential for RAP reuse [4].

This study draws on reclaimed asphalt pavement (RAP) data provided by Highway Office 7 (Khon Kaen), which oversees the maintenance of registered highways spanning a total of 2,867.35 kilometers [4]. As shown in Fig. 1 and 2, RAP residue generated from 2020 to 2022 totaled 156,250 cubic meters, with an average annual yield of 52,083 cubic meters. This quantity accounts for approximately 5.5% of the total RAP residue generated nationwide. By extrapolating these figures, it is estimated that Thailand produced about 946,963 cubic meters of RAP residue annually during the same period.

Fig. 1 Reclaimed asphaltic pavement: (RAP)

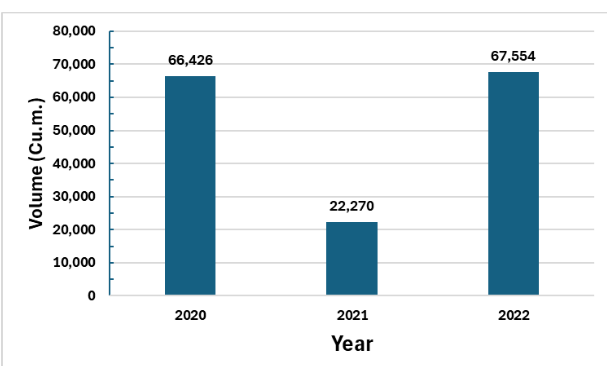

Fig. 2 RAP quantity, Highways Office No. 7 (Khon Kaen)

Srichanin & Luakphap [5]demonstrated that reclaimed asphalt concrete can effectively substitute for coarse aggregates in concrete mixtures with mix ratios of 1:1.5:3 and 1:1:1. The resulting concrete achieved compressive strengths exceeding Department of Highways standards by approximately 19–57%. One of the main drawbacks of using reclaimed asphalt pavement (RAP) as aggregate in concrete is that the residual asphalt coating on the RAP particles significantly impairs their ability to bond with the cement paste. This leads to the formation of a weaker interfacial transition zone (ITZ), resulting in reduced concrete strength and modulus. The asphalt layer acts as a physical barrier, hindering the chemical reactions and mechanical interlocking that are essential for developing a strong bond between the cement paste and the aggregate [6].

However, several studies have shown that replacing fine aggregates with reclaimed asphalt concrete results in a corresponding decrease in compressive strength as the replacement ratio increases [7, 8]. Building on these findings, the present study introduces a new approach to both reutilize and add value to reclaimed asphalt pavement (RAP) stockpiled by the Department of Highways. Specifically, this methodology involves substituting RAP for traditional aggregates in concrete production, with a focus on its application in small-scale structural elements.

According to DPT Standard 1101-64 (Standard for Concrete and Reinforced Concrete Works by the Department of Public Works and Town & Country Planning, Thailand), the minimum compressive strength of concrete specified for construction is 180 ksc. This grade of concrete is typically utilized in non-structural or lightly loaded applications such as sidewalks, drainage channels, garage floors, fence foundations, ditch linings, and curb & gutter works. In this study, the concrete mix was designed for a compressive strength of 240 ksc. Therefore, the targeted compressive strength range for this research was set between 180 and 240 ksc, representing both the minimum and design strengths. Compressive strength was determined using 15×15×15 cm cube specimens after 28 days of curing. In addition, flexural strength testing was performed on 15×15×60 cm beams, also cured for 28 days. As per DOR Standard (TH) 105.2-2545 (Flexural Strength of Concrete by the Department of Rural Roads), the flexural strength of concrete is expected to fall within 11–23% of the design compressive strength (240 ksc); therefore, the acceptable flexural strength should be in the range of 26.4–55.2 ksc.

This research is expected to offer several benefits: reducing material costs, conserving natural resources, lessening environmental impact, and promoting sustainable construction by limiting the disposal of waste materials through the incorporation of reclaimed asphalt pavement (RAP) in concrete.

2. Materials and Methods

Reclaimed asphalt pavement (RAP) obtained from the Department of Highways, Region 7 (Khon Kaen), was used to partially replace coarse aggregates at replacement levels of 0%, 15%, 30%, 50%, and 80% by weight. All concrete mixtures were prepared with a fixed water-to-cement ratio of 0.58. The materials, equipment, and experimental procedures are described in detail below.

Materials

Cement: Type 1 Portland cement by SCG, Structural Work Cement, compliant with TIS 15 Part 1-2555.

Fine aggregate: River sand from Phutthaisong sand depot, Buriram Province.

Coarse aggregate: Limestone from Chanyut Quarry, Loei Province.

RAP: Reclaimed asphalt concrete from Department of Highways Region 7 (Khon Kaen). The RAP used in this study was utilized as-received, without any washing or pre-treatment. According to the sieve analysis, the RAP sample consists mainly of medium to fine aggregates, with over half of the material passing the #4 sieve (4.75 mm) and only 0.5% passing the #100 sieve (0.15 mm).

Equipment

The following equipment was used throughout the experimental procedures:

Concrete mixer: Utilized to prepare homogeneous concrete mixtures.

Aggregate sieve shaker: Employed for gradation analysis and particle size distribution of aggregates.

Slump test apparatus: Used to determine the workability of fresh concrete in accordance with relevant standards.

Cube molds (15×15×15 cm): Used for casting specimens for compressive strength testing.

Prismatic molds (15×15×30 cm): Used for preparing specimens for modulus of elasticity tests.

Beam molds (15×15×60 cm): Used to produce beams for flexural strength testing.

Compression testing machine: Employed to measure compressive strength of concrete cubes.

Flexural testing machine: Utilized for evaluating the flexural strength of concrete beams.

Compressometer with dial gauge: Used in conjunction with the compression testing machine for measuring the modulus of elasticity.

All equipment was calibrated and operated in accordance with the relevant standards to ensure the reliability and repeatability of the test results

Methods

The experimental methodology was structured to systematically evaluate the performance of concrete mixtures containing reclaimed asphalt pavement (RAP) as a partial replacement for coarse aggregate. The primary objectives were to assess the engineering properties of the resulting concretes including workability, compressive strength, flexural strength, and modulus of elasticity as well as to analyze the cost implications associated with RAP use. The detailed experimental procedures are outlined as follows:

1. Concrete was mixed according to the proportions presented in Table 1, with each batch prepared for one cubic meter. For each mix, the coarse aggregates (limestone and RAP) were first placed into the mixer, followed by sand and then Portland cement, with all dry materials blended for about 1 minute. Approximately 80–90% of the total mixing water was gradually added, and the remaining water was introduced as needed to achieve the desired consistency. The mixing process continued for a total of 3–4 minutes to

ensure uniformity. The fresh concrete was then visually inspected for homogeneity, and its workability was evaluated using the slump test according to ASTM C143. Concrete samples were promptly collected for further testing, and the mixer was thoroughly cleaned before preparing the next batch.

Table 1 Concrete Mix Proportions for Replacing Aggregate with RAP (1 m³).

Mix	*Portland Cement (Kg)*	*Sand (Kg)*	*Lime Stone (Kg)*	*RAP (Kg)*	*Water (Kg)*
C-00	345	768.00	1,076.00	0.0	200
C-15	345	497.88	1,069.52	276.6	200
C-30	345	350.36	940.44	553.2	200
C-50	345	239.72	682.28	922.0	200
C-80	345	147.52	221.28	1,475.2	200

2. Slump Test (Fig. 3): The workability of the freshly mixed concrete was assessed using the slump test, following the procedures outlined in ASTM C143. For each batch, immediately after mixing, a representative sample of concrete was obtained and used to conduct the slump test.

Fig. 3 Slump test

3. Compressive Strength Testing (Fig. 4): Cube specimens measuring 15×15×15 cm were prepared in accordance with BS 1881. For each mix proportion, concrete was placed into the cube molds in layers and compacted to eliminate air voids. The specimens were demolded after 24 hours and then cured in a water tank at ambient temperature. Compressive strength tests were conducted at curing ages of 7, 14, and 28 days. On each testing day, the specimens were removed from the curing tank, surface dried, and immediately subjected to compressive strength testing. The results were recorded for all mix proportions.

4. Flexural Strength Testing (Fig. 5): Beam specimens measuring 15×15×60 cm were cast according to ASTM C78. For each mix proportion, three beams were prepared to evaluate flexural strength. After curing in water for 28 days, the beams were removed from the curing tank, surface dried, and tested for flexural strength using a standard third-point loading method. The results were recorded for each mix proportion.

5. Modulus of Elasticity Testing (Fig. 6): Specimens measuring 15×15×30 cm were cast for concrete mixes with 0%, 30%, and 80% RAP as aggregate replacement. Six specimens were prepared for each RAP percentage. All samples were cured by water immersion until the designated testing age to ensure adequate hydration and strength development. At 28 days, the specimens were removed from the curing tank, surface dried, and tested to determine the modulus of elasticity of the concrete.

All test results were systematically recorded and analyzed to assess the performance of concrete with different RAP replacement levels. The results were compared to design specifications and evaluated for cost implications to determine the feasibility of incorporating RAP in concrete production. This methodology provides a comprehensive assessment of both the mechanical properties and economic viability of using RAP in concrete mixtures, offering valuable insights for sustainable construction practices

Fig. 4 Compressive strength test

Fig. 5 Flexural strength test

Fig. 6 Measured modulus of elasticity of concrete

3. Results and Discussion

This study evaluated the performance of concrete mixtures in which coarse aggregates were partially replaced with Reclaimed Asphalt Pavement (RAP) at replacement levels of 0%, 15%, 30%, 50%, and 80% by weight. The concrete was designed to achieve a compressive strength greater than 240 ksc. Key engineering properties including compressive strength, flexural strength, and modulus of elasticity were investigated, alongside a cost analysis of concrete production. The results and their implications are presented and discussed below.

Results of Aggregate Gradation Testing

The aggregate gradation analysis revealed that as the replacement level of natural aggregates with RAP increased from 0% to 80%, there was a significant deviation from the desired gradation curve. This deviation became more pronounced with higher RAP content, indicating that the incorporation of RAP alters the particle size distribution of the aggregate blend. Such deviations from the target gradation can influence the workability, density, and mechanical properties of the concrete. The detailed results of the gradation analysis are illustrated in Fig. 7.

This finding underscores the importance of carefully considering the gradation of RAP when used as a partial replacement for natural aggregates, as it directly impacts the overall performance and consistency of the concrete mixture. Further optimization of the mix design may be necessary to mitigate the effects of gradation deviations, particularly at higher RAP replacement levels.

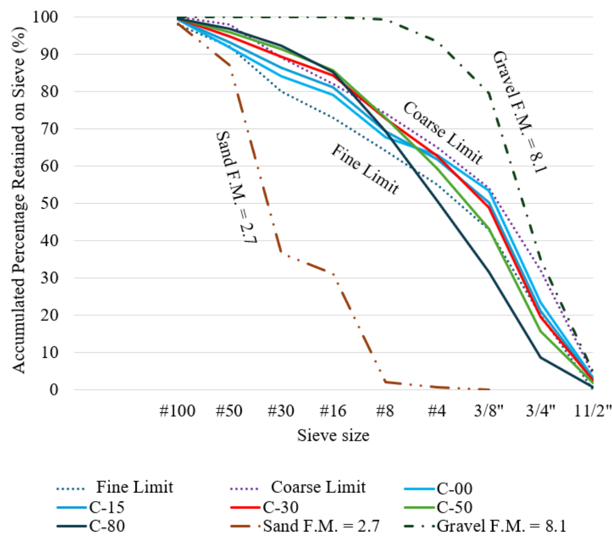

Fig. 7 Mixed sizes of aggregates

Results of Concrete Slump Test

The effect of Reclaimed Asphalt Pavement (RAP) aggregate replacement on the workability of concrete was evaluated using slump tests. The results showed that mixtures with RAP replacement rates of 0%, 15%, 30%, and 50% maintained slump values within the acceptable design range. In contrast, the mixture containing 80% RAP exhibited a slump value below the specified minimum threshold. These results are illustrated in Fig. 8.

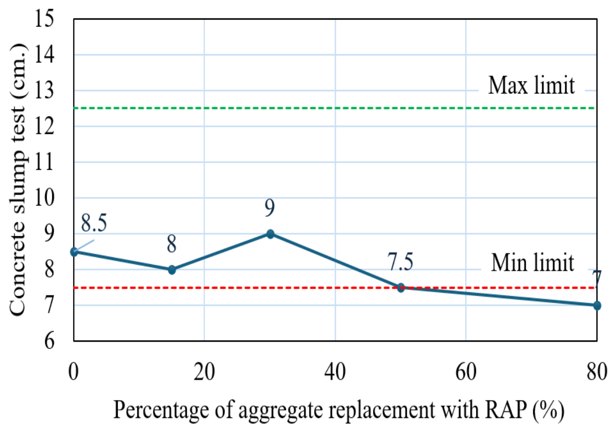

Fig. 8 Effect of RAP Aggregate Replacement Percentage on Concrete Slump Value

Results of Concrete Compressive Strength Test

The effect of replacing natural aggregate with Reclaimed Asphalt Pavement (RAP) on concrete compressive strength was evaluated. Figure 9 presents the compressive strength development at different curing ages for RAP replacement levels of 0%, 15%, 30%, 50%, and 80%. As expected, all mixtures showed an increase in compressive strength with age. However, higher RAP replacement ratios consistently resulted in lower ultimate compressive strengths, indicating a clear inverse relationship between RAP content and the compressive strength of concrete. This can be primarily attributed to several factors. Firstly, the asphalt coating on RAP particles leads to a weaker bond with the cement paste compared to natural aggregates. This weak interfacial bond inhibits effective stress transfer and lowers the overall mechanical strength of the concrete. In addition, RAP typically exhibits higher porosity and may contain microcracks generated during its previous use and milling process, which further compromise the structural integrity of the concrete. The residual asphalt can also impede the hydration of cement, thereby limiting the development of a robust microstructure. Collectively, these factors account for the observed reduction in compressive strength when RAP is incorporated into concrete mixtures [9, 10].

In terms of practical application, the design compressive strength for this study was set at 240 ksc, in accordance with the minimum standard for engineering works as specified by the Department of Public Works and Town & Country Planning, which requires a compressive strength of at least 180 ksc. At 28 days of curing, it was observed that all samples with RAP replacement levels up to 30% achieved compressive strengths exceeding the design value of 240 ksc. Furthermore, even at a 50% RAP replacement level, the compressive strength remained above the minimum acceptable limit of 180 ksc, indicating that such mixtures may still be suitable for use in non-structural elements or applications where high compressive strength is not critical. However, the results indicate that a RAP replacement level of 80% leads to compressive strengths below the specified threshold, suggesting that such high replacement ratios are not suitable for use as aggregate substitutes in concrete (Fig. 10).

As illustrated in Fig. 11, increasing the RAP content in the concrete mixtures was associated with a clear reduction in compressive strength. This trend was also accompanied by a corresponding decrease in the density of the concrete specimens. The data indicate that as the proportion of RAP increased, the concrete became less dense, which is likely due to the inherently higher porosity and lower specific gravity of RAP compared to natural aggregates. The combined effects of reduced density and the presence of more porous, weaker interfacial zones contribute to the observed loss in compressive strength. These findings suggest that the mechanical performance of concrete is significantly affected by RAP content, and careful consideration must be given to the trade-off between sustainability and structural integrity when incorporating RAP into concrete mixes.

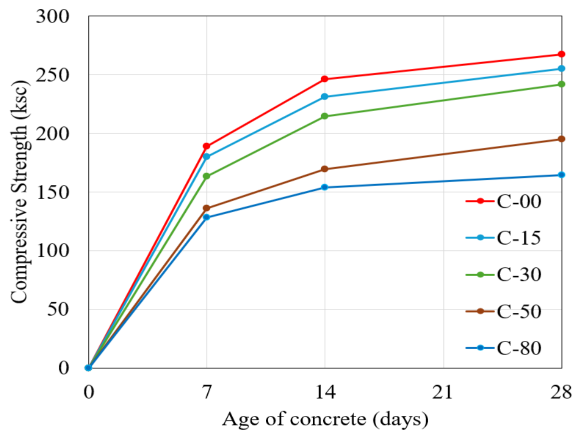

Fig. 9 Compressive strength development of concrete at different ages

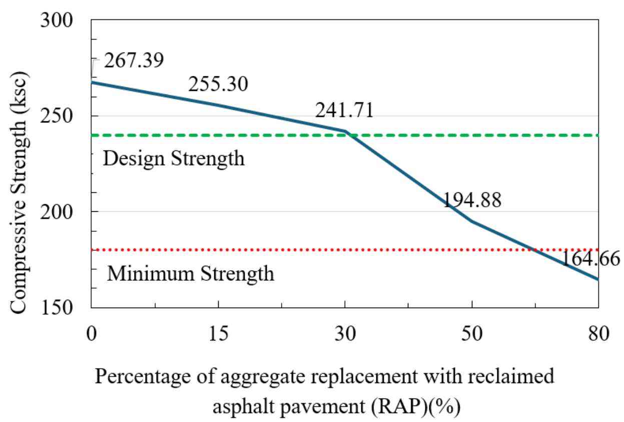

Fig. 10 Relationship between concrete compressive strength and percentage of aggregate replacement with RAP

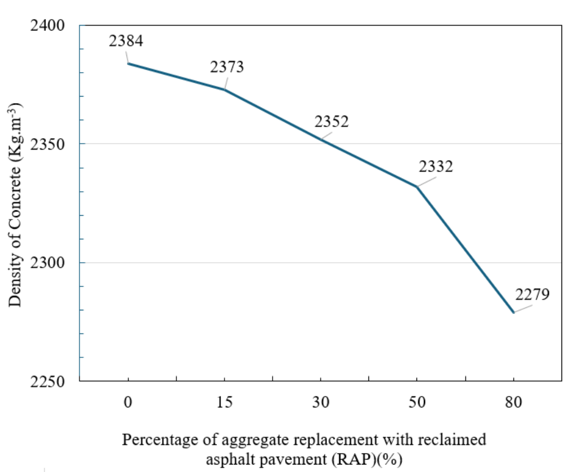

Fig. 11 Relationship between concrete density and percentage of aggregate replacement with RAP

Results on the Flexural Strength of Concrete

An investigation was carried out to evaluate the flexural performance of concrete incorporating Reclaimed Asphalt Pavement (RAP) aggregate. As shown in Fig. 12, the flexural strength of the concrete decreased with increasing RAP replacement levels (0%, 15%, 30%, 50%, and 80%). Despite this downward trend, all specimens achieved flexural strength values above the minimum specified requirement of 26.4 ksc. Notably, this minimum value accounts for more than 11% of the target compressive strength of the concrete (240 ksc).

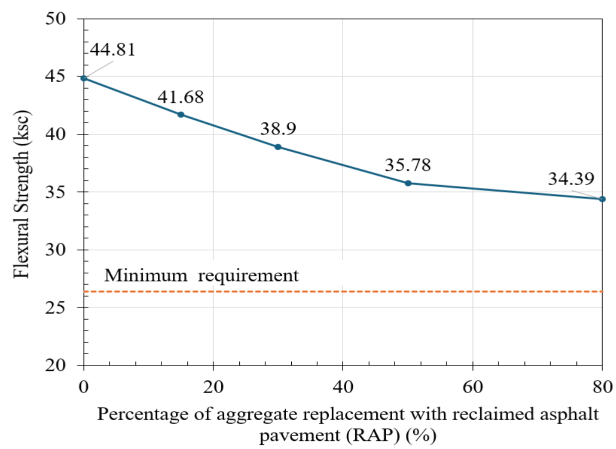

Fig. 12 Relationship between flexural strength and percentage of aggregate replaced with RAP

Results on the Modulus of Elasticity of Concrete

The effect of Reclaimed Asphalt Pavement (RAP) aggregate replacement on the modulus of elasticity of concrete was experimentally investigated. As illustrated in Fig. 13, the modulus of elasticity decreases as the RAP content increases (at replacement levels of 0%, 30%, and 80%). The measured values ranged from 5,000 to 25,000 MPa (53,986 to 254,930 ksc).

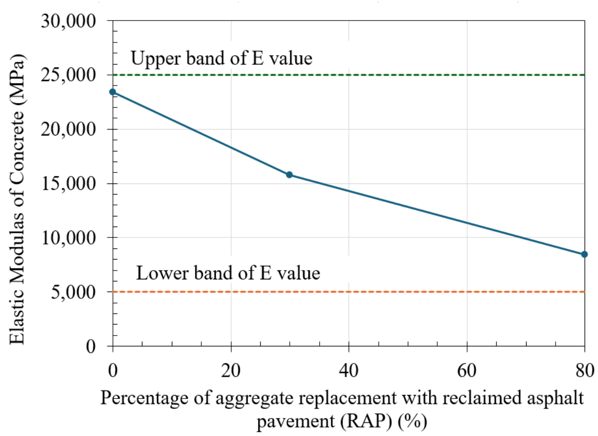

Fig. 13 Relationship between Elastic Modulus of Concrete (MPa) and percentage of aggregate replacement with RAP

Although the modulus of elasticity (E) typically correlates with compressive strength (fc′) following the empirical relationship $E = 15{,}100\sqrt{fc'}$ which yields an estimated value of 22,940 MPa (233,924 ksc) in this case the results clearly indicate a reduction in stiffness as the RAP content increase.

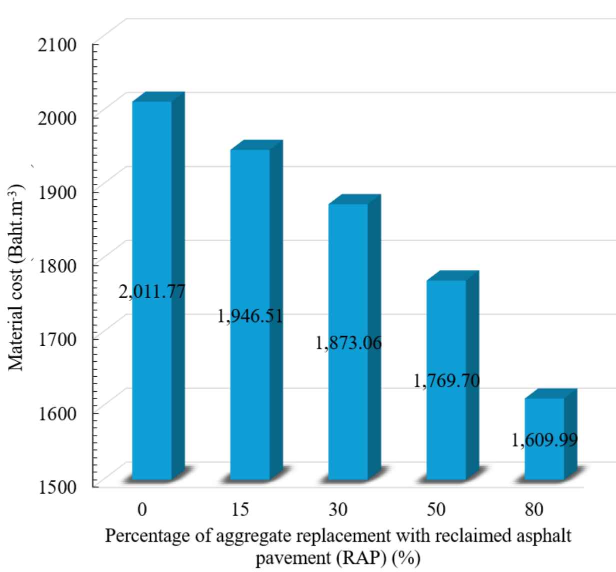

Fig. 14 Relationship between material cost and percentage of aggregate replacement with RAP

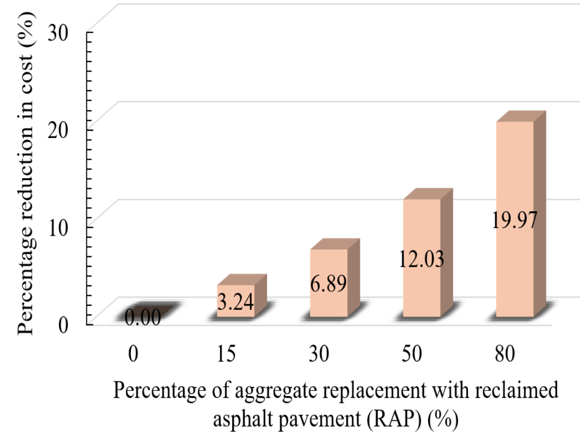

Fig. 15 Effect of RAP aggregate replacement on cost reduction

Comparison of Production Costs for Concrete

An analysis of material costs for concrete production, based on standard mix designs, was carried out. As shown in Fig. 14, increasing the percentage of Reclaimed Asphalt Pavement (RAP) aggregate in the mix (at replacement levels of 0%, 15%, 30%, 50%, and 80%) led to a corresponding decrease in material costs.

At a 30% RAP replacement the highest level at which the concrete still achieved the target compressive strength of over 240 ksc a material cost reduction of 6.89% was observed

Moreover, when the RAP replacement level was increased to 50%, the concrete continued to meet the minimum required compressive strength of 180 ksc, resulting in a 12.03% reduction in material costs (Fig. 15).

4. Conclusion

This study examined the performance of concrete mixtures incorporating reclaimed asphalt pavement (RAP) as a partial replacement for natural aggregates at rates of 0%, 15%, 30%, 50%, and 80% by weight. The investigation focused on key mechanical properties compressive strength, flexural strength, and modulus of elasticity as well as the economic impact of RAP utilization in concrete production. The main findings can be summarized as follows:

Aggregate Gradation: Incorporating RAP as a partial replacement for natural aggregates significantly alters the aggregate gradation. As the RAP content increases, the gradation increasingly diverges from the optimum range, which may affect both the workability and structural performance of the concrete.

Mechanical Properties: Both compressive and flexural strengths decrease as the RAP replacement level increases. This reduction in strength is primarily due to the distinct physical properties of RAP compared to natural aggregates.

Performance at Specific Replacement Ratios:

- Concrete with up to 30% RAP replacement achieved a compressive strength greater than 240 ksc. Notably, even at 50% RAP replacement, compressive strength remained above 180 ksc, indicating suitability for non-structural or light structural applications.
- At all RAP replacement levels, the flexural strength exceeded 11% of the compressive strength, meeting the relevant design specifications.

Modulus of Elasticity: The modulus of elasticity decreases as the RAP content increases, ranging from 5,000 to 25,000 MPa (53,986 to 254,930 ksc). This downward trend indicates a reduction in concrete stiffness as higher proportions of RAP are used.

Cost-Effectiveness:

- Concrete containing 30% RAP achieved a compressive strength greater than 240 ksc and a flexural strength exceeding 26.4 ksc, resulting in a 6.89% reduction in production costs compared to conventional concrete.
- At a 50% RAP replacement, the concrete maintained a compressive strength above 180 ksc and a flexural strength greater than 26.4 ksc, leading to a 12.03% cost reduction. This grade of concrete is suitable for non-structural or lightly loaded applications such as sidewalks, drainage channels, garage floors, fence foundations, ditch linings, and curb and gutter works.

These findings underscore the potential of RAP as a sustainable and cost-effective alternative to natural aggregates in concrete production, especially for applications with moderate strength requirements. Nonetheless, careful attention to aggregate gradation and mechanical properties is crucial to ensure optimal performance when incorporating RAP into concrete mixtures.

5. References

[1] Rout, M. K. D., Sahdeo, S. K., Biswas, S., Roy, K., & Sinha, A. K. (2023). Feasibility study of reclaimed asphalt pavements (RAP) as recycled aggregates used in rigid pavement construction. *Materials*, *16*(4), 1504.

[2] Chaikaew, C., Chaikaew, P., & Na Songkhla, W. (2022). The use of waste materials from RAP and FGD gypsum to compensatory the pavement material. *The Journal of Industrial Technology*, *18*(1), 75-84.

[3] Tsakoumaki, M., & Plati, C. (2024). A critical overview of using reclaimed asphalt pavement (RAP) in road pavement construction. *Infrastructures*, *9*(8), 128.

[4] Bureau of Highway Maintenance, Department of Highways. (2021, April 10). Road maintenance work. http://bmm.doh.go.th/website/

[5] Srichanin, T., & Luakphap, P. (2021, April 29–30). The use of asphalt concrete debris in concrete work to produce car-proof concrete barriers. *The 5th National Academic Conference of Suvarnabhumi Rajamangala University of Technology*, Rajamangala University of Technology Suvarnabhumi, Huntra Campus, 262–267.

[6] Brand, A. S., & Roesler, J. R. (2016). Bonding in cementitious materials with asphalt-coated particles: Part II – Cement-asphalt chemical interactions. *Construction and Building Materials*, *130*, 182-192. https://doi.org/10.1016/j.conbuildmat.2016.10.013

[7] Russo, N., Filippi, A., Carsana, M., Lollini, F., & Redaelli, E. (2024). Recycling of RAP (reclaimed asphalt pavement) as aggregate for structural concrete: Experimental study on physical and mechanical properties. *Discover Civil Engineering*, *1*, 99. https://doi.org/10.1007/s44290-024-00101-y.

[8] Karthikeyan, K., Kothandaraman, S., & Sarang, G. (2023). Perspectives on the utilization of reclaimed asphalt pavement in concrete pavement construction: A critical review. *Case Studies in Construction Materials*, *19*, e02242.

[9] Safiuddin, M., Alengaram, U. J., Rahman, M. M., Salam, M. A., & Jumaat, M. Z. (2013). Use of recycled concrete aggregate in concrete: a review. *Journal of Civil Engineering and Management*, *19*(6), 796-810. https://doi.org/10.3846/13923730.2013.799093

[10] Nedeljković, M., Visser, J., Šavija, B., Valcke, S., & Schlangen, E. (2021). Use of fine recycled concrete aggregates in concrete: A critical review. *Journal of Building Engineering*, *38*, 102196. https://doi.org/10.1016/j.jobe.2021.102196