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A Review of Mechanical Properties on the Potential Use of Reclaimed Asphalt Pavement (RAP) as Aggregate Substitute in Concrete Mixtures

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Abstract: The use of industrial and infrastructural waste has gained considerable significance in civil engineering applications. The result of removing old material from the asphalt pavement is the Reclaimed Asphalt Pavement (RAP). RAP consists of a well-graded, asphalt-cement-coated aggregate of high quality. RAP in concrete mixing formulation is a system that is part of a strategy for sustainable production as it eliminates the use of new aggregates and reuses a resource considered waste. This paper determines the mechanical properties on the potential of using RAP waste as a substitute to aggregate, neither to fine or coarse aggregate. The use of RAP in concrete as an aggregate substitute is increasingly driven by potential challenges relating to the loss of good aggregate supplies and the maintenance of stocks of surplus RAP. In contrast to the control concrete mixture, the RAP concrete mixtures exhibited improved ductility and high strain power. Earlier experiments showed the viability of making concrete with RAP aggregate; previous studies, however, focused on the material's mechanical properties. All published results assert that the strength of concrete decreases with an increase in the incorporated percentage of RAP.

Keywords: Reclaimed Asphalt Pavement, Concrete, Strength

1. Introduction

Concrete is one in all the oldest and most familiar construction materials within the world. The worldwide production of concrete is ten times that of steel by tonnages. Concrete mixtures consume large amounts of natural aggregates. The Assyrians and Babylonians exploitation mud as a cement in their concrete, whereas the traditional Egyptians use sedimentary rock and mineral cement. Concrete characteristics were adjusted since Roman and Egyptian times once found to add volcanic ash to the combination in hardening underneath the water.

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Reclaimed Asphalt Pavement (RAP) is the residue produced for maintenance and restoration purposes during the milling of deteriorated pavements. In lightweight surface construction, RAP recycling requires a large amount of energy to soften the aged asphalt. The method of recycling RAP attempts to prevent the need to remove additional natural aggregates. There is some concern that the days of infinite supply for concrete surfaces of high-quality virgin aggregates have ended. The overall cost also accounts for 20-30 percent of the concrete pavement's material cost. The rise of aggregate expenses is primarily due to higher energy usage during aggregate output and shipping.

1.1 Research Background

The rapid development of the construction industry has led to a higher demand for construction material, especially concrete. Reclaimed Asphalt Pavement (RAP) is recycled material from the existing road that makes a difference in cost to the users. About 80.00 % of the RAP, which is reclaimed during road resurfacing and widening projects are recycled and used in pavement applications. RAP materials that were generated are used at the same site as a landfill, embankment fill materials and as a sub-base that is economical and saves time. Since the mixture includes recycled products, the use of RAP satisfies environmental growth.

1.2 Problem Statement

Asphalt pavements constitute more than 90.00 % of aggregates. Agents and contractors worry that the use of RAP will cost more money because of reduced material strengths. The use process is not solely reducing the material to be removed; however, it can also avoid wasting valuable material that's to be reused. The most straightforward step is to cut back the construction price for a brand-new building that features a supply of materials.

1.3 Objective

The study is done to achieves several objectives. All objectives must be considered to ensure that the findings are precise with what the study case is trying to search out. The study aims:

- To investigate the mechanical properties of RAP as replacement materials in concrete mixture.
- To determine the mechanical properties on the potential of reclaimed asphalted pavement (RAP) in normal concrete mixtures as the aggregate substitute.

1.4 Scope of Study

The research was performed based on the scope limit to ensure that the study's purpose could be accomplished. The goal is to understand better the viability of using Reclaimed Asphalt Pavement (RAP) in the concrete mix as an aggregate substitute. This is intended to reduce the use of natural aggregates derived from environmental sources.

2. Literature Review

2.1 Theory of Study

Property concrete is related to reducing polluting and carbonic acid gas gases emitted throughout the concrete production. Concrete is one among the foremost wide used artificial construction material. Main actions that meet the wants for property construction development area reusable materials, and a lower environmental impact which will be gained through reduced carbonic Acid gas emission and reduced natural resources extraction from quarries. For performing arts, property development, one in each of the solutions suggests mistreatment the waste product.

2.2 Materials

This chapter describes the various combination materials that are being tested as part of this analysis. Numerous other materials have been proposed as substitutes for conventional ingredients of concrete. The research used either a fine aggregate replacement or a coarse aggregate replacement. Features available on concrete as heat resistant and do not burn, do not rust or rot concrete and harden, and freeze water's presence. The strength of concrete depends on the mix. Concrete is a building material that is important to building today.

(a) **(b)** **(c)**

Figure 1: Main materials contained in the concrete;
(a)coarse aggregates, (b)fine aggregates, (c)Portland cement

2.2.1 Cement

Cement or Ordinary Portland Cement (OPC) is known as the base material for concrete manufacture. The use of cement in a concrete mix is important because it binds between the concrete materials. A concrete mixture produces a reliable, robust, and durable content, cement is a suitable material. There are many types of cement produced by cement production. OPC is used in the production of concrete in the UK. OCC is a cement form that has different shapes and hardens rapidly and slowly

Table 1: Characteristic of Ordinary Portland Cement

Parameter	Value
Compressive strength	20 – 40 MPa
Flexural strength	3 – 5 MPa
Strength cleavage	2 – 5 MPa
Elastic modulus	14000 – 41000 MPa
Permeation rate	1x1010 cm/sec
Constant thermal expansion	10^{-5}/ºC
Drying shrinkage	4 – 8x10
Drying shrinkage concrete reinforcement	2 – 3x10
Poisson's ratio	0.20 - 0.21
Stress strain	6000 – 17000 MPa
Density	2240 – 2400 kg/m

2.2.2 Natural Aggregate

Aggregates are the most widely used where it is three-quarters of the volume of concrete. Aggregates of a size not more than 5 mm are fine aggregate. Coarse aggregate consists of rock fragments that vary in size from 5 mm to 50 mm. Smaller aggregates known as sand is produced by crushing and mineral the form of particle.

Table 2: The maximum size of coarse aggregate in the mix

Concrete Grade	Mixing Ratio	Maximum Size of Aggregate(mm)	
30	1 : 1 : 2	20	30

25	1 : 1.5 : 3	17	25
20	1 : 2 : 4	14	21

2.2.3 Reclaimed Asphalt Pavement (RAP)

RAP defines as reclaimed and recycled pavement selectively bind asphalt and aggregates. RAP can be successfully reused for new construction. Old asphalt pavement material is recycled from highways and parking lots for repair and renovation programs every day. More than 100 million tons of reusable asphalt pavements have been obtained for reuse in the US during 2018, saving landfill space of some 61.4 million cubic yards. Almost 100.00 % of RAP is used for beneficial purposes, primarily new pavements. The Eco-Costs/Value Ratio Model proves the benefits of using concrete with recycled aggregates [14].

Figure 2: Asphalt milling machine

2.3 Mix Design

Concrete mix design will be designed according to "Design of Normal Concrete Mixes" recommended by FIP. Grade 30 concrete pad ages of 7 and 28 days to be created using this method. Flowability is among the latest characteristics of concrete that is of significant concern. Depending on the type of substance desired (lightly or firmly stabilized), the standard cement content is variable. Some strategies recommend high cement concentrations as the minimum substance because of the variability of the current materials. The stabilizer (ICS) test's initial consumption, which is typical in many countries, is crucial for maintaining a minimum quantity of binders for cement stabilized materials. However, it is not presented by any of the methods listed.

A limit of 40.00 % RAP is permitted in the surface mix under the new Public Building Commission quality assurance/quality assurance requirements in Taiwan. The Asphalt Institute developed the compounds based on the RAP mixture design technique. Three RAP origins and one RAP percentage, i.e. 40.00 %, were mixed. A modern AC-10 binder was combined with virgin aggregate in the black rock and RAP aggregate removed without an aged binder. The w/cm ratio was selected to be 0.40, with a cement content of 309 kg/m^3. Aggregate weights are dependent on the state of the saturated dry surface (SSD). The cement materials were 20.00 % fly ash (by weight), and a sufficient amount of air-training agent was applied to achieve an air content in the simple mixture of 5.00 %. The mix design for all the studied mixtures is shown in Table 3 [16].

Table 3: Mix design (saturated surface dry conditions) [16]

Materials	REF	20HOU	0.40_520_ 40HOU	20BRY	40BRY
Cement (kg/m^3)	247	247	247	247	247
Fly Ash (kg/m^3)	62	62	62	62	62

Virgin Course Aggregate (kg/m^3)	1058	825	604	830	611
RAP (kg/m^3)	0	206	403	208	408
FA (kg/m^3)	769	787	804	776	783
Water Reducer (kg/m^3)	402	402	402	402	402
Air Entrainer agent (ml/m^3)	60	60	60	60	60
Water (kg/m^3)	123	123	123	123	123
Total asphalt volumetric fraction (TAVF) (%)	0	1.080	2.127	1.653	3.285

Note: Total asphalt volumetric fraction is defined as the asphalt volume fraction in the total aggregate mixture (i.e. RAP and virgin aggregates).

2.4 Ideal RAP Gradation

Due to RAP aggregates' uncertain packing properties in concrete mixtures, fine and coarse RAPs were sculpted in various ratios to attain a minimal variety of porosity and achieve maximum efficiency. Dense-graded PCC can be generated by replacing a certain proportion of virgin coarse aggregate with coarse RAP with a sufficient number of intermediate particles, resulting in improved workability efficiency and fewer mechanical properties. The origins of BRY and SA RAP will have fractions of medium size in the combination, making it possible to obtain concrete with thick mixed aggregate gradation.

Table 4: Aggregate gradation [5]

Sieve size (mm)	37.5	25	12.5	9.5	4.75	2.5	0.63	0.3	0.075
Percentage passing (%)	100	100	94	71	57	45	24	18	5.5

Note: Binder content: 5.1%, VMA: 16.5%

From Al-Oraimi et al. [2], the average aggregate coarse fraction was substituted by 0.00 % by coarse RAP, 25.00 %, 50.00 %, 75.00 % and 100.00 %. Overall, the slump and weight of the unit decrease as the percentage of RAP rises. Compressive and bending strengths and elasticity modules have all seen a decrease with rising RAP percentage. For 28-day flexural intensity, slump or air quality, the RAP content appeared to be a statistically important independent variable.

The unit weight, ultrasonic pulse speed, compressive and bending strength and module Elasticity decrease with the increasing percentages of RAP. Later cracking time and smaller maximum crack widths were obtained by measuring restricted ring with RAP mortar. Free shrinkage and abrasion grew as the RAP material improved. RAP was substituted for part of the excellent portion of CTBref gradation while retaining the coarse aggregate structure that provides interlocking. Due to the compaction effort, large agglomerates of Rap appear to crumble into smaller parts, thereby increasing the percentage of fine particles.

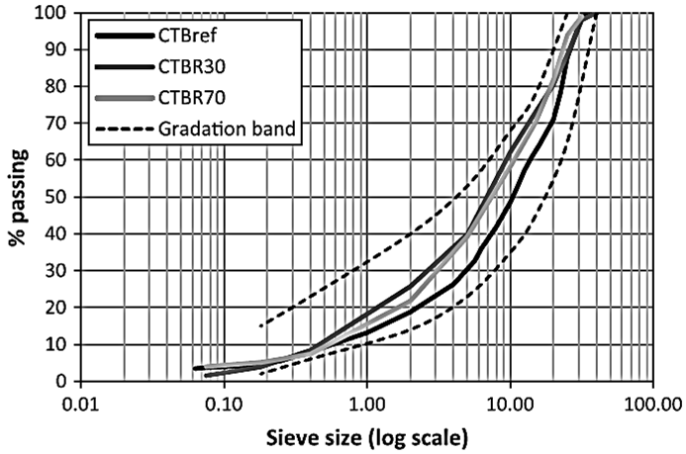

Figure 4: Size distribution of designed CTB mixtures [11]

Table 5: Summary of Mix Design and RAP Properties [4]

Materials	References	W/C Ratio	Cementitious	Cementitious Content	RAP Properties
Concrete	[21]	5.5% water by mass	Cement	17.5:1, aggregate:cement	1.5% asphalt applied to aggregate, then mixed into concrete
Concrete	Delwar et al (1997)	0.4, 0.5	Cement	n/a	Course (SG: 2.45, UW: 92pcf, Absorption: 2.35%), Fine (SG: 2.22, Absorption: 2.97%); asphalt content approximately 5.2% - 5.6%
Concrete	[9]	0.5	Cement, fly ash(30%)	325 kg/m^3	Course (SG:2.56), Fine (SG:2.41)
Concrete	[2]	0.45, 0.5	Cement	425 kg/m^3 (w/c-0.45), 380 kg/m^3 (w/c-0.5)	Course (SG:2.40, Absorption: 1.8%), Fine (SG:2.45, Absorption: 1.6%)
Mortar	[22]	0.5	Cement	580 kg/m^3	Absorption: 0.7 – 0.8%
Concrete	[10]	0.43, 0.48, 0.53	Cement	628 lb/yd^3 (w/c-0.43), 562 lb/yd^3 (w/c-0.48), 508 lb/yd^3 (w/c-0.53)	RAP 1: Same as Hossiney et al. (2008); RAP 2: Course (SG:2.309, Absorption: 2.20%), Fine (SG:2.325, Absorption: 1.77%)
Concrete	Bermel (2011)	0.35 – 0.45	Cement, fly ash(15%)	Paste volume: 27% - 40%	Asphalt content: 6.7% (Course (SG:2.50), Fine (SG:2.18))

3. Methodology

RAP use not only aids in reducing the landfill issue, but it's also economically helpful, financially efficient. Waste disposal has been an essential job in the present day. A new and creative method of handling excessive RAP needs to be discovered.

Start

Selection on Research Title

Objective, Background of Study,
Scope of Study

Literature Review

Review on Previous Research Findings

Study and collecting Data / Results

Data Analysis & Discussion

Conclusion & Recommendation

Finish

Figure 4: Flowchart order of methodology

3.1 Method of Testing

Previous research findings have shown that specific basic mechanical properties of concrete all decrease with the addition of RAP. The study presumed that the thin film of asphalt covering each portion prevents the particles from breakup and promotes increased energy dissipation in a breakage event. The researchers observed that concrete containing RAP could be blended and cast by traditional means with no content changes. The authors concluded that fine RAP had more harmful effects than the finished product's coarse recycled content. To view the full article, please go to the page you came from.

Cement density and optimum moisture content are determined using a compaction test for the cement content. It is also essential to carry out strength testing using three different cement contents. The split tensile strength of concrete was calculated by preparing 100 mm X 200 mm cylindrical specimens. At 3, 7, and 28 days of wet curing, hardened concrete properties were measured. JSM-6060LV SEM was used to conduct electron microscopy [4]. At a magnification of 500X, all photographs were taken, resulting in an 8-bit greyscale image.

Cylindrical specimens 16cm in diameter by 32 cm in length were examined for compressive and indirect tensile forces [13]. Tests of 3-point bending and free-shrinkage were carried out. The flexural and breaking tensile strength was assessed at 3, 7, 28, and 90 days of wet curing. The use of gap-graded/coarser fine RAP resulted in dramatic reductions in concrete mechanical properties [17].

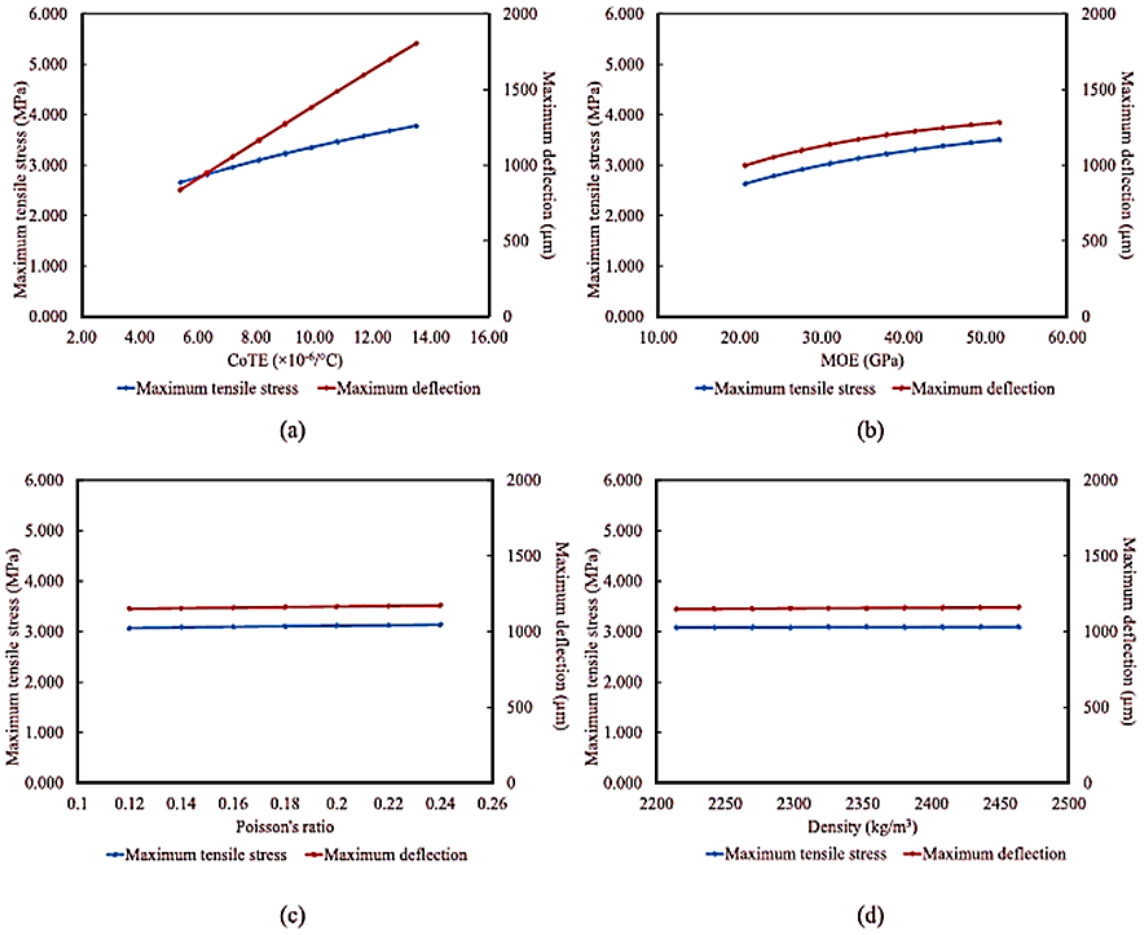

Figure 5: Sensitivity analysis results for jointed bare concrete pavement bottom-up cracking: (a) Effect of CoTE (b) Effect of MOE (c) Effect of Poisson's ratio (d) Effect of density [16]

4. Discussion

This chapter will discuss previous researchers' results, including analyzing data obtained from the study. Concrete mix design will be designed according to "Design of Normal Concrete Mixes" recommended by FIP. Fine RAP aggregates partly replaced fine Natural Aggregate (NA) after venturing out the best aggregate skeleton. Some researchers claim that RAP does not affect shrinkage behaviour, while others contend that RAP decreases PCC shrinkage. One potential alternative for RAP as an aggregate replacement for portland cement concrete is reducing the volumes of extra reclaimed asphalt pavement (RAP) stocks.

The leading causes responsible for the drop in overall intensity are asphalt film and agglomerated particles in RAP. Up to 50.00 % coarse and fine RAP (individually) can be used as minimum intensity benchmarks can be met. With different cement mixtures, the mechanical efficiency could not be improved due to the lack of asphalt cohesion associated with these hybrid mixtures. Further studies are required for the effective characterization of RAP properties considering the variations in the RAP sampling, asphalt properties, parental composition of RAP, natural aggregates considered, and the method of RAP exclamation. Therefore, Table 6 below shows the summary of the physical properties with the trend to respect the control [7].

Table 6: Physical properties of RAP as compared to natural aggregates [7]

Aggregate properties	Trend with respect to the control	References
Specific Gravity (Coarse)	Lower	[4], [7], [16], [18], [19]
Specific Gravity (Fine)	Lower	[1], [2], [7], [19]
Water Absorption (Coarse)	Higher	[4], [7], [19]
	Lower	[7], [10], [19]
Water Absorption (Fine)	Higher	[1], [10] [19]
	Lower	[4], [7]
Unit Weight	Lower	[4], [16]
Grading (Coarse)	Finer	[4], [7], [10], [19]
Grading (Fine)	Coarser and Gap-Graded	[4], [7], [19]
Fineness Modulus (fine)	Higher	[4], [10], [19]
Abrasion Value	Higher	[19]
Crushing Value	Lower	[19]
	Not Possible	[24]
Impact Value	Lower	[19]
Flat & Elongated	Higher	[19]

5. Conclusion

Asphalt film and agglomerated particles in RAP have been established as the main factors responsible for lowering overall strength characteristics. The use of these aggregates in concrete cement pavements seems to be an innovative solution. Among the advantages of using it as a substitute for aggregates can be summarized as follows:

- RAP is a waste material. Indirectly when using this material in the concrete, it can reduce material costs.
- Can reduce the problem of aggregates sources.

For concrete applications such as sidewalks, driveways, curbs, and gutters, concrete mixes including RAP may qualify. It has more detrimental consequences to replace only the delicate component of aggregates with its corresponding RAP than to substitute both fine and coarse.

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