Comparative Study on Physical Characterization of Reclaimed Asphalt Pavement and Natural Aggregate in Flexible Pavement

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Abstract. Reclaimed Asphalt Pavement (RAP) has gained significant attention in recent years as a sustainable alternative to natural aggregate in road construction. This study presents a comparison of the physical attributes of RAP and natural aggregate, with a focus on their potential use as base and subbase materials in flexible pavements. The physical attributes of RAP and natural aggregate were evaluated using standard laboratory tests, including particle size distribution, specific gravity, water absorption, impact value test, Los Angles Abrasion test, flakiness and elongation test. The research concluded that RAP is comparable to natural aggregate in terms of particle size distribution and bulk density but has lower water absorption, impact, and abrasion values. The results shows that RAP is almost 53% more tougher that natural aggregate when tested for Aggregated Impact test and 30% more harder than natural aggregate when compared by Los Angeles abrasion test. Also, heatmap was used to analyse the relationship between physical attributes of natural aggregate and reclaimed asphalt pavement which depicted 93% similarity The findings suggest that RAP has the potential to replace natural aggregate in flexible pavements, further study is required to determine its long-term performance and durability.

Keywords: Reclaimed Asphalt Pavement, Natural Aggregate, Physical property tests, Sustainability, Flexible Pavement

1. Introduction

Asphalt pavements are one of the most common types of roadways used worldwide, with a large portion of them being flexible pavements[1]. These pavements are designed to be flexible and bend under traffic loads, which helps to distribute the stresses on the road surface and reduce the potential for cracking and deformation. The performance of flexible pavements is significantly influenced by quality and attributes of the materials used in their construction, including the base and subbase layers[2]. Traditionally, natural aggregates such as crushed stone and gravel have been used as base and subbase materials in flexible pavements[3]. However, the limited availability of high-quality natural aggregates and the environmental concerns associated with quarrying and transportation of these materials have led to the exploration of alternative materials such as RAP[4].

RAP is a recycled material that is obtained from milling and crushing old asphalt pavements, which is then processed and reused as aggregate in new pavement construction. The use of RAP reduces the need for virgin aggregates, which results in cost savings and reduces the environmental impact associated with quarrying and transportation of natural aggregates[5]. Moreover, the use of RAP can also reduce the amount of waste sent to landfills, which helps to promote sustainable development. Despite the potential benefits of RAP, there are still concerns about its performance and suitability as a construction material. One of the main concerns is the variation in the physical properties of RAP, which can affect its performance in pavement structures[6]. In order to assess RAP's viability for use in pavement construction, it is necessary to study its physical qualities and compare them to those of natural aggregates. [7].

This study aims to investigate the physical attributes of RAP and natural aggregates and compare their performance as base and subbase materials in flexible pavements[8]. The physical properties of RAP and natural aggregates will be evaluated using standard laboratory tests, including particle size distribution, bulk density, water absorption, and California Bearing Ratio (CBR). The results of this study will provide valuable insights into the potential use of RAP as an alternative to natural aggregates in flexible pavement construction[9]. The findings suggest that RAP could be a viable alternative to natural aggregate in flexible pavements, but further research is needed to evaluate its long-term performance and durability.

2. Processing of Reclaimed Asphalt Pavement

RAP is the reclaimed asphalt pavement material which is obtained during the process of pavement's resurfacing, rehabilitation or reconstruction operation. RAP is essentially old pavement that is reclaimed for use[10]. The production of RAP results in an aggregate that can be well graded and of nominal quality. RAP is becoming more common as a result of recent technological advances. In the past, excavators were used to scarify pavement, resulting in massive slabs of RAP materials. This made it difficult to include RAP components in new pavement construction. Because of recent technological advancements, milling machines are now commercially accessible; these machines grind the pavement to the necessary thickness, simplifying the process of recycling asphalt pavement.

Fig. 1. Milling Machine for RAP extraction from Old Pavement

Milling machines removes the existing asphalt pavement to a predetermined depth, creating a textured surface that can be used as a base for new pavement layers. The milling operation begins with the deployment of milling machines that are equipped with a rotating drum with cutting teeth. The drum is lowered onto the surface of the pavement, and the teeth cut into the asphalt material, removing it in small pieces[10,11]. The removed material is then transported by a conveyor belt system into a truck or other transport vehicle. The milling machines are equipped with sensors and control systems that allow the operator to adjust the depth of cut, the speed of the drum rotation, and other factors that can affect the quality of the milled material[12]. After the milling operation is complete, the resulting RAP material can be processed and recycled for use in new pavement construction, thereby reducing the need for virgin materials and saving on costs[13–15]. The use of RAP material also contributes to the sustainability of the asphalt pavement industry by reducing the amount of waste material sent to landfills and conserving natural resources.

2.1 Step-by-step instructions for processing Reclaimed Asphalt Pavement:

The processing of RAP involves several steps, including scarifying, crushing, screening, blending, heating, mixing, storage, application, compaction, and finishing which are discussed below in detail:

1. **Scarifying:** First, the old asphalt pavement is scarified by a milling machine to remove the top layer of pavement to the necessary depth.
2. **Crushing:** The RAP material obtained from the milling machine is then crushed into smaller pieces using a crushing machine. The size of the RAP material is usually determined based on the specifications of the application.
3. **Screening:** The crushed RAP material is then screened to remove any oversized particles or debris, which may affect the quality of the final product.
4. **Blending:** The screened RAP material is then blended with virgin aggregates, asphalt cement, and other additives, as needed, to meet the specifications of the application.
5. **Heating:** The blended RAP material is then heated to a desired temperature, which allows for better mixing and compaction.
6. **Mixing:** The heated RAP material is then mixed with asphalt cement and other additives in a mixing plant to produce a homogeneous mixture.
7. **Storage:** The final RAP mixture is stored in silos or other storage facilities until it is transported to the job site for application.
8. **Application:** The RAP mixture is then transported to the job site and applied to the pavement surface using a paving machine. The RAP mixture is typically used as a base or subbase layer in flexible pavements.
9. **Compaction:** The RAP mixture is compacted using a compactor to ensure proper density and strength.
10. **Finishing:** The final step in the RAP processing is to apply a surface treatment, such as a seal coat or a thin overlay, to protect the pavement surface and improve its appearance.

2.2 Advantages and disadvantages of using Reclaimed Asphalt Pavement (RAP):

Overall, the use of RAP in pavement construction offers numerous advantages, such as cost savings, reduced environmental impact, and improved sustainability[16,17]. However, there are also some potential disadvantages, such as variation in properties, quality concerns, compatibility issues, processing requirements, and regulatory restrictions, which must be carefully considered when deciding whether to use RAP in a specific pavement construction project[18,19]. The advantages and disadvantages of using RAP is discussed below in detail:

2.2.1 Advantages of using RAP

1. **Cost savings:** The use of RAP can result in significant cost savings compared to using virgin materials for pavement construction.
2. **Reduced environmental impact:** The use of RAP reduces the need for virgin materials, which reduces the environmental impact associated with quarrying and transporting these materials.
3. **Sustainability:** The use of RAP promotes sustainable development by reducing waste sent to landfills and conserving natural resources.
4. **Improved performance:** When properly processed and mixed with virgin materials, RAP can perform as well as or better than virgin materials in pavement construction.
5. **Easy availability:** RAP is readily available from existing pavement sources, which can be milled and processed on-site or at a nearby facility.

2.2.2 Disadvantages of using RAP

1. **Variation in properties:** The properties of RAP may vary greatly based upon the age, condition, and source of the original pavement material. This variation can affect the performance of the RAP in pavement structures.
2. **Quality concerns:** There may be concerns about the quality of RAP, such as the presence of contaminants or degradation of the asphalt binder.
3. **Compatibility issues:** The use of RAP may not be compatible with certain types of asphalt binder or pavement structures, which can affect the performance of the pavement.
4. **Processing requirements:** The processing of RAP requires specialized equipment and expertise, which can add to the overall cost of pavement construction.
5. **Regulatory restrictions:** There may be regulatory restrictions on the use of RAP in pavement construction, such as limitations on the amount of RAP that can be incorporated or the types of pavement structures where RAP can be used.

3. Literature Review of Papers Incorporating Rap in Flexible Pavements

F. Xiao and S.N. Amirkhanian (2009) [20]evaluated the moisture resistance of RAC (rubberized asphalt concrete) combinations with RAP (reclaimed asphalt pavement). The authors performed Indirect tensile strength (ITS) testing, toughness testing, and viscosity testing on the binder. The addition of RAP was shown to increase ITS values and decrease moisture susceptibility, whereas the addition of crumb rubber was found to have a little detrimental impact. E.Y. Hajj et al. (2010)[5] reviewed Airfield pavements that included RAP into their Hot Mix Asphalt, along with their documented applications and outcomes.

Researchers looked at the effects of RAP on the lifespan of HMA airfield pavements under real-world traffic conditions. Using LEDFAA1.3, researchers compared the performance of HMA pavements made with and without RAP materials during their anticipated service lifetimes.
F. Moghadas Nejad et al. (2014) [9] performed experimental research to investigate the causes behind permanent deformation in warm mix asphalt (WMA) mixtures incorporated with reclaimed asphalt pavement (RAP). The rutting capabilities of asphalt mixes were shown to be enhanced when up to 60% of the virgin material was replaced with RAP. However, excessive RAP may make flexible pavements more vulnerable to moisture degradation, which is why an indirect tensile strength test was performed. The research found that mixes including up to 50% RAP met the required minimum tensile strength ratio (TSR) of 70%, whereas those containing 60% RAP had a TSR lower than 70%. It was determined that 50% RAP replacement was the optimum replacement amount. P. Kriz et al. (2014) [7] investigated the characteristics of virgin binder, recycled asphalt pavement (RAP), and their relative mixtures. It was found that it was not always appropriate to follow the current AASHTO standard recommendation to use one-grade softer performance graded asphalt at >15% RAP addition. At normal temperatures and timeframes for producing and placing asphalt mixes, a dynamic shear rheometer (DSR) was performed to examine how well RAP and virgin binders mix through diffusion. A simulation showed that complete binder blending was accomplished within minutes of mixing in both hot-mix and warm-mix asphalt applications. Finally, the authors advised that, in order to accurately estimate the degree of blending, further information regarding the binder film thickness in asphalt mix is necessary. Using both laboratory and field tests, Z. Xie et al. (2017) [21] assessed the effectiveness of recycled asphalt pavement in foamed warm mix asphalt. Two water-injection plant foamed WMA combinations with 20% and 30% RAP were created and compared to two hot-mix asphalt (HMA) mixtures with the same percentages of RAP. In May of 2013, four portions of Interstate 70 in Eagle, Colorado were paved as a test. Laboratory performance characteristics of plant-produced mixes were evaluated, and the field performance of the four test sections was evaluated after 13, 25, and 38 months. Laboratory performance attributes, construction quality, and field performance were not significantly affected by water foaming WMA and RAP. Therefore, the scientists reasoned, WMA combinations containing 20% and 30% RAP might be produced using the water-injection plant foaming method at a lower manufacturing temperature. The impact of RAP on the functionality of bituminous binders and mixes was studied by K. L. Roja et al. (2020) [6]. In addition, the authors calculated the RAP material's blending effectiveness in the bituminous mixture. Multiple stress creep recovery (MSCR), frequency sweep, and linear amplitude sweep (LAS) tests were used to characterise the binders, and the mixes were created with 15%, 25%, and 35% RAP. Additionally, tests such as the Hamburg Wheel Tracking (HWT), dynamic modulus, Flow Number (FN), Ideal Cracking Tolerance (Ideal-CT), and Semi-Circular Bend (SCB) were used to assess the bituminous mixes' mechanical characteristics. The authors concluded that using up to 20% RAP in asphalt mixes was acceptable based on the test results.

Overall, these recent papers suggest that the use of RAP in flexible pavements can offer numerous benefits, such as improved sustainability, cost savings, and enhanced performance. However, the percentage of RAP should be carefully controlled to maintain the desired performance, and further research is needed to fully understand the properties and behavior of RAP materials in pavement structures.

4. Experimentation Work

In this study, the physical attributes of both processed RAP and NA were investigated using a complete set of standard tests, including Los Angeles abrasion test, Aggregate Impact Value, combined flakiness and elongation, water absorption, and specific gravity test.

4.1 Materials

In order to examine the physical properties, processed Reclaimed Asphalt Pavement (RAP) and Natural Aggregates (NA) were gathered from Apollo Hot Mix Plant, Tangori, Punjab. Different sized RAP and NA were used in the study, as shown in Figure 1.

Fig 2: a) Reclaimed Asphalt Pavement (RAP) b)Natural Aggregate (NA)

4.2 Analysis of Physical Characteristics

The physical characteristics of Reclaimed Asphalt Pavement and Natural Aggregates were analysed at the Transportation Engineering Lab, NITTTR, Chandigarh and results of the tests are presented in table 1.

Table 1. Physical characteristics of Reclaimed Asphalt Pavement and Natural Aggregate

S. No.	Property	Reclaimed Asphalt Pavement (RAP)	Natural Aggregate (NA)
1.	Aggregate Impact Value (%)	11.71	25
2.	Aggregate Abrasion Value (%)	23.96(C)*	34(B)*
3.	Combined Flakiness and Elongation Index (%)	34.50	27
4.	Specific Gravity		
	10mm	2.40	2.55
	20mm	-	2.62
	40mm	-	2.70
5.	Water Absorption (%)		
	10mm	1.15	1.0
	20mm	-	0.68
	40mm	-	0.27

*(C) and (B) represents aggregate abrasion values for Grading C and Grading B respectively as per IS:2386 (Part-IV).

The grading of RAP and NA was performed before conducting the physical property tests which concluded that it's much better to perform aggregate abrasion value test on Grading C for RAP and Grading B for NA. Further, when the tests were conducted, the aggregate impact value and aggregate abrasion value for RAP was quite less than natural aggregate which resembles that RAP has better toughness and hardness properties in comparison to NA. The test results for combined flakiness and elongation test is good for natural aggregates which depicted presence of less flaky and elongated aggregates in NA among both the samples. Specific gravity and water absorption test results depicted decreased value for RAP when compared to natural aggregates, reason for which being removal of binder coating at the time of wetting and cleaning the RAP.

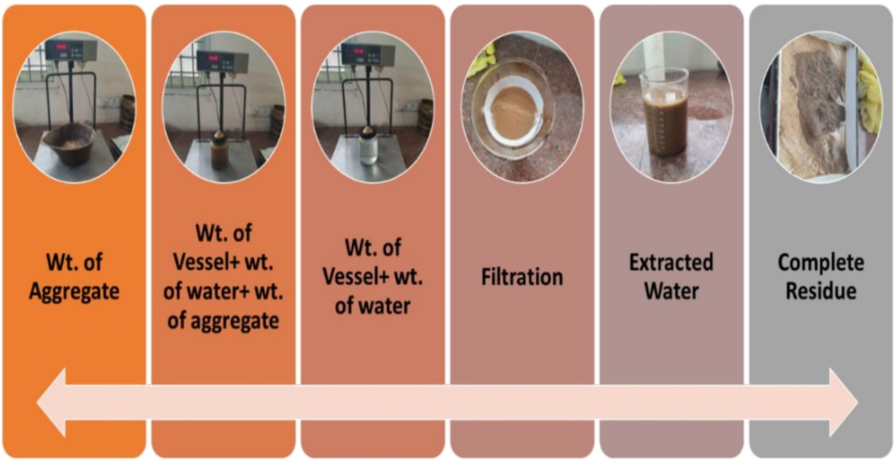

Fig. 3. Pictorial Description for testing of Specific gravity and water absorption

The key aspects involved in performing specific gravity and water absorption test for aggregates smaller than 10mm are shown with help of pictorial flow diagram in figure 2. The test is performed as per IS2386: Part III. The final results for specific gravity of RAP and NA were 2.40 and 2.55 respectively. The water absorption test results depicted decreased value for RAP when compared to natural aggregates, reason for which being removal of binder coating at the time of wetting and cleaning the RAP.

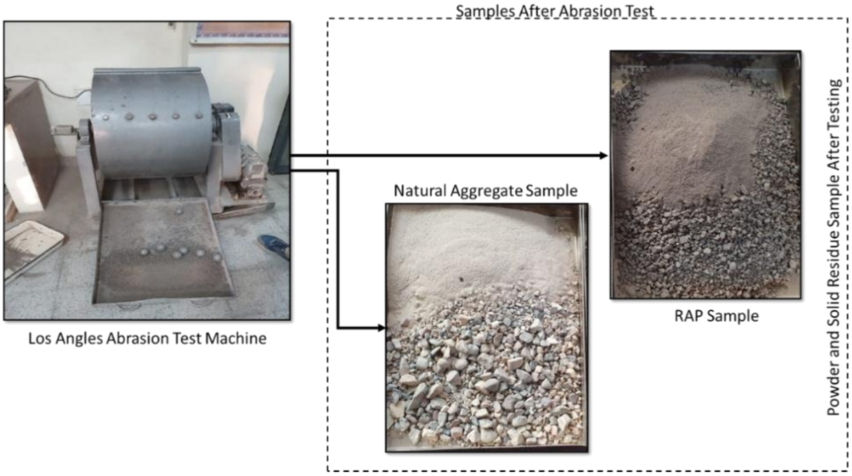

Fig. 4. Pictorial Description for testing of Los Angles Abrasion Test

The Los Angles abrasion test is used to evaluate the hardness property of aggregate which is one of the major attributes to be considered before its application into the field. Figure 3 shows the pictorial description for testing of Los Angles abrasion test for both natural aggregate and reclaimed asphalt pavement. The drum completes a full cycle after being spun at a rate of 30-33 revolutions per minute for a grand total of 500 revolutions. The test is performed as per IS2386: Part IV. The aggregate abrasion value for RAP and NA were 23.96% and 34% respectively.

4.3 Natural Aggregate (NA) vs. Recycled Asphalt Pavement (RAP): A Correlation Heatmap

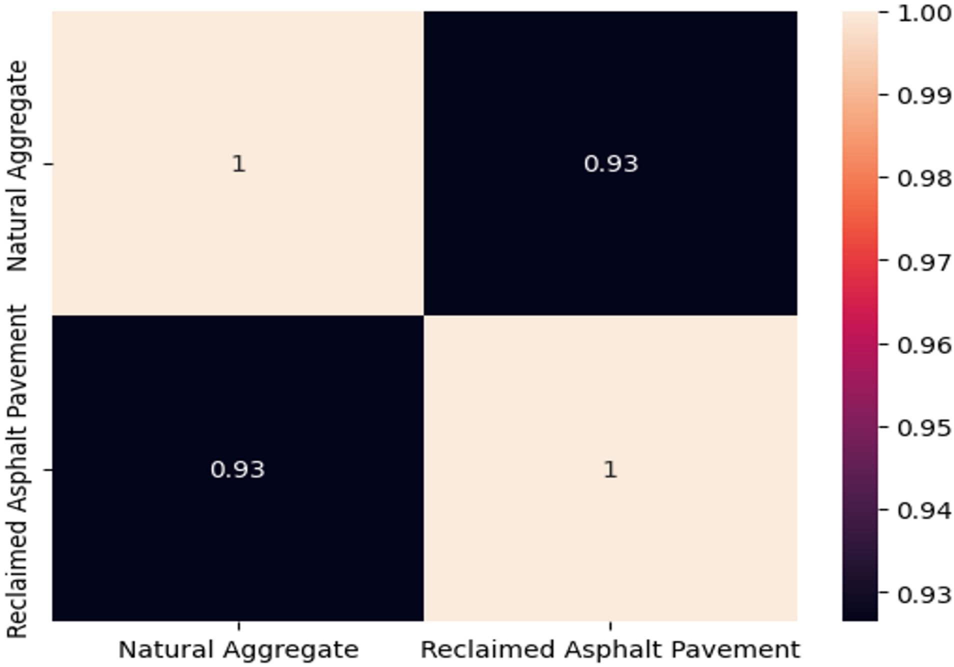

Fig. 5. Heatmap of NA-RAP Correlation

Figure 5 depicts the correlation heatmap, which was created to investigate the relationship among different physical characteristics of natural aggregate (NA) and reclaimed asphalt pavement (RAP). The figure 5 represents that RAP and NA have 93% similarity when compared and tested with physical, mechanical and durability attributes. This analysis helps us to determine that natural aggregate and recycle asphalt pavement possess a strong correlation that can be easily substituted and compatibility used in the highway construction. However before using RAP as partial or full replacement with natural aggregate it should be tested and verified as they may contain a degree of variability from source to source. In the present study we have thoroughly tested and analysed that our RAP has 93% similarity with the natural aggregate.

5. Conclusions And Recommendations

The main objectives were to analyse the important physical attributes of natural aggregate and reclaimed asphalt pavement and establish a relationship among these attributes using correlation heatmap. The results of the physical property test may be evaluated in a number of ways, depending on the area in which its use is required. In the case of asphaltic pavements, the results will be compared to the standards given by the Ministry of Road Transport and Highways (MORTH), while in the case of concrete applications, the results will be compared to the standards set out by the Indian Standard (IS) 383.The main finding that can be concluded from the present study is mentioned below:

- The aggregate impact value and aggregate abrasion value for RAP was quite less than natural aggregate which resembles that RAP has better toughness and hardness properties in comparison to NA.
- The test results for combined flakiness and elongation test is good for natural aggregates which depicted presence of less flaky and elongated aggregates in NA among both the samples.
- Specific gravity and water absorption test results depicted decreased value for RAP when compared to natural aggregates, reason for which being removal of binder coating at the time of wetting and cleaning the RAP.

The usage of RAP has the potential to lower expenses associated with primary production while also preventing an excessive build-up of this material in the environment. Overall, the incorporation of RAP in pavement construction offers numerous advantages, such as cost savings, reduced environmental impact, and improved sustainability. However, there are also some potential disadvantages, such as variation in properties, quality concerns, compatibility issues, processing requirements, and regulatory restrictions, which must be carefully considered when deciding whether to use RAP in a specific pavement construction project.

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