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Araştırma Makalesi / Research Article

Experimental Investigation of Usability of 100% Recycled Asphalt Pavement (RAP) as a Cold Patching Material in Turkey

Orhan KAYA[1*]

Abstract

In this study, the usability of 100% RAP as a cold patching material (CPM) was experimentally investigated. As part of this study, first, the RAP material has been characterized to determine its binder content and particle size distribution of the extracted aggregate. Then, three sets of RAP specimens (each set has three specimens) were prepared. These specimens were conditioned at 22°C, 40°C and 45°C for three hours. Then, the specimens were compacted with 75 Marshall hammer blows. The compacted specimens were then tested for their Marshall stability, and flow at 22°C. Air contents of the test specimens were also determined . It was observed that as conditioning temperatures of the compacted test specimens increased, their Marshall stability test results increased but their flow and air content test results mostly decreased. Marshall stability test results of all three sets of specimens were well above the specification limits. Moreover, all test specimens except for only one specimen conditioned at 22°C met the flow and air content criteria. It could be concluded that 100% RAP could be used as a CPM especially above 22°C. If it is needed to be used at around 22°C, it must be ensured that it is well compacted so that its air content is below 8% for a durable and comparably long-lasting cold patching application.

Keywords: RAP, Cold Patching Material, Asphalt Concrete, Marshall Stability.

%100 Geri Dönüştürülmüş Asfalt Kaplamanın Türkiye'de Soğuk Karışım Bakım Malzemesi Olarak Kullanılabilirliğinin Deneysel Olarak İncelenmesi

Öz

Bu çalışma kapsamında, %100 geri dönüştürülmüş asfalt kaplamanın (RAP) soğuk karışım bakım malzemesi (yama malzemesi) olarak kullanılabilirliği deneysel olarak araştırılmıştır. Bu çalışmanın bir parçası olarak, ilk olarak RAP malzemesi, bitüm içeriğini ve ekstrakte edilen agreganın gradasyonunu belirlemek için karakterize edildi. Daha sonra, üç set RAP numunesi (her sette üç numune vardır) hazırlandı. Bu numuneler 22°C, 40°C ve 45°C'de üç saat süreyle etüvde bekletildi ve bilahare 75 Marshall tokmak darbesi ile sıkıştırıldı. Sıkıştırılmış numuneler daha sonra bekletildi ve Marshall stabilite ve akma değerleri 22°C'de test edildi. Test numunelerinin hava muhtevaları da belirlendi. Sıkıştırılmış test numunelerinin sıkıştırılma sıcaklıkları arttıkça Marshall stabilite test sonuçlarının arttığı ancak çoğunlukla akma ve hava muhtevası test sonuçlarının düştüğü görülmüştür. Her üç numune setinin Marshall stabilite test sonuçları yönetmelik alt sınırının oldukça üzerindeydi. Ayrıca, 22°C'de şartlandırılmış bir numune dışındaki tüm test numuneleri, akma ve hava muhtevası kriterlerini karşılamıştır. Özellikle 22°C'nin üzerinde %100 RAP'ın soğuk karışım bakım malzemesi olarak kullanılabileceği sonucuna varılabilir. 22°C civarında kullanılması gerekiyorsa dayanıklı ve nispeten uzun ömürlü bir soğuk karışım bakım malzemesi uygulaması için hava muhtevasının %8'in altında olacak şekilde iyice sıkıştırıldığından emin olunmalıdır.

Anahtar Kelimeler: RAP, Soğuk Karışım Bakım Malzemesi, Asfalt Betonu, Marshall Stabilite.

[1]Adana Alparslan Türkeş Science and Technology University, Department of Civil Engineering, Adana, Turkey, okaya@atu.edu.tr

[1]https://orcid.org/0000-0001-6072-3882

[*]**Sorumlu Yazar/Corresponding Author**
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1. Introduction

Patching in asphalt pavements could be defined as the process of filling excavated areas and potholes. Patching materials have been broadly categorized as hot patching materials (HPMs) and cold patching materials (CPMs), depending on the temperature at the time of their placement (Chen et al., 2016; Dong et al., 2014). While HPMs are mostly preferred for concentrated and large areas, CPMs are mostly preferred for dispersed and small areas. Especially in winter and wet days, CPMs have greater advantages compared to HPMs; some of their advantages are easier material storage and transportation, better adaptability to environment and easier application procedures (Biswas et al., 2016; Biswas et al., 2018; Wang et al., 2022). Conventional CPMs are produced mostly using cutbacks or emulsions as asphalt binders along with aggregates, as well as preferably other materials such as anti-stripping agents to improve their performance (Dah et al., 2022; Jain and Singh, 2021; Yu et al., 2017). Properties of these materials affect the performance of CPMs. The CPMs with open aggregate gradation and higher air contents have been reported to have lower stability and durability but higher workability (Liu et al., 2013). CPMs are expected to have some of the performance requirements such as workability, initial stability/strength, moisture susceptibility, in-service durability, interfacial bonding (Wang et al., 2022). Although, some or all of these performance requirements are used to evaluate CPMs, there are no universal test and evaluation methods reported to be used for the performance evaluation of CPMs. Moreover, most of the reported test methods have been originally developed for hot mix asphalt or (HMA) or HPMs. Some of the most commonly observed failures of CPMs have been listed as bleeding, dishing, shoving, edge disintegration, missing patch, raveling and alligator cracking (Han et al., 2019).

Recycled asphalt pavement (RAP) is obtained from excavated or milled old asphalt pavements. Being a valuable commodity, reuse of this material has various ecological and economic benefits such as: reducing demand for natural aggregates, reducing greenhouse gases, energy and cost due to the production of natural aggregates and new HMA, and reducing the need for landfills. Sustainable use of RAP as part of asphalt pavements has been investigated by many studies especially as part of regular HMA (Rinkal et al., 2021; Nazaal et al., 2015), as an aggregate substitute in cold in place asphalt pavement technologies (Dughaishi et al., 2022), or as an embankment material (Soleimanbeigi and Edil, 2015; Plati and Cliatt, 2018; Al-Shujairi et al., 2021). Some other studies partially or fully used RAP as an aggregate as part of conventional In-Plant Recycling (CIPR) and Cold In-Place technologies; these technologies use RAP along with asphalt emulsion so that they could be constructed in lower temperatures (Giani et al., 2015; Turk et al., 2016; Pakes et al., 2018). However, there are very few numbers of studies investigating the use of RAP as part of CPMs (Kwon et al.

2017). This might be because that the aged binder in RAP could not be easily activated and blended with unaged binder at low temperatures (Wang et al., 2022).

As stated earlier, there are no universal test and evaluation methods to be used for the performance evaluation of CPMs. In Turkish highway technical specification (KGM, 2013), CPMs and HPMs are designed and evaluated based on their Marshall stability, air content and flow values, obtained based on Marshall mix design methodology. Table 1 shows design criteria used for HPMs and CPMs in Turkey (KGM, 2013).

Table 1. Design criteria for HPMs and CPMs.

Criteria	Limits in HTS (KGM, 2013)	
	HPMs	CPMs
Number of Marshall blows	75	75
Marshall stability (kgf), minimum	750	250*
Air content (%)	3-6	Maximum 8
Flow (mm)	2-5	2-5

*Marshall stability test shall be conducted at 22±1°C

This study experimentally investigates the usability of 100% RAP as CPMs. As part of this study, first, the RAP material has been characterized to determine its binder content and particle size distribution of the extracted aggregate. Then, three sets of RAP specimens (each set has three specimens) were prepared. These specimens were conditioned at 22°C, 40°C and 45°C for three hours. Then, the specimens were compacted with 75 Marshall hammer blows, as specified in Table 1. The compacted specimens were then tested for their Marshall stability, and flow at 22°C, as specified in Table 1. Air contents of the test specimens were also determined . Then, the test results were compared with the design criteria for CPMs in Turkey (Table 1). It was found that almost all specimens met the criteria, and as conditioning temperature increased, Marshall stability values increased, and air content and flow values decreased.

2. Materials and Methods

RAP used in this study was obtained from a local Municipality. As part of this study, first, the RAP material has been characterized to determine its binder content and particle size distribution of the extracted aggregate.

Binder content of the RAP material has been determined using a reflux extraction test set, based on ASTM D2172/D2172 M. As part of this test, specimens with a weight of 1.5-2 kg, depending on the nominal maximum size of aggregate in RAP, are placed on a cylindrical metal frame with a filter paper, and then placed in a glass jar. Then, binder in the RAP specimens are extracted with a chemical solvent, trichloroethylene. Binder content of the RAP specimen is calculated considering the mass of RAP and the extracted aggregate (Equation 1).

$$Binder\ content\ =\ [(W1-W2)\ /W2]\ *100 \quad (1)$$

Where

W1: Original sample weight (RAP)

W2: Aggregate weight after the test

Extracted aggregate blend after the binder extraction test has then been tested for its particle size distribution, following ASTM C136/C136M-19.

After the characterization of RAP material has been finished, three sets (each set consists of three specimens) of Marshall specimens with 100% RAP have been prepared. The Marshall specimens in each set were conditioned at a preheated oven at 22°C, 40°C and 45°C, respectively. These three temperatures were selected that way because:

- 22°C simulates an average day-time temperature where RAP could be applied as CPMs and compacted Marshall specimens are tested at this temperature for their Marshall stability and flow values, as described in Table 1, based on Turkish highway technical specification (KGM, 2013).
- 40°C and 45°C simulate summer day-time temperatures, the pavement surface temperatures could easily reach above 45°C during daytime especially in Southern part of Turkey. Figure 1 shows long-term maximum September temperature distribution in Turkey, provided by Turkish State Meteorological Service (MGM, 2022). As can be seen in Figure 1, temperatures reach as much as 45°C during summer in Adana, where this study has been conducted.

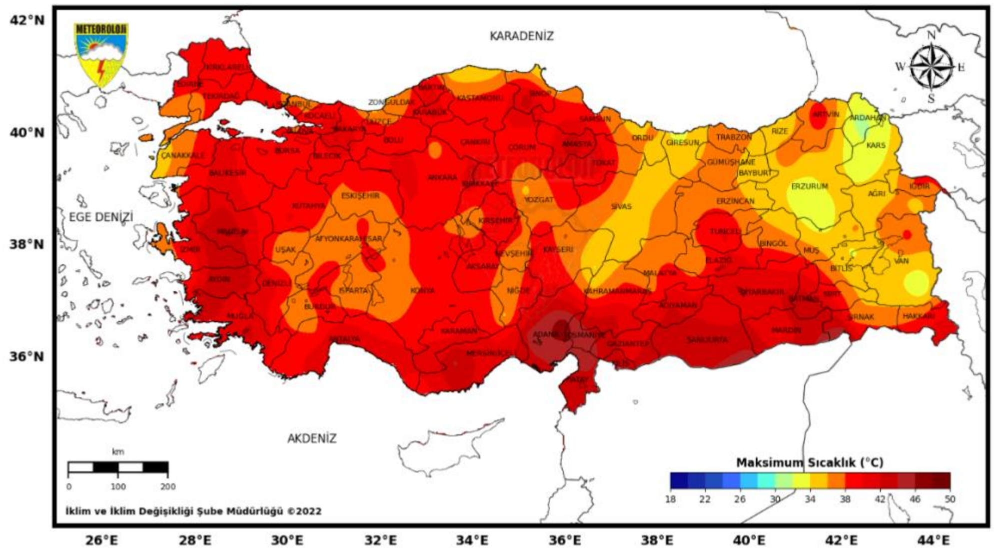

Figure 1. Long-term maximum September temperature distribution in Turkey (MGM, 2022).

The conditioned specimens were then compacted with 75 Marshall hammer blows on each side, as specified in Table 1. Then, sizes of the specimens were measured three times and noted following the Marshall mix design procedure (ASTM D6926). Bulk specific gravities (Gmb) of the compacted specimens were determined based on ASTM D2726. Thereafter, the specimens were placed in a water-bath with a temperature of 22°C for about an hour to ensure that the specimens were stabilized at this temperature. The specimens were then immediately tested for Marshall stability and flow based on ASTM D6926. Maximum theoretical specific gravities (Gmm) of the specimens were also determined so that their air void values could be calculated based on Equation 2.

$$Va = (1 - Gmb/Gmm) \times 100 \quad (2)$$

Where

Va: air void (%) of the compacted specimens

Gmb: Bulk specific gravities of the compacted specimens

Gmm: Maximum theoretical specific gravities of the compacted specimens

3. Results and Discussion

3.1. Binder Content and Particle Size Distribution of the Extracted Aggregate in RAP Material

In Turkey, the Highway Technical Specification (KGM, 2013) states that the asphalt pavements must have three stabilized asphalt concrete layers (an asphalt wearing course, and below it, another layer (named binder course), followed by an asphalt stabilized base layer). Although all of these three layers are composed of asphalt concrete, design and performance requirements of each layer differ.

As a result of the binder extraction test, binder content of the RAP specimen was found to be 4.35%. This binder content was found to be within the limits specified by Turkish highway specification for all three asphalt concrete layers. Table 2 shows the particle size distribution of the extracted aggregate in RAP material along with the specification limits for all three stabilized asphalt concrete layers. As shown in Table 2, extracted aggregate in the RAP materials has a particle size distribution mostly similar to the one in binder course.

Table 2. Particle size distribution of the extracted aggregate in RAP material and specification limits.

Sieve size (mm)	Percent passing	Specification Limits (Percent passing) (KGM, 2013)			
		Wearing Course	Binder Course	Stabilized Base (Type A)	Stabilized Base (Type B)
25	100.0	100	100	72-100	80-100
19	93.6	100	80-100	60-90	70-90
12.5	70.6	88-100	58-80	50-78	61-81
9.5	61.8	72-90	48-70	43-70	55-75
4.75	44.7	42-52	30-52	30-55	42-62
2	25.9	25-35	20-40	18-42	30-47
0.425	8.8	10-20	8-22	6-21	15-26
0.18	5.1	7-14	5-14	2-13	7-18
0.075	2.6	3-8	2-8	0-7	1-8

3.2. Marshall stability, Flow and Air Content Test Results

Figure 2 shows Marshall stability, flow and air content test results of the test specimens conditioned at 22°C, 40°C and 45°C for three hours. A total of nine specimens were tested as three sets. As can be seen in Figure 2, as conditioning temperatures of the compacted test specimens increased, their Marshall stability test results increased but their flow and air content test results mostly decreased. This relationship between mixing or conditioning temperatures of the compacted specimens and their Marshall stability and flow test results were also observed in some other studies (Balık et al., 2019). As specified in Table 1, compacted specimens must have a minimum 250 kgf. of Marshall stability value to be used as a CPM. As can be seen in Figure 2, Marshall stability values of all three sets of specimens were well above this limit. Moreover, as specified in Table 1, the compacted specimens must have a maximum 8% of air content value to be used as a CPM. As can be seen in Figure 2, all test specimens except for only one conditioned at 22°C met the air content criterion. As stated earlier, as conditioning temperature increased, air content results decreased; the specimens conditioned at 22°C mostly showed the highest air content results. Furthermore, as specified in Table 1, the compacted specimens must have a flow value of 2-5 mm. to be used as a

CPM. As can be seen in Figure 2, all test specimens except for only one conditioned at 22°C met the flow criterion.

Based on the Marshall stability, flow and air content test results shown in this study, it could be concluded that 100% RAP could be used as a CPM especially above 22°C. If it is needed to be used at around 22°C, it must be ensured that it is well compacted so that its air content is below 8% for a durable and comparably long-lasting cold patching application.

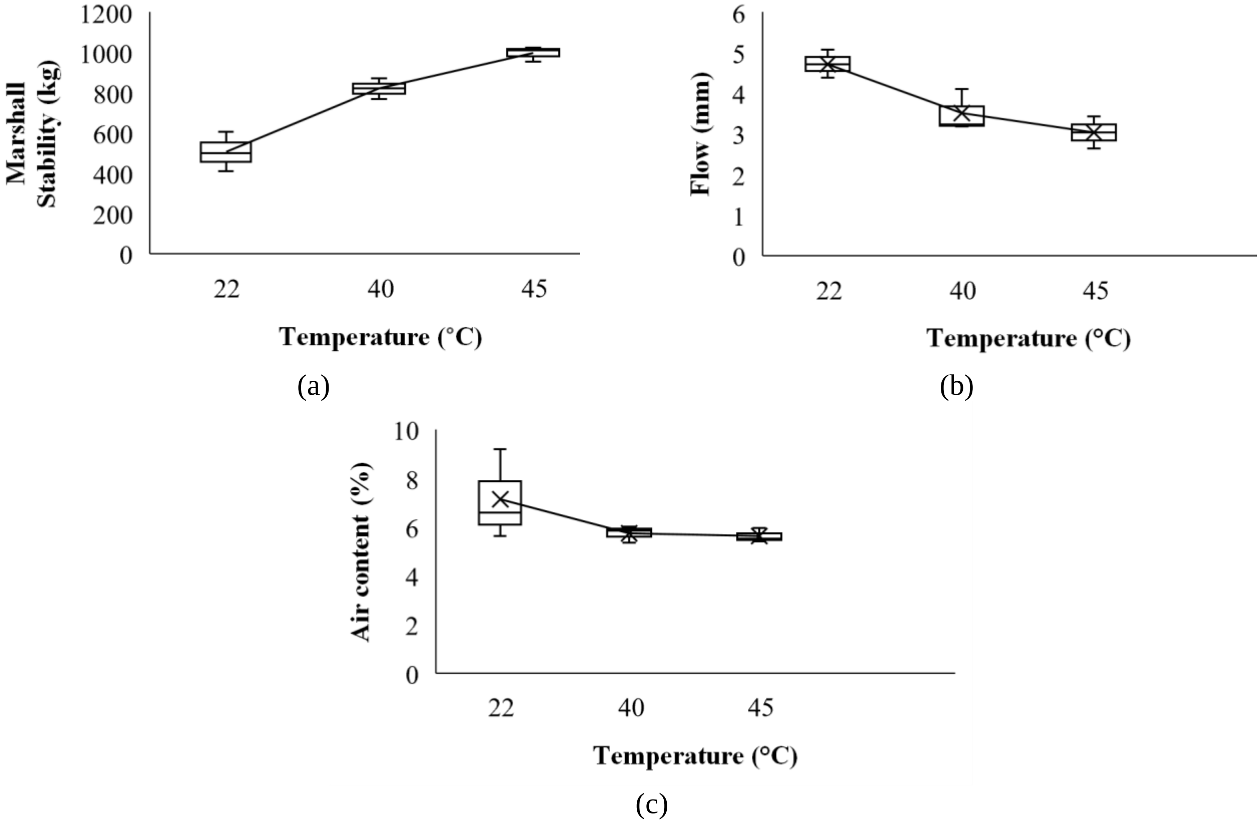

Figure 2. (a) Marshall stability, (b) flow and (c) air content results.

4. Summary and Recommendations

This study experimentally investigated the usability of 100% RAP as CPMs. As part of this study, first, the RAP material has been characterized to determine its binder content and particle size distribution of the extracted aggregate. As a result of the binder extraction test, binder content of the RAP specimen was found to be 4.35%. This binder content was found to be within the limits specified by Turkish highway specification for all three asphalt concrete layers. Moreover, extracted aggregate in the RAP materials was found to have a particle size distribution mostly similar to the one in binder course.

Then, three sets of RAP specimens (each set has three specimens) were prepared. These specimens were conditioned at 22°C, 40°C and 45°C for three hours. Then, the specimens were compacted with 75 Marshall hammer blows. The compacted specimens were then tested for their Marshall stability, and flow at 22°C. Air contents of the test specimens were also determined . It was observed that as conditioning temperatures of the compacted test specimens increased, their Marshall stability test results increased but their flow and air content test results mostly decreased. Marshall stability test results of all three sets of specimens were well above the specification limits. Moreover, all test specimens except for only one conditioned at 22°C met the air content criterion. Furthermore, all test specimens except for only one conditioned at 22°C met the flow criterion.

Based on the test results shown in this study, it could be concluded that 100% RAP could be used as a CPM especially above 22°C. If it is needed to be used at around 22°C, it must be ensured that it is well compacted so that its air content is below 8% for a durable and comparably long-lasting cold patching application.

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Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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