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The effect of using activated dates seed on Hot Mix Asphalt performance

Sharaf AlKheder [a,*], Mohammad Alkhedher [b], Khaled A. Alshraiedeh [c]

[a] Civil Engineering Department, College of Engineering and Petroleum, Kuwait University, Kuwait, P.O. Box 5969, SAFAT 13109, Kuwait
[b] Mechanical Engineering Department, Abu Dhabi University, Abu Dhabi 59911, United Arab Emirates
[c] Department of Civil Engineering, Faculty of Engineering, Jordan University of Science and Technology, Irbid 22110, Jordan

HIGHLIGHTS

- Date seeds were used to enhance HMA performance.
- Marshall tests were used to study the effect of date seeds on HMA performance.
- HMA prepared using 10% activated date seed has the highest stability value.
- HMA prepared using 7% has the highest retained strength value.
- HMA prepared using 15% date seed has the highest flow value.

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ABSTRACT

The increasing demand for construction materials and the need to improve the performance of asphalt mixes have led to the depletion of available resources of aggregates. Lots of aggregate alternatives had been studied to partially or fully replace aggregate in asphalt concrete mixes. Indeed, date seeds are found easily in Kuwait. Their properties; such as light weight, very low crushing strength, and low impact value; represent a potential domain to enhance asphalt mix performance. The main objective of this paper is investigating the possibility of using activated date seeds additives in Hot Mix Asphalt (HMA) as a partial replacement of Fine Aggregates (sand). A total of 3 asphalt concrete mixes with different percentages by weight were prepared. Physical and mechanical properties of date seeds and Fine Aggregates (sand) were determined and compared in the asphalt concrete mix design of ratios 7, 10, and 15%. Compressive Strength and Marshall Stability tests were performed to investigate the effect of activated date seeds additives on HMA. Eventually, the findings indicated that the ratio of 10% gave the highest Marshall Stability. On the other hand, the ratio of 7% found to give the highest retained strength index. a deeper statistical analysis is performed to evaluate the robustness and significance of studied factors on response variables represented in Marshal Stability and Flow. The first part of the analysis included recognizing data outliers in data sets and eliminating them to compare basic statistical values with raw data. The minor differences in these values implies minor variability in the measurement and indicates minimal experimental error. T-test analysis was performed to study the influence of date seed percentages on different performed measurements. ANOVA tests were also represented to demonstrate the statistical significance factors on considered response variables. The results supported the significant influence of the included measurements on Marshal stability and flow values.

1. Introduction

In recent times, enhancement of pavement materials is important to avoid problems such as shortage in existing materials. Reusing wasted materials considered very useful in the road construction because it usually provides a good performance asphalt pavement. Ordinary HMA is the most commonly used mix in road pavement due to its good performance and lower construction cost, especially when compared to rigid pavement cost. In this paper, fine aggregate is the component that is partially replaced and influences the changes on the results (Fig. 1). Recently, there is a dramatic increase in the use of wasted materials and available natural resources in what's known today as waste recycling. Reusing wastes in asphalt pavement save the used materials, reduce pavement construction costs, and lessen environmental pollution.

* Corresponding author.
E-mail addresses: sharaf.alkehder@ku.edu.kw (S. AlKheder), mohammad.alkhedher@adu.ac.ae (M. Alkhedher), kaalshraiedeh12@eng.just.edu.jo (K.A. Alshraiedeh).

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Fig. 1. (a) Date seeds, (b) date seeds after grinding.

The seeds are found easily in Kuwait as it is ranked among the top 20 countries in producing dates with approximately 36,978 tons in 2014 [1]. Date seeds are the extracted waste from dates that remains after eating the cover as a fruit. Date seeds are brown oblong hard seeds. The seed of palm date varies in weight from 0.5 g to 4 g with a size of about 6 to 20% of the fruit weight depending on maturity [2]. Date seeds are normally used to feed animals and in decaf coffee. It was also used in chemical industry as a raw material for activated carbon. Recently, a new usage appeared for date seeds in the construction field as a replacement of aggregates.

In asphalt mixtures, bitumen plays an important role in bonding aggregates and collecting them together by coating aggregate particles. Many researches were conducted in literature to improve the quality of asphalt mix through improving the properties of aggregates. This can be achieved by partially replacing aggregates with wasted materials such as date seeds that have less weight and high compressive resistance. The replacement of wasted date seeds to aggregates of asphalt mixtures is very simple; as it requires no modification to existing plant facilities or technology. This replacement of aggregates is one of the important construction tricks for improving the quality of the product; which enhances flexible road pavement.

Since 2013, considerable researches have been performed to check the effects of date seeds in construction materials. Proving the utility of date seeds as an additive material needs evidence and evidence comes from testing the material in various ways [3]. This paper showed the experiments made on date seeds to involve them in asphalt mixtures.

2. Literature review

Even though reusing wasted materials in pavement mixtures as alternatives for aggregates is not a new concept, it still remains a very popular topic. In fact, aggregates occupy 80–85% of the total volume of asphalt mixtures [4]. Therefore, alternative materials could partially or totally replace the aggregates [5]. 2.5% replacement of date seed ash increased the consistency, initial and final setting time [6]. Date seed ash was used to replace ordinary Portland cement OPC, and the optimum percentage of replacement of OPC was 4% [7]. The effect of using of date seed ash on HMA fatigue behavior was also investigated, the finding indicated that date seed ash improved fatigue behavior for both asphalt and asphalt mix [8]. Further study investigated the feasibility of using date seed ash to modify HMA. The results indicated that adding date seed ash increased tensile stress ratio for both limestone and siliceous mixture [9]. The effect of filler type on asphalt mastic properties was investigated; the results indicated that filler behavior depends on chemical and mineralogical properties of the material [10]. Polymeric waste such as tayers rubber could increase the resistance against plastic deformation [11]. When using crushed concrete as a full replacement of coarse aggregates in base or sub-base layers, it was found that an increase in stiffness modulus has occurred [12,13]. Also, researchers found that when asphalt mixtures contained steel furnace slag, their rutting and moisture resistance was increased [14]. More than that, steel furnace slag can be used in concrete mixtures to make obvious improvement particularly for concrete pavements in airports [15,16]. Waste brick powder, waste glass powder, and rice husk ash were used as a replacement for HMA filler. The results indicated that mixes prepared using waste brick powder and waste glass powder had a higher fatigue life [17]. Crumb rubber and Polyethylene Terephthalate were used also to modify HMA. The results showed that the highest performance was for HMA prepared using 6% Crumb rubber and Polyethylene Terephthalate [18]. Wasted rubber powder could also affect rutting performance. It was found that rubber powder increased rutting resistance of HMA [19]. The effect of waste glass powder was also studied. The results showed that glass powder could be beneficial against rutting [20]. Using waste foundry sand as an alternative of fine aggregate can improve the quality in concrete mixtures [21,22]. If 20% of waste foundry sand used as a partial replacement of fine aggregate, it would be beneficial to mechanical properties [23,24], not only in concrete mixtures but also in sub-base pavement [25]. Moreover, studies [26,27] found that using recycled crushed glass in asphalt and concrete mixtures improved the overall pavement performance including durability, strength, workability, and hydraulic conductivity. It had also low environmental impacts. Finally, it was found that crumb rubber could reduce tensile strength of HMA [28].

3. Methodology

The adopted methodology in this paper studied the effect of utilizing activated date seeds to replace a portion of fine aggregates (sand) in HMA. First, a control sample was prepared with 0% activated date seeds; this reference was taken from Public Authority for Roads and Transportation (PART). Afterwards, it is important to decide how to activate the date seeds to be used as an additive in the asphalt mix. Samples with different percentages of activated date seeds were prepared; 7%, 10%, and 15% as a replacement by weight of sand in the asphalt mix. Marshall Stability and ICR tests were selected to evaluate the effect of using activated date seed on HMA performance.

Laboratory experiments that were conducted on the test samples included Marshall Stability and Flow Test, In-place Air Voids Measurement, Retained Strength, Extraction Test, and Stripping Test. Whereas, tests conducted on raw materials included Sieve Analysis and Specific Gravity.

As shown in Fig. 2, methods of the study were conducted in two phases. Phase 1included preparing asphalt mixes materials to test behavior and performance in lab such as sieve analysis test and

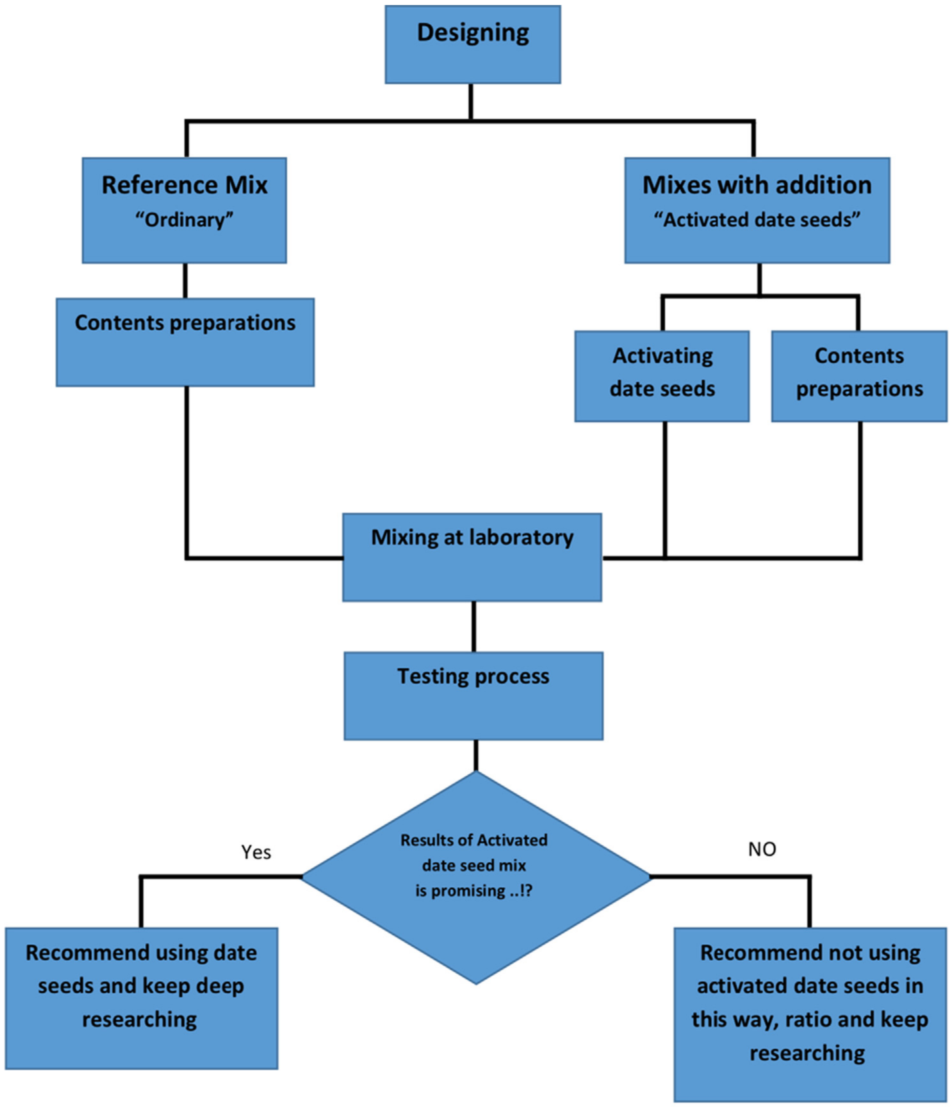

Fig. 2. Work flow chart.

date seed activation. Whereas Phase 2 covered Asphalt mixtures testing of both mixes; control mix and modified mix by replacing sand with activated date seeds with various ratios. Such tests included retained strength test, Marshall stability and flow test.

3.1. Asphalt mixtures preparing

3.1.1. Ordinary asphalt pavement mixture

Ordinary asphalt pavement mixture is frequently used for paving roads and highway surfaces because it is very easy to construct and repair. Asphalt pavement is a long-life paving method; so it's a very valuable way of reducing both initial construction and maintenance costs. In this section, the laboratory testing and results of the ordinary asphalt mixture are shown to be compared with the activated date seeds mixture.

a) Sieve analysis test results

A gradation test was performed on aggregate size 3/4 (Medium Gabbro), aggregate size 3/8 (Fine Gabbro), crushed sand, natural sand, and filler in the laboratory as per ASTM test procedure. The test results are provided in Table 1 along with graphical representations shown in Fig. 3.

b) Blending aggregate to meet reference mix Specifications

Aggregate blending was done in order to meet the required job mix of the reference samples as obtained from the Governmental Center for Testing, Quality Control and Research in Kuwait. Hence, the blending data (Table 2) and the results of cumulative weights of reference sample (Table 3) are shown. The blending results and the percentages of aggregate obtained from the governmental center are proportions of:

- 3/4″ Medium Gabbro (24%)
- 3/8″ Fine Gabbro (37%)
- Crushed Sand (20%)
- Natural Sand (16%)
- Filler (3%)

3.1.2. Activated date seeds asphalt mixture

Date is the main focus in here and especially for date seeds (Each seed is approximately about 18 mm in size and weighs 4 g [29]). The first try was to use the seeds as an additive material without crushing. This was attempted on M20 grade for concrete and the replacement percentages were 10% and 20% of the sand. M20 is a grade to measure compressive strength parameter of

Table 1
Sieve analysis test results.

ASTM Sieve	Medium Gabbro 24%	Fine Gabbro 39%	Crushed sand 18%	Natural sand 15%	Filler 4%	Specification	
						Job mix	General
1 1/2″	100	100	100	100	100		
1″	100	100	100	100	100	100	
3/4″	97	100	100	100	100	99	100
1/2″	47	100	100	100	100	87	66–95
3/8″	14	96	100	100	100	78	54–88
No.4	3	37	98	100	100	52	37–70
8	2	6	75	97	100	35	26–52
16	2	3	44	84	100	26	18–40
30	1	2	27	62	100	19	13–30
50	1	2	22	20	95	12	8–23
100	1	1	13	7	90	8	6–16
200	0.1	0.5	5.8	1.8	85	4.9	4–10
Sand equivalent			59	45			

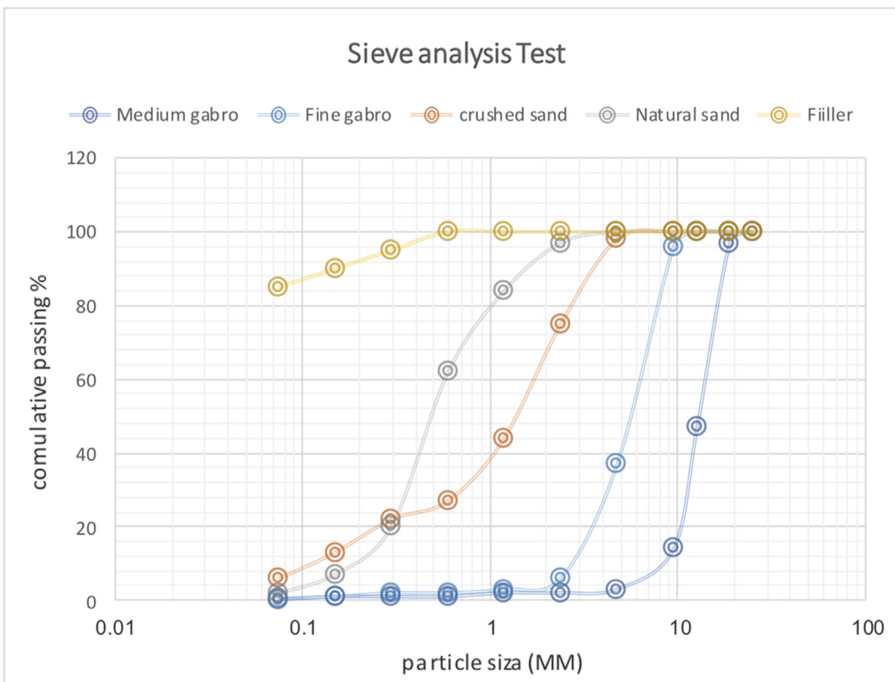

Fig. 3. Sieve analysis test results.

Table 2
Asphalt mix blending data.

No. of Blows	75	% Voids in Mineral Aggregate	
Optimum bitumen (% by Wt. of mineral aggregate)	4.2	% Voids (total mix)	4.7
Marshall Stability (Kg)	1861	% Aggregate Voids Filled	
Marshall Flow (0.01″)	13	Filler-Bitumen Ratio	1.2
Marshall Density (g/cm3)	2.4753	Mixing temperature	150
Immersion-Compression AASHTO T-165 (% Retained)	80	Net Retained Strength (Kg/cm2)	21.5

Table 3
Cumulative weights for Marshall and ICR samples for ordinary mixture.

Agg. Size	ASTM sieve retained	Marshall	ICR
3/4″	3/4″	2.9	4.6
	1/2″	144.0	228.0
	3/8″	247.7	392.2
	Pass 3/8″	288.0	456.0
3/8″	3/8″	296.9	470.1
	No.4	558.8	884.8
	No.8	705.4	1116.8
	Pass No.8	732.0	1159.0
Crushed Sand		972.0	1539.0
Natural Sand		1152.0	1824.0
Filler		1200.0	1900.0

concrete, in other words it is 20 Mpa strength that is achieved after 28 days of curing. Curing is a process of keeping concrete cubes under adequate level of moisture to enhance hydration reaction at the early age of concrete. It was observed that on the seventh day of curing concrete cubes partially replaced with date seeds, prominent cracks appeared all over the surface of the cubes. All specimens showed the same phenomena of cracks, which indicates that the seeds lacked binding property when used without crushing due to its smooth surface. The second trial was to crush the seeds and replace up to 10% and 20% of the aggregate in concrete. When the seeds were crushed and used, it was found that specimens did not develop any cracks after curing. When tested for compressive strength, the strength values were almost equal to that of the conventional concrete. The study attempted to investigate the possibility of usage of date seeds as an alternative of aggregate, which was successful in terms of compressive strength. However, the durability factor needs to be studied in a longer term for a successful practical application.

(a) Activating date seeds

Turning ordinary date seeds into activated date seeds require a few steps. First, date seeds were washed to remove dirt and all attached materials on the seed surface. After that, washing with water was repeated to ensure that all dirt was removed. Then, date seeds were dried in an air oven at (100–150) C for 5–10 min. After drying, the samples were placed in a water path at boiling temperature for 1 h (Fig. 4a). Afterwards, the seeds were set into flat rectangular pots where they were mixed with H3PO4 (98% of purity) at impregnation ratio (IR) of (0.9–1.0). IR is the grams of phosphoric acid per gram of dry date seed (Fig. 4b). Date seeds were stirred with phosphoric acid for 5 min to make sure that they are completely soaked in phosphoric acid. The mixture was dried in an air oven at 300C until it was completely dry and turned into a crisp material shape (Fig. 4c). The dried date seeds were crushed using a mixer machine grinder (Fig. 4d) into a powder form. When the experiment was completed, the samples were cooled to room temperature. Samples were washed repeatedly in batches to ensure that all phosphoric acid salts were removed from the activated sample. After crushing the date seeds, crushed seed powder was placed (Fig. 4e) in sieve no.20 (850 μm).

(b) Preparation of Asphalt-Concrete Specimens using Marshall method

Optimum asphalt content was determined using Marshall mix design procedure. Marshall method aims to find asphalt content at a desired density that satisfy minimum stability and specific range of flow. The resulted optimum asphalt content was 4.2%. Marshall specimens were prepared for testing at 3 different ratios as per ASTM standards. First, prepared aggregate types were sieved, and retained aggregate on each sieve were collected in separate bowls and labeled in a descending order of size. Cumulative weights from aggregate bowls needed for Marshall and ICR samples are shown in Table 4.

After that, a mixture of different ratios was patched separately and weighted. Four patches (1250 gm) for each ratio were weighted for Marshall test. Five specimens of 1900 gm per ratio were weighted for ICR test.

Afterwards, the whole specimen contents were mixed together 9 times with a metal rod. All specimens were heated up to a temperature of 110 °C to dry in the oven for 24 h. Bitumen was also heated up to 150 °C. The optimum asphalt content of 4.2% was added to the aggregate, Table 5, and mixed using a mechanical mixer. The mixing temperature was set at 150 °C as shown in Fig. 5 a and b.

3.2. Asphalt mixtures testing

3.2.1. Marshall tests

Marshall Specimens were prepared as per ASTM in the previous step. Bulk specific gravity of compacted HMA was determined according to ASTM following these steps; first, samples' volume was determined by weighting in super saturated case and in water. Then, samples were submerged in water for 30 min at 60 °C temperature, then dried. Secondly, Bulk specific gravity was determined of compacted HMA by measuring specimen's weights in air, water, and at saturated surface dry (SSD) conditions. Afterward, Marshall Stability and Flow Tests were conducted. Results were collected and analyzed.

3.2.2. In-place Air Voids measurement

According to ASTM, theoretical maximum specific gravity was carried out for loose mixes. Total Air Voids (VTM) of compacted specimen, Voids in Mineral Aggregate (VMA), and Voids filled with bitumen (VFM) were calculated.

3.2.3. Retained strength test

Cylindrical specimens of (1900gm) were prepared; six samples were prepared for the control mix date seeds and for other

Fig. 4. Steps to turning ordinary date seeds into activated date seeds.

Table 4
Cumulative weights for Marshall and ICR samples for modified date seeds mixtures.

Agg. Size	ASTM sieve retained	Marshall		ICR		
3/4″	3/4″	3		4.6		
	1/2″	150		228.0		
	3/8″	258		392.2		
	Pass 3/8″	300		456.0		
3/8″	3/8″	309.3		470.1		
	No.4	582.1		884.8		
	No.8	734.8		1116.8		
	Pass No.8	762.5		1159.0		
Crushed Sand	1012.5			1539		
Replacement ratio of sand	7%	10%	15%	7%	10%	15%
Natural Sand	1186.875	1181.25	1171.875	1804.05	1795.5	1781.25
Activated Date Seeds Powder	1200	1200	1200	1824	1824	1824
Filler	1250	1900				

Table 5
Weight of bitumen added to mixtures.

Bitumen ratio	Marshall mineral aggregate wt. (g)	Bitumen wt. (g)	ICR mineral aggregate wt. (g)	Bitumen wt. (g)
4.2%	1250	52.5	1900	79.8

Fig. 5. Preparation of Asphalt-Concrete samples using Marshall.

modified mixtures of 7, 10 and 15% activated date seeds. Molds were assembled by Loading Machine, and labeled. Then, the samples were divided into 2 groups. In the first group (Wet Group), specimens were submerged in water for 24 h at 60 °C, then moved to the second water bath at 25 °C for 2 h. For the second group (Dry Group), specimens were brought to test temperature at 25 °C by keeping them in air bath for at least four hours. Afterwards, the sample was placed and centered under the loading strips of the compression machine. Then the test proceeded quickly with diametrical loading and the maximum compressive load was recorded. Loading continued until the specimen failed. Finally, the Net Retained Strength (Kg/cm2) and Index of Retained Strength were calculated.

4. Experimental tests results

The Marshall stability and flow test determine the performance prediction for the Marshall Mix design method. The stability test determines the maximum load supported by the test samples at loading rate of 50.8 mm/minute. Load is applied to the samples till failure, and the maximum load is known as stability. During the

Table 6
The results for the control sample (0% date seed).

% AC by wt. of agg.	Bulk Density (gm/cm^3)	Stability (Kg)	Flow (mm)
Control sample	2.4753	1861	13

Table 7
The Air Voids results for the control sample.

Bitumen content %	4.2
Marshall density (gm/cm^3)	2.4753
Air Voids % = [(V.M.D) - Marshall density / (V.M.D)]*100	3–8%

loading, an attached dial gauge measures the sample's plastic flow (deformation) due to the loading process. The flow value is recorded at the same time when the maximum load is recorded.

4.1. Marshall stability and flow test results

The properties that are most of interest in Marshall Stability test include weight of the mix in the air, weight of the mix at super saturated case, weight of the mix in water, and the bulk specific gravity of the mix. The results for the control sample with no partial replacement (0% date seeds) are shown in Table 6. The results of the samples with partial replacement 7%, 10%, and 15% date seeds by the weight of sand are shown in Table 1A in the Appendix. The average of four replicates was recorded for each percentage.

4.2. In-Place Air Voids measurement

In-place air voids describe the compaction situation of the mixtures. For dense- graded mixtures, in-place air voids initially should be within ranges from 3% to 8% [30]. If there is a problem in the mixture compaction and the percent of in-place air voids is below the average, it may lead to rutting and bleeding. Also, if the percent of in-place air voids is above the average, it will permit the entrance of water and air into the permeable pavement, therefore the HMA will be exposed to moisture stripping [31]. Hence, the results of Air Voids Measurement of specimens for different percentages of date seeds as a replacement of sand are presented s. The results for the control sample are shown in Table 7. The results for the samples with partial replacement 7%, 10%, and 15% date seeds by weight of sand are shown in Table 8.

4.3. Retained strength test results

Retained strength results for the control sample with no partial replacement (0% date seeds) are shown in Table 9. The results for the samples with partial replacement 7%, 10%, and 15% date seeds by the weight of sand are shown in Table 2A.

Table 9
Retained strength results for the control sample.

% AC by wt. of agg.	Bulk Density (gm/cm3)	Net retained strength	ICR
Reference sample	2.4753	21.9	Min 90%

Table 10
The average value of Marshall Stability and Flow for the 4 samples.

DS replacing ratio	Bulk Specific Gravity of Compacted Material (gm/cm^3)	Corr. Stability (kg)	Flow (cm)
0%	2.4753	1861	1.3
7%	2.5472	1980	1.3
10%	2.5335	2242.5	1.28
15%	2.5103	2118	1.5

5. Results analysis

Results of laboratory work had been obtained and analyzed in order to achieve the study goals. To improve the asphalt properties, the effect of adding different percentages of date seeds and finding the optimum replacement content in the mixture were studied.

5.1. Analysis of Marshall Stability and flow results

Marshall Stability value is defined as the minimum vertical load at which the failure of the samples occurs. However, Marshall Flow value is defined as the deformation undergone by the specimen at the maximum load where the failure occurs [32]. For each percentage of date seeds content, the results of 4 specimens have been collected and analyzed. The average value of the 4 specimens was calculated as shown in Table 10. The highest stability was for HMA prepared using 10% activated date seeds, followed by those prepared using 15%. However, the least stability was for HMA prepared using 7%. This can be explained by the fact that the average volume of activated seeds has approximately the same volume of filler particles. Therefore, the increase in such part increases the mastic asphalt content. This increase enhances aggregate lubrication as well as aggregate bonding. Nevertheless, the excess increase in fine particles could reduce mixes workability. Consequently, coarse aggregate could not be coated perfectly, and therefore the stability of the mix decreases.

5.2. Analysis of in-place air voids measurement

Air voids are the whole amount of void spaces between the aggregates that the binder did not fill. Air voids should be provided to allow for additional compaction under traffic and a slight expansion of asphalt due to temperature increase. This eventually produces asphalt bleeding. Fig. 6 shows the effect of date seeds on the IRC of HMA. It can be noticed that air voids decrease with

Table 8
Air Voids results for the samples with partial replacement 7%, 10%, and 15% date seeds.

	7%	10%	15%
Bitumen content %	4.2	4.2	4.2
Marshall density (gm/cm3)	2.5472	2.5335	2.5102
A- Weight of sample in Air (gm)	1981.0	1998.2	1948.6
E- Weight of sample + Flask filled with water at 25 °C (gm)	10216.0	10221.8	10193.9
D- Weight of Flask filled with water at 25° C (gm)	8986.6	8986.6	8986.6
Specific Gravity (V.M.D) = A / (A + D-E)	2.6357	2.6189	2.6286
Air Voids % = [(V.M.D) - Marshall density / (V.M.D)]*100	3.4	3.3	4.5

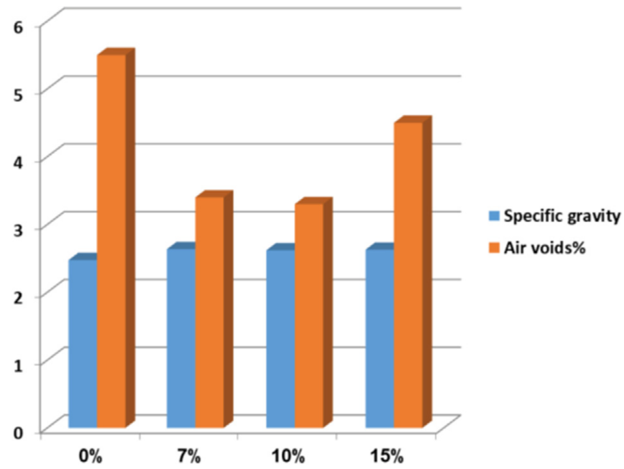

Fig. 6. Specific gravity vs air voids%

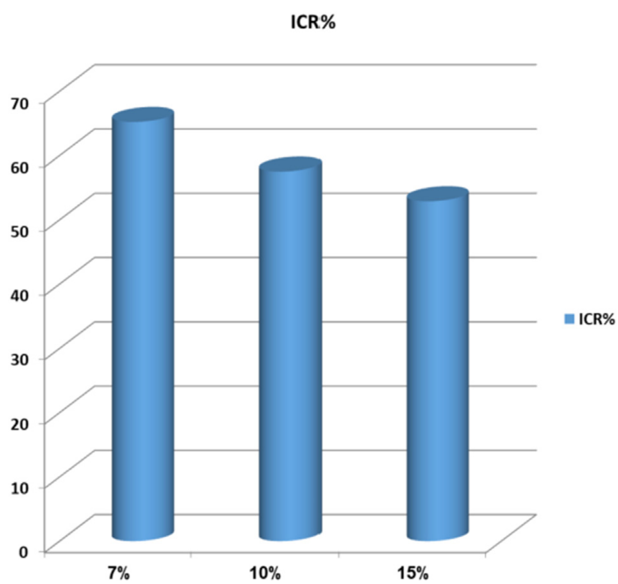

Fig. 7. Comparison between ICR% values.

the increase in activated seeds up to 10%. This can be explained by the fact that the increase in the activated seeds causes an increase in the fine materials as well as asphalt mastic. Therefore, more voids were filled. However, for HMA prepared using 15% activated seeds, excess increase in activated seed could reduce coarse aggregate lubrication. Consequently, coarse aggregate could not be coated perfectly, and therefore air voids of the total mix increased.

5.3. Analysis of retained strength results

This test is performed to find the compressive strength of HMA after being immersed in water, which is defined by ASTM as loss of compressive strength resulting from the action of water on compacted bituminous mixtures containing asphalt cement. A numerical index of retained strength was obtained by comparing loss of strength with the strength of dry specimens. Six samples were prepared to be tested. Each set of the six samples were sorted into two groups, wet group (three replicates) and dry group (three replicates). The average values were calculated and the average is obtained as shown in Table 3A and Fig. 7.

5.4. Statistical analysis

Since the 1970 s, statistically based specifications had been incorporated into quality assurance of pavement construction [33]. Various statistical methods are implemented to perform assessment of pavement construction through a variety of procedures to determine the quality of materials used. These methods include testing of impact levels of one or more factors [34]. Robust statistical methods are used to evaluate the characteristics and behavior of pavement relative to different parameters, the statistical results determine the measurements robustness and significance of studied parameters [35,36].

5.4.1. Data description

Marshall stability and flow tests are studied as a performance assessment of the Marshall Mix design method [37]. The samples are analyzed for three different date seeds percentages of sand weight: 7%, 10% and 15%. Fig. 8 shows the normalized measurements of Marshall stability and flow at different date seeds percentages of sand weight. It is apparent that the higher the date seeds percentages the higher stability and flow values. The stability and flow regression lines are parallel, this demonstrates the direct

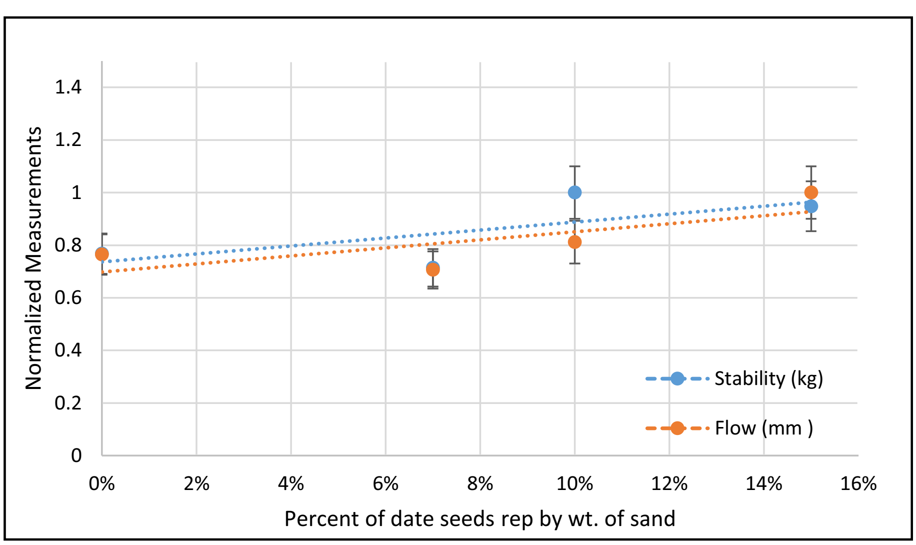

Fig. 8. Marshall stability and flow tests at date seeds percentages of sand weight: 7%, 10% and 15%.

relation between the two variables. To validate this effect, statistical analysis is performed to recognize the significance of measured parameters as Bulk specific gravity of compacted HMA measured in air, water, and at saturated surface dry conditions. Other studied parameters include studying specimen's Bulk Volume and Bulk Density. T-test and Analysis of variance (ANOVA) statistical analysis are implemented to support the study of these parameters' significance related to Marshall stability and flow results.

To check robustness of parameter measurements and examine the existence of outliers, a comparison between data Mean, Median and standard deviation (STD) and 20% trimmed outliers is summarized in Table 11. As noted, the statistical results of trimmed data are close to the original data. Some variances are shown for the STD results, due to elimination of outliers of the two-tailed data.

5.4.2. t-test Analysis

The *t*-test is a robust method in identifying mean differences due to its insensitivity to deviations from data normality [38]. *T*-test (hypothesis test) is used in this study as a robust statistical test to identify mean difference in two datasets as summarized in Table 12. The p-values of two tailed *t*-test in the table prove the rejection of null hypothesis and that studied parameters are statistically significant as all p-values below 0.05.

5.4.3. ANOVA results

To compare the experimental results between the different measurement sets for different date seeds percentage by sand weight, ANOVA is implemented as an effective tool to analyze data sets with different source of variations. The F-value is used to define whether the studied parameter is related with the response variable or not. Based on F-value, the statistical significance is determined by p-value that measures the confidence of the null hypothesis. If the P-value is above than the chosen significance level (0.05), the factor influence is not considered statistically significant but if the P-value is lower than 0.05, then the factor influence is statistically significant [39–41].

To test the robustness of measurements retrieved and significance of used measurements, one-way ANOVA test is used for studying the Bulk Sp. Gravity as the response variable at different date percentages as the factor, as shown in Table below. ANOVA assumptions include independent random samples, normally distributed populations and equal population variances. The calculated P-value demonstrated the significance of considered listed measurements. The F-value is found beyond the F-critical, this resulted in rejection of the null hypothesis and proves the depen-

Table 14
ANOVA, Percent of date seeds and Load (KN). (F crit = 4.3).

Parameters	F	P-value
Bulk Sp. Gravity Air	31635.47	3.07E-36
Bulk Sp. Gravity SSS	31901.99	2.8E-36
Bulk Sp. Gravity Water	24056.42	6.23E-35
Bulk Volume	35103.95	9.79E-37
Bulk Density (gm/ cm3)	646.8007	8.33E-18

Table 15
ANOVA, Percent of date seeds and Flow (mm). (F crit = 4.3).

Parameters	*F*	*P-value*
Bulk Sp. Gravity Air	32078.94	2.64E-36
Bulk Sp. Gravity SSS	32349.32	2.4E-36
Bulk Sp. Gravity Water	24662.14	4.74E-35
Bulk Volume	37079.19	5.36E-37
Bulk Density (gm/ cm3)	432.6549	5.86E-16

Table 11
Comparison of statistical analysis between raw data and after outliers elimination.

Parameters/Statistics	Raw data Mean	20% Trimmed Mean	Raw data Median	20% Trimmed Median	Raw data STD	20% Trimmed STD
Bulk Sp. Gravity Air	1257.11	1258.44	1259.80	1259.80	22.96	19.03
Bulk Sp. Gravity SSS	1259.08	1260.44	1261.15	1261.15	22.90	18.72
Bulk Sp. Gravity Water	762.28	763.25	766.10	766.10	15.72	12.76
Bulk Volume	496.81	496.69	496.60	496.60	8.14	5.43
Bulk Density (gm/cm^3)	2.53	2.53	2.53	2.53	0.02	0.02
Stability (kg)	2113.33	2120.30	2115.50	2115.50	187.81	134.25
Flow (mm)	13.44	13.32	13.2	13.20	1.74	1.32

Table 12
P-value of two tailed paired *t*-test.

Parameters	Bulk Sp. Gravity SSS	Bulk Sp. Gravity Water	Bulk Volume	Bulk Density (gm/cm^3)	Stability (kg)	Flow (mm)
Bulk Sp. Gravity Air	8.96E-06	5.64E-21	7.46E-20	1.80E-20	1.37E-08	2.33E-20
Bulk Sp. Gravity SSS		5.37E-21	6.72E-20	1.72E-20	1.41E-08	2.25E-20
Bulk Sp. Gravity Water			5.69E-17	6.92E-20	9.32E-11	1.1E-19
Bulk Volume				5.68E-21	1.26E-11	1.1E-20
Bulk Density (gm/cm^3)					6.25E-13	3.59E-10

Table 13
ANOVA, Percent of date seeds rep by wt. of sand, Bulk Sp. Gravity In (Air, SSS, Water).

Source of Variation	SS	df	MS	F	P-value	F crit
Percent of date seeds	6030.421	2	3015.21	8.624917	0.001269	3.354131
Bulk Sp. Gravity	1,966,730	2	983364.9	2812.885	4.65E-32	3.354131
Interaction	118.9778	4	29.74444	0.085083	0.986326	2.727765
Within	9439.01	27	349.593			
Total	1,982,318	35				

dence of Bulk Sp. Gravity results on used percentage of date seeds. P-values were statistically significant for the two parameters, the interaction was not statistically significant. The relation is considered statistically significant for p-values < 0.05 and insignificant for p-values > 0.05. The results in table 13 shows clearly the dependency in attained results for Bulk Sp. Gravity for different percent of date seeds. As a one-way ANOVA, the (low P-value = 0.001269 < 0.05, and F-Value = 8.624917 > Fcrit) shows the significance and dependency effect of used percent of date seeds on Bulk Sp. Gravity. As expected, the (high P-value = 0.986326 and F-value = 0.085083 < Fcrit) shows the strong relation between of Bulk Sp. Gravity measurements and percent of date seeds used in the mixture.

The Two-Way ANOVA differs from the One-Way ANOVA in considering more than two factors with multiple levels. A balanced design is used with same number of observations for each set of factors. This method demonstrate the existence of a significant influence by studied factors on the response variable (stability load and flow) and the interaction between these factors [42,43].

Tables 14, 15 display the resulting p-values of variance analysis of parameters effect, corresponding to each combination of factors on stability load and flow results. F-value and p-value calculated by variance analysis demonstrates the significance of each factor on the stability load and flow. A p-value lower than 0.05 indicates a statistically significant influence of studied factor on the response variable.

6. Conclusions

A total of 3 asphalt concrete mixes with different percentages by weight were prepared to investigate the effect of date seeds on HMA performance. The selected percentages were 7, 10, and 15%. It can be concluded that, HMA prepared using 7% activated date seeds showed the highest ratio of Retained Strength Index. This means that the resistance against moisture would be improved. The highest flow value was for HMA prepared using 15%. Marshall Stability, Flow and Air voids were good enough to keep asphalt pavement satisfactory for the design functions. Eventually, HMA prepared using 10% activated date seeds had the highest Marshall stability. Therefore, availability and workability with the mixture is very promising.

Further studies are needed to determine the durability of date seeds in asphalt pavement mixtures in certain aggressive environments such as fire and chemicals. Activated date seeds are better to be crushed particles extracted from grinder machine that is not so smooth. Finally, a complete set of experiments should be designed for a comprehensive check of HMA performance that includes tests on Rutting, Fatigue, and Indirect Tensile Strength. A statistical analysis using *t*-test and ANOVA is carried out to evaluate the effect of activated date seed on HMA performance measure. The statistical results implied the statistical significance of studied factors on Marshal Stability and Flow tests.

CRediT authorship contribution statement

Sharaf AlKheder: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software. **Mohammad Alkhedher:** Software, Validation. **Khaled A. Alshraiedeh:** Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table 1A
The results for the samples with partial replacement 7%, 10%, and 15% date seeds.

Percent of date seeds rep by wt. of sand		Bulk Sp. Gravity			Bulk Volume	Bulk Density (gm/cm^3)	Stability Data			Flow (mm)
		In Air	SSS	In Water			Load (KN)	Volume Corr	Stability (kg)	
7%	1	1272.1	1274.5	772.4	502.1	2.5336	17.32	1	1732	12
	2	1285.3	1286.8	781.7	505.1	2.5446	19.59		1959	11
	3	1269.9	1271.6	773.4	498.2	2.5490	19.62		1962	13
	4	1280.5	1282.6	782.7	499.9	2.5615	22.65		2265	15
	Average				2.5472				1980	13
10%	1	1264.7	1266.3	770.1	496.2	2.5487	22.87	2332	2425	13.8
	2	1218.7	1221.7	740.1	481.6	2.5305	18.17	1852	2018	13.12
	3	1246.6	1248.4	752.6	495.8	2.5143	21.98	2241	2330	13.28
	4	1254.9	1256.0	762.1	493.9	2.5407	20.73	2113	2197	11.04
	Average					2.5336			2242.5	12.81
15%	1	1247.9	1248.7	753.6	495.1	2.5205	14.88	2027	2209	17
	2	1214.4	1215.7	732.1	483.6	2.5111	18.30	1866	2034	15
	3	1243.8	1247.8	750.8	497.0	2.5026	21.15	2156	2242	12
	4	1286.5	1288.9	775.7	513.2	2.5068	19.49	1987	1987	15
	Average					2.5103			2118	15

Table 2A
Retained strength results for the samples with partial replacement.

Percent of date seeds rep by wt. of sand		Bulk Sp. Gravity			Bulk Volume	Bulk specific gravity of compacted material (gm/cm^3)	Stability Data	
		In Air	SSS	In Water			Load (KN)	Stress (kg/cm2)
7%	Wet 1	1974.2	1978.9	1191.3	787.6	2.5066	2500	30.64
	Wet 2	1955.6	1961.0	1174.0	787.0	2.4849	2000	24.51
	Wet 3	1964.9	1969.9	1182.6	787.3	2.4957	2250	27.57
	Dry 4	1938.7	1944.7	1166.6	778.1	2.4916	3150	38.60
	Dry 5	1941.8	1945.6	1166.2	779.4	2.4914	3750	45.96
	Dry 6	1940.2	1945.1	1166.4	778.7	2.4916	3450	42.28
	Average wet 1,2,3						2250	27.57
	Average Dry 4,5,6						3450	42.28
ICR = (2250/3450)*100 = 65.22%								
10%	Wet 1	1955	1958.7	1167.1	791.6	2.4697	2500	30.63
	Wet 2	1924.9	1932.3	1147.0	785.3	2.4512	2250	27.57
	Wet 3	1932.4	1939.2	1152.2	787.0	2.4554	2350	28.80
	Dry 4	1928.2	1933.2	1151.2	782.0	2.4657	3500	42.88
	Dry 5	1957.7	1962.3	1167.4	794.9	2.4628	4750	58.20
	Dry 6	1938.4	1953.1	1167.2	785.9	2.4665	4100	50.24
	Average wet 1,2,3						2367	29
	Average Dry 4,5,6						4117	50.44
ICR = (2367/4117)*100 = 57.5%								
15%	Wet 1	1966.8	1971.0	1165.5	805.5	2.4417	2250	27.57
	Wet 2	1946.2	1955.5	1151.7	803.8	2.4212	2000	24.51
	Wet 3	1956	1963.2	1158.6	804.6	2.4316	2150	26.35
	Dry 4	1949.0	1956.3	1155.7	800.6	2.4344	4250	52.08
	Dry 5	1963.8	1970.0	1160.9	809.1	2.4271	3750	45.96
	Dry 6	1956.4	1963.1	1158.3	804.8	2.4309	4100	50.25
	Average wet 1,2,3						2133.33	26.14
	Average Dry 4,5,6						4033.33	49.43
ICR = (2133.33/4033.33)*100 = 52.89%								

Table 3A
Retained Strength Test results.

DS replacement by wt. of sand	Samples	Load (kg)	Stress (kg/cm^2)	ICR %
7%	Average Wet	2250	27.57	65.22%
	Average Dry	3450	42.28	
10%	Average Wet	2367	29	57.5%
	Average Dry	4117	50.44	
15%	Average Wet	2133.33	26.14	52.89%
	Average Dry	4033.33	49.43	

References

[1] S.A. Tahami, M. Arabani, A.F. Mirhosseini, Usage of two biomass ashes as filler in hot mix asphalt, Constr. Build. Mater. 170 (2018) 547–556.

[2] S.S. Neham, Improving rutting resistance of hot mix asphalt by dates keneral powder, Iraqi J. Mech. Mater. Eng. 18 (2) (2018) 296–310.

[3] Annual Book of ASTM Standards, 1999. ASTM D-6373, Standard Specification for Performance Graded Asphalt Binder, pp: 1102–1136.

[4] FHWA, Towards Sustainable Pavement Systems: A Reference Document, U. S. Department of Transportation, Federal Highway Administration, Washington, DC, 2015.

[5] C. Plati, Sustainability factors in pavement materials, design, and preservation strategies, a literature review, Constr. Build. Mater. 211 (2019) 539–555.

[6] A.S.J. Smith, E.N. Ogork, A. Aboshio, Effect of particle size of date palm seed ash (DPSA) on concrete properties, J. Res. Inf. Civil Eng. 15 (1) (2018).

[7] G. I. Gunarani, S. P. Chakkravarthy, Experimental studies on effect of Date Seed Ash (DSA) on strength properties of cement sand mortar. In IOP Conference Series, Earth and Environmental Science. 80 (1) (2017) 012015.

[8] A. Mirhosseini, A. Kavussi, M. Kamali, M. Khabiri, A. Hassani, Evaluating fatigue behavior of asphalt binders and mixes containing Date Seed Ash, J. Civil Eng. Manage. 23 (8) (2017) 1164–1175.

[9] S.F. Mirhosseini, M. Khabiri, A. Kavussi, M. Kamali, Applying surface free energy method for evaluation of moisture damage in asphalt mixtures containing date seed ash, Constr. Build. Mater. 125 (2016) 408–416.

[10] D. Movilla-Quesada, A.C. Raposeiras, D. Castro-Fresno, D. Peña-Mansilla, Experimental study on stiffness development of asphalt mixture containing cement and Ca(OH)2 as contribution filler, Mater. Des. 74 (2015) 157–163.

[11] P. Lastra-González, A. Calzada-Pérez, D. Castro-Fresno, Á. Vega-Zamanillo, I. Indacoechea-Vega, Comparative analysis of the performance of asphalt concretes modified by dry way with polymeric waste, Constr. Build. Mater. 112 (2016) 1133–1140.

[12] L. Chai, C.L. Monismith, J. Harvey, Re-Cementation of Crushed Material in Pavement Bases, California Department of Transportation, Sacramento, CA, 2009.

[13] NCPTC, 'Sustainable, Concrete Pavements, National Concrete Pavement Technology 2012 Center, Ames, IA.

[14] J.S. Chen, S.H. Wei, Engineering properties and performance of asphalt mixtures incorporating steel slag, Constr. Build. Mater. 128 (2016) 148–153.

[15] A.S. Brand, J.R. Roesler, Steel furnace slag aggregate expansion and hardened concrete properties, Cem. Concr. Comp. 60 (2015) 1–9.

[16] A. Jamshidi, K. Kurumisawa, T. Nawa, M.O. Hamzah, Analysis of structural performance and sustainability of airport concrete pavements incorporatingblast furnace slag, J. Cleaner Prod. 90 (2015) 195–210.

[17] M. Arabani, S. Tahami, M. Taghipoor, Laboratory investigation of hot mix asphalt containing waste materials, Road Mater. Pavem. Des. 18 (3) (2017) 713–729.

[18] R. Maharaj, C. Maharaj, A. Hosein, Performance of waste polymer modified road paving materials, Prog. Rubber Plast. Recycl. Technol. 34 (1) (2018) 19–33.

[19] H. Shafabakhsh, M. Sadeghnejad, Y. Sajed, Case study of rutting performance of HMA modified with waste rubber powder, Case Stud. Constr. Mater. 1 (2014) 69–76.

[20] A. Simone, F. Mazzotta, S. Eskandarsefat, C. Sangiorgi, V. Vignali, C. Lantieri, G. Dondi, Experimental application of waste glass powder filler in recycled dense-graded asphalt mixtures, Road Mater. Pavem. Des. 20 (3) (2019) 592–607.

[21] T. Van Dam, J. Harvey, S. Muench, K. Smith, M. Snyder, I. Al-Qadi, A. Kendall, Towards Sustainable Pavement Systems: A Reference Document, U. S. Department of Transportation, Federal Highway Administration, 15-002, Washington, DC, 2015.

[22] R. Siddique, G. Singh, Utilization of waste foundry sand (WFS) in concrete manufacturing, Resour. Conserv. Recycl. 55 (2011) 885–892.

[23] H.M. Basar, N.D. Aksoy, The effect of waste foundry sand (WFS) as partial replacement of sand on the mechanical, leaching and micro-structural characteristics of ready-mixed concrete, Constr. Build. Mater. 35 (2012) 508–515.
[24] G.G. Prabhu, J.H. Hyun, Y.Y. Kim, Effects of foundry sand as a fine aggregate in concrete production, Constr. Build. Mater. 70 (2014) 514–521.
[25] O.Y. Marzouk, N. Vulcano-greullet, L. Cantegrit, L. Friteyre, A. Jullien, Recycling foundry sand in road construction–field assessment, Constr. Build. Mater. 61 (2014) 69–78.
[26] A. Jamshidi, K. Kurumisawa, T. Nawa, T. Igarashi, Performance of pavements incorporating waste glass: the current state of the art, Renew. Sustain. Energy Rev. 64 (2016) 211–236.
[27] M.M. Disfani, A. Arulrajah, M.W. Bo, N. Sivakugan, Environmental risks of using recycled crushed glass in road applications, J. Cleaner Prod. 20 (1) (2012) 170–179.
[28] F. Navarro, M. Gámez, Influence of crumb rubber on the indirect tensile strength and stiffness modulus of hot bituminous mixes, J. Mater. Civil Eng. 24 (6) (2012) 715–724.
[29] S. Priya, D. Nagarajan, Exploratory study on partial replacement of coarse aggregate by talipot palm seed, Int. J. Civil Eng. Technol. 8 (7) (2017) 208–213.
[30] US Army Corps (2000) Hot-Mix Asphalt Paving Handbook. USA: US Army Corps of Engineers, AC150/5370–14A Appendix 1 (No. AC 150/5370-14A.
[31] A. Kumar, W. Goetz, Asphalt hardening as affected by film thickness, voids and permeability in asphaltic mixtures, Proc. Assoc. Asphalt Paving Technol. 46 (1977) 571–605.
[32] S. Mamlouk, J. Zaniewski, Materials for Civil and Construction Engineers, second ed., Upper Sadle River, New Jersey, Pearson Prentice Hall, 2006.
[33] J.H. Willenbrock, A manual for Statistical Quality Control of Highway Construction, Vol. II, FHWA, National Highway Institute, Washington, D.C., 1975.
[34] D. Gupta, A. Peterson, Statistical Methods for Materials Testing", Minnesota Department of Transportation, MN/RC 2009-41, National Technical Information Services, Springfield, Virginia, 2009.
[35] M.A. Khasawneh, Investigation of factors affecting the behaviour of subgrade soils resilient modulus using robust statistical methods, Int. J. Pavement Eng. 20 (10) (2019) 1193–1206.
[36] N.I. Shbeeb, M.A. Khasawneh, A.A. Al-Omari, The development of a predictive tool to reduce experimentation time for the polishing and frictional evaluation of asphalt pavement surfaces, Constr. Build. Mater. 186 (2018) 740–750.
[37] W. Wang, Y. Cheng, G. Tan, Design optimization of SBS-modified asphalt mixture reinforced with eco-friendly basalt fiber based on response surface methodology, Materials 11 (8) (2018) 1311.
[38] AASHTO, Implementation Manual for Quality Assurance, AASHTO Highway Subcommittee on Construction, Washington, D.C, 1996.
[39] B. McCabe, S. AbouRizk, J. Gavin, Time of sampling strategies for asphalt pavement quality assurance, J. Constr. Eng. Manage. 128 (1) (2002) 85–89.
[40] R.G. O'Brien, A general ANOVA method for robust tests of additive models for variances, J. Am. Stat. Assoc. 74 (1979) 877–880.
[41] S. Hussan, M.A. Kamal, I. Hafeez, D. Farooq, N. Ahmad, S. Khanzada, Statistical evaluation of factors affecting the laboratory rutting susceptibility of asphalt mixtures, Int. J. Pavement Eng. 20 (4) (2019) 402–416.
[42] S. Aflaki, M. Memarzadeh, Using two-way ANOVA and hypothesis test in evaluating crumb rubber modification (CRM) agitation effects on rheological properties of bitumen, Constr. Build. Mater. 25 (4) (2011) 2094–2106.
[43] G. Saha, K.P. Biligiri, Cracking performance analysis of asphalt mixtures using response surface methodology: experimental investigations and statistical optimization, Mater. Struct. 50 (33) (2017) 1–12.