Al-Qadisiyah JournalFor Engineering Sciences 18 (2025) 054–064

Contents lists available at: http://qu.edu.iq

Al-Qadisiyah Journal for Engineering Sciences

Journal homepage: https://qjes.qu.edu.iq

Research Paper

Effects of breakage of construction and demolition waste materials (C&DWMs) at asphalt mixtures

Abbaas I. Kareem [1,2]✉, ***Estabraq N. Ezzat*** [1], ***Teba T. Khaled*** [1,3], ***and Rwayda Al-Hamd*** [4]

[1] *Highway and Transportation Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq.*
[2] *Department of Civil Engineering, Curtin University, Perth, Australia.*
[3] *Department of Civil Engineering, Faculty of Engineering, Universiti Malaya, 50603 Kuala Lumpur, Malaysia.*
[3] *School of Applied Sciences, Abertay University, Dundee, UK.*

ARTICLE INFO

Article history:
Received 16 April 2024
Received in revised form 29 July 2024
Accepted 12 December 2024

Keywords:
C&DWMs breakage
Hot mix asphalt
Mixing and compaction
ANOVA
Resilient modulus
Damage analysis

ABSTRACT

This study aims to evaluate the effects of breakage of construction and demolition waste materials (C&DWMs) on aggregate gradation, aggregate characteristics, moisture damage, and resilient modulus using Hot Mix Asphalt (HMA). Asphalt mixtures containing 0%, 25%, 50%, and 75% C&DWM wastes were investigated. The characteristics of C&DWMs were investigated through the surface inspection, the particle size distribution, the water absorption, and the density tests. The indirect tensile strength test, the tensile strength ratio test, and the indirect tensile stiffness modulus test were performed. Moreover, the analysis of variance (ANOVA) and damage analysis were also performed. The results showed that the amount of optimum asphalt content increases as the dosage of C&DWMs increases. The change in gradation has led to a variation in the properties of coarse, fine, and combined aggregates. The breakage of C&DWMs during mixing and compaction processes contributes to the redistribution of aggregate particles after mixing and compaction processes. The breakage has led to better resilient modulus and lower water stability exhibited by C&DWMs mixes than control mixes. The damage analysis and ANOVA testing indicate that asphalt mixtures with no more than 50% C&DWMs have a performance like that of the control mix. In this regard, the pavement section with 0%, 25%, and 50% of C&DWMs achieved a design life of around 19 years. Although the results were encouraging, the C&DWMs asphalt mixtures require more investigation in future studies. This would elevate the use of C&DWMs in the pavement industry and promote more sustainable asphalt mixtures.

1. Introduction

Nowadays, massive construction actions create enormous quantities of construction and demolition waste materials (C&DWMs) [1, 2, 3]. Such enormous quantities of C&DWMs can produce several concerns to the environment, [3, 4, 5, 6, 7, 8] economic, [8, 9, 10], and community sectors [11]. Therefore, the suitable approach to obviate these environmental and social concerns is through reusing and recycling the C&DWMs. This approach can provide relief for the shortage of natural aggregates in certain regions [12], ease the following of C&DWMs in society [9], and lead to several ecological and monetary benefits [13]. Therefore, many scholars have inspected the use of recycled solid materials such as C&DWMs to achieve the optimal use of recycled materials and promote sustainable pavement construction [14, 15, 16]. The level of use of the C&DWMs in the evolving states is still far from that of the normal worldwide level in urbanized states. In this regard, the C&DWMs have been recycled in many pavement applications. For instance, Hot Mix Asphalt (HMA) [17], base layers, subbase layers [18, 19], and filling material [20]. However, recycling C&DWMs still experiences some problems, such as inconsistency within the final product. The inconsistency may come from the type of C&DWMs used [21, 3] or due to the breakage of C&DWMs as a result of the mixing and compaction processes, which produces a change in the asphalt mixture gradation. In this regard, many previous studies examined the impact of the variability of C&DWMs that comes from the type of the source product and from the materials, types, and proportions that form the C&DWMs [22, 8]. On the other hand, only limited efforts were carried out to examine the other causes of variability, which originate from mixing and compaction processes. In this field of research, previous researchers mentioned that a change in the gradation of C&DWM asphalt mixtures after mixing/compaction is expected without analyzing or studying this change. Scholars stated that C&DWMs could break due to mixing and compaction [23, 24]. Another study indicated that a variation in aggregate gradation might take place after mechanical compaction [24]. A different investigation documented growth in the dosage of fine particles that passed the 4.75 mm sieve after mixing and compaction [25]. Another study revealed that the C&DWMs can be broken because of compaction/traffic loading, which changes the properties of asphalt mixtures made with C&DWMs [8]. A different study stated that the gradation of C&DWMs tended to be changed after the mechanical mixing and compaction. However, the resulting gradation remains within the limits indicated by the standards [26]. Therefore, there is no doubt that a change in gradation of C&DWMs-mix is produced after the mixing and compaction, and thus, a part of coarse particles (those greater than 4.75 *mm*) of C&DWMs will pass through a 4.75 *mm* sieve. As a result, it is vital to examine the impact of breakage of C&DWMs on C&DWMs properties and C&DWMs-asphalt mixtures properties. This is imperative to better understand the effects of breakage of C&DWMs on C&DWMs mixture's behaviour, develop future models to predict the breakage of different C&DWMs, and identify new strategies to mitigate the breakage of recycled materials used in asphalt pavement construction.

* *Corresponding Author.*
E-mail address: abbaaskareem@uomustansiriyah.edu.iq ; Tel: (+964 773 820-6543) (Abbaas Kareem)

https://doi.org/10.30772/qjes.2024.148821.1202

Nomenclature:

List of variables:

$CDWMs$	Construction And Demolition Waste Materials
TS_2	The conditioned set tensile strength (kPa)
TS_1	The unconditioned set tensile strength (kPa)
ITS	The tensile strength (kPa).
P	The peak force (kN)
H	The asphalt specimen height (mm)
D	The asphalt specimen diameter (mm)
RM	The resilient modulus (MPa)
P	The maximum applied load (N)
V	The Poisson ratio which is 0.4
H_r	The recovered horizontal deformation (mm)
hc	The height of the specimen (mm)

Greek Symbols:

t	Time, (s)
τ	Period, (s)
m^3	Volume
μ	Micro (10^{-6})
C°	Celsius temperature

Sub Scripts:

a	After mixing
b	Before mixing
$*, **$	ANOVA included mixtures

For example, the breakage of C&DWMs leads to more uncoated surfaces or not fully coated surfaces with asphalt binder. Consequently, evaluating the resistance of C&DWMs mixtures to moisture damage is crucial. In this study, four asphalt mixtures were made with 0%, 25%, 50%, and 75% C&DWMs respectively. Marshall mixes design was used to determine the optimum binder content (OBC) of C&DWMs mixtures. Marshall testing, moisture sensitivity test, resilient modulus test, and damage analysis were investigated. ANOVA testing was also carried out to assess the findings. This work contributes to the field of sustainable asphalt pavements using recycled materials, increasing the level of C&DWMs recycling, and reducing the rates of natural aggregate consumption in pavement construction.

2. Materials

The materials in this investigation are commonly used in the asphalt paving industry. Asphalt mixtures with 0%, 25%, 50%, and 75% C&DWMs were prepared and evaluated in accordance with Australian requirements [27].

2.1 Aggregates

Two types of aggregates are used in this study. The C&DWMs are from a main provider in the Perth metropolitan area. The natural aggregates (NAs) were crushed granite, which was obtained from a local contractor. The NAs were satisfied with all Australian requirements for pavement construction [28]. The C&DWMs exhibited a lower density $(2.233\ t/m^3)$ when compared to that of natural aggregates $(2.662\ t/m^3)$. In addition, the fine and coarse particles of C&DWMs did not satisfy the water absorption limit specified in Australian standards for fine and coarse aggregates respectively [28, 29]. The absorption of C&DWMs was %6.9 for fine particles and %5.5 for coarse particles. On the other hand, the percentage of water absorption of the fine and coarse particles of NAs were %0.6 and %0.5 respectively. Additionally, the coarse C&DWMs did not comply with the Los Angeles (LA) requirements compared with NAs [29, 30]. According to Australian standard AS 1141.23, an aggregate sample should exhibit an LA value of less than %35. However, the C&DWMs exhibited a value of %41.4, while the NAs sample showed a better resistance to abrasion at an LA value of %24.1. Taking into consideration these findings, only the coarse fractions of C&DWMs were used in this study as a partial replacement for NAs. The target gradation of aggregates used is shown in Table 1 as per the Australian standard [27]. In addition, Table 2 presents the four asphalt mixes made and evaluated in this investigation, and their contents of NAs and C&DWMs waste aggregates.

2.2 Asphalt binder and mineral filler

Class 320 binder was chosen for this investigation. It had a penetration reading of 51 at 25 $C°$, a viscosity of 0.547 $Pa.s$ at 135 $C°$, a flashpoint of more than 300 $C°$, and a dynamic viscosity of 320 $Pa.s$ at 60 $C°$. Additionally, the natural dust filler is used in all asphalt mixtures. The natural dust filler has an apparent density of 2.452 (t/m^3) [31].

3. Testing protocols

The testing program for asphalt mixtures with C&DWMs consisted of the following: the Marshall testing, aggregate testing (i.e. PSD test, density test, and absorption test), the TSR test, the ITSM test, besides the damage analysis. Asphalt mixture type AC14 was made in this investigation. According to Australian standards and practices, this type of AC14 mix is suitable for the manufacture of wearing and intermediate layers. Asphalt specimens with 0%, 25%, 50%, and 75% of C&DWMs are prepared in the laboratory using the Marshall procedure, which is applied to asphalt specimens with aggregates not exceeding 20 mm nominal maximum size [27]. The Marshall procedure is used to determine the optimum asphalt content (OAC) of different asphalt mixtures.

3.1 Surface inspection of NAs and C&DWMs

It is important to inspect the surface inspection of NAs and C&DWMs. This importance relates to the fact that the nature of the surface (i.e. porosity, roughness, irregularity, etc.) has a significant impact on the absorption of water/asphalt and the number of frictional forces generated. The surface inspection is carried out using an optical microscope with a digital camera. The device was located at the Material Research Centre at Curtin University, Western Australia. This device has the capability of taking digital images using appropriate software. In Fig. 1 the optical microscope in this investigation is shown.

3.2 Marshall mix design

As mentioned earlier, the optimum asphalt content was measured using the Marshall method [27]. During preparation, each specimen was subjected to 75 $(blows/face)$. The influence of mechanical compaction is evaluated in this study to check its effects on C&DWMs-asphalt mixtures.

Figure 1. The optical microscope used in this study.

3.3 Gradation of C&DWMs- asphalt mixtures

Gradation of bituminous mixes with C&DWMs before and after the mixing processes is measured and evaluated, Table 1. The gradation before denotes the original gradation of designed asphalt mixtures with C&DWMs. Keeping in with this, the gradation after the mixing and compaction denotes aggregate gradation after the breakage of some C&DWMs during mixing and compaction. The particle size distribution test is performed after the bitumen binder is extracted using the appropriate solvent [32]. The PSD test was repeated three times, and the average result was considered. The following procedure was considered to measure the amount of particle breakage of C&DWMs-asphalt mixtures. In the beginning, the sample is conditioned in an oven until the bitumen becomes soft. Then, an appropriate solvent was added to the sample. After that, the sample is subjected to centrifugal force to separate the asphalt film from aggregates. The centrifuge device is capable of rotating the bowl in the region of 3000 to 3500 rpm. This is important to separate the asphalt from all surfaces of aggregate particles without producing any further breakage.

Table 1. The selected graduation of aggregates.

Sieve size (*mm*)	19.00	13.20	09.50	06.70	04.75	02.36	01.18	00.60	00.30	00.15	00.075
Passing, (%)	100.00	93.00	77.00	62.50	53.50	35.50	28.50	20.50	14.00	08.50	05.00

The final product is then sieved to calculate the number of aggregates retained on each sieve.

3.4 Aggregates testing

The relative density and absorption are two critical properties of aggregates used in pavement construction. In this study, these two properties were checked according to Australian practices before and after mixing and compaction [28, 29]. The C&DWMs demonstrated lower relative density and greater water absorption than that of control aggregates. The lower the density and the higher the water absorption rate, the more the porosity of aggregates and the easier it is to break the connection between the binder and aggregates, Table 2. In this field, the lower density and higher water absorption rate can translate into a higher asphalt content (i.e. higher cost). Therefore, it is crucial to evaluate the variation in relative density and water absorption of C&DWMs due to mixing and compaction processes.

Table 2. Types of asphalt mixtures.

Mix type C&DWMs waste	**Dosage of natural fine aggregates**	**Dosage of coarse C&DWMs**	**Dosage of coarse NAs**
00% (Control)	100 %	00 %	100 %
25%	100 %	25 %	75 %
50%	100 %	50 %	50 %
75%	100 %	75 %	25 %

3.5 Moisture sensitivity test

The damage of asphalt mixtures in the presence of water is a challenge for flexible pavement engineers [33]. Therefore, four asphalt mixtures were prepared and tested to evaluate their resistance to water sensitivity. The TSR test was performed according to AG: $PT/T232$ standard [34].
Each asphalt mixture consisted of six specimens made with 0%, 25%, 50%, and 75% of C&DWMs respectively. The asphalt samples were made using a gyratory compactor to have a diameter of 100 *mm* and a height of 65 *mm*. Two sets of samples were tested: unconditioned (i.e. dry) and conditioned (i.e. wet). The wet group was exposed to a cycle of freeze-thaw. The tensile strength of the dry and wet specimens has been evaluated at a testing temperature of 25 *C*. The loading rate during testing was 50mm/min and the tensile strength was calculated by Eq. 1. The moisture-induced damage is measured using the tensile strength ratio (TSR) which represents the percentage of the conditioned (wet) to unconditioned (dry) indirect tensile strength, which is called, is used as a measure to the of asphaltic mixtures. The tensile strength ratio can be found utilizing Eq.1:

$$TSR = \frac{TS_2}{TS_1} \times 100 \tag{1}$$

3.6 Resilient modulus (RM) test

The Indirect Tensile Stiffness Modulus (ITSM) test was used by the (AS/NZS 2891.13.1) protocol [35, 36] to find the resilient modulus (RM). In line with the test procedure, the specimen must have uniform curved surfaces, and have dimensions as shown in Table 3. In addition, during testing the test conditions shown in Table 4 shall be applied. The load is applied vertically in the direction of vertical diameter, while the resultant horizontal displacement is measured. The linear variable displacement transducers (LVDTs) are used to compute horizontal displacement accurately. The RM for each test loading was established using Eq.3. Furthermore, the indirect tensile strength of the asphalt mixture is calculated using Eq.2.

$$TSR = \frac{2P}{HD\pi} \times 10^6 \tag{2}$$

$$RM = P \times \frac{V + 0.27}{H_r \times hc} \tag{3}$$

Table 3. Specimen dimensions made for resilient modulus test.

Maximum Particle Size of Aggregates (*mm*)	**Diameter** (*mm*)	**Height** (*mm*)
≤ 20	100 ± 2	$35 - 70$

Table 4. Conditions during the ITSM test.

Parameter	**Values**
Rise time (10% to 90%), $\tau(ms)$	40.0 ± 05
Pulse repetition period (10% to 10%), $\tau(ms)$	03.0 ± 05
Recovered horizontal strain, (μs)	50.0 ± 20
Temperature, C°	20 ± 0.50

3.7 ANOVA testing

One-way analysis of variance ANOVA was conducted to examine the relationship between the independent variables, such as the C&DWMs dosages, and dependent variables, such as TSR and resilient modulus. ANOVA tests are used to investigate the difference between two or more groups to decide if these groups are statically similar or different. This study uses a 0.05 significance level is used to test the statistical importance. If the tested groups are significantly different, the null hypothesis is rejected and not supported.

3.8 Marshall testing and surface inspection

The effect of adding 0%, 25%, 50%, and 75% of C&DWMs at Marshall parameters of asphalt mixtures is shown in Fig. 2. It can be seen that the asphalt mixtures with C&DWMs exhibited lower density Fig. 2a, and higher stability [Fig. 2b, than that of the control mix made with 100% natural aggregates. This finding can be explained by the lightweight and porous irregular surfaces of C&DWMs compared with natural aggregates respectively. The lightweight produces lower density while the rough surface textures produce higher stability. The flow results shown in Fig. 2c reveal that the control mix exhibited lower flow values than that of C&DWMs-asphalt mixtures. The higher asphalt content with C&DWMs may explain these results. During mixing and after compaction, the C&DWMs break down into smaller particles, which adds additional surfaces that need to be shielded with hot asphalt. Therefore, it is common that C&DWMs-asphalt mixtures absorb more asphalt binder than that of the control mix with 100% natural aggregates. Figure 2d shows the voids in mineral aggregates (VMA) results of asphalt mixtures made with 0%, 25%, 50%, and 75% of C&DWMs. It can be seen that the addition of C&DWMs leads to a decrease in the values of VMA. The breakage and irregular shapes of C&DWMs can reduce the overall available space within the mix structure. In addition, Fig. 2e presents the results of voids filled with bitumen (VFB). In general, the addition of C&DWMs leads to a decrease in the values of VFB. The reason behind this finding may be explained as follows. The rougher surface texture of C&DWMs besides the breakage phenomenon increases the surface area. The more surface area, the more the bitumen is required to achieve the same rate of coating as in the case of virgin aggregates. Therefore, a lower VFB is obtained in the case of asphalt mixtures with C&DWMs. Additionally, the Marshall quotient values shown in Fig. 3 revealed that adding C&DWMs leads to poorer Marshall stiffness of the mix. In this regard, the lower resistance of C&DWMs to abrasion can explain such an outcome. The mix made with 100% natural aggregates exhibited lower optimum asphalt content (OAC) compared to mixes with 25%, 50%, and 75% of C&DWMs. The rough surface textures of C&DWMs, Fig. 4 as compared with smooth textures of natural aggregates Fig.4b, besides the breakage of C&DWMs through the mixing and compaction Fig. 5, are the reason behind this phenomenon.

3.9 Results of particles size distribution (PSD) tests

Tables 5, 6, and 7, as well as Figs. 6, 7, and 8 respectively show PSD test results of the mixtures made with 0%, 25%, 50%, and 75% of C&DWMs. It can be denoted that the dosage of coarse particles that remained on the 4.75 *mm* sieve decreased as the percentage of the C&DWMs grew in the mixture. While the dosage of fine fractions that passed 4.75 *mm* increased as the percentage of the C&DWMs improved in the mix. This is because of the breakage of C&DWMs due to the mixing and compaction procedures as illustrated in Fig. 5. It should be mentioned that the tolerance boundaries in the percentage of passing by mass delivered in Australian specification were met only after mixing and before compaction [8]. Table 8 shows the typical accepted tolerances for differences from selected gradation after the mixing process. All asphalt mixtures met these tolerances limits after mixing and before compaction. However, after the mixtures were compacted, the PSD test showed that these tolerances were

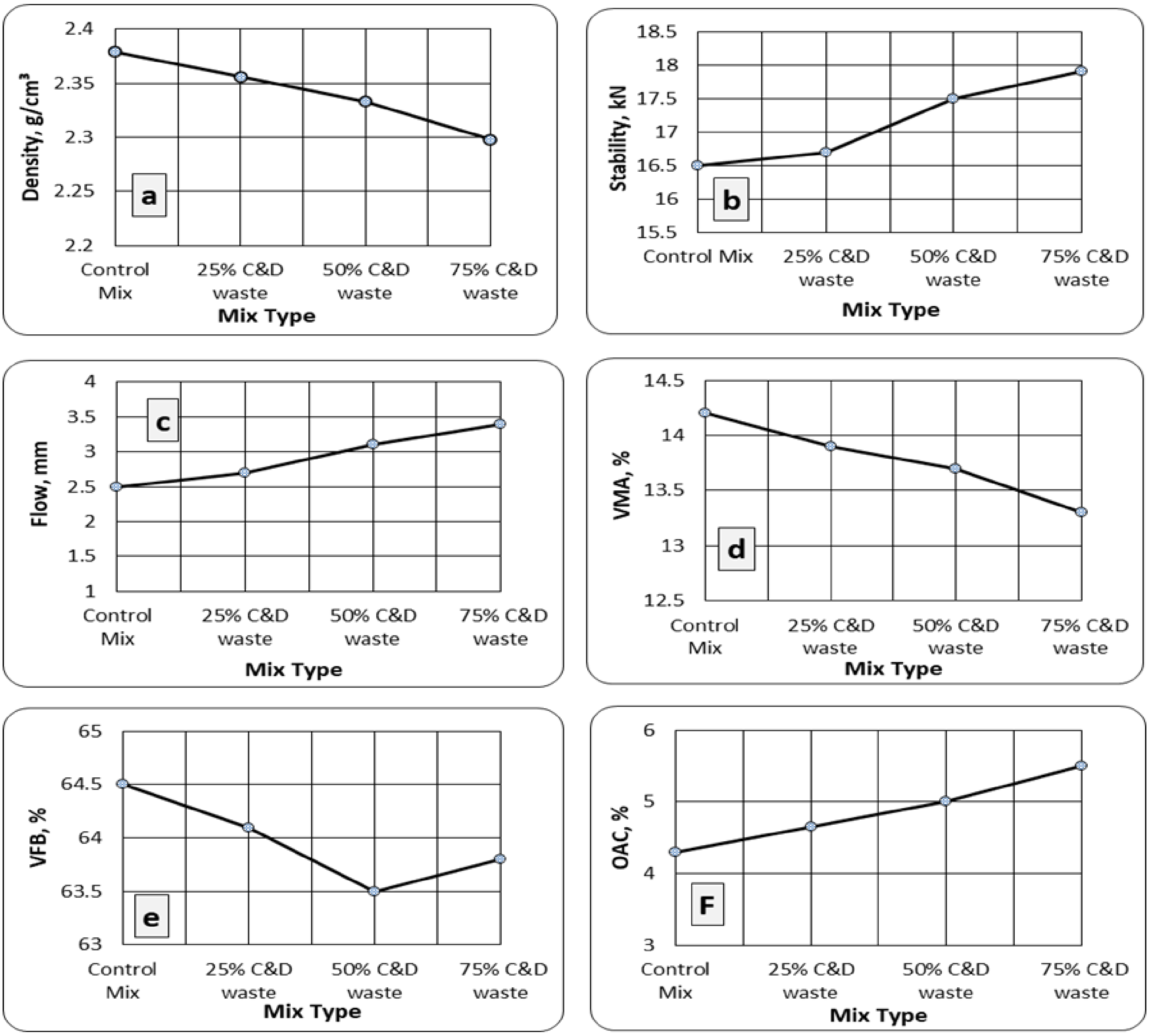

Figure 2. Marshall properties of asphalt mixtures.

Table 5. The PSD after mixing and compacting.

Sieve size (*mm*)	**Specification limits**	**Gradation**[b]	Gradation[a]			
			0% C&DWMs mix	25% C&DWMs mix	50% C&DWMs mix	75% C&DWMs mix
19.00	100.00	100.00	100.00	100.00	100.00	100.00
13.20	90-100	93.00	93.50	95.20	94.30	94.70
09.50	72-83	77.00	78.00	80.10	81.90	82.50
06.70	54-71	62.50	64.60	68.10	68.20	69.80
04.75	43-61	53.50	53.30	57.70	59.20	60.30
02.36	28-45	35.50	36.50	42.60	43.80	43.80
01.18	19-35	28.50	27.60	31.50	31.80	32.50
00.60	13-27	20.50	20.40	23.60	23.00	23.80
00.30	09-20	14.00	13.70	15.10	15.30	15.30
00.15	06-13	08.50	08.40	09.20	08.90	08.80
00.075	04-70	05.00	05.03	05.05	05.04	05.05

The superscribe ([a]) refers to gradation after mixing and compaction, and ([b]) refers to Gradation before mixing and compaction.

exceeded only for mixtures made with C&DWMs. This is evidence for the percentage of passing by mass for fractions 6.7 *mm*, 4.75 *mm*, 2.36 *mm*, 1.18 *mm*, 0.6 *mm*, 0.3 *mm*, and 0.15 *mm* respectively, as shown in Table 6. Generally, the percentage of retained coarse fractions of mixtures made with C&DWMs decreased as the dosage of C&DWMs increased in the mix. The percentage of fine fractions of C&DWMs was raised as the dosage of C&DWMs grew in the mix. These outcomes can be seen in Table 7. This finding proves that the main reason for the change in the gradation after the mixing and compaction methods is the breakage of C&DWMs and not the breakage of NAs. There is also another evidence of this, which is the visual inspection shown in Fig. 5, as the breakage of aggregates occurred only in the mixes made with C&DWMs.

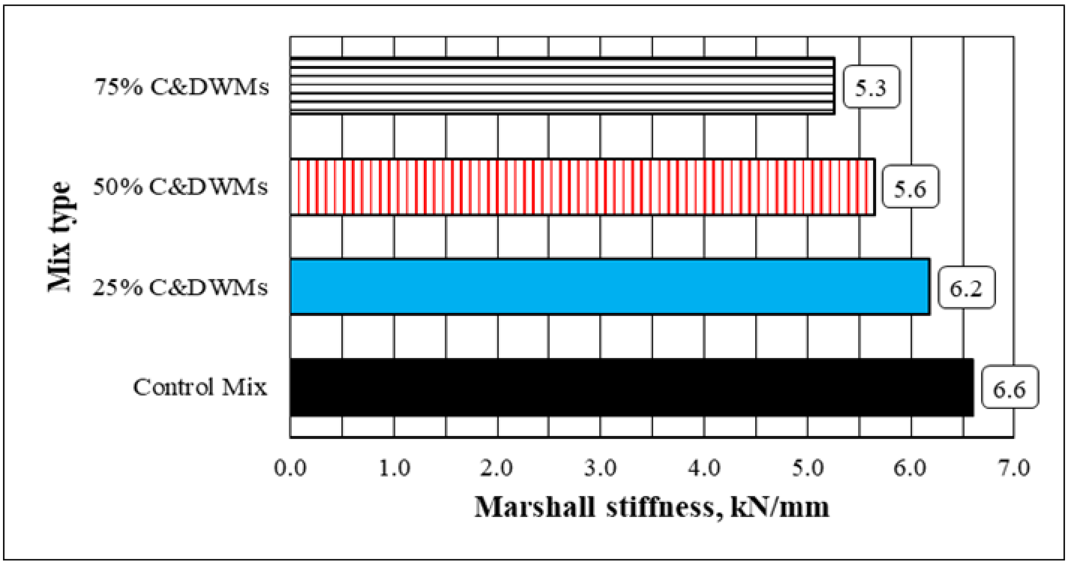

Figure 3. Marshall stiffness of asphalt mixtures.

Table 6. The results of % passing before and after the mixing and compaction.

Sieve size (*mm*)	(%) **Passing**[b]	The change in the % passing[a] (%)			
		0% C&DWMs mix	25% C&DWMs mix	50% C&DWMs mix	75% C&DWMs mix
19.00	00.00	00.00	00.00	00.00	00.00
13.20	93.00	00.54	02.37	01.40	01.83
09.50	77.00	01.30	04.03	06.36	07.14
06.70	62.50	03.36	08.96	09.12	11.68
04.75	53.50	-00.37	07.85	10.65	12.71
02.36	35.50	02.82	20.00	23.38	23.38
01.18	28.50	-03.16	10.53	11.58	14.04
00.60	20.50	-00.49	15.12	12.20	16.10
00.30	14.00	-02.14	07.86	09.29	09.29
00.15	08.50	-01.18	03.53	04.71	08.24
00.075	05.00	00.60	01.00	00.80	01.00

The superscribe ([a]) refers to % passing after mixing and compaction, and ([b]) refers to % passing before mixing and compaction.

Table 7. The results of % retained before and after mixing and compaction.

Sieve size (*mm*)	(%) **Passing**[b]	The percentage of retained∗*a*			
		0% C&DWMs mix	25% C&DWMs mix	50% C&DWMs mix	75% C&DWMs mix
19.00	00.00	00.00	00.00	00.00	00.00
13.20	07.00	06.50	04.80	05.70	05.30
09.50	16.00	15.50	15.10	12.40	12.20
06.70	14.50	13.40	12.00	13.70	12.70
04.75	09.00	11.30	10.40	09.00	09.50
02.36	18.00	16.80	15.10	15.40	16.50
01.18	07.00	08.90	11.10	12.00	11.30
00.60	08.00	07.20	07.90	08.80	08.70
00.30	06.50	06.70	08.50	07.70	08.50
00.15	05.50	05.30	06.30	06.40	06.10
00.075	03.50	03.37	03.75	03.86	04.15
Pan	05.00	05.03	05.05	05.04	05.05

The superscribe ([a]) refers to % retained after mixing and compaction, and ([b]) refers to % retained before mixing and compaction.

Table 8. The typically accepted tolerances for differences from selected gradation after mixing [27].

Sieve size (*mm*)	19.00	13.20	09.50	06.70	04.75	02.36	01.18	00.60	00.30	00.15	00.075
Tolerances in the % passing by mass	±7					±5		±4		±2.5	±1.5

Table 9. Effect of C&DWMs dosage on TSR.

Source of variation	**Sum of squares, (SS)**	**Degree of freedom, (df)**	**Mean squares, (MS)**	**F-value**	**P-value**	**F critical**
Between Groups	14970.02	01	14970.02	31.67163	0.000	4.30095
Within Groups	10398.59	22	472.6632	—-	—-	—-
Total	25368.61	23	—-	—-	—-	—-

3.10 Aggregates properties

ıl mixing and compaction lead to an unavoi-
ation caused by the breakage of C&DWMs,

Table 10. The effects of C&DWMs dosage on resilient modulus*.

Source of variation	Sum of squares, (SS)	Degree of freedom, (df)	Mean squares, (MS)	F-value	P-value	F critical
Between Groups	1378457.00	03	459485.6	19.81267	0.000464	4.066181
Within Groups	0185532.00	08	023191.5	—	—	—
Total	1563989.00	11	—	—	—	—

*This one-way ANOVA included mixtures with 0%, 25%, 50% and 75% C&DWMs.

Table 11. The effects of C&DWMs dosage on resilient modulus**.

Source of variation	Sum of squares, (SS)	Degree of freedom, (df)	Mean squares, (MS)	F-value	P-value	F critical
Between Groups	049816.22	2	24908.11	0.939728	0.441535	5.143253
Within Groups	159034.00	6	26505.67	—	—	—
Total	208850.20	8	—	—	—	—

**This one-way ANOVA included mixtures with 0%, 25%, and 50% C&DWMs.

Table 12. Details of pavement section used and layer properties.

Type	Thickness, (cm)	Type of Mix	Resilient modulus,(Mpa)	Poisson's ratio
Asphalt	7.5	00%C&DWMs	4977	0.4
		24%C&DWMs	4804	
		50%C&DWMs	4938	
		75%C&DWMs	4138	
Base	20	—	350	0.35
Subbase	30	—	250	0.35
Subgrade	—	—	150	0.45

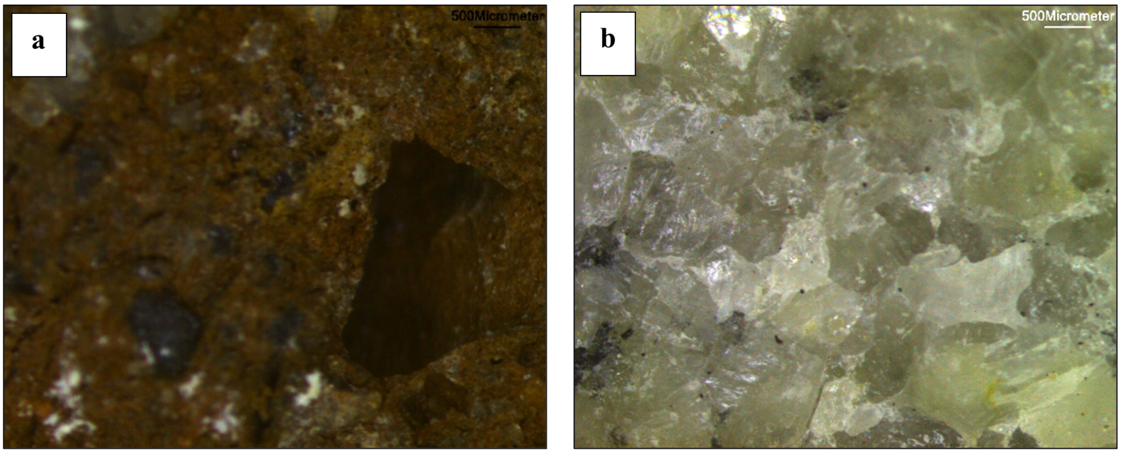

Figure 4. Surface examination of (a) C&DWMs, and (b) NAs using an optical microscope.

Fig. 5, and Tables 5, 6, and 7, respectively. Therefore, the coarse C&DWMs are broken and pass via a 4.75 *mm* sieve. This phenomenon leads to a rise in the percentage of fine aggregates in the combined aggregates mixture after mixing and compaction. In the same way, this leads to a decrease in the dosage of coarse aggregates in the combined aggregates mixtures after mixing and compaction. Accordingly, the breakage of C&DWMs will lead to a change in the Density of Coarse (DC) aggregates, and the Density of Fine (DF) aggregates, as shown in Fig. 9. It can be seen that the DC aggregates after the mixing and compaction were higher than before mixing and compaction, Fig. 9a. While the DF aggregates after the processes of mixing and compaction were lower than those before the mixing and compaction. This is due to a decrease in the dosage of C&DWMs in the coarse aggregate mixture, and an increase in the dosage of C&DWMs in the fine aggregate mixture after mixing and compaction procedures. For the same reason, the percentage of water absorption (WA) of the coarse aggregate mixture (natural + C&DWMs) was found to be less than that before the mixing and compaction procedures, Fig. 10a. On the other front, the WA of the fine aggregate mixture (natural + C&DWMs) was found to be more than that before the mixing and compaction procedures, Fig. 10b. This finding is considered to be extremely related to the breakage of C&DWMs owing to mechanical efforts of mixing and compaction. Figure 10 shows the change in the WA of coarse and fine aggregate mixtures after mechanical mixing and compaction. This finding is consistent with outcomes presented in Fig. 5, and Tables 5, 6, and 7, respectively.

3.11 TSR test results

Figure 11 shows the outcomes of water sensitivity test results. The results reveal that the dosage of C&DWMs can negatively influence the water stability of C&DWMs mixtures. This may be explained by the higher tensile strength (TS) of dry specimens and the lower TS of wet specimens of C&DWMs mixtures compared with the control mix of 0% C&DWMs. The rough surfaces of C&DWMs shown in Fig. 4, besides the breakage of C&DWMs presented in Fig. 5 are the two main reasons behind the higher TS of unconditioned C&DWMs specimens. However, the absorptive nature of C&DWMs as well as the uncoated surfaces of C&DWMs that are produced after the mixing and compaction provide an easy way for water to inter and damage the affinity between C&DWMs aggregate and asphalt binder in the presence of water. Thus, lower TS is produced in the case of conditioned C&DWMs specimens as compared to that of control specimens. It can be seen that asphalt mixtures with 75% C&DWMs did not satisfy the specification limit of 80% of tensile strength ratio (TSR). A one-way ANOVA is carried out to examine the effect of C&DWMs dosage on TSR values. The results of ANOVA are presented in Table 9. The ANOVA shows that adding C&DWMs into asphalt mixtures can significantly affect the water stability of asphalt mixtures with C&DWMs (p-value less than 0.05).

Figure 5. Asphalt specimen with C&DWMs after mixing and compaction.

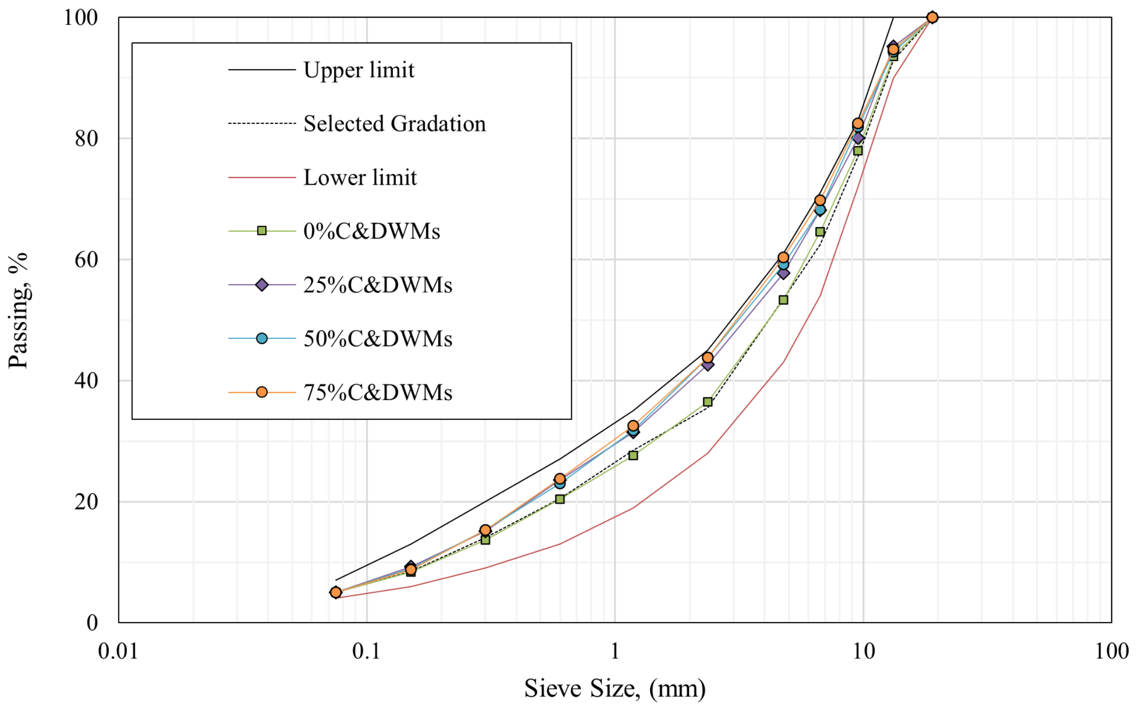

Figure 6. The results of the PSD test of C&DWMs mixtures after mixing and compaction.

4. Resilient modulus test results

This investigation uses the indirect tensile stiffness modulus test to calculate the resilient modulus of control asphalt mix and alternative mixes made with C&DWMs. Figure 12 shows the results of resilient modulus at 25 $C°$. The presented results confirmed that the use of C&DWMs produces a slight decrease in resilient modulus up to 50% C&DWMs addition. The breakage of C&DWMs after the mixing and compaction processes leads to a dense aggregate structure; thus, no substantial effect on resilient modulus is produced. Moreover, a different story can be seen when 75% of natural aggregates are replaced with C&DWMs. The results reveal that the asphalt mixture with 75% of C&DWMs exhibited a significant decrease in the resilient modulus as presented in Fig. 12. According to Australian standards, a typical dense asphalt mix should exhibit a resilient modulus within a range from 3000 MPa to 4000 MPa, [37]. In this perspective, all asphalt mixtures made with C&DWMs showed an acceptable resilient modulus to be used in pavement construction. Furthermore, two tests of one-way ANOVA are carried out to check the effects of the percentage of C&DWMs on resilient modulus. The first ANOVA test consisted of all four mixtures in this investigation, while the second test included all mixtures except the mixtures made with 75% C&DWMs. The results of the first ANOVA reveal that the dosage of C&DWMs can significantly affect resilient modulus as shown in Table 10. This is explained by the p-value of 0.000464. On the other front, the results of the second ANOVA analysis show a different story. The results presented in Table 11 confirm that preparing asphalt mixtures with a dosage of C&DWMs not exceeding 50% did not significantly affect the resilient modulus (P-value=0.441535). In light of these outcomes, it is not recommended to replace a high proportion of natural aggregates with C&DWMs (i.e. higher than 50%). This conclusion is drawn taking into account the subsequent impact of mixing and compaction on C&DWMs-asphalt mixtures in terms of aggregate gradation, Marshall stiffness, asphalt absorption, TSR results, resilient modulus results, and ANOVA analysis.

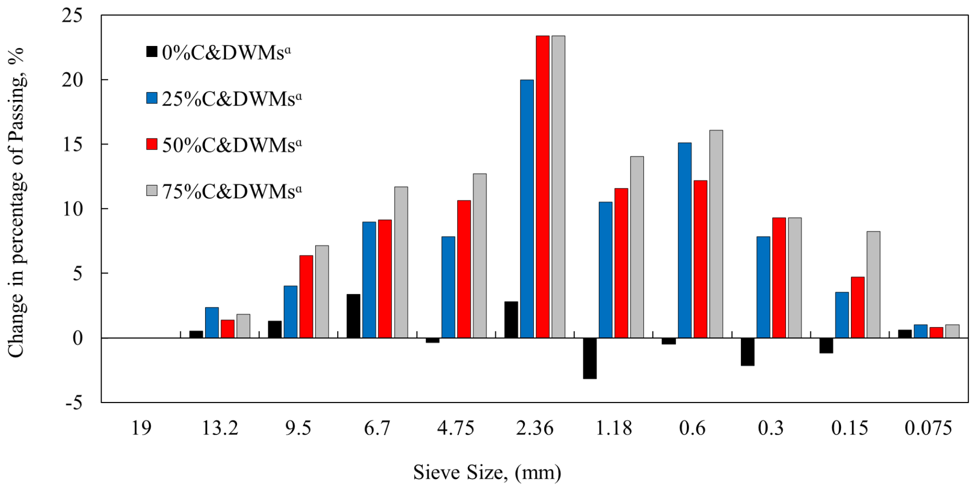

Figure 7. The change in the percentage of Passing of C&DWMs mixtures after mixing and compaction.

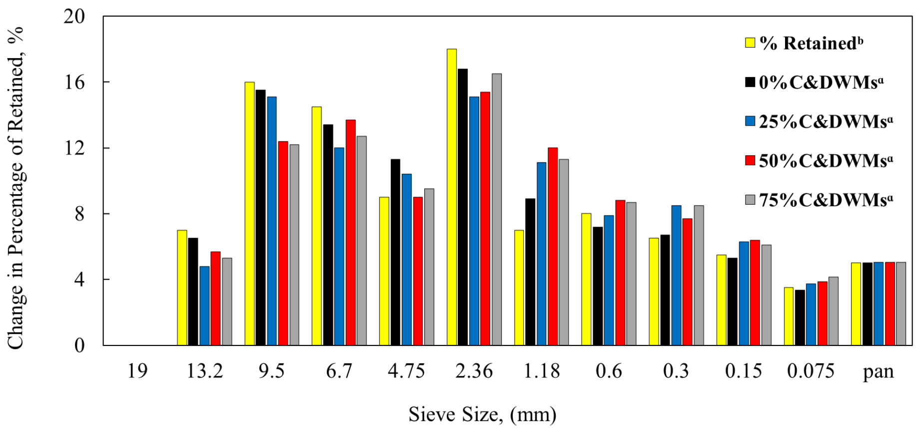

Figure 8. The change in the percentage of Retained of C&DWMs mixtures after mixing and compaction.

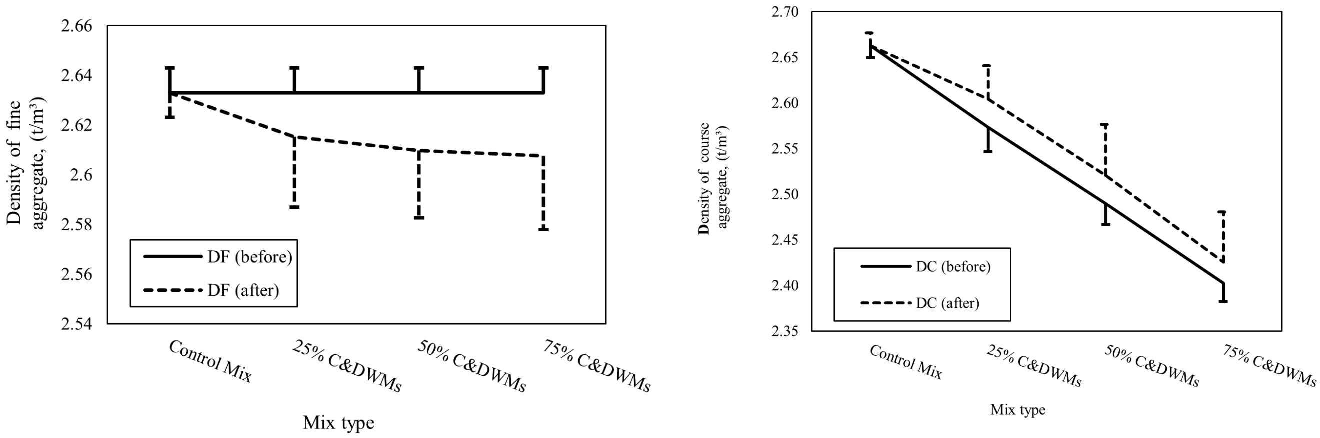

Figure 9. The change in aggregate density after the mixing and compaction processes.

5. Damage analysis

In this section, the KENPAVE software was used to evaluate the damage analysis of asphalt mixtures with C&DWMs. The damage analysis was carried out using a typical pavement section to study rutting and fatigue distresses. The information on the pavement section is shown in Table 12. The applied load used in the analysis was compatible with the Australian practices as documented in the Guide to Pavement Technology, *Part* 2, [38]. The results of the damage analysis are tabulated in Table 13. According to the results

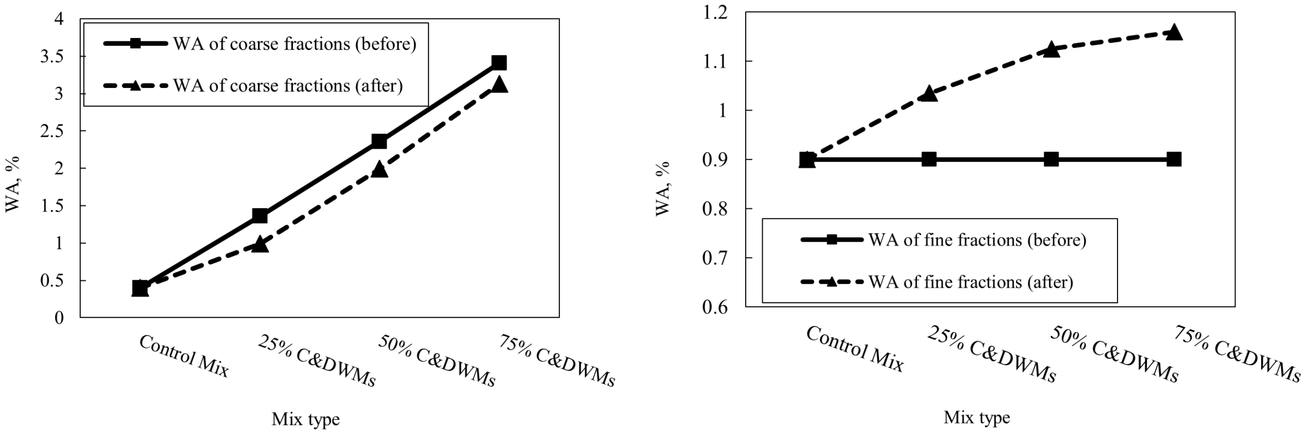

Figure 10**.** The change in WA (%) of fine and coarse aggregate mixture after mixing and compaction.

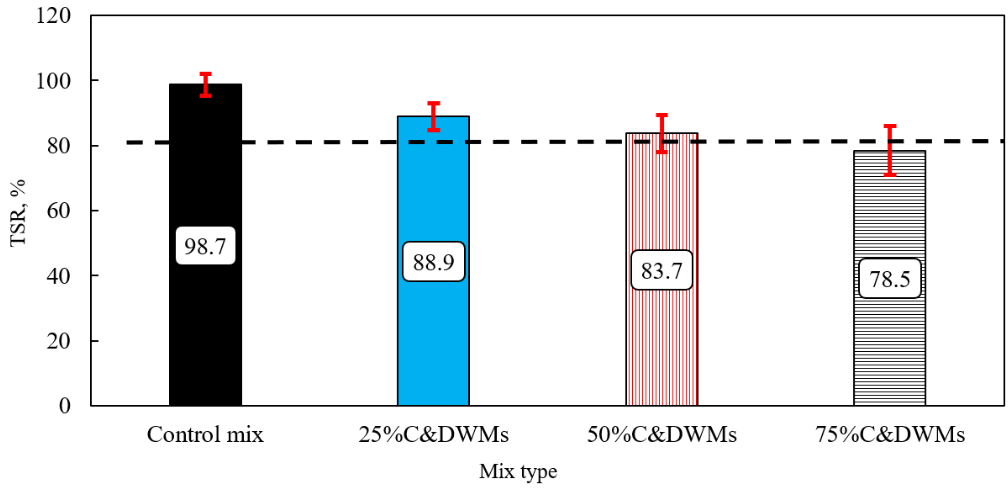

Figure 11**.** Results of TSR test of mixtures with C&DWMs.

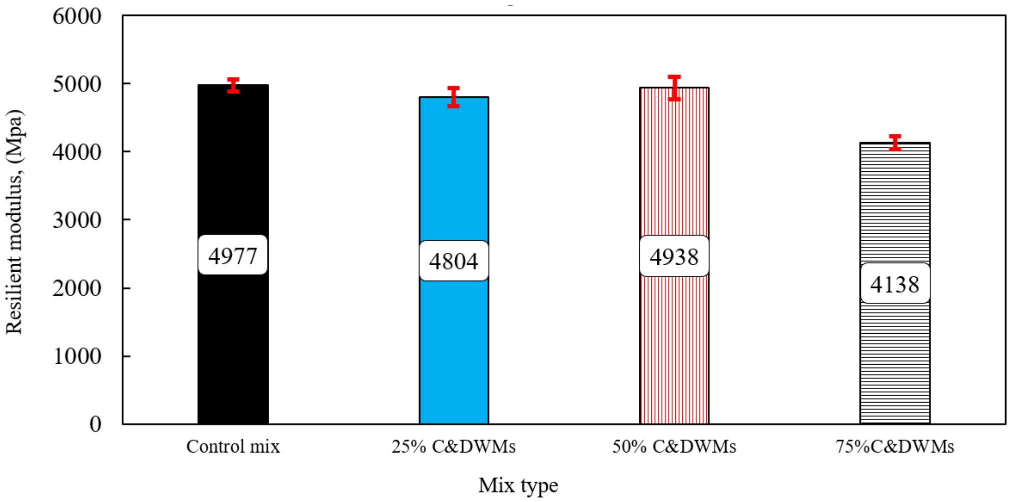

Figure 12**.** ITSM test results of asphalt mixtures with 0%, 25%, 50%, and 75% C&DWMs.

presented, the higher the resilient modulus, the lower the tensile strain and compressive strain at the bottom of the asphalt layer and the top of the subgrade layer, respectively. It can be seen that the mixtures made with 25% and 50% of C&DWMs exhibited nearly similar performance compared to control mix. As presented in Table 13, the pavement section constructed with 0%, 25%, and 50% of C&DWMs achieved a design life of about 19 years. While the pavement section with 75% C&DWMs has a design life of about 17 years. It was documented that the use of C&DWMs can reduce energy consumption and CO_2 emissions [39], and maintain sustainable practices [40, 41, 42]. Therefore, the results of asphalt mixtures made with no more than 50% of C&DWMs are promising. In this perspective, the results presented may encourage policymakers to support the endorsement of new regulations for the use of C&DWMs in the pavement industry.

Table 13. Outcomes of damage analysis.

Mix type	Tensile strain at bottom of layer 1 (Asphalt layer)	Allowable load repetitions in case of fatigue distress	Compressive strain at the top of layer 4 (Subgrade layer)	Allowable load repetitions in case of rutting distress	Design life of pavement in years
00%C&DWMs	-2.131E-04	9.554E+05	1.852E-04	7.002E+07	19.11
25%C&DWMs	-2.167E-04	9.328E+05	1.858E-04	6.901E+07	18.66
50%C&DWMs	-2.167E-04	9.328E+05	1.858E-04	6.901E+07	18.66
75%C&DWMs	-2.318E-04	8.484E+05	1.882E-04	6.507E+07	16.97

6. Conclusion

In this study, the mixing and compaction effects on the asphalt mixture made with C&DWMs were considered. Asphalt mixtures with 0%, 25%, 50%, and 75% C&DWMs were made and evaluated. In the light of outcomes and examination, the following conclusions can be made:

- The breakage of C&DWMs cannot be avoided, and the amount of breakage increases as the content of C&DWMs increases in the mix. The coarse broken C&DWMs particles will pass the 4.75 *mm* sieve. This, in turn, produces a decrease in the dosage of C&DWMs in the coarse fraction and an increase in the dosage of C&DWMs in the fine fractions. The latter outcome translates to a reduction in the absorption rate of the coarse aggregate mixture and an increase in the absorption rate of the fine aggregate mixture. On the other hand, this leads to an increase in the density of the coarse aggregate mixture and a decrease in the density of the fine aggregate mixture.
- The results from PSD and visual inspection revealed that the core reason for the change in gradation was the breakage of C&DWMs.
- The breakage of C&DWMs had a satisfactory impact on water stability and the resilient modulus of asphalt mixtures. In this regard, the breakage produces uncoated surfaces of C&DWMs mobilize high friction forces throughout aggregate structure during testing. Broken and partially coated C&DWMs contributed to affecting the water stability of asphalt mixtures.
- According to the ANOVA testing and damage analysis, asphalt mixtures made with no more than 50% C&DWMs revealed approximate performance to that of 0% C&DWMs mix. The results revealed the crucial role of breakage of C&DWMs and its effects on aggregates and asphalt mixture properties.

While this study provided positive evidence for adding C&DWMs (i.e. not more than 50%) in aspahlt mixtures. It is not recommended to utilize high dosage of C&DWMs (i.e. more than 50%) due to the negative impact on mix strength, water stability, and resilient modulus. Additionally, utilizing only one type of C&DWMs limits the generalizability of the outcomes. Therefore, future studies could employ more diverse types of C&DWMs to achieve generalizability of findings and validate the conclusion.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

Funding source

This study didn't receive any specific funds.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments

The researchers would like to show their deep appreciation to Mustansiriyah University `www.uomustansiriyah.edu.iq.` for the support provided during this investigation.

References

[1] L. Z. et al., "Characterizing the generation and flows of construction and demolition waste in china," *Constr. Build. Mater.*, vol. 136, no. 12, p. 405–413, April 2017. [Online]. Available: https://doi.org/10.1016/j.conbuildmat.2017.01.055

[2] J. A. Ferriz-Papi and S. Thomas, "Recycled aggregates from construction and demolition waste in the production of concrete blocks," *J. Constr. Mater.*, vol. 2, no. 1, pp. 1–6, October 2020. [Online]. Available: http://dx.doi.org/10.36756/jcm.v2.1.6.

[3] M. G. C. F. F. M. P. Saiz Martinez, "Comparative study of three types of fine recycled aggregates from cdw.pdf https://doi.org/10.." *J. Clean. Prod.*, vol. 118, no. 1, p. 162–169, 2016. [Online]. Available: http://dx.doi.org/10.1016/j.jclepro.2016.01.059

[4] B. H. Al-Humeidawi, "Utilization of waste plastic and recycle concrete aggregate in production of hot mix asphalt," *Al-Qadisiyah J. Eng. Sci.*, vol. 7, no. 4, p. 322–330, 2014. [Online]. Available: http://dx.doi.org/10.30772/qjes.v7i4.365

[5] A. J. For, "Study of using the crushed clay bricks with natural aggregate as unbound subbase pavement layer in segregated form," *Al-Qadisiyah J. Eng. Sci.*, vol. 10, no. 4, pp. 496–505, 2018. [Online]. Available: http://dx.doi.org/10.30772/qjes.v10i4.497

[6] S. E.-B. A. Arisha, A. Gabr and S. Shwally, "Using blends of construction demolition waste materials and recycled clay masonry brick in pavement." *Procedia Eng.*, vol. 143, no. Ictg, p. 1317–1324, 2016. [Online]. Available: http://dx.doi.org/10.1016/j.proeng.2016.06.148.

[7] I. Pérez, A. Pasandín, and L. Medina, "Hot mix asphalt using cd waste as coarse aggregates," *Materials Design (1980-2015)*, vol. 36, pp. 840–846, 2012, sustainable Materials, Design and Applications. [Online]. Available: https://doi.org/10.1016/j.matdes.2010.12.058

[8] S. Fatemi and R. Imaninasab, "Performance evaluation of recycled asphalt mixtures by construction and demolition waste materials," *Construction and Building Materials*, vol. 120, pp. 450–456, 2016. [Online]. Available: https://doi.org/10.1016/j.conbuildmat.2016.05.117

[9] B. F. L. Ding, J. Zhang and C. Li, "Performance evaluation of recycled asphalt mixtures containing construction and demolition waste applicated as pavement base." *Adv. Civ. Eng.*, vol. 2020, no. 1, p. 8875402, 2020. [Online]. Available: http://doi.org/10.1155/2020/8875402

[10] F. G. J. Zhang and Y. Zhang, "Use of building-related construction and demolition wastes in highway embankment: Laboratory and field evaluations," *J. Clean. Prod.*, vol. 230, no. 1, p. 1051–1060, 2019. [Online]. Available: http://doi.org/10.1016/j.jclepro.2019.05.182.

[11] S. Kumbhar, A. Gupta, and D. Desai, "Recycling and reuse of construction and demolition waste for sustainable development," *OIDA International Journal of Sustainable Development*, vol. 6, no. 7, p. 83–92, 2013. [Online]. Available: https://ssrn.com/abstract=2383436

[12] R. Cardoso, R. V. Silva, J. de Brito, and R. Dhir, "Use of recycled aggregates from construction and demolition waste in geotechnical applications: A literature review," *Waste Management*, vol. 49, pp. 131–145, 2016. [Online]. Available: https://doi.org/10.1016/j.wasman.2015.12.021

[13] S. Lockrey, H. Nguyen, E. Crossin, and K. Verghese, "Recycling the construction and demolition waste in vietnam: opportunities and challenges in practice," *Journal of Cleaner Production*, vol. 133, pp. 757–766, 2016. [Online]. Available: https://doi.org/10.1016/j.jclepro.2016.05.175

[14] G. O. Bamigboye, D. E. Bassey, D. O. Olukanni, B. U. Ngene, D. Adegoke, A. O. Odetoyan, M. A. Kareem, D. O. Enabulele, and A. T. Nworgu, "Waste materials in highway applications: An overview on generation and utilization implications on sustainability," *Journal of Cleaner Production*, vol. 283, p. 124581, 2021. [Online]. Available: https://doi.org/10.1016/j.jclepro.2020.124581

[15] J. L. G. A. Ossa and E. Botero., "Use of recycled construction and demolition waste (cdw) aggregates: A sustainable alternative for the pavement construction industry," *J. Clean. Prod.*, vol. 135, no. 1, p. 379–386, 2016. [Online]. Available: http://doi.org/10.1016/j.jclepro.2016.06.088

[16] A. Gedik, "A review on the evaluation of the potential utilization of construction and demolition waste in hot mix asphalt pavements," *Resources, Conservation and Recycling*, vol. 161, p. 104956, 2020. [Online]. Available: https://doi.org/10.1016/j.resconrec.2020.104956

[17] G. Zou, J. Zhang, X. Liu, Y. Lin, and H. Yu, "Design and performance of emulsified asphalt mixtures containing construction and demolition waste," *Construction and Building Materials*, vol. 239, p. 117846, 2020. [Online]. Available: https://doi.org/10.1016/j.conbuildmat.2019.117846

[18] J. T. S. J. I. Vegas, J. A. Ibañez and A. Urzelai., "Construction demolition wastes, waelz slag and mswi bottom ash: A comparative technical analysis as material for road construction," *Waste Manag.*, vol. 28, no. 3, p. 565–574, 2008. [Online]. Available: https://doi.org/10.1016/j.wasman.2007.01.016

[19] A. H.-A. G. Tavakoli Mehrjardi, A. Azizi and G. Asdollafardi., "Evaluating and improving the construction and demolition waste technical properties to use in road construction," *Transp. Geotech.*, vol. 23, no. February, p. 100349, 2020. [Online]. Available: https://doi.org/10.1016/j.trgeo.2020.100349

[20] F. L. J. Zhang, L. Ding and J. Peng., "Recycled aggregates from construction and demolition wastes as alternative filling materials for highway subgrades in china," *J. Clean. Prod.*, vol. 255, no. 1, p. 120223, 2020. [Online]. Available: https://doi.org/10.1016/j.jclepro.2020.120223

[21] D. C. Montgomery, "Recycled concrete aggregates (rca) appear to be suitable materials to use in hot-mix asphalt (hma) for flexible road pavements . however," *J. Clean. Prod.*, vol. 255, no. February, p. 120223, 2015. [Online]. Available: https://doi.org/10.1016/j.jclepro.2020.120223

[22] B. Gómez-Meijide and I. Pérez, "Binder-aggregate adhesion and resistance to permanent deformation of bitumen-emulsion-stabilized materials made with construction and demolition waste aggregates," *J. Clean. Prod.*, vol. 129, no. 15, p. 125–133, 2016. [Online]. Available: https://doi.org/10.1016/j.jclepro.2016.04.106

[23] A. A. E. Yaghoubi, M. M. Disfani and J. Kodikara, "Impact of compaction method on mechanical characteristics of unbound granular recycled materials," *Road Mater. Pavement Des..*, vol. 19, no. 4, p. 912–934, 2018. [Online]. Available: https://doi.org/10.1080/14680629.2017.1283354

[24] E. Yaghoubi, M. M. Disfani, A. Arulrajah, and J. Kodikara, "Impact of compaction methods on resilient response of unsaturated granular pavement material," *Procedia Engineering*, vol. 143, pp. 323–330, 2016, advances in Transportation Geotechnics III. [Online]. Available: https://doi.org/10.1016/j.proeng.2016.06.041

[25] F. A.-A. H. A. A. M. Yosri, A. Azam and M. A. Okail, "Shear strength and particle breakage of construction and demolition waste as a function of moisture state and compaction level: Insights for sustainable highway engineering," *PLoS One.*, vol. 19, no. 3, p. 1–19, March 29 ,2024. [Online]. Available: https://doi.org/10.1371/journal.pone.0298765

[26] G. A. B. Gómez-Meijide, I. Pérez and N. Thom, "Stiffness of cold asphalt mixtures with recycled aggregates from construction and demolition waste," *Constr. Build. Mater.*, vol. 77, no. 15, p. 168–178, 2015. [Online]. Available: https://doi.org/10.1016/j.conbuildmat.2014.12.045

[27] S. A. Corporate Authors, "Hot mix asphalt: a guide to good practice," *The National Academies of Sciences, Engineering, and Medicine*, vol. 77, p. 168–178, 2005. [Online]. Available: http://worldcat.org/isbn/0733766862

[28] C. A. AUSTRALIA, "Aggregates and rock for engineering purposes; part 5: asphalt aggregates," *The National Academies of Sciences, Engineering, and Medicine*, vol. 5, ISBN: 733707432, no. 5, 1996. [Online]. Available: http://worldcat.org/isbn/733707432

[29] A. Fernández-Fanjul, A. Tenza-Abril, and F. Baeza-Brotons, "A new methodology for determining particle density and absorption of lightweight, normal-weight and heavy weight aggregates in aqueous medium," *Construction and Building Materials*, vol. 146, pp. 630–643, 2017. [Online]. Available: https://doi.org/10.1016/j.conbuildmat.2017.04.052

[30] E. T. Tunc and K. E. Alyamac, "A preliminary estimation method of los angeles abrasion value of concrete aggregates," *Construction and Building Materials*, vol. 222, pp. 437–446, 2019. [Online]. Available: https://doi.org/10.1016/j.conbuildmat.2019.06.176

[31] *Methods for sampling and testing aggregates, Method 7: Apparent particle density of filler*. [Online]. Available: https://books.google.iq/books?id=Kv0J0AEACAAJ

[32] S. A. A. 1141.5, "Bitumen content and particle size distribution of asphalt and stabilised soil: Centrifuge method perth, 2011," *Main Roads Westren Australia*, p. 168–178, 2011. [Online]. Available: https://doi.org/10.1016/j.conbuildmat.2014.12.045

[33] S. H. Ali and M. Q. Ismael, "Improving the moisture damage resistance of hma by using ceramic fiber and hydrated lime." *Al-Qadisiyah J. Eng. Sci.*, vol. 12, no. 1, pp. 48–58, 2021. [Online]. Available: https://doi.org/10.30772/qjes.v13i4.681

[34] A. Alfalah, A. Ali, and Y. Mehta, "Estimating tensile strength ratio of asphalt mixtures using surface free energy (sfe) and fourier transform infrared attenuated total reflectance (ftir-atr)," *Construction and Building Materials*, vol. 409, p. 133900, 2023. [Online]. Available: https://doi.org/10.1016/j.conbuildmat.2023.133900

[35] R. F. P. Kamdem, J. A. Adedeji, and M. M. H. Mostafa, "A study on indirect tensile strength for the determination of resilient modulus of warm mix asphalt," *Transportation Research Procedia*, vol. 69, pp. 783–790, 2023, aIIT 3rd International Conference on Transport Infrastructure and Systems (TIS ROMA 2022), 15th-16th September 2022, Rome, Italy. [Online]. Available: https://doi.org/10.1016/j.trpro.2023.02.236

[36] K. R. Messer, A. Fahem, A. T. Guthai, and R. P. Singh, "The experimental methods and elastic properties of shale bedding planes materials state-of-the-art review," *Al-Qadisiyah Journal for Engineering Sciences*, vol. 15, no. 2, pp. 126–130, 2022. [Online]. Available: https://qjes.qu.edu.iq/article_179071.html

[37] SAustroads, "Testing asphalt in accordance with the austroads mix design procedures," *The National Academies of Sciences, Engineering, and Medicine*, vol. 13, no. 01120933, p. 274–283, 2013. [Online]. Available: http://worldcat.org/isbn/9781921329906

[38] M. A. Moffatt, "Guide to pavement technology: part 2: pavement structural design," 2017. [Online]. Available: https://api.semanticscholar.org/CorpusID:116476608

[39] A. M. A. M. Ghanbari and M. Ravanshadnia, "Production of natural and recycled aggregates: the environmental impacts of energy consumption and co2 emissions," *J. Mater. Cycles Waste Manag.*, vol. 20, no. 2, p. 810–822, 2018. [Online]. Available: https://doi.org/10.1007/s10163-017-0640-2

[40] R. b. A. A. O. Uga, "Sustainable approach to managing construction and demolition waste: An opportunity or a new challenge?" *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 4, no. 11, p. 10368–10378, 2015. [Online]. Available: https://doi.org/doi:10.15680/ijirset.2015.0411007

[41] M. S. A.-C. E. M. Yeheyis, K. Hewage and R. Sadiq, "An overview of construction and demolition waste management in canada: A lifecycle analysis approach to sustainability," *Clean Technol. Environ. Policy*, vol. 15, no. 1, p. 81–91, 2013. [Online]. Available: https://doi.org/10.1007/s10098-012-0481-6

[42] M. P.-G. J. Cárcel-Carrasco, E. Peñalvo-Lòpez and F. Salas-Vicente, "An overview about the current situation on cd waste management in italy: Achievements and challenges." *Buildings*, vol. 11, no. 7, p. 284, 2021. [Online]. Available: https://doi.org/10.3390/buildings11070284

How to cite this article:
Abbaas I. Kareem, Estabraq N. Ezzat, Teba T. Khaled1, and Rwayda Al-Hamd (2025). 'Effects of breakage of construction and demolition waste materials (C&DWMs)at asphalt mixtures', Al-Qadisiyah Journal for Engineering Sciences, 18(1), pp. 054-064. https://doi.org/10.30772/qjes.2024.148821.1202