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Effects of Acrylonitrile-Butadiene-Styrene on Sustainable Paving Mixtures

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ABSTRACT

This study evaluated the effects of acrylonitrile- butadiene- styrene (ABS) polymer on the paving mixtures made with calcium carbonate ($CaCO_3$) as a common filler and Blowdown (B) waste as a sustainable filler. Both mixtures, Unmodified and ABS-modified containing both fillers were subjected to Marshall stability (MS), Marshall Quotient (MQ), tensile strength (TS), tensile strength ratio (TSR), cracking tolerance index (CT_{index}) and deformation strength (DS) in Kim tests. Statistical analyses of the results show that a B-mixture owned higher MS and DS, with lower TSR and CT_{index} than $CaCO_3$ mixture, while ABS modified-B mixture depicted higher marshall stability, cracking and fatigue resistance with lower moisture, rutting resistance comparable to the ABS-modified $CaCO_3$-mixture. In addition, B-mixture is a cost-effective solution and eco-friendly than $CaCO_3$ mixture for pavement application since its properties located within the specification's limits.

Keywords:

ABS polymer; Blowdown wastes; Calcium carbonate; Cracking tolerance index; Fatigue resistance.

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1. INTRODUCTION

The ecology of our planet is greatly impacted by the increasing amounts of trash produced globally as a result of commercial and industrial activity. Now it is a common practice to turn waste products such as fibers, polyethylene, sulfur waste, etc. into building materials. This strategy works really well and it is a good choice for our environment and economy. According to many studies, these substances enhance asphalt mixes in a number of ways. They improve durability, moisture resistance, fracture resistance, and tensile strength, offering a promising replacement for virgin material [1]. Every year, Iraq generates and disposes about 7,000 to 20,000 tons of solid rubbish and blowdown waste (BW), at a cost of \$665,000 to \$2 million [2]; hence, the utilization of waste materials in construction as partial or whole replacements for the virgin resources has increased. Fiber, crumb rubber, polyethylene, sulfur waste, polypropylene, reclaimed asphalt pavement, recycled waste lime, carbon black, waste ceramic materials, recycled red brick powder, fly ash, volcanic ash, and coal gangue have all been found to be cost-effective, environmentally responsible, and efficient in improving the performance properties of asphalt mixtures [3].

Research by (Al-Mohammed & Al-Hadidy, 2023) [4] investigates how, as Iraq faces the challenge of increasing solid waste generation while decreasing disposal site capacity, providing a useful use for waste materials, such as blowdown into asphalt mixtures as mineral filler, may minimize landfilling costs and promote sustainability in the construction industry. One of the by-products of sulfur producing is blowdown, which will be added to solid waste and it is hard to break down.

Normal bitumen is a viscoelastic substance whose insufficient elastic, low temperature, and adhesive capabilities prevent it from controlling rutting deformation and cracking under circumstances of unfavorable weather and strong traffic loads. To improve the quality of asphalt binder, various additives must be included in the mix to increase bitumen performance. Various types of modifiers, such as polymers, carbon fibers, anti-stripping compounds, etc., are often used to enhance the physical and mechanical quality of the asphalt binder [5].

The addition of polymer to asphalt mixtures in varying doses and types appear to offer the most potential success in the construction of flexible pavements. Among these attempts, the use of polymer-modified asphalt binders has demonstrated promising results in minimizing early pavement failures, particularly in places with considerable seasonal climate fluctuations and large truck traffic volumes [6].

ABS, which is a strong, durable engineering material made from acrylonitrile, butadiene, and styrene polymers, is used in various production processes like injection molding, FDM, and CNC machining. Engineers and production teams use ABS for its flexibility, affordability, and accessibility. ABS is produced through the emulsion or polymerization of styrene and acrylonitrile in the presence of polybutadiene, with continuous mass polymerization being a patented method. It is used in injection molding pellets, additive manufacturing filaments, and CNC machining [7].

Numerous studies investigate the effects of different polymers and non-traditional mineral fillers on the asphalt mixtures. For example, research by (Ali & Khoshnaw, 2020) [8] examined the impact of two asphalt modifiers: propylene (PP) and styrene butadiene styrene (SBS). Conversely, research [9] investigated the effects of polybutylene on the moisture-handling properties of asphalt mixtures. Tests for surface-free energy and the indirect tensile strength ratio are used to evaluate the impact on aggregates made of granite and limestone. Simultaneously, these investigations [4,10] integrated sulfur waste and blowdown as by-product materials, approximated the optimal compositions, and evaluated their impacts on asphalt mixture performance.

Meanwhile, to the authors' knowledge, there is no research has been done before to examine the feasibility of incorporating blowdown as a mineral filler in asphalt mixtures and its role in facilitating a homogeneous distribution of the Acrylonitrile Butadiene Styrene (ABS) polymer within the mixtures and emphasizes the use of ABS, examining its effect on asphalt mixtures. There is still a need for more research on this subject.

2. RESEARCH OBJECTIVES

The main objective of this study is to determine how ABS Polymer Modified Asphalt (ABSMA) affects on densely graded mixtures that included blowdown and calcium carbonate as filler, with determining the ideal ABS dosages for the best-performing mix. This study also assesses the asphalt mixtures' resistance to rutting and moisture damage after being made using exactly the same unmodified and modified binders.

3. MATERIALS

3.1. Coarse and Fine Aggregates

The hot mix company in Al-Kazer, Mosul city, will provide river sand, crushed gravel, and aggregate, as illustrated in Figure 1. There is a significant quantity of silica in the sedimentary rock that makes up the gravel [11]. As has been shown in Fig. 2, these aggregates underwent sorting and grading procedures utilizing ASTM D 3515 criteria to ensure that they met the requirements of binding layer suitability standards. As has been done by the Iraqi standard specification (SCRB), these instructions recommend to use dense-graded gradation with midway gradation between the higher and lower limits stated therein. When cited, Table 1 offers crucial information on the coarse and fine aggregate materials utilized in this study.

Fig. 1 Samples of coarse and fine aggregates were utilized.

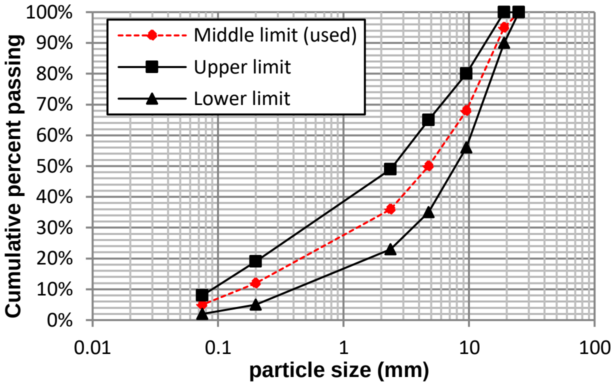


Fig. 2 Gradation limitations for ASTM D 3515 D-4 mix designation, as well as the gradation curves utilized.

Table 1: Coarse and fine aggregate properties.

Property	Coarse aggregates	Fine aggregates	Specification
Toughness	19.6%	-	ASTM C131 [12]
Angularity	96.2%	44.7%	ASTM D5821 [13] & C1252 [14]
Soundness Na_2SO_4	0.95%	0.72%	ASTM C88 [15]
Water absorption	0.981%	1.43%	ASTM C127 [16] & C128 [17]
Bulk specific gravity	2.731	2.652	ASTM C127 [16] & C128 [17]
Apparent specific gravity	2.769	2.715	ASTM C127 [16] & C128 [17]

3.2. Minerals Fillers

This study uses locally available calcium carbonate ($CaCO_3$) as the reference mineral filler for asphalt mixtures; as seen in Fig. 3 blowdown, a solid, black, grainy by-product will be used as a mineral filler replacement. Both fillers undergo through an ASTM 200 sieve before use, with physical and chemical properties shown in Table 2.


(a) (b)

Fig. 3 Blowdown material (a-Before crushing, b-After crushing).

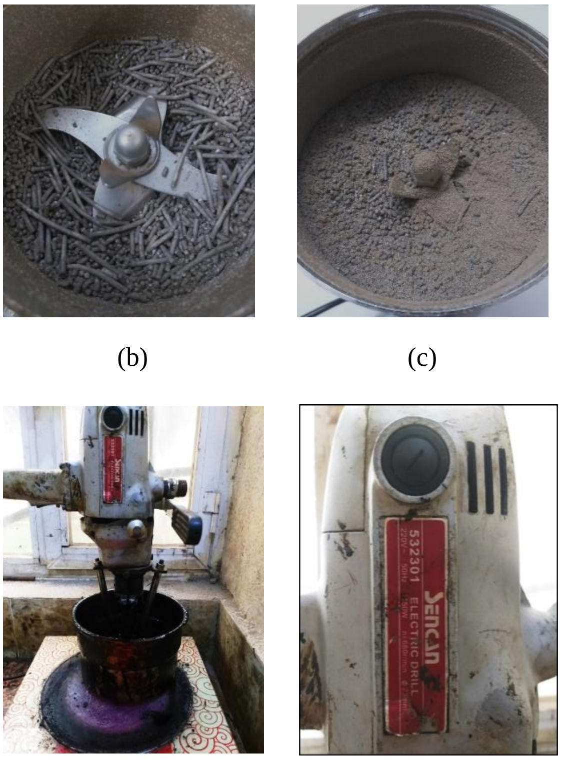
Table 2: Physicochemical properties of calcium carbonate and blowdown fillers.

Calcium carbonate filler		Blowdown filler	
Chemical			
component	Weight % [18]	component	Weight % [19]
SiO_2	2.7	Free sulfur	81.04
Al_2O_3	0.35	Car-sul	18.21
Fe_2O_3	0.93	Ash	0.31
CaO	50.67	Acidity	0.001
MgO	0.64	Moisture	0.42
Na_2O	0.02		
SO_3	0.75		
Physical			
Specific Gravity	2.731	Specific Gravity	2.20
Gradation			
Sieve Opening (mm)	% passing	Iraqi standard specification (SCRB) limits [20]	
0.6	100	100	
0.3	100	100-95	
0.075	100	100-70	

3.3. Asphalt cement

The asphalt cement (AC) used in this study was of (40-50) penetration grade (P40) and obtained from the Dura refinery. This asphalt grade is mostly utilized in the pavement construction of roads around the country [11]. In order to make ABS-modified asphalt (ABSMA), ABS filaments were crushed into asphalt cement (P40) with a food grinder to reduce its molecular weights and achieve a homogeneous mixing process. ABS was added to AC at a temperature of 170 ± 3℃ using a laboratory shear mixer at 680 rpm for 1.5 hours [21], as seen in Fig. 4.

(a)



(b) (c)

(e) (f)

Fig. 4 Mixing ABS and AC (a-ABS filaments, b-ABS filaments during grinding, c-ABS filaments after grinding, and e-details of the shear mixer utilized in the ABS mixing process).

It should be mentioned that these ABS rates (0.5%, 1%, 1.5, and 2.0%) were chosen to be added to the optimum asphalt content (O.A.C). ABS and asphalt were shown to be compatible using the ASTM D 6230 test [22]. This test process is dependent on whether the polymer and asphalt binder can produce a homogeneous mixture that can pass through an ASTM 100 sieve. The sample was heated to mixing temperature for one hour before being put through an ASTM 100 sieve, and it was determined that more than 95% of mixes went through for this rate, implying compatibility between ABS asphalt binder. ABSMA's rheological characteristics have been studied and compared to those of P40, as shown in Table 3.

Table 3: The rheological properties for P40 and ABSMA.

Property	Test method	P40	NCCL limits [23]	ABSMA	NCCL limits [23]
Penetration at 25°C (0.1mm)	ASTM D 5 [24]	40	40-50	32	-
Softening point (°C)	ASTM D 36 [25]	51	51-62	52	-
Ductility at 25°C (cm)	ASTM D 113 [26]	>100	100 min.	67	-
Rotational viscosity at 135°C (cP)	ASTM D 4402 [27]		-		3000 max.
Elastic recovery at 25°C (%)	ASTM D 6084 [28]	35	-	15	75 min.
Homogeneity (%Passing)	ASTM D 6230 [22]	-	-	Passed	-

4. EXPERIMENTAL METHODS

4.1. Asphalt Mixture Design

Asphalt concrete mixtures may be optimized by using the Marshall mix design (ASTM D 6927) approach as a standard operation [29]. When designing asphalt concrete mixtures, the Marshall method of mix design is frequently used to guarantee that the voids are sufficient. Five asphalt percentages were used: 4.0%, 4.5%, 5.0%, 5.5%, and 6.0%. It is found that 5.0% of asphalt was needed at 4% air voids. Using a shear mixer, the modified samples are mixed for two minutes at this asphalt ratio at the recommended mixing temperature of 170 ˚C. A Marshall mechanical compactor was used to compact the samples. The samples were then heated to a compaction temperature of 10 ˚C lower than the comparable mixing temperature. At a tire pressure of 1379 kPa, the specimens were crushed for heavy-duty application at a rate of 75 Marshall blows per face. They were allowed to air-cure for a full 24 hours after being taken out of the mold, the specimens [30].

Then they were sorted into groups and titled as follows:

- F: Mixes containing 5% normal filler.
- B: Mixes containing 5% blowdown filler.
- FA: Mixes containing 5% normal filler and 1.5% wt. of ABS polymer.
- BA: Mixes containing 5% blowdown filler and 1.5% wt. of ABS polymer.

4.2. Marshall Stability and Flow Tests

Stability and flow testing were performed in accordance with the ASTM D 6927 [29]. In addition to what was stated in Section 4.1, a minimum of three specimens of a specific mix must be examined.

Fig. 5 shows that the addition of ABS increases the FV of P40. Furthermore, the bulk specific gravity for each specimen must be established prior to testing. After soaking the specimens in a 60 ˚C water bath for about 30–40 minutes, the interval between extracting the test specimens and estimating the final load cannot exceed 30 seconds. As illustrated in Fig. 6 (a), the addition of load to the specimen continued until the dial gage releases or the load starts to decrease by moving the loading jack or loading machine head at a constant rate of 50 ± 5 mm/min.

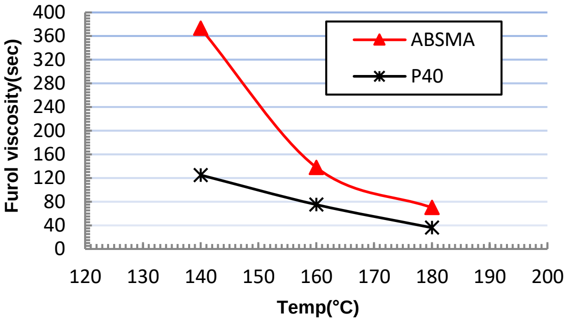


Fig. 5 Furol viscosity of ABSMA.

(a) (b)

Fig. 6 Marshall test (a-Marshall testing machine, b-Specimens after failure).

4.3. Kim test for deformation strength

This study applied the Kim test to determine the rutting resistance of the asphalt mixtures at high temperatures. The Kim test is a short test that provides a method for estimating the deformation and rutting strength using static loads. The S_D (resistance to deformation) is strongly related to the rut characteristics of asphalt mixtures. S_D is beneficial for testing the high-temperature performance and rutting resistance of asphalt mixtures [11, 32]. The Marshall specimens are tested by placing them in a water bath at 60 ˚C for 30 minutes, then dried and placed in a loading mold. A loading head applies a continuous perpendicular load, causing compaction at a speed of 50.8 mm/min, as shown in Fig. 7. The test method yields force and sample displacement results, with deformation strength calculated using Eq. (1):

$$S_D = \frac{4P}{\pi\,[D-2(r-\sqrt{2ry-y^2})]^2} \qquad (1)$$

where:
S_D = deformation strength (Mpa),
P = peak load (N),
D = diameter of the loading head (30mm),
r = curvature radius at the loading head's bottom (7.5mm), and.
y = deformation (mm).

(a) (b)

Fig. 7 Kim test (a-Automatic multi-tester machine with Kim equipment and tested specimen, b-Specimens after failure).

4.4. Moisture Susceptibility and Indirect Tensile Strength (ITS) test

The ASTM D 6931 [32] was followed in performing this test. This standard, "Resistance of Compacted Mix Asphalt to Moisture-Induced Damage," explains how to predict the sensitivity of an asphalt mixture to moisture. This sensitivity is usually brought on by a reduction in the asphalt binder's cohesion strength and/or adhesion failure in the binder-aggregate system with the presence of water [33]. The Marshall method's procedure was followed in order to prepare specimens for the ITS test. The prepared specimens have a diameter of 101.6 mm and an air void content of 7.0 ± 1%. They were divided into two groups for the ITS test after compaction stage: the unmodified asphalt mixtures and the ABSMA mixtures, which were then merged. The conditioned samples (C) were immersed in a water bath at 60 ˚C for 24 hours, then another 2 hours at 25 ˚C. The unconditioned samples (U) were immersed in a water bath at 25 °C for 2 hours. The samples were next tested on the automatic multi-tester machine (Fig. 8) until they failed at a rate of 51 mm/min. ITS has been computed using Eq. (2) based on the specimen's maximum failure load:

$$\mathrm{ITS} = \frac{2000\mathrm{P}}{\pi \mathrm{dt}} \qquad (2)$$

where:

ITS = indirect tensile strength (kPa),
P = ultimate load (N),
t = specimen thickness (mm), and.
d = specimen diameter (mm).

The moisture sensitivity can be determined by the tensile strength ratio (TSR). The ASTM D4867/D4867M [34] standard may be used to compute the tensile strength ratio (TSR) from ITS conditioned ($\mathrm{ITS_C}$) and ITS unconditioned ($\mathrm{ITS_U}$), and Eq. (3) can be used to get the final percentage:

$$\mathrm{TSR}\ (\%) = \frac{\mathrm{ITS_C}}{\mathrm{ITS_U}} \times 100 \qquad (3)$$


(a) (b)

Fig. 8 ITS (a- Automatic multi-tester machine with ITS equipment and tested specimen, b- Specimen after failure).

4.5. Indirect Tension asphalt cracking test (IDEAL-CT) at intermediate temperatures

Based on the ASTM D 8225 [35], the IDEAL-CT test evaluates the cracking resistance of the asphalt mixtures, dependenting upon the local environment. In this investigation, the binder was utilized at 25 °C, as seen in Fig. 8. The specimen was centered in the fixture while the identical procedures for the unconditioned samples (Section 4.4) were carried out. Throughout the test, the load was applied at an average constant load-line displacement (LLD) rate of 50.0 ± 3.0 mm/min. Both the load and the LLD, which are measured throughout the test, are used to determine the $\mathrm{CT_{index}}$. A mixture's resistance to cracking is assessed using the $\mathrm{CT_{index}}$ (Cracking Tolerance Index). Based on the load-displacement curve, it is computed as shown in Fig. 9:

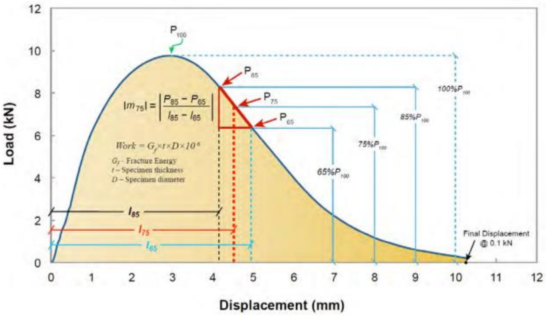


Fig. 9 Load-line displacement (l) and recorded load (P) curve.

CT index has been computed using Eq. (4):

$$\mathrm{CT_{index}} = \frac{\mathrm{t}}{62} \times \frac{\mathrm{l_{75}}}{\mathrm{D}} \times \frac{\mathrm{G_f}}{|\mathrm{m_{75}}|} \times 10^6 \qquad (4)$$

where:

$\mathrm{CT_{index}}$ = cracking tolerance index,
$\mathrm{G_f}$ = failure energy (Joules/m^2),
$|\mathrm{m_{75}}|$ = absolute value of the post-peak slope $\mathrm{m_{75}}$ (N/m),
$\mathrm{l_{75}}$ = displacement at 75 % of the peak load after the peak (mm),
D = specimen diameter (mm), and.
t = specimen thickness (mm).

Failure energy ($\mathrm{G_f}$) is calculated by dividing the work of failure (the area under the load versus the average LLD curve; like Fig. 8) by the cross-sectional area of the specimen (the product of the diameter and thickness of the specimen):

$$\mathrm{G_f} = \frac{\mathrm{W_f}}{\mathrm{D} \times \mathrm{t}} \times 10^6 \qquad (5)$$

where:

$\mathrm{G_f}$ = fracture energy (Joules/m^2),
$\mathrm{W_f}$ = work of failure (Joules),
D = specimen diameter (mm), and.
t = specimen thickness (mm).

5. TEST RESULTS AND DISCUSSION

5.1. Statistical Considerations

In this study, FA and BA mixes were compared statistically using analysis of variance (ANOVA) in Minitab software version 21.1 [36], with the null hypothesis $\mathrm{H_o}$= 0 and 0.05 level of significance. The least significant difference value (LSDV) was used to determine if the two averages varied considerably. Two averages are considered significantly different if their difference is more than or equal to the LSDV, and vice versa. In Table 4, shows the average differences as letters. When the two averages have the same letter, it means that there is no significant difference between them [37]. The letter 'A' represents the highest test results, with successive letters showing a sequential drop in these values.

Table 4: Comparison of the mixes.

Property	Mix type			
	F	FA	B	BA
Marshall stability (kN)	D	B	C	A
Marshall flow (mm)	A	A	A	A
Marshall quotient (kN/mm)	B	A	AB	AB
Air voids (%)	A	A	A	A
Deformation strength (Mpa)	B	A	B	B
ITS at 25 ˚C (kPa)	B	A	C	B
ITS at 60 ˚C (kPa)	AB	A	C	B
TSR (%)	A	A	A	A
m_{75} (kN/mm)	A	A	A	A
CT_{index}	A	A	A	A

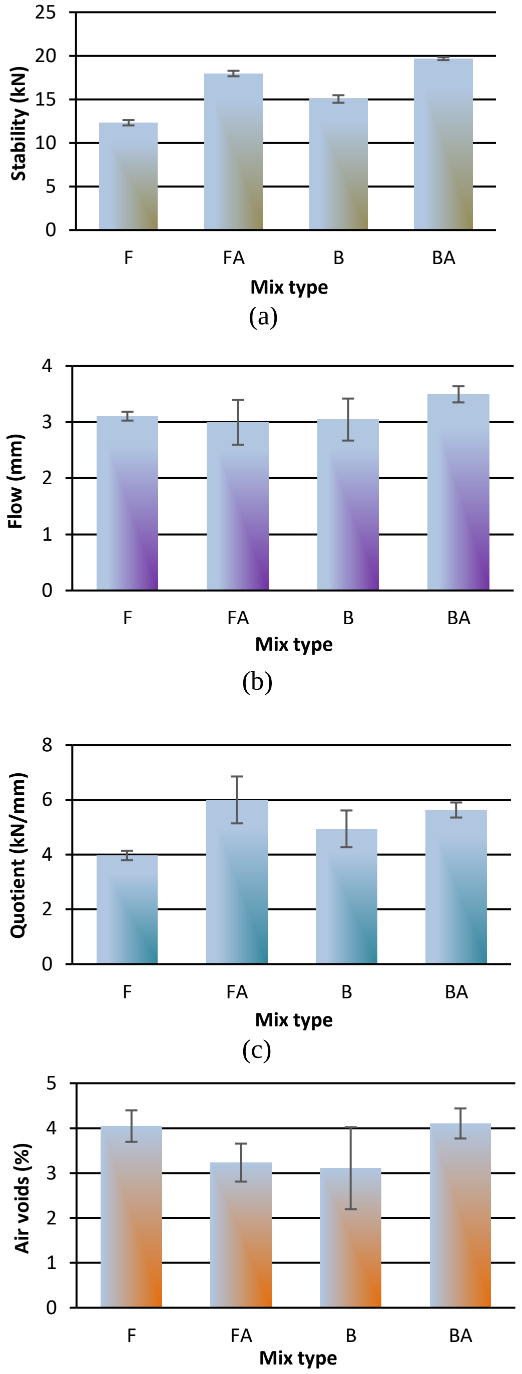
5.2. Marshall Parameters

Marshall stability (MS), flow, Marshall quotient (MQ), and air voids (AV) characteristics are all listed in Fig. 10. MS determines the maximum load that may be applied to hot mix asphalt (HMA). The test results exceeded the allowed limit for all asphalt mixes that included the control mix, which is equivalent to 7 kN for the binder course [20, 39]. It should be noted that adding ABS polymer to both mixtures with normal and blowdown filler improves their stability, as shown in Fig. 10(a). The stability of the unmodified asphalt mixtures, including $CaCO_3$/blowdown filler specimens, was equivalent to 12.32 and 15.05 kN, respectively, indicating that the inclusion of blowdown filler raised MS by a significant 22.07%, whereas ABSMA mixtures enhanced MS compared to the unmodified mixtures. Also, adding ABS improves MS by 45.86% of the unmodified mix; however, the addition of polymers to BA mixtures has the reverse effect since polymers can alter asphalt and make it stiffer and more viscous. In the meantime, the filler's primary function is to improve the viscosity of the binder by filling up the voids between aggregate particles. Despite the fact that blowdown has a lower specific gravity than $CaCO_3$, blowdown required a larger dosage of ABS to increase binder viscosity, which increased adhesion and ultimately improved MS.

Flow refers to the vertical deformation of the specimen following the failure stage. High flow numbers often imply a plastic mix that could be susceptible to long-term deformation. Lower flow rates might indicate fewer air voids, which could lead to early cracking. Fig. 10(b) inferring that the unmodified mix's flow was 3.5% lower when blowdown was used. Additionally, all the mixes met the specified limitations of 2-4 mm flow [20, 39], as shown in the same figure.

Greater stiffness and resistance to deformation are indicated by higher MQ values, as shown in Fig. 10(c). FA has about 51.13% greater MQ value than the unmodified, which may be the result of increasing both the density and viscosity. Increased material toughness, which is beneficial in asphalt mixes prone to low-temperature cracking and thermal fatigue, is a result of higher stability values. Increased toughness may aid in reducing the development and spread of cracking [3].

ANOVA analysis; this outcome is mostly attributable to the same O.A.C. All of the mixes illustrated in Fig. 10(d) met the 3-5% limitations [20].



(a)

(b)

(c)

(d)

Fig. 10 Marshall parameters (a-Stability, b-Flow, c-Marshall quotient, d-Air voids).

5.3. Deformation strength

The minimum criteria for deformation strength (S_D) value is more than 3.20 Mpa, based on the standards guidelines by the Korean Ministry of Land [39]. Regarding the unmodified mixture, it is clear from Table 4 and Fig. 11 that S_D has increased by 12.5% with the presence of blowdown; however, for ABSMA mixes, S_D showed an enhancement of rutting resistance simply for FA mix by 35.59%. FA increased by 37.34% when comparing the BA mix to the unmodified mixture; this might be due to the chemical reaction effect. When polymer and $CaCO_3$ compositions are altered, chemical reactions occur, enhancing particle bonding and asphalt strength. The addition of blowdown and polymer to the unmodified mixture may alter particle distribution and asphalt properties, resulting in a decrease in the S_D value, suggesting less rigidity and resistance to deformation and rutting.

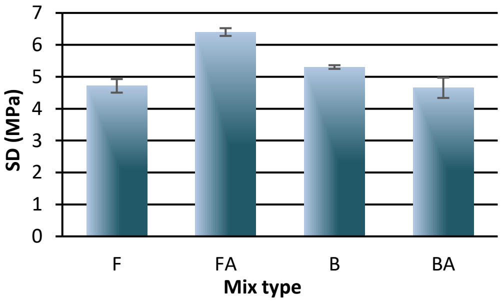
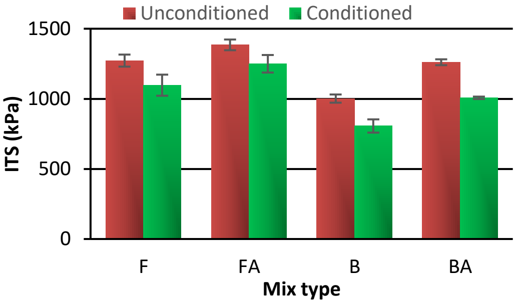


Fig. 11 Kim test results.

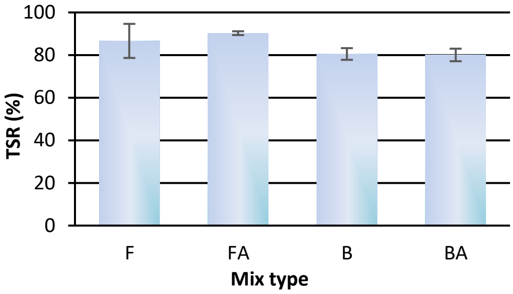
5.4. Moisture Susceptibility and Indirect Tensile Strength (ITS) test

The effect of moisture and temperature on tensile strength was evaluated in the study using ITS. As for uncondioned, the tensile strength of the FA mix was 8.81% higher than that of the unmodified mix, while the BA mix showed a 25.87% improvement. While for the conditioned, the BA mix showed a 24.92% improvement, whereas the FA mix showed a 13.91% improvement in tensile strength. Overall, it is clear from (Fig. 12a) mentioned that, for both conditioned and unconditioned mixtures, FA mixes have higher ITS values than BA mixes. This shows that mixtures with blowdown filler are somewhat lower resistant to cracking than mixes with normal filler.

By determining the tensile strength ratio (TSR) for the conditioned and unconditioned groups, moisture susceptibility was also evaluated. In Iraq, mixtures with appropriate moisture susceptibility may be identified using a minimum TSR value of 0.85, which is a standard value that is applicable globally [41, 42]. F and FA mixes have slightly greater TSR values than B and BA in Fig. 12(b), indicating that a stronger resistance to moisture damage. Moreover, it is clear from the previous section that the conditioning process weakens B and BA. The Asphalt Institute [42] considered TSR values of 0.8 or higher to be acceptable, whereas other agencies deemed TSR values of 0.7 or higher to be acceptable. Nevertheless, all of the TSR findings from this study are sufficient. According to the study, temperature and type of asphalt have a major impact on the ITS value. Higher tensile strength and tensile strength ratios lead to higher adhesion between aggregate and asphalt, which decreases control mix stripping [43].



(a)

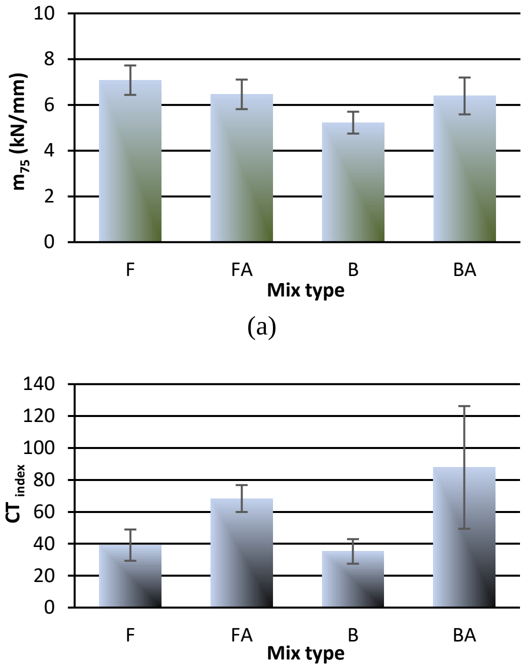


(b)

Fig. 12 Indirect tensile strength properties (a-Indirect tensile strength, b-Tensile strength ratio).

5.5. IDEAL-CT at intermediate temperatures

The CT_{index} analysis approach was used in this study to evaluate the asphalt mixes' cracking potential for the ITS test. The load-displacement curve from an ITS unconditioned test was used to compute it [40]. When m_{75} (Fig. 13a) decreased as it did for BA mix, as shown in Fig. 13, it is an evident that the CT_{index} increased, indicating greater resistance to fatigue damage [41]. From the ANOVA analysis shown in Table 4, it can be noticed that there is no significant difference between the averages for all of the mixes because they all achieve the specified limits in ASTM D 8225 [35].



(a)

(b)

Fig. 13 IDEAL-CT parameters (a- absolute value of the post-peak slope, b-Cracking tolerance index).

6. LIFE CYCLE COST ANALYSIS RESULTS

A LCCA was used to compare the costs of four DG mixtures: control $CaCO_3$ mixture (i.e., F-5% prepared using P40), modified $CaCO_3$ mixture containing modified asphalt binders (i.e., FA-1.5% prepared using P40 with 1.5% ABS added), control blowdown mixture (i.e., B-5% prepared using P40), and modified blowdown mixture containing modified asphalt binders (i.e., BA-1.5% prepared using P40 with 1.5% ABS added). In this study, the density and cost of the materials utilized and mixes are considered as follows:

1. Cost of asphalt binder, aggregates, blowdown, calcium carbonate, and ABS, respectively: 400 \$/ton, 10 \$/ton, 5 \$/ton, 35 \$/ton, and 2.8 \$/kg.
2. F-5%: 2380 kg/m^3 and 135 \$/ton.
3. FA-1.5%: 2400 kg/m^3 and 138 \$/ton.
4. B-5%: 2400 kg/m^3 and 105 \$/ton.
5. BA-1.5%: 2380 kg/m^3 and 108 \$/ton.

The calculation of Net Present Value (NPV) from Eq. (6):

$$NPV = C \times (1 + i)^{-N} \qquad (6)$$

where:
C = Initial cost of the mix (\$/ton),
i = Discount rate (assumed 7%), and.
N = Service life (years) (assumed 20yrs.).

Fig. 14 presents the NPV values for mix F-5% and mix B-5% along with the dollar value of cost savings per one-ton mix production (difference between NPV for mix F-5% and mix B-5%, and FA-1.5% and BA-1.5% were 7.52 and 8.04, respectively). The NPV for mix B-5% and BA-1.5% was lower than that for mix F-5% and FA-1.5%, respectively. Therefore, it can be concluded that the use of blowdown and ABS is cost effective. The results in Fig. 14 show that, construction of a pavement structure using B-5% and BA-1.5% on a same area and thickness (8.4m^2 ×5.0cm) of road way leads to \$7.52 and \$8.04 in cost savings when compared to constructing the same structure using F-5% and FA-1.5%, respectively.

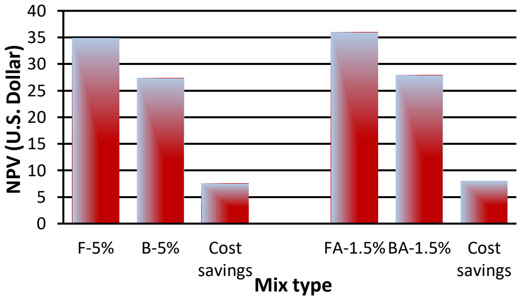


Fig. 14 Net Present Value.

7. CONCLUSIONS AND RECOMMENDATIONS

ABS polymer was used in this study as a compound in different dense-graded asphalt mixtures containing calcium carbonate and blowdown as a binder layer filler. The effect of the ABS polymer on moisture, rutting susceptibility, and cracking resistance was examined using the MS, ITS, and Kim tests. The following were the study's overall conclusions:

- The FA and BA mixes exhibit higher Marshall stability and Marshall quotients with somewhat lower air voids comparing to the unmodified (F and B) mixes.
- The Kim test results for deformation strength indicate that the FA mix have greater rutting resistance, whereas BA mix do not exhibit any improvement over the unmodified (B) mix but still meet the minimum 3.20 Mpa requirement.
- The FA and BA mixes have superior tensile strength and tensile strength ratios, while the FA mix shows better resistance against moisture damage, indicating superior strength and tensile strength compared to the BA mix.
- The cracking tolerance index of the FA and BA mixes is greater than that of unmodified mixes. Additionally, BA mix has a greater cracking tolerance index

(CT$_{index}$) comparing to the FA mix. This indicates that the BA mix is more resistant to fatigue damage.
- The life cycle cost analysis which has been conducted as a part of this study showed that the use of blowdown and ABSMA for modifying asphalt mixtures is a cost-effective solution.

The authors suggest that future research should be done to look for the impact of both short- and long-term aging on the performance of blowdown waste asphalt mixes with and without ABS in light of the study's findings. Furthermore, the construction of a field pavement section is crucial for verifying laboratory findings.

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تأثير ABS على مزجات الرصف المستدام

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الملخص

تقيم الدراسة تأثير مادة ABS *على مزجات الرصف الحاوية على مادة كاربونات الكالسيوم كفلرشائع الاستخدام ومخلفات الكبريت كفلر مستدام. تم تعريض المزجات غير المطورة والمطورة بمادة* ABS *الى اختبارات المارشال، مقاومة الشد غير المباشر، ضرر الرطوبة، دليل التشققات، ومقاومة التشوه من خلال فحص كيم. أوضحت نتائج التحليل الاحصائي بامتلاك المزجات الحاوية على الفلر المستدام ثباتية ومقاومة ضد التشوه عالية مع دليل التشققات ونسبة الفقدان بمقاومة الشد واطئة مقارنة مع المزجات الحاوية على الفلر الاعتيادي. بينما اظهرت مزجات فضلات الكبريت (المستدامة) ثباتية، مقاومة للتشققات والتآكل عالية مع نقصان في مقاومتها للرطوبة والتشوهات. اضافة لذلك بالامكان استخدام مزجات فضلات الكبريت غير المطورة والمطورة في تطبيقات الرصف خاصة وانها تمتلك خصائص تقع ضمن حدود المواصفات.*

الكلمات الدالة:

ABS، المخلفات، كاربونات الكالسيوم، دليل التشققات، مقاومة التآكل.