Abstract: Asphalt mixtures exhibit deterioration in properties due to several factors; one of these factors is the moisture damage. Many kinds of research have focused on this matter in Iraq; however, up to now, the pavement is suffering from moisture failure due to the penetration of surface water. Asphalt concrete is modified in this research by adding anti-stripping agent and polymer to withstand the moisture damage that occurs in the pavements. Key factors to enhance the mixtures to withstand the damages due to moisture are aggregate–binder cohesion and adhesion. Therefore, the aim of this research is to evaluate the effect of the addition of the anti-stripping agent and the polymer on the moisture susceptibility of asphalt concrete mixtures before and after conditioning. Indirect tensile strength test, Marshall test, and double punching shear test are used to satisfy the evaluation of the mixture properties. The anti-stripping agents that are used were WetFix with styrene butadiene styrene (SBS) polymer with different percentages. It is found that the modified asphalt mixture has good mixture properties in terms of Marshall stability, retained Marshall stability, and better resistance of moisture and stripping.
It has been found that the addition of 0.5% WetFix and 3% SBS polymer maximizes the properties among other percentages. It is also observed that the mixing technique of modifiers is important to the resulting performance of asphalt mixtures.

**Subjects:** Transportation Engineering; Pavement Engineering; Road Transport Industries

**Keywords:** Moisture sensitivity; asphalt mixtures; anti-stripping agent; polymer

1. **Introduction and significance of work**

   The increase in traffic volume combined with an increase in weather temperature causes pavement distress. These factors affect the durability and performance of the asphalt concrete. Meanwhile, low performance of pavement layers would affect the national economy of the country (Fattah, Ibrahim Al Helo, & Qasim, 2016); therefore, it is worth to improve the properties of the pavement layers.

   The strength and durability reduction in asphalt pavements due to infiltration of water between the asphalt mixture particles is called moisture damage. In Iraq, there are several types of pavement distress; some of them are the raveling and stripping which occur due to the poor aggregate–binder bonding due to the water infiltration (Alaa et al., 2015). The occurrence of moisture damage in the asphalt pavement layer will accelerate the chance of other types of distress to happen in the mixture such as rutting, fatigue cracking, and structural rutting due to the high stresses arrived to the unbound materials and roadbed materials. If the water infiltrates in an unloaded pavement mixture, the water will try to soften the asphalt binder and decrease the mixture stiffness and strength, but they will be recovered if the water was evaporated or removed (Hall et al., 2009). However, if the pavement was loaded in this case of damage, the pavement will deteriorate rapidly. In some areas of Iraq, it was noticed that the addition of SBS alone to the binder did not improve the moisture resistance significantly in areas that have a poor drainage system, and operations of scrape, milling, and overlaying were conducted. This will add more cost to the maintenance and would motivate the efforts to find a suitable modifying agent to overcome such problems. Researchers have focused on the analysis of life cycle related to the viscosity of bitumen and showed there is a strong effect of the binder viscosity on the life cycle and cost and also on the effect of the use of polymer modified binder on the quality of the asphalt pavement (Praticó, Casciano, & Tramontana, 2010).

   Several researchers have shown that modifying asphalt binder with polymer would enhance the bitumen and improve its durability, rheological properties, and temperature susceptibility (Wallman and Astron, 2001). Elastomers and plastomers are the most common polymers used to improve the performance of asphalt mixtures. The elastomers and plastomers are styrene butadiene styrene (SBS), styrene-butadiene rubber (SBR), ethylene vinyl acetate, and polyethylene (Gandhi, Colucci, & Gandhi, 1991; Hanson & Prowell, 2004). West, Choi, Bruner, Park, and Cho (2001) studied the adhesion between the aggregate particles and asphalt binder when polymers are added. The research found that the addition of SBS and SBR to the mixture would increase the mixture resistance to moisture damage. This happened due to the increase in the binder stiffness and the formation of bond network in the binder that will increase the aggregate–binder adhesion forces.

   The addition of anti-stripping agent to asphalt concrete has been studied by several researchers. Hamedi (2017) utilized two types of anti-stripping agents (namely WetFix N422 and WetFix 312) in asphalt mixtures with variable contents. The research focused on using the anti-stripping agents to investigate whether they improve the moisture resistance of the modified asphalt concrete. The research showed that the tensile strength ratio (TSR) and the indirect tensile strength (ITS) were improved by testing the samples in modified Lottman test. The goal of the research, therefore, is to evaluate the effect of moisture resistance of the modified asphalt concrete by adding a hybrid...
anti-stripping agent WetFix in different percentages (0.25%, 0.5%, 0.75%, 1%, and 2% by weight of total mix).

2. Anti-stripping additives
The aggregate particle interlock and the strength of the asphalt binder are significant to the stability of the asphalt concrete. The failure of the asphalt mixture occurs either in the bitumen or through the particles of aggregate if a full binder–aggregate bond and good bitumen stiffness are assumed (Kanitpong, 2004). When water infiltrates in the mixture, the aggregate particles will try to absorb the water because of their surface porosity, leading to a weak bond between aggregate and binder (Kanitpong, 2004); this weakness is called stripping of asphalt mixtures. Therefore, the physical characteristics of aggregate particles and bitumen are important factors affecting the adhesion and stripping failure that occur in the mixtures. Regarding the binder properties, the viscosity of the binder is a key factor of this failure, and it has been found that a binder with high viscosity is able to prevent water from reaching the aggregate particles, unlike the low viscosity binder. However, using a high viscosity binder could solve the stripping failure, but it affects the whole performance of the mixture in terms of mixing and construction of the mixture, low temperature, and fatigue cracking; therefore, viscosity optimization should be considered.

The addition of the anti-stripping agents is used when the mixture fails in the TSR test specification requirements which represent the moisture damage. The anti-stripping agents work in the mixture and force the aggregate surface to react with asphalt rather than the water (D’Angelo & Anderson, 2003). Researchers have shown that adding anti-stripping agents to the mixture improves the adhesion of binder with the aggregate particles (Bahia and Kanitpong, 2004; Kanitpong, 2004; Kanitpong & Bahia, 2003). The agents are usually come in liquid states and contain an active ingredient (amines); also, they should work effectively at high mixing temperatures of asphalt (D’Angelo & Anderson, 2003).

The agent is added to the binder as a percent by weight (0.5% for instance), despite some agents do not reach the aggregate surface, but it is the most economical method of anti-stripping agent application. The content of the agents should be optimized because a high content will decrease the mixture resistance to permanent deformation (Sebaaly, Hitti, & Weitzel, 2003). The function of anti-stripping agents in the mixture is different to the function of polymers which are used to improve the permanent deformation and fatigue resistance and also to increase the viscosity of the binder which helps with the agents to prevent water to reach the aggregate surface.

3. Laboratory testing
The testing program that is used to achieve the aim of this research is classified into the characterization of the materials used in the asphalt mixture and the mechanical tests to evaluate the end mixture product performance. The characterization of the binder was represented by the typical bitumen tests which are penetration, specific gravity, ductility, softening point, and viscosity. The aggregate characterization tests were represented by specific gravity, water absorption, Los Angeles abrasion, and particle shape tests. On the other hand, the mechanical tests for the modified asphalt mixture were the Marshal test, double punching shear test, and indirect tensile test. The mechanical tests were carried out before and after the addition of the anti-stripping agent.

3.1. Materials
Local materials were used to establish the objectives of this study which are asphalt binder, crushed aggregate, mineral filler, and anti-stripping agents.
3.1.1. Bitumen and aggregate
Asphalt cement (bitumen) was obtained from Al-Dura refinery, south-west of Baghdad. The binder was tested to be characterized, and it was found that it is of 40–50 penetration grade and the other physical properties are listed in Table 1. The performance grade (PG) testing was also conducted and will be shown in the Results section. Meanwhile, the coarse and fine aggregate was obtained from Al-Nibaie quarry, and the gradation of the aggregate is shown in Figure 1.

Mineral filler plays an important role in the performance of the mixture; it is those particles which pass sieve No. 200 (0.075 mm) and considered as non-plastic materials. Limestone filler (dust) was used in this research which is obtained from Karbala lime factory having the physical properties shown in Table 2 and compared to the State Commission for Roads and Bridges (SCRB) R/9 specifications.

3.1.2. Additives
Additives and anti-stripping agents were used in the mixture, and they are expected to improve the performance of the mixture and the moisture susceptibility using different test methods. The additives and agents that were used are lime, WetFix, and SBS.

| Table 1. Bitumen properties |
|-----------------------------|
| **Property**               | **ASTM designation** | **Test result** | **SCRB specification** |
| Penetration, 25°C, 100 g, 5 s (1/10) mm | D-5 | 47 | 40–50 |
| Ductility, 25°C, 5 cm/min (cm) | D-113 | 109 | >100 |
| Softening point, °C | D-36 | 52.8 | – |
| Flash point, °C | D-92 | 278 | Min. 232°C |
| Specific gravity | D-70 | 1.03 | 1.05–1.01 |

| Figure 1. Gradations with Iraqi specifications and Superpave requirements. |

| Table 2. Limestone filler properties |
|-----------------------------|
| **Property** | **Test result** |
| Specific gravity | 2.73 |
| %Passing sieve No. 200 (0.075 mm) | 98 |
| Specific surface area | 307.2 m²/kg |
Lime is a calcium-containing inorganic minerals that are mainly composed of oxides and hydroxide, and it is the product of coal seam fires and in altered limestone xenoliths in volcanic ejecta (Anthony, Bideaux, Bladh, & Nichols, 2007). The origin of the word lime is from its early use of building mortar which is used for sticking and adhering; nowadays, it is hugely used in asphalt mixtures, more than 400,000 tons each year (Roque, Zhang, & Sankar, 1999). Lime affects the mechanical and rheological properties of asphalt mixture and improves the moisture resistance of the mixture (Sebaaly et al., 2003).

WetFix is known as an anti-stripping material that has thermal constancy; it contains amines and is usually used in asphalt mixture to improve the adhesion between the aggregate particles and bitumen. Thermal stability of these materials increases the possibility of keeping them in the tanks for a long time. The addition of WetFix in asphalt mixture is used to be in dozes which is measured by the weight of the asphalt binder (0.25 to 1.0)% (Arifuzzaman & Tarefder, 2013). The WetFix viscosity that is used for this research is 3,500 mPa.s at 20°C and 400 mPa.s at 40°C. The percentage of liquid anti-stripping material used in this study is about 0.25–2% by weight of asphalt. The characteristics of this material are provided in Table 3.

SBS is a polymer which has an elastomeric property consisting of styrene (C6H5CH = CH2), butadiene (CH2 = CH-CH = CH2), and styrene (C6H5CH = CH2). It is widely used as a modifier to the asphalt mixtures among other types of polymers although it has economical and technical limitations (Becker, Méndez, & Rodríguez, 2001). The properties of the used SBS are tabulated in Table 4, and it is used in this research as 3% of asphalt binder weight.

### Table 3. Characteristics of WetFix liquid additives used in this study

| Characteristics                  | Wetfix BE                      |
|----------------------------------|--------------------------------|
| Appearance at 20°C               | Brown, viscous liquid          |
| Density at 20°C, kg/m³           | 980                            |
| Pour point, °C                   | <0                             |
| Flash point, °C                  | >100                           |
| Viscosity at 20°C, cP            | 3,500                          |
| Viscosity at 40°C, cP            | 400                            |

### Table 4. Characteristics of styrene butadiene styrene (SBS)

| Characteristics       | SBS  |
|-----------------------|------|
| Molecular formula     | C20H22 |
| Molecular weight      | 262.39 g/mol |
| Tensile strength      | 43 MPa |
| Elongation (strain)   | 95%   |
| Shear modulus         | 1.26–1.78 MPa |

3.2. Sample preparation

Marshall mix design is used in this research with different material compositions. Fourteen asphalt concrete samples (100 mm in diameter and 60 mm in height) were manufactured to range the different compositions to accomplish the mix design requirements according to ASTM Designation: D6926-2010. Figure 2 shows the preparation steps prior to testing. Two specimens are made for each test. Based on the obtained results, the optimum content of modified binder PG 76-16 is 4.5% for the selected gradation as shown in Table 5. Figure 3 shows the relationship between asphalt content and Marshall properties for modified mix. It can be seen that the increase in binder content would tend to increase the flow of the material because the load will be dominated by...
the binder rather than the aggregate particles. Moreover, the increase in binder content will also tend to increase the bulk specific gravity because the voids will be filled with asphalt; however, this will decrease the air void content which will affect negatively the performance of the mixture.

3.3. Mechanical tests

3.3.1. Indirect tensile strength test

This test is conducted according to AASHTO T-283 which gives an indication of the moisture susceptibility of the asphalt mixture. The test is used to estimate the ITS and the TSR. For the purpose of this test, a set of samples were manufactured for each mixture and according to Marshall procedure. The set of samples was divided into two groups, one is to be conditioned in one cycle of freezing and thawing and the other group is to be unconditioned which eventually both were tested at 25°C.

The load is applied statically with a rate of increase equals to 2.0”/min until failure occurs. The \( \text{ITS}_{\text{unconditioned}} \), which depends on the maximum load applied \( (P) \) and sample height and diameter \( (t, D) \), and the TSR can be calculated by using Equations (1) and (2) and as follows:

\[
\text{ITS} = \frac{2000P}{\pi t D} \quad (1)
\]

\[
\text{TSR} = \left( \frac{\text{ITS}_{\text{cond.}}}{\text{ITS}_{\text{uncond.}}} \right) \times 100 \quad (2)
\]

Specifications allow a minimum ratio of the tensile strength is to be 80%.

3.3.2. Retained Marshall stability test

This test is used to measure the retained stability after conditioning the sample in a water bath for 24 h at 60°C. This test is required, besides the Marshall test, by the local highway authority in Iraq (SCRB) for wearing course and according to ASTM D1075. The samples were grouped into two sets, one is the normal Marshall test, which is conditioning the samples for 30 min at 60°C in a water bath; this set is named “unconditioned”. The samples were then loaded until failure occurs at a loading rate of 50 mm/min. The second set of samples was conditioned for 24 h at 60°C in
a water bath and then tested in the Marshall test (shown in Figure 4); this set was named “conditioned”. The retained stability was then estimated using the following formula:

$$\text{RMS} = \frac{\text{Conditioned stability}}{\text{Unconditioned stability}} \times 100\%$$  \hspace{1cm} (3)

where

RMS = retained Marshall stability.

3.3.3. Retained double punching shear test

The retained double punching shear test was developed by the University of Arizona by Jimenez (1974), which is normally used to estimate the binder–aggregate stripping, and it is used by several researchers such as Solaimanian, Harvey, Tahmoressi, & Tandon (2003) and Turos (2010). The specimen used for this test is the standard Marshall specimen which is conditioned in a water bath for 30 min at 60°C. The test was performed by applying the load through two cylindrical steel punches which are located on the surface edges of the sample (top and bottom) and aligned perfectly in the vertical direction. The rate of the loading is 2.54 cm/min and the maximum load reached before failure is noted. The punching strength ($\sigma_t$) can be obtained by using the following
equation which depends on the maximum load applied \(p\), punch radius \(a\), and specimen radius and height \(b\) and \(h\):

\[\sigma_t = \frac{p}{\pi(1.2bh - a)^2}\]

(4)

4. Results and analysis

4.1. Binder characterization

The PG of asphalt binder is used to improve the general performance of the binder itself, and this would result in good resistance to the failure occur in the mixture. It is a comprehensive system that relates climate, traffic conditions, and aging with critical pavement distress. PG of asphalt binders is selected to meet expected weather conditions as well as aging considerations. According to the Superpave system, the asphalt binder tests simulate three critical stages. The first stage is the original asphalt binder which represents its storing, transporting, and handling stages before mixing with aggregate. The second stage is the short-term aging that simulates mixing, production, and construction of Hot Mixed Asphalt (HMA). The third stage represents aging during its service life which is named as long-term aging. Superpave tests and specification are applied for both modified and unmodified asphalt cements.

The binder characteristics are obtained from the routine Superpave tests which are the dynamic shear rheometer (DSR), bending beam rheometer (BBR) test, and the rotational viscosity (RV). The samples can be simulated for the short- and long-term aging by using the rolling thin film oven test (RTFO) and pressure aging vessel (PAV). Some tests used are shown in Figure 5.
4.2. The indirect tensile strength and TSR values

The ITS and TSR values were measured for the conditioned and unconditioned samples and shown in Table 8. It can be seen that the ITS of the conditioned and unconditioned control mixtures was 970 and 845, respectively. The addition of the 3% SBS has increased the ITS of both conditions to 1,070 and 970.5, respectively. However, the samples that contain SBS and WetFix have much higher values of ITS which indicates a better cohesive strength, and the prevention of stripping occurs between asphalt and aggregate, as shown in Figure 6.

In the same manner, the TSR values, which are presented in Figure 7, have increased sufficiently when SBS was added and when SBS and WetFix were added together to the mixture. The control mixture had a TSR value of 87.1%, SBS modified mixture about 90.7%, and the SBS and WetFix modified mixture reached to a peak of 97.2% when 0.5% of WetFix and 3% SBS were added to the mixture. It is noticed that the addition of WetFix on its own would decrease the ITS, and this is mainly due to action of the WetFix which modifies the chemical composition and charges of the binder, and this sometimes affects negatively the adhesion of the binder and aggregate. The addition of SBS with the WetFix would increase the elasticity of the bitumen and strengthen the chemical bonds.
4.3. Marshall stability and retained Marshall stability

The effect of additives on the Marshall stability values is shown in Figure 8. Marshall stability for the control mixture was 10 kN, and when using SBS, it increased to 11.4 kN, while when using SBS with WetFix, the stability increased gradually and reached to a maximum value of 14.9 kN at 0.75% of WetFix.
It is clear that there is a rise in Marshall stability values at 0.25%, 0.5%, and 0.75% WetFix + 3% SBS, which is 12.3, 13, and 15 kN, respectively, and then, it decreased at 1% WetFix + 3% SBS, but it still higher than that of control mixture.

The moisture damage of the asphalt mixture was measured using the retained Marshall stability (RMS) test. The reduction in stability is measured in this test by testing the samples after conditioning them for 1, 3, and 7 days at 60°C. A comparison between the original sample stability with those after the conditioning is shown in Figure 9.

It can be seen that the stability of mixtures containing additives is greater than that of the control mix, and the stability value reduces with the increase in immersing periods. However, when WetFix was added, the stability performed better. For instance, with the addition of 0.25% WetFix, the stability value is 10.4 kN for 1-day immersion and is 10.7 kN for 7-day immersion. The stability...
has a maximum increase for the mixes that contain 0.75% WetFix and 3% SBS compared to the control mix for 1, 3, and 7 days of immersion.

The RMS values were estimated for the mixtures and the control mixture and found to be 88%, and then, the RMS tends to increase for the mixture that contains SBS and WetFix + SBS. The optimum increase is at 0.75% WetFix + 3% SBS, where RMS equals to 102%, which indicates that the WetFix and SBS tend to reduce the effect of water action and increase binder–aggregate adhesive strength.

The RMS has decreased when the immersion time increased; however, specimens which are modified by WetFix have an increased RMS with the increment of the immersion period; the results are listed in Table 9. It can be seen that the maximum increase in RMS value is when 0.75% of WetFix was added to the binder at 7 days of immersion period; the results for this test are shown in Figure 10. In the same manner, the Marshall stability for all the mixes was decreased except those which are mixed with 0.75% WetFix + 3% SBS.

### 4.4. Double punching shear strength

As mentioned earlier in this research, this test is used to evaluate the stripping that occurs between the aggregate particles and binder. Figure 11 shows the value of the punching shear strength increase from 147 kPa for the control mixture to 222 kPa for mixtures that are modified.
with SBS and to 191 kPa when 0.75% of WetFix was used. However, when 3% SBS + 0.5% of WetFix were used, the punching shear strength has jumped to 278 kPa. This would add more solid knowledge that the combination of SBS and WetFix as modifiers to the binder would improve the mechanical properties of the asphalt mixtures.

5. Conclusion

Moisture damage of asphalt mixtures was studied in this research when anti-stripping agents and polymers are added to the mixture. Different percentages of WetFix and SBS were used, and the optimum percentage is when a combination of 0.5% WetFix and 3% SBS is used. This percentage improves the properties of asphalt mixture in terms of rutting resistance, Marsha stability, viscosity, ITS, TSR, and punching shear resistance. Based on the results obtained from this research, several points are concluded:

(1) The performance grade of the control asphalt (PG 64-16) increased by two degrees (PG 76-16) with the addition of hybrid modifier (0.5% WetFix + 3% SBS).

(2) The viscosity was increased by more than two times when SBS and WetFix were added to the mixture; therefore, there is a need to increase mixing and compaction temperature for modified hot-mix asphalt mixtures.
(3) Rutting parameter (G*/sinδ) was increased by 140% when 0.5% WetFix and 3% SBS binder were added.

(4) The addition of 3% SBS polymer by weight of asphalt binder improves tensile strength and the TSR value increased by 3% from the control mixture.

(5) When using SBS and WetFix together, the ITS and TSR values increased significantly, and the optimum content was at 0.5% WetFix fume + 3% SBS where the TSR value increased from 87.1% at control mixture to 97%.

(6) Marshall stability was highly increased when SBS and WetFix were added, and it increased by 50% compared to the control mixture when WetFix + SBS was used.

(7) The higher value of RMS was 102% at 0.75% WetFix +3% SBS which is approximately 30% greater than the control mixture.

(8) Punching shear strength was also improved at 0.5% WetFix + 3% SBS content compared to the control mixture results.

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