Evaluation of moisture-induced damage of stone matrix asphalt mixture with polymer modified binder

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Abstract. Moisture – induced damage is one of the most common reasons for the premature deterioration of Hot Mix Asphalt (HMA) pavements. Over the years, extensive research has been carried out by scientists and engineers on this subject; however, pavements still succumb to early failure from infiltrating moisture. The purpose of this research is to study the moisture induced damage performance of Stone Matrix Asphalt (SMA) asphalt pavements using Styrene Butadiene Styrene (SBS) polymer modified asphalt binder. To achieve the objective of this research the Superpave gyratory compactor was used for preparing the asphaltic samples and determining the volumetric properties of mixtures. The physical properties of aggregate, bitumen and other mix materials were assessed and evaluated with the laboratory tests. The mixtures were prepared using penetration Graded (40-50) bitumen and a chemical named Polypropylene Fiber was used as a stabilizing additive. Volumetric properties, Marshall Stability, behaviour to moisture action etc. were determined in laboratory. From the results it is seen that addition of SBS to the asphalt binder has significantly improved the cohesion as well as adhesion properties of the asphalt binder, and hence the stripping performance. Therefore, it can be concluded that the SBS is suitable to be used as a modifier in order to enhance the properties of the asphalt binder and thus improving the performance of asphalt in and SMA mixes.

1. Introduction
Stone Matrix Asphalt (SMA) can be defined as a hole sorted bitumen blend with high convergence of coarse aggregate as well as high mastic (bitumen and filler) contents. Such blend is fundamentally utilized on asphalts conveying overwhelming traffic volume or on asphalts conveying substantial burdens or potentially high tire weights [1]. It is very appropriate for high pressure asphalt places, for example, at crossing points and truck terminals [2]. SMA blends with high ostensible aggregate size and aggregates plus fantastic protection from wear have been favored for such reason [3]. The blend had been observed to be preferred trench safe and sturdy over traditional dese sorted blends and this provoked numerous European nations as well as USA to embrace this kind of blend [4]. The coarse aggregates skeleton furnishes the blend of stone to stone contacting, providing quality and turning it groove and slide safe, as appeared in Figure 1 [5]. The high fastener contents mortar which is made out of smooth aggregate, mineral filler, paving cover, and balancing out added substance provides toughness to the blend. The balancing out added substance functions to hold the paving cover in the blend amid the large temperature of generation and arrangement to stop draining down [6].
Dampness induced harm in paving blends results in loss in quality and solidness because of water's existence. Iraqi street system demonstrates extreme weakening, for example, problems of ravel as well as strips were caused as the bind among aggregates and paving stripe could be damaged because of the interruption of water [7]. It frequently straightforwardly interrupts the uprightness of the blend by diminishing the asphalt performing period by quickening each method of distressing of concern for asphalt configuration, this includes weakness splitting, lasting distortion (rutting) and warm breaking in paving cement, and rutting in the unbound soil layers because of the decreased burden conveying limit of troubled paving solid layers. Now and again when asphalts aren't stacked, dampness may essentially debilitate the paving blend by mellowing or incompletely emulsifying the paving film without expelling from aggregate's surface. The subsequent loss of solidness or quality may be recuperated when waters are expelled from the blend [8]. Nonetheless, when asphalt is stacked amid this debilitated condition, harm is quickened and may become irreversible.

**Figure 1.** Difference in aggregate structure between dense-graded and SMA in core samples [5]

Among many types of polymer modifier, styrene-butadiene-styrene (SBS), which had been initially created by Shell Company for chemicals, is generally utilized in most of the altered paving fasteners [9, 10]. This modifier makes a system of three dimensions inside the virgin paving stage, bringing about a fantastic holding solidarity to aggregate that prompts tough and durable asphalt [11, 12]. According to constructional norms, its spine tie is comprised of three portions. Polystyrene represents a hard plastic, which gives solidness at high temperature, while butadiene is elastic which adds to the versatility of the fastener at low temperature. It is imagined that the SBS arrangement cooperates with the asphaltene and gum portions of the fastener [13]. The impacts of counter striping added substances on polymer-changed paving blend are explored [14], it is discovered that utilizing of polymer, for example, SBS, improves blend properties to exhaust splits, rutting obstruction, and dampness harm as contrasted to blends having EVA polymer.

West et. al., examined the impact of polymer expansion on the grip power between aggregates and paving binders, it is discovered that blends changed via polymer (SBS and SBR) displayed more noteworthy protection from dampness harm than the unmodified blends, because of expanded attachment power to the aggregate, in addition to making a system with the bitumen [15]. Goodman et. al., contemplated the impact of utilizing SBS with hydrated lime on the dampness harm affectability opposition of paving blends, it has been discovered that SBS have great impact on dampness harm obstruction and increment its obstruction [16].

The fundamental motivation behind this exploration is to decide the impacts of utilizing SBS polymer on the building properties of stone mastic paving (SMA) blends and furthermore to assess dampness incited harm of polymer adjusted blend as contrasted with control blend. It is felt that the expansion of SBS to paving binders may present a magnificent potential for paving cover alteration because of their inborn similarity with paving concrete and superb mechanic properties.
2. The Material used and Experimental Techniques

2.1 Material used

SMA refers to a top-notch blend that needs excellent material with cubical, low scraped area, and pulverized stone since the blend increases the greater part of its quality from the stone-on-stone total skeleton. Mineral filler and added substances likewise decrease the measure of black-top channel down in the blend amid development, expanding the measure of black-top utilized in the blend, improving its strength. Table 1 gives general rules to material utilized in SMA blends [5].

In this research, Bitumen fastener graded as (40/50) penetration with properties, as shown in Table 2, has been utilized to set up the adjusted cover; it is obtained from Al-Dourah Refinery, south west of Baghdad. The tests are complied with Iraqi detail (SCRB, 2003) and ASTM requirements.

SBS polymer had been utilized to change the bitumen for the arrangement of adjusted cover. The properties of SBS utilized in this examination have 1247 Kg/m³ Density and 197 °C Melting point. The coarse aggregate used is crushed quartz having a maximum nominal size of 19 mm, it was brought from Al-Nibaee quarry; this aggregate is widely used in Local asphalt paving in Baghdad. The physical properties of used aggregate are shown in Table 3. One kind of filler was utilized in the current examination: limestone dust obtained from lime processing Karbalaa's plant; the physical properties of the utilized filler are determined as 2.91 of bulk specific gravity and 97% of passing sieve No.200 (0.075 mm). For stabilization; one of the serious issues normally experienced in SMA blends can be the draining down of the cover amid blending, transportation and compaction. To conquer this issue, filaments are normally added to SMA blends. Polypropylene Fibers PF could be utilized as settling operators in SMA blends, at the rate of 0.3% and 0.5% by weight of blend. The technical specifications of PE are presented in Table 4. Figure 2 shows the materials used in this study.

Table 1. Materials for SMA Mixtures, [5]

| Layer                          | Materials                  | Medium Traffic                      | High Traffic                     |
|-------------------------------|----------------------------|-------------------------------------|----------------------------------|
| Surface & Intermediate /cover | Aggregates                 | smashed stones/smashed gravels      | produced sands                   |
|                               |                            |                                     | Mineral fillers                  |
| Asphalt Binder                | Changed binder normally    | utilizing, Unchanged could be       | changing probable                |
|                               |   utilized, Unchanged could | utilized at lower traffic level      | unchanged paving                 |
|                               |   be                       |                                     | depends on domestic              |
|                               |   utilized                 |                                     | experiment                       |
| Others                        | Fibers / Antistrip as      |                                     |                                  |
|                               |   defined via tests        |                                     |                                  |
Table 2. Results of Physical Properties of Selected Aggregate

| Property                                      | Value          | ASTM Designation       |
|-----------------------------------------------|----------------|------------------------|
| Wear % (Loss Angeles abrasion)                | 21.3 %         | AASHTO_T96, 30 %       |
| Soundness (Loss by Na₂SO₄),%                 | 3.2%           | AASHTO_T104 20% max    |
| Angularity, %                                 | 97%            | ASTM D 5821, min 95%   |
| Flat and elongated particles, %               | 0.9%, 2.5%     | ASTM D4791, max 10%    |

Table 3. The physical properties of asphalt cement

| Test                                      | Test Conditions                  | ASTM Designation | Units    | Test results | SCR B/ R9 Specif.,2003 |
|-------------------------------------------|----------------------------------|------------------|----------|--------------|------------------------|
| Penetration                               | 100 gm, 25°C, 5 sec., (0.1mm)    | D5               | 1/10 mm  | 49           | 40-50                  |
| Ductility                                 | 25°C, 5 cm/min                   | D113             | cm       | 120          | >100                   |
| Softening Point                           | (4±1) °C/min.                    | D36              | °C       | 48.5         | ----                   |
| Specific gravity                          | 25°C                             | D70              | ----     | 1.031        | ----                   |
| Flash and fire points                     | ----                             | D92              | °C       | 230          | >232 °C                |
| Rotational Viscosity                      | 135°C                            | D4402            | pas.sec  | 0.524        | ----                   |
| Residue from Thin Film Oven Test, D-1754  | 165°C                            |                  |          | 0.14         |                        |
| %Retained Penetration of Original         | 25 °C, 100 gm , 5 sec            | D5               | 1/10 mm  | 28.7         | >55                    |
| Mass Loss                                 | 163 °C, 50gm, 5 hr               | D-1754           | %        | 0.6          | < 0.75                 |
| Ductility of Residue                      | 25 °C , 5 cm/min                 | D113             | cm       | 87           | > 25                   |

Table 4. Technical properties of Polypropylene Fibers stabilizer

| Property                  | Test Result |
|---------------------------|-------------|
| Fiber’s length            | 12mm        |
| certain weight            | 0.911 (g/cm³) |
| Alkali contents           | Nil         |
| Sulphate contents         | Nil         |
| Chloride contents         | Nil         |
| ingredients               | polypropylene fiberC3 H6,     |
| Fiber thickness           | 18 micron 2denier  |
| certain surface area      | 244.2 m²/kg |
2.2 Mix Design
Superpave gyratory compactor method was adopted to design asphalt mixture. Three aggregate gradations were selected according to AASHTO Designation: (M 325-08, 2012) [17] for surface course. The gradations of aggregate blends are shown in Figure 3. The design asphalt binder content is established at 4% air voids and the design asphalt content was 6.8% to paving grade as (40-50). The blend features were examined at the design paving cover contents to confirm that these features comply with AASHTO M325.

2.3 Drain Down test
Drain down test was conducted as per ASTM D 6390 on loose SMA mixtures with and without Polypropylene Fibers. Loose SMA mixture with Polypropylene Fibers was prepared for bitumen contents 5.8, 6.3, 6.8, and 7.3% by weight of mixtures, as shown in Figure 4. For Polypropylene Fibers application, 0.4% of concentrated Polypropylene Fibers (by weight of bitumen) should be added with bitumen.

2.4 Marshall and Volumetric features
Theoretical maxi definite gravity (G_mm) of uncompact loose SMA mixtures with Zycosoil was determined as per ASTM D 2041. After preparing them, the sizes along with weightiness of the samples had been calculated so as to determine the size definite gravity (G_mm), air void (V_v), Void in Mineral Aggregate (VMA), in addition to Voids Occupied with Bitumen (VFA) etc. of compacted specimens. SGC specimens were tested for conventional Marshall Stability and flow as per ASTM D
6927, Figure 5 shows the samples preparation. Voids in Coarse Aggregate (VCA) to aggregate in Dry Rod Conditions (VCA \text{DRC}) as well as for blend (VCA \text{MIX}) had also been measured by employing the following equations; (Brown and Cooley, 1999) [18]:

\[
VCA_{\text{DRC}} = \left( \frac{\rho_{\text{ca}} \cdot \gamma_w - \rho_{\text{ca}} \cdot \gamma_{\text{fr}}} {\rho_{\text{ca}} \cdot \gamma_w} \right) \times 100 \\
VCA_{\text{MIX}} = 100 - \left( \frac{\rho_{\text{mb}} \cdot P_{\text{CA}}} {\rho_{\text{ca}}} \right) 
\]

Where:
GCA = size of definite gravity of the rough aggregates portion; YW = water's unit weightiness (998 kg/m³); YS = portion of rough aggregates unit weightiness in dry-rod condition (kg/m³) (Defined as per ASTM C 29); GMB = Bulk specific gravity of compacted mixture; PCA = Percent coarse aggregate in the total mixture.

2.5 Indirect tensile strength test
The bond between aggregate mixture and asphalt binder film may lose due to presence of water or cause stripping, and it depends on several factors: asphalt characteristics, environment, traffic and aggregate characteristics. This was accomplished by applying AASHTO T283 "Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage" [19] and ASTM D 4867 [20], compaction was done for samples to 6% air voids according to AASHTO Designation: M 325-08 (2012) Standard Specification For Stone Matrix Asphalt (SMA). Single subsection of three examples was regarded as controlling example the other one of three examples represents the conditioning subsection. The conditioning subsection is exposed to vacuum immersion pursued by a discretionary freezing cycle, then adding an additional immersion period for the specimens at 60 °C for different periods (1, 3 and 7 days). Previous researchers examined water immersion periods of (1, 3 and 7) to assess moisture damage for longer periods than standard duration [7, 21]. Subsequent to the process of conditioning, the two subsets have been tried for indirect rigidity that is cultivated by indirect Tensile Machine in state of equivalent velocity (50.8mm/min) and the greatest burden is registered. The dampness affectability is resolved as a proportion of the tensile qualities of the conditioning subsection separated by the rigidities of the controlling subsection. Indirect tensile strength is determined as follows:

\[
S_t = \frac{2P} {\pi \cdot t \cdot D} 
\]

As:
Sₜ = tensile strength, kPa,  \( P \) = maximum load, N,  \( t \) = specimen height immediately before tensile test, mm and  \( D \) = specimen diameter, mm. After that the tensile strength ratio is determined as follows:

\[
\text{TSR} = (S_2/S_1) \times 100 
\]

As:
TSR = tensile strength ratio, per cent,  \( S_2 \) = average tensile strength of conditioned subset, kPa, and  \( S_1 \) = average tensile strength of the dry subset, kPa.

2.6 Marshall Test
In general, the motivation behind such testing is to quantify the solidness and stream esteems for blends. The examples had been drenched in a water way at a temperature of 60± 1°C for a time of 30-40 minutes. At that point, the example was put in the Marshall soundness test machine. The loading is at a steady ratio of twisting of 50.8 mm (2 in) every moment until disappointment. The most extreme stacking that causes disappointment of the example was reordered as Marshall Dependability and the entire sum of distortion was taken as Marshall stream.
2.7 Double Punch Shear Testing

Such testing methodology had been progressed at the University of Arizona by Jimenoz (1974) [22]. It was utilized for estimating the stripping of the binder from the aggregates, this test was reported by many studies (Solaimanian, 2004 [23]; Sarsam, 2006 [24]; Turos, 2010 [25]; Hasan, 2012[26]; and Mashkoor, 2015[27]). Marshall Specimens were utilized for testing and three examples were subjected to conditioning by setting them in water at 60 ± 1°C for 30 minutes. The example was focused between two tube shaped steel punches (2.54 cm in measurement) consummately adjusted one over the other and after that stacked a rate of (2.54 cm/minute) until disappointment. At that point the most extreme opposition was registered. The punching quality is determined via the condition below:

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

As: \( \sigma_t = \) Punching shear stress, Pa , \( p = \) Maximum load, N., \( a = \) Radius of punch, mm., \( b = \) Radius of specimen, mm., \( h = \) Height of specimen, mm.

3. Results Analysis and Discussion

3.1 Drain Down

Drain down was observed to be about 0.380% for SMA without Polypropylene Fibers whereas it was 0.282% for mix with Polypropylene Fibers. This showed that Polypropylene Fibers can be used for steadying additives to manage draining down to keep it within the limit of 0.3% and hence further tests were conducted on mixes with Polypropylene Fibers.

3.2 Volumetric and Marshall Properties

The bitumen contents equivalent to 4% air void were calculated for mixtures and was considered as the Optimum Binder/Bitumen Content (OBC). The volumetric properties and Marshall Characteristics of samples prepared in SGC, at their corresponding OBC, are tabulated in Table 8. All properties were observed to be improved for SMA samples compacted in SGC. VA\(_{\text{DRC}}\) was obtained as 99.8% and VA\(_{\text{MIX}}\) was less than VA\(_{\text{DRC}}\) for all samples. This ensures the presence of stone to stone contact between coarse aggregates in SMA mixtures. Table 5 shows the design mixture properties at design asphalt content (6.8%).

| Property                  | Requirement | Test Results |
|---------------------------|-------------|--------------|
| Asphalt binder content %  | 6 min       | 6.8          |
| VFA (%)                  | -           | 80.52        |
| VMA%                     | 17 min      | 20.46        |
| Air voids %              | 4           | 4            |
| Flow value (mm)           | -           | 3.5          |
| Marshall stability (kN/mm)| -           | 16.3         |
| VA\(_{\text{MIX}}\)       | Less than VA\(_{\text{DRC}}\) | 42.13       |
| TSR                      | 80 Min      | 93.1         |

3.3 Indirect tensile strength test

Indirect Tensile Testing (ITS) represents a strategy for deciding the elasticity of an example by applying a compressing burden on a barrel shaped example. Rigidity is utilized to anticipate the water helplessness of the example. For this situation, the elasticity had been estimated after water treatment to decide the held quality rate. From figures 4 and 5, the indirect elasticity for unconditioned and adapted examples increment with expanding SBS polymer content. Figure 8 shows the non-direct
rigidity proportion. It tends to be plainly seen that the loss in ITS for blends having SBS is lower than blends without SBS.

3.4 Marshall Test
Marshall Steadiness and flow test results are illustrated in figures 7 and 8 respectively. Figure 3 clearly shows that by adding the SBS polymer to gap, graded blend enhances the Marshall steadiness. It can be seen that the steadiness incremented approximately 14, 15.8, 16.3 and 15.5% when adding 1, 2, 3 and 4% SBS content, respectively. Regarding flow which represents the quantity of vertical deforming for the sample when failing, in outcome it appeared that the flowing increases when SBS contents increase in figures 11 and 12, respectively. It can be noticed that the outcomes conform to the specifying scope that is 2-4 mm consistent with (SCRB/R9, 2003) [28].

3.5 Double punch shear test
Double punch shear test indicates the shear resistance action between aggregate and binder. Figure (11) presents double punch shear test results for hot recycled mixture. Three per cent of SBS polymer was added. It can be noticed that the punching quality values increase with increase in SBS contents. It increases approximately by 3.6%, 3.9%, 4.25% and 3.8% when adding 1%, 2%, 3% and 4% SBS polymer content respectively for the mixtures. This may be credited to the way that SBS adjusted paving enhances the glue quality of a blend that gives the ideal qualities of flexibility, versatility and extension and furthermore increments the consistency of cover, thus more protection from the loading is conveyed via the machine (punching loading).
Figure 6. Tensile Strength Ratio for long term conditioned specimen

Figure 7. Marshall Stability versus SBS polymer content at 0 days immersion period

Figure 8. Marshall Stability versus SBS polymer content at different days immersion period

Figure 9. Marshall Flow versus SBS polymer content.
4. Conclusions

In this study, the mechanical properties and dampness induced damage performing of gap sorted mixture with SBS polymer–modified asphalt mixtures have been assessed to define the resisting of SMA paving blends. The subsequent findings depend on concentrated investigational effort:

1. Addition of SBS polymer to paving blend is important, as SBS has improved its moisture-induced damage resisting because of better elasticity provided via the particles of SBS.
2. SBS polymer seems to enhance the strip resisting because of trivial dissimilarity amid the non-conditioning and conditioning outcomes for changed blends.
3. The indirect tensile strength (ITS) for non-conditioning and conditioning specimens increments as SBS polymer contents increase, leading to increase in the stripping resistance, which indicates that mixes, would withstand the loading from automobiles once subjected to strong conditions devoid of big structure’s degrading.
4. The punching strengthening value increments as SBS content increases, which is increased by about 4.25% after adding 3% SBS polymer.
5. The addition of the SBS polymer to SMA mixture has clearly improved the Marshall stability by about 16.3% with 3% SBS polymer content.
6. From the experimental results of the three percentages (2%, 3% and 4%) of SBS polymer for gap graded modified mixture, it can be concluded that 3% of SBS content gave the best results due to its improvement of mechanical properties of the mixture as compared with the control mixture.
7. Thus, the addition of SBS polymer to the asphalt binder in gap graded asphalt mixture has significantly improved the cohesion as well as adhesion properties of the binder, and hence the performance of the mix to moisture induced damage.

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