Improvement the Shear strength of Asphalt Mixture by using crumb tire Rubber

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Abstract Rutting is one of the big problems in hot-mix asphalt (HMA) pavements. The primary mechanism of HMA rutting is shear deformation, often caused by high stress in HMA layers during traffic loading, especially at high temperatures. Current HMA rutting tests are not necessarily designed to capture HMA shear properties such as shear strength, shear strain, and shear module. The present work explores the behavior of the shear strength properties of HMA modified with Crumb Tire Rubber (CTR) and two types of filler (brick and lime dust in comparison with passing sieving No.200 as control filler) by developing a Simple Punching Shear Test (SPST) under control of temperature and loading rate. A series of laboratory sample tests to formulate and set up the SPST protocol and the related test parameters, derive the SPST results analysis sample to capture the HMA shear parameters from the results and comparatively evaluate the shear properties of HMA mixes. Results have shown that the SPST is relatively receptive to the form of modifier and filler. Using limestone dust as with (5%) CTR content increased higher shear strength, the rate of increase was about (44.44%) and (51.38%). Also 5% to 7% CTR content with lime dust filler lowering shear strain more than for brick dust filler.

Keywords: Shear strength ; Asphalt Mixture, CTR.

1. Introduction

Highways in Iraq or in any other countries are expose to different types of stresses. These stresses will induce pavement deteriorations, which are not only produced from of poor design and construction practices but may be caused by the inevitable wear and tear that occurs over a period of years (Garber and Hoel, 2002).

Pavement structures categories in two group namely flexible and rigid pavement structures. Asphalt pavement exhibits three primary distresses: rutting, fatigue cracking, and thermal cracking. Rutting is the plastic deformation of asphalt concrete or the underlying layers along the wheel path. Fatigue cracking includes alligator cracking, which is cause by repeated tension at the bottom of the asphalt layer, and longitudinal cracking, which results from the repeated tension/shear at the edge of the wheel. Thermal cracking is manifested in transverse cracks and is caused by low temperature contraction or repeated temperature cycles (Khattak, and Baladi, 2017).
In recent years, the advance of technology in the field of asphalt paving materials has mainly focused on developing solutions to pavement distress such as permanent deformation, moisture damage, and fatigue or low-temperature cracks, in order to extend the pavement durability. As a solution, pavement technologists have developed asphalt mix additives for mitigating those distresses in hot mix asphalt (HMA). Table 1 illustrates the classification of asphalt modifiers and additives that have been used in HMA pavement.

Table 1. The Classification of Some Asphalt Modifiers and additives (Roque et al, 2005)

| Modifier type | Example |
|---------------|---------|
| filler        | Carbon black, hydrated lime, lime, fly ash |
| extenders     | Sulfur, lignin |
| elastomers    | Styrene-butadiene-styrene (SBS) |
|               | Styrene-butadiene-rubber (SBR) |
|               | Styrene-ethylene-butadiene-styrene (SEBS) |
|               | Isobutene-isoprene copolymer (IIR) |
|               | Natural rubber |
|               | Crumb tyre rubber |
|               | Polybutadiene(PBD) |
|               | polysisoprene |
| Thermoplastic elastomers | Ethylene vinyl acetate (EVA) |
|               | Ethylene methyl acetate (EMA) |
|               | Ethylene butyl acetate (EBA) |
|               | Atactic polypropylene (APP) |
|               | Polyvinyl chloride (PVC), polystyrene (PS) |
| Anti-stripping agents | Amines, lime |
| Hydrocarbons (natural asphalt) | Trinidad lake asphalt (TLA), gilsonite recycling and rejuvenating |
| Anti-oxidants | Lead compounds, carbon, calcium salt |
| oxidants      | Manganese salt |
| miscellaneous | Deicing calcium chloride, silicones |

Several researches have been conducted to investigate the effectiveness of using modifier crumb rubber (CTR) at different percentage to improve behavior of asphalt binder and mixtures (Baha et al. 2009; Farag 2010; Abed et al. 2011; Fengxia and Zhifei Liu 2017; Naser 2018; Chen et al. 2019; Xuncang et al., 2019 and Ahmed et al. 2020). These researchers found that using (CTR) modifier for asphalt mixture will improve the properties of HAM such as rutting resistance, rheological properties, long fatigue life, increase of Marshall Stiffness, indirect tensile strength and decrease of temperature susceptibility of mixtures, increased in flash point, the ductility, and viscosity while decreased the solubility.

2. Simple Punching Shear

For assessing the rutting or PD susceptibility of HMA in the laboratory, several testing methods such as the Hamburg Wheel Tracking Test (HWTT), Repeated Loading Permanent Deformation (RLPD), and Dynamic Modulus (DM) tests, are often used. In particular, the HWTT is routinely used in Texas for assessing HMA mixes’ susceptibility to rutting moisture damage (stripping). Whilst these tests have a fairly proven history of successfully identifying and screening HMA mixes that are prone to rutting, several rutting failures have recently occurred in the field with HMA mixes that performed acceptably in the laboratory (Walubita et al., 2013). These failures occurred mostly in high shear locations, in particular with slow moving (accelerating/ decelerating) traffic at controlled intersections, in areas of elevated temperatures, heavy/high traffic loading, and/or where lower asphalt-binder performance grades (PG) have been used. Indeed, one of the contributing mechanisms of permanent
deformation in HMA is the lateral movement, i.e., the shear failure of the HMA under traffic; as shown in Figure 1 (Brown et al., 2001). To address this issue, several tests have been developed and explored in the recent years for evaluating the shear resistance of HMA mixes in the laboratory.

![Figure 1. Mechanisms of Rutting in HMA Pavements (Brown et al., 2001).](image)

William 1987, discussed efforts to improve the strength and durability of asphalt concrete by incorporating chemical additives in hydrocarbon asphalt cements. It was found manganese modifiers might improve the strength and reduce the deflection of full depth asphalt concrete.

Jimenez 1974 and Wen et al. 2014, carried out a cylindrical asphalt concrete specimen is compressed vertically through two steel punches placed concentrically on the top and bottom sides. It was conclude the failure modes of the two tests are quite different.

Chen et al. 2006, study evaluated the uniaxial penetration test for its suitability to characterize the shear resistance of hot-mix asphalt mixtures at elevated temperatures. The results indicated that the uniaxial penetration test was able to provide consistent results for the mixtures selected.

Walubita et al. 2014 develop SPST a supplementary and/or surrogate HMA rutting shear test to complement the existing tests, such as the HWTT, RLPD, DM test, etc. It was found the SPST was to be reasonably sensitive to test input parameters (e.g., loading rate and temperature) and HMA mix variables (e.g., asphalt-binder type and content), shear strain and the SSE index parameters did not show any definitive trend with changing test input parameters and HMA mix-design variables. In addition, the shear resistance of the tested HMA mixes increased with test loading rate and decreased with test temperature and with asphalt-binder PG grading and decreased with asphalt-binder content (AC).

Faruq et al. 2015, carried out new test method, namely the Simple Punching Shear Test (SPST), was developed as a supplementary and/or surrogate HMA rutting shear test to complement the existing rutting and PD tests. The results are analyzed in comparison and validation with the standard HWTT test and field performance. It have been shown that the SPST can be a useful tool for characterizing the HMA shear properties and can be practically used as a surrogate test method.

3. Research Objective

The research aims to

1. Enhance the performance of the existing HMA shear resistance and permanent deformation (PD)/rutting tests and to
2. Develop supplementary and/or surrogate rutting tests including apply developed a new HMA shear test and give additional guidance to designers on the SPST has promising potential in evaluating the HMA shear properties and can be practically used as a surrogate test method.

4. Experimental work

4.1 Asphalt cement
One type of asphalt cement with penetration grade (40-50) was used in this study as natural asphalt binder, provided from Al-Dura refinery south of Baghdad. Tests conducted on asphalt cement confirmed that its properties complied with the specification of State Corporation of Roads and Bridges (SCRB 2003, R9). Table (2) illustrate the physical properties of asphalt cement. From PI will find the asphalt cement used in this study sensitive to temperature.

Table 2. Physical properties of asphalt cement.

| Property                                      | Result | Unit   | SCRB Specification |
|-----------------------------------------------|--------|--------|--------------------|
| Penetration, (25°C,100g,5 sec) ASTM D5 / D5M - 20 | 45     | 1/10mm | 40-50              |
| Softening Point temperature, (Ring & Ball) ASTM D36 / D36M - 14 | 51     | °C     |                    |
| Ductility (25°C,5cm/min) ASTM D113-17         | 132    | cm     | >100               |
| Flash point (Cleave land open cup). ASTM D-92 | 292    | °C     | Min232             |
| Specific gravity, at 25 ºC ASTM D-70          | 1.04   | -      | (1.01 to 1.05)     |
| PI                                            | -1.186 | -      |                    |

4.2 Aggregate

The aggregate used in this work was crushed and obtained from Al-Nibaie quarry. The coarse and fine aggregates were sieved and recombined as shown in plate 1. The gradation of coarse aggregate for surface layer ranges between 3/4 in. (19.0 mm) and No.4 sieve (4.75 mm) while the gradation of fine aggregates ranges between passing 4.75mm (No.4) sieve and retains on 0.075mm (No.200) sieve, it consists of tough grains free of amount of clay, loam or other deleterious substance as required (SCRB, R/9, 2003). Traditional tests were performed on the aggregate to evaluate their physical properties. The results together with the specification limits as set by the SCRB are summarized in Table (3 and 4) chemical composition was shown in Table 5. Tests results show that the chosen aggregate met the SCRB specifications.

Plate 1. Aggregate Gradation used in the study
### Table 3. Physical Properties of the Fine Aggregate

| Property                              | ASTM Designation   | Test Results |
|---------------------------------------|--------------------|--------------|
| Bulk Specific Gravity (g/cm$^3$)       | (ASTM C128, 2001)  | 2.632        |
| Apparent Specific Gravity (g/cm$^3$)  | (ASTM C128, 2001)  | 2.66         |
| Water Absorption %                    | (ASTM C128, 2001)  | 0.54         |
| Sand equivalent%                      | (ASTM D2419, 2002) | 60           |

### Table 4. Physical Properties of the Course Aggregate

| Property                              | ASTM Designation   | Test Result | SCR B Specification |
|---------------------------------------|--------------------|-------------|---------------------|
| Bulk Specific Gravity (g/cm$^3$)       | ASTM C127          | 2.64        |                     |
| Apparent Specific Gravity (g/cm$^3$)  | (ASTM C127, 1997)  | 2.65        |                     |
| Percent Water Absorption              | ASTM C127          | 0.5208      |                     |
| Percent Wear (Loss Angeles Abrasion)  | (ASTM C131, 2003)  | 20.8        | 30 max.             |

### Table 5. Chemical composition of the Aggregate *

| Chemical Compound | Content % |
|-------------------|-----------|
| SiO$_2$           | 82.52     |
| CaO               | 5.93      |
| MgO               | 0.78      |
| SO$_3$            | 2.71      |
| Al$_2$O$_3$       | 0.49      |
| Fe$_2$O$_3$       | 0.68      |
| Loss on Ignition  | 6.5       |
| Total             | 99.61     |

**Mineral composition**

- Quartz: 80.1
- Calcite: 10.95

* (by National Center for Construction Laboratories and Research)

4.3 Filler
The filler is a non-plastic material passing sieve No.200 (0.075mm). Three types of non-conventional filler are used; the control mixes were prepared using material passing sieve No.200, limestone and brick dust as mineral filler at different content.

4.3.1 Brick dust

Construction waste is generated during construction of buildings and other facilities, and during renovation, renewal and maintenance of such buildings and facilities. This waste group includes concrete, bricks, tiles and other materials. In their study conclude that waste brick particles passing sieve No. 200 in size can be considered acceptable as replacement for filler. The brick parts obtained from landfill and rubble, then transformed to laboratory for washing and drying in oven and crushed manually then pulverizing by machine to ultrafine, and sieved on No. 200 to obtain a desired range of particle sizes that used as filler. Brick dust at a content of 7 % by total weight of aggregate (1.5% by dry weight of aggregate as suggested by SCRB specification for surface layer) is added in a mixer immediately after the asphalt is introduced. Table 6 illustrates the basic physical and chemical properties of brick dust used for this study as shown in plate 2.

Table 6. Physical and chemical properties of brick dust

| Property                  | Test Result |
|---------------------------|-------------|
| Specific Gravity          | 2.54        |
| Specific surface (m²/Kg)  | 1900        |
| % passing No. 200 sieve   | 95          |
| % CaO                     | 7.812       |
| % SiO₂                    | 54.46       |
| % Al₂O₃                   | 23.69       |
| % Fe₂O₃                   | 7.2         |
| % MgO                     | 0.20        |
| % SO₃                     | 0.12        |
| % L. O. I.                | 5.89        |

* (by National Center for Construction Laboratories and Research)

4.3.2 Limestone dust

Limestone dust acquired from a lime factory in Kerbala governorate, south east of Baghdad. Limestone has been known to be a promising potential material for pavements due to its unique physical/chemical/mechanical characteristic. The use of limestone dust has been recommended by SRCB with 7 % by total weight of aggregate (1.5% by dry weight of aggregate as suggested by SCRB specification for surface layer). Plate 3 shows the limestone dust used. Table 7 illustrates the basic physical and chemical properties of limestone dust used for this study.
Table 7. Physical and chemical properties of limestone dust *(by National Center for Construction Laboratories and Research)*

| Property                        | Test Result |
|---------------------------------|-------------|
| Specific Gravity                | 2.45        |
| Specific surface (m²/Kg)        | 390         |
| % passing 75 μm                 | 99          |
| % CaO                           | 50.7        |
| % SiO₂                          | 2.32        |
| % Al₂O₃                         | 3.1         |
| % Fe₂O₃                         | 0.1         |
| % MgO                           | 7.21        |
| % SO₃                           | 0.31        |
| % L. O. I.                      | 36.1        |

*(by Babil Tire factory; Najaf)*

4.4 Crumb Tire Rubber (CTR)

Crumb tire rubber in fine particles form was used in this study; it was made by scrap tires from a manufacturing plant of tire in Iraq, Babil Tire factory; Najaf, into small pieces as shown in Plate (6). Table (8) demonstrated the properties of tire rubber crumbe as given by the tire industrial facility. Different percentages (5, 7, 10 %) by weight of asphalt cement were added

Table 8. Tire Rubber Physical Properties *(by Babil Tire factory; Najaf)*

| Property                        | Value                | Specification       |
|---------------------------------|----------------------|---------------------|
| specific gravity                | 0.88                 | ASTM D6270-98       |
| Void ratio, e                   | 1.5-2.5 (Uncompacted)|                     |
|                                 | 1.2-0.9 (Compacted)  |                     |
| Modulus of elasticity, E        | 1240-5173 kPa        | ASTM D6270-98       |
| Poisson’s Ratio, μ              | 0.5                  | -                   |
| Capacity of water absorption    | 2%-4%                | -                   |
| Density (Kg/m³)                 | 1300                 | -                   |

*(by Babil Tire factory; Najaf)*
5. Simple Punching Shear Test (SPST)

The SPST was developed as a simple performance test to characterize HMA shear properties. In the SPST setup, a cylindrical HMA specimen is compressed vertically via a steel punch placed concentrically on the top of an opening at the base. The specimen fails along the diametrical plane due to the shear strain generated in the tangential direction. Plate 5 shows the manufactured mold of diameter 6 in. (150 mm), height 2.5 ± 0.1 in. (63.5 ± 2.5 mm), and base plate consisting of a 6.0 in. diameter cylindrical metal base with a 2.5 in. diameter concentric opening, the height of the loading Base is at least 2.5 in. to allow enough space for accommodating the dislodged parts of the HMA, loading head consisting of a 1.5 in. diameter cylindrical metal head to be attached to the loading shaft of the loading press and confined ring consisting of a cylindrical enclosure able to provide lateral confining, these component manufactured in workshop of technology institute. Table 9 present the SPST setup and the test parameters that used in this study under controlled condition [loading rate 0.2 mm/s (0.50 inch/min), test temperatures 50 ± 2°C (122°F).

| Property          | Described                                      |
|-------------------|------------------------------------------------|
| Mold              | 3" (75 mm) thick × 6.0" (152.4 mm) φ           |
| Base plate        | 6.0 in. diameter with a 3 in. diameter          |
|                   | concentric opening, the height of the loading   |
|                   | Base is at least 3 in.                          |
| Loading head      | 1.5" (38.1 mm)                                 |
| Confined ring     | 6 in. (150 mm), and height 3 in. (75 mm)        |
| Loading rate      | 0.2 mm/s (0.50 inch/min)                       |
| Temperature test  | 50 ± 2°C (122°F)                               |
| Test termination  | 2.49" (63.2 mm) vertical movement              |
| Total test time   | ≤ 10 minutes                                   |

Plate 5. Manufactured mold and SPST

6. Mixing method

The first stage prepared samples with and without modified, the aggregate was sieved, washed, and dehydrated to a stable weight at 109°C. The combined aggregate is then heat to a temperature of (150-165°C) before blending with asphalt cement. The asphalt binder is heat to a temperature of (150°C) then added to the heated aggregate to achieve the desired amount, and mixed thoroughly by hand using a spatula for 2 minutes while all aggregate particles are painted with asphalt binder ASTM
D1559-98. The preparation of modified asphalt with CTR was taken according to ASTM D6114-19 (standard specification for asphalt-rubber binder). The second stage was determined the required quantity of the mix that taken so as to produce compacted asphalt mix specimens of 75 mm thickness and 152.4 mm in diameter as approximately (3300 gm) of aggregates and filler were required to produce the desired thickness. After mixing thoroughly the material was cast in the manufactured steel mold 152.4 mm in diameter and 75 mm thickness then cast the mixture was compacted by an hand compactor with 75 blows each face according to Marshall test requirements as shown in plate 8.

Plate 6. Specimen preparation before and after test.

7. Results and Analysis

The shear strength at failure calculates by dividing the peak shear load from load displacement response on the punching area of sample.

\[ \tau_s = \frac{P_{max}}{\pi D t} \]  

Where:
- \( \tau_s \): shear strength at failure (kN/m²)
- D: diameter of the punching (loading) head (mm)
- t: thickness of the sample (mm)

Figure (7) shows the effect of modifier content with different filler (brick dust and limestone dust) in comparing with passing No.200 as control filler on peak shear load and max. Shear strain that calculated from equation:

\[ \gamma_s = \frac{d_{p_{max}}}{t} \]  

Where:
- \( \gamma_s \): shear strain at failure (mm/mm) *10²
- \( d_{p_{max}} \): maximum displacement at failure load (mm)
- t: thickness of the sample (mm)

The SSE is defined as the total work required fracturing the HMA by a unit area or volume. The total required work is measured by the area under the load–displacement curve as calculated from equation below:

\[ SSE = \frac{1}{A} \int_0^{\infty} (f_x) \, d_x \]  

SSE index= SSE \( \frac{\gamma_s}{\tau_s} \times 10^3 \)  

Where:
- SEE: shear strain energy
- \( \tau_s \): shear strength at failure (kN/m²)
- \( \gamma_s \): shear strain at failure (mm/mm)
- A= the area under the shear load-displacement curve

Table (10) summarized the results of SPST test (shear strength and strain at failure).
Figure 2. Peak shear strength and max. shear strain relation with different modifier content and filler.

### Table 10. Shear strength and shear strain at failure for CTR mixture with different fillers

| Type of filler | Brick dust | Limestone dust |
|----------------|------------|----------------|
| CTR (%)        | 0          | 5              |
|                | 7          | 10             |
|                | 0          | 5              |
|                | 7          | 10             |
| Shear strength (kN/m²) | 947.3 | 1368.4 |
|                | 894.7      | 776.3          |
|                | 947.3      | 1434.2         |
|                | 1342.1     | 1210.5         |
| (psi)          | 137.4      | 198.5          |
|                | 129.8      | 112.6          |
|                | 137.4      | 208            |
|                | 194.7      | 175.6          |
| Shear strain (mm/mm)*10² | 34.64 | 44.72 |
|                | 33.07      | 33.07          |
|                | 34.64      | 34.64          |
|                | 31.65      | 34.64          |
| SSE (kJ/m²)    | 9.14       | 26.656         |
|                | 9.53       | 9.273          |
|                | 9.14       | 17.706         |
|                | 17.127     | 14.715         |
| SSE index      | 52.63      | 137.18         |
|                | 55.48      | 62.20          |
|                | 8          | 52.63          |
|                | 52.63      | 117.16         |
|                | 63.6       | 66.312         |

Proposed Draft Test Specification For SPST by TxDOT Designation: Tex-2XX-F: HMA mixes with $\tau_s \geq 300$ psi and/or $SSE \geq 25$ kJ/m² at 50°C SPST temperature have preliminarily exhibited good correlation with computational model simulations and field data. If testing at 60°C, the following should tentatively be considered as a preliminary guidance for screening mixes: $\tau_s \geq 200$ psi, and $SSE \geq 17$ kJ/m².

8. Conclusions

A series of experimental models have been tested to evaluate shear properties HMA modified with and without CTR modifier, also with filler brick dust, limestone dust and comparing with passing sieve No.200. The following conclusions are drawn from this study:

1. Peak shear strength increased by about (44.44%) for 5% CTR with brick dust filler then reduced as the CTR content increased, also peak shear strength increased by about (51.38%) for 5% CTR with lime in comparing both filler with passing sieve No.200.
2. Lower value of shear strain was obtained at 5% to 7% CTR content combined with lime dust filler rather than for brick dust filler.
3. The value of SSE increased as the modifier content (CTR) increased until reached content of 5-7% then decreased for two types of filler as comparing with passing No.200, and the effect of lime filler is similar with CTR while brick filler with 5%CTR shows high SEE.
4. Less shear resistant mixes lead to higher amount of energy was expended to impart shear failure to the mix and Higher shear strength of a mix would indicate lower rutting susceptibility.
5. The modified cement asphalt using 5% CTR content with brick dust, and 5% and 7% CTR with limestone filler more benefits for HMA under SPST and exhibited good simulation with specification for SPST by TxDOT Designation: Tex-2XX-F.
6. Using CTR with limestone dust and brick dust improves fatigue resistance for modified cement asphalt binder at different percent.

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