Effect of Polymer on the Properties of Bitumen and Pavement Layers, Case Study: Expressway No.1, Republic of Iraq

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Abstract. Increasing attention has been paid to use polymer as a modifier in bituminous mixtures manufacturing. Unmodified bituminous mixtures are highly affected by the undesirable environmental conditions at which such mixtures present brittle behaviour and crack at cold weather, whereas present soft behaviour at elevated temperatures resulting in rutting and surface deformation. As a result of bituminous mixtures modification using polymers, more elastic and durable bituminous materials that show developed stability at high temperatures can be obtained. In this present study, using 4% polymer with bitumen grade of 40/50 leads to improve bitumen properties such as viscosity, penetration, flash point, softening point, dynamic shear and creep stiffness. The results of investigation samples which were cutting from pavement show improvement of these pavement properties according to results of tests at site lab and independent lab. The use of polymer in design mixture of asphalt help in improving pavement properties which lead to the successful road and increases the age of pavements and become more resistant to hard conditions such as high temperature in the middle east region.

Keywords: Durability; hot mix asphalt; Marshall stability; polymer modified asphalt; stripping.

1. Introduction

1.1 Background

Flexible pavements with their excellent mechanical properties are widely used due to various advantages such as low cost, abrasion resistance, lower tire-road noise and short construction period. However, the durability of asphalt pavements can be deteriorated due to traffic loads and environmental factors [1-3].

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Expressway No.1, which is the main north-south road in Iraq, is considered as the main international road. The study area is conducted on two sections of this expressway have an approximate length of 257 km; these sections are section R7 and section R8 which extended through three districts: Rumaila, Basra and Safwan, as can be seen in figure 1. The roads in this area are exposed to the combined effect of extremely high traffic and high temperature. To avoid the hazard of these hard conditions, high shear resistance of hot mix asphalt (HMA) should be applied.

The engineering characteristics of bituminous mixes have been investigated by several studies [4-15]. Water sensitivity is one of the essential damages that affect road pavement performance [16, 17]. Due to the effects of water, it can activate the action of stripping which in turn decreases the connection between the bitumen and aggregate particles [2]. Different factors can develop the resistance to water damage such as bitumen, aggregates type and mineral filler [18, 19]. Also, bituminous mixes modification can play a major role to improve the performance of such mixes against different failure modes [20, 21]. One of the most performed additives in bituminous mixes is polymer, which is commonly applied as a bitumen modifier and can be classified to different classes, namely: plastic, elastomers, fibers, and coatings [22-24]. Stuart [25] evaluated the influence of including polymer in bituminous mixes on the bitumen-aggregates adhesion. It was noticed that the modified mixes using styrene-butadiene-styrene (SBS) and styrene-butadiene-rubber (SBR) polymers, displayed higher water sensitivity resistance than the conventional mix. This developed behavior is based on the improved bond between the bitumen and aggregates. Isacsson and Lu [26] used SBS copolymer in the modification of the bitumen to assess the rheological characterization. It was found that a substantial enhancement in the rheological characterization was observed when the SBS content increased from 2% to 6% by the weight of bitumen content. Insufficient compatibility of polymer modified bitumen (PMB) can form poor storage stability that can be controlled by properties of bitumen and polymers such as density, molecular weight, polarity and solubility [27]. However, polymers’ chemical structure and reactivity are also supposed to affect their compatibility with bitumen, which may have a direct relationship with the resulting PMB properties [28]. European Asphalt Pavement Association [29] indicated that PMB is varying with all types of bitumen used based on the variation in the climate and traffic conditions in different countries. Based on the EAPA [29], the consumption of PMB in most European countries during the whole year is usually less than 20% during the last 3 years. Regarding the polymer dosage, Eurobitume which is the main European bitumen industry stated that the 3.5% SBS is a typical content for producing bituminous mixes [30]. Several common plastomers and thermoplastic elastomers in bitumen modification are considered regarding their advantages and disadvantages, including polyethylene (PE), polypropylene (PP), ethylene-vinyl acetate (EVA), ethylene-butyl acrylate (EBA), styrene-butadiene-styrene (SBS), styrene-isoprene-styrene (SIS) and styreneethylene/butylene-styrene (SEBS). Even if the positive effects of PMB, still different problems are exist for example, the high cost, low aging resistance and poor storage stability [31]. Asmael [8] examined the impact of polymer improvement for developing pavement behavior. Recently, waste low-density polyethylene derived from plastic carry bags has been used by Abduljabbar et al. [32] to improve the durability properties of dense graded thin asphalt overlay. Their results proved that 2% of this waste polyethylene enhanced aging properties by 30% improvement to abrasion resistance compared to the control mixture. An extensive experimental research was conducted to investigate the performance of modified bituminous mixes using (40-50) penetration grade bitumen supplied by Dourah refinery in Iraq. Additionally, a comparative laboratory investigation has been carried out to study the behavior of incorporating three types of polymers: polyvinyl chloride (PVC), phenol resin, and polystyrene in bituminous paving mixes. The modified bituminous mixes were modified using three different percentages of polymer (2, 4 and 6) % by weight of bitumen [33]. The influence of polymer modification was calculated using indirect tensile strength and retained stability tests to evaluate mixes behavior. Finally, to assess the mix performance under the effect of temperature variation, two different testing temperatures are performed (25 and 45) °C. The outcomes specified that the modified mixes showed developed behavior when the polymer was applied [34].
1.2. Scope of the present study

The main purpose of this present study is:

- Treating the problematic quartz coarse aggregates which did not give a good adhesion with bitumen.
- Improving bitumen properties after adding polymers.
- Observing the performance of the modified mix after paving on the road.

2. The used materials

The coarse aggregate represents the crushed stone size from 4.75 to 19 mm, while the screenings of crushed stone size from 0 to 4.75 mm are called fine aggregates. The used aggregates were composed mainly of quartz mineral which has acidic chemical characters where they give a weak bond with bitumen. The source of the coarse and fine aggregates was the Shlyat area in the Al Amara region which is located about 400Km from the study area. The mineral filler that has been used was non-plastic limestone dust. The source of mineral filler is the Karbala region.

The bitumen utilized in this investigation was 40-50 penetration grade. The source of bitumen is the Nasiriya refinery.

3. Experimental work

3.1 Investigation of Course and fine aggregates and mineral filler

Several tests were involved to obtain the properties of coarse aggregates such as gradation [35], abrasion and impact in the Los Angeles machine [36], sulfate content according to BS812 [37], and specific gravity [38]. The results are shown in Table 1. Similarly, many tests involved investigating the properties of fine aggregates such as gradation [35], sulfate content (BS812) and specific gravity [39]. The results are shown in Table 2. The type of used mineral fillers was non-plastic limestone. Sieve analysis and plasticity limits [35] were conducted to investigate the mineral filler properties. The results are shown in Table 3.
### Table 1. The results of course aggregates

| Sieve, mm | Retained on each sieve, % | Passing based on mass, % | Flat and elongated grains, % | Grains at least 50% of the surface fractured, % | Grains with least one surface fractured, % |
|-----------|---------------------------|--------------------------|-----------------------------|---------------------------------------------|---------------------------------------------|
| 19.0      | 0.0                       | 100                      |                             |                                             |                                             |
| 12.5      | 32.3                      | 68                       | 7.3                         | 87.3                                        |                                             |
| 9.5       | 27.0                      | 41                       | 6.4                         | 100.0                                       | 100.0                                       |
| 4.75      | 37.0                      | 4                        |                             |                                             |                                             |
| 2.36      | 3.4                       | 0                        |                             |                                             |                                             |
| <2.36     | 0.2                       |                           |                             |                                             |                                             |

| Relating to the mix (4.75-19mm) | 6.7 | 92.5 | 99.9 |
|----------------------------------|-----|------|------|
| Required by SS 3502.02, max 20   | 19  |
| min 75                           | 8   |
| min 100                          | 15.9|
| Abrasion and impact in the Los Angeles Machine for coarse aggregate (ASHTTO T 96) |
| The nominal maximum size, mm     | 19  |
| Grading of the test sample       | 8   |
| Loss by abrasion and impact, %    | 15.9|
| Required by SS 3502.02, %        | 20  |

| Sulfate content (BS 812)         | 0.04|
|----------------------------------|-----|
| Required by SS 3502.01, %        | 0.6 |

| Specific gravity (ASHTTO T 85)   | 2.610|
|----------------------------------|------|
| Test result, %                   |      |

### Table 2. The results of fine aggregates

| Sieve, mm | Retained on each sieve, % | Passing based on mass, % |
|-----------|---------------------------|--------------------------|
| 9.5       | 0.0                       | 100                      |
| 4.75      | 1.3                       | 99                       |
| 2.36      | 29.1                      | 70                       |
| 1.00      | 19.4                      | 50                       |
| 0.60      | 9.6                       | 41                       |
| 0.30      | 18.2                      | 22                       |
| 0.125     | 18.4                      | 4                        |
| 0.075     | 2.3                       | 1                        |
| <0.075    | 1.2                       | -                        |

| Sulfate content (BS 812)         | 0.27|
|----------------------------------|-----|
| Required by SS 3502.01, %        | 0.6 |

| Specific gravity (ASHTTO T 84)   | 2.622|
|----------------------------------|------|
| Test result, %                   |      |

### Table 3. The results of mineral filler

| Sieve, mm | Passing, % | 1.18(16) | 0.6(No. 30) | 0.3(No. 50) | 0.075(No. 200) |
|-----------|------------|----------|-------------|-------------|----------------|
| 100       | 99         | 97       | 95          |             |
| Required limits by ASSHTO M 17   | 100      | 97-100   | 95-100      | 70-100       |

| Plasticity Index (AASHTO T 27)   | Non-plastic |
|----------------------------------|-------------|
| Plasticity limit, %              | max 4       |
| Required by AASHTO M 17, %       |             |
3.2 Investigation of bitumen without polymers

For producing the polymer modified bitumen of PG76-10 grade, the bitumen of 40/50 penetration grade was used. The source of bitumen is the Nasiriyah refinery. The test results are shown in Table 4.

**Table 4. Required tests for bitumen without polymer**

| Properties                                      | Test standard   | Test results | Required ASTM D 946 |
|-------------------------------------------------|-----------------|--------------|---------------------|
| Penetration at 25°C, 100gm, 5 sec.)             | ASTM D5         | 43           | 40-50               |
| Retained penetration after thin-film oven test, %| ASTM D1754, D5  | 62           | Min 55% of initial  |
| Softening Point, °C                             | ASTM D36        | 53.4         | 49 min              |
| Flash point (Cleveland open cup), °C             | ASTM D92        | >300         | 230 min             |
| Ductility at 25°C, 5 cm/min, cm                 | ASTM D113       | >150         | 100 min             |
| Ductility at 25°C after thin-film oven test, 5 cm/min, cm | ASTM D1754, D113 | >150         | Min 55% of initial  |

3.3 Investigation of polymer modified bitumen

The typical properties of the used polymer (kraton D1192) to modify bitumen, are shown in Table 5. It is a clear linear block copolymer based on styrene and butadiene with bound styrene of 30% of the mass. The used physical form was powder dusted with amorphous silica.

**Table 5. The typical properties of kraton D1192**

| Properties                      | Test standard   | Units       | Typical value |
|---------------------------------|-----------------|-------------|---------------|
| Hardness, shone A (sec)         | ASTM D2240      | Hardness, shone A (15 sec) | 70 *         |
| Bulk density                    | ASTM D1895, Method B | Kg/dm³ | 0.40          |
| Specific gravity                | ISO 2781        | Kg/dm³     | 0.94          |
| Melt flow rate, 200 °C/5 kg     | ISO 1133        | g/10 min   | < 1           |

*- Measured on compression molded slabs

3.4 The properties of polymer modified bitumen

The polymer-modified bitumen was prepared by mixing bitumen of 40/50 penetration grade with 4% of SBS (kraton D1192) in a laboratory with high shear mixer at temperature 180-190 °C within 2 hours, and then for 4 hours of curing at temperature 180-190 °C to achieve the homogeneity. The results of required tests are shown in Table 6.
Table 6. The results of required tests for (PMB)

| Properties                                      | Test standard | Bitumen 40/50 + 4% Kraton D1192 | Required ASTM D6373 for PG 76-10 |
|------------------------------------------------|---------------|---------------------------------|----------------------------------|
| Penetration at 25°C, dmm                        | ASTM D5       | 31                              | ---                              |
| Softening Point, °C                             | ASTM D36      | 68.7                            | ---                              |
| Flash point (Cleveland open cup), °C            | ASTM D92      | >330                            | 230 min                          |
| Viscosity (Brookfield) at 135 °C, cP            | ASTM D4402    | 1482                            | max 3000                         |
| Dynamic shear before RTFOT, G*/sin δ, test temperature 76 °C@ 10 rad/s, KPa | ASTM D7175    | 2.47                            | min 1.0 KPa                      |
| RTFOT mass change, %                            | ASTM D2872    | -0.28                           | max 1%                           |
| Elastic recovery after RTFOT at 25°C, %         | ASTM D2872    | 89                              | ---                              |
| Dynamic shear after RTFOT, G*/sin δ, test temperature 76 °C@ 10 rad/s, KPa | ASTM D2872    | 3.97                            | min 2.2 KPa                      |
| Dynamic shear after PAV, G*/sin δ, test temperature 37 °C@ 10 rad/s, KPa | ASTM D7175    | 110                             | at 110 °C                        |
| Creep stiffness at temperature 0 °C@60 s, m-value | ASTM D6648    | 0.353                           | max 300 MPa                      |
| Softening Point, °C                             | Bottom        | 63                              | Required by SS                   |
| Difference                                      | Bottom        | 63                              | 3502.5.4.1                       |
| Separation tendency test                        | Bottom        | 2.39                            | Required by SS                   |
| G* at 76 °C@ 10 rad/s, KPa                      | (up+ bottom)/2 | 2.345                           | 3502.5.4.1                       |
| (up+ bottom)/2 G*                               | Bottom        | 2.345                           | 3502.5.4.1                       |

3.5 Treatment of problematic aggregates

To increasing the adherence of bituminous binder with quartz aggregates, two types of heat-stable adhesion agents were used: WETFIX BE and Morlife 5000. The agents were added and mixed with a modified binder in an amount of 0.5% for 15 minutes before the end of the binder preparing cycle. The typical properties of WETFIX BE and Morlife 5000 are shown in Tables 7 and 8.

Table 7. The typical properties WETFIX BE

| Chemical and physical data | Typical value                           |
|---------------------------|-----------------------------------------|
| Appearance                | Brown, viscous liquid at 20 °C          |
| pH                        | 11 (5% in water)                        |
| Density                   | 980 kg/m³ at 20 °C                      |
| Flash point               | > 218 °C                                |
| Melting point             | < -20 °C                                |
| Viscosity                 | 800 mPa.s at 20 °C                      |

Table 8. The typical properties Morlife 5000

| Chemical and physical data | Typical value |
|---------------------------|---------------|
| Appearance                | Dark brown liquid |
| Specific gravity          | 1.09          |
| Pour point                | -12 °C        |
| Flash point               | > 145 °C      |
| Amine value               | > 600 mg KOH/g |
4. Results and Discussion
The results of the coating and stripping test according to AASHTO T182 [40], are shown in Figures 2, 3 and 4.

Figure 2. PMB PG76-10 without agent – coating < 95%.

Figure 3. PMB PG76-10 with WETFIX BE – coating > 95%.

Figure 4. PMB PG76-10 with Morlife 5000 – coating > 95%.

4.1 Determination of optimum binder content in asphalt mixture
To find the optimum content of modified binder PG76-10, six trail mixtures had been prepared and tested according to [41] and [42]. These trails are 3.5%, 4.0%, 4.5%, 5.0%, 5.5% and 6.0%. The number of blows for specimen compaction was 75 per face, for each trail mixture three Marshall specimens were prepared for stability, flow tests and determination of bulk specific gravity (Gmb). The theoretical maximum specific gravity (Gmm) of asphalt trail mixture was determined with no compacted mixture of 2.0 kg mass. The test results of trail mixtures are shown in Table 9 and Figures 5-11.

According to the obtained results, the optimum binder content was 4.3%. At this binder content, the asphalt specimens meet all the required design parameters. The test results of specimens with optimum binder content are shown in Figures 5-11 and Table 10.

Table 9. Physical and mechanical properties of trail mixtures

| Properties                                | Binder content, % |
|-------------------------------------------|-------------------|
|                                           | 3.5   | 4.0   | 4.5   | 5.0   | 5.5   | 6.0   |
| Stability of Marshall specimen, KN        | 22.0  | 28.0  | 27.5  | 22.5  | 21.5  | 20.5  |
| Flow of Marshall specimen, mm             | 3.2   | 3.8   | 4.3   | 5.2   | 6.1   | 7.6   |
| Bulk specific gravity of Marshall specimens | 2.291 | 2.334 | 2.359 | 2.383 | 2.381 | 2.372 |
| Theoretical max. specific gravity of asphalt mixture | 2.488 | 2.468 | 2.449 | 2.43  | 2.412 | 2.397 |
| Air voids in Marshall specimens, %         | 8.0   | 5.4   | 3.8   | 1.8   | 1.1   | 0.30  |
| VMA of Marshall specimens, %               | 15.6  | 14.5  | 14.0  | 13.5  | 14.0  | 14.2  |
| VFA in Marshall specimens, %               | 51    | 63    | 74    | 86    | 91    | 94    |
Figure 5. The bulk specific gravity of Marshal specimens in relation to binder content.

Figure 6. The maximum specific gravity of Marshal specimens in relation to binder content.

Figure 7. Stability of Marshal specimens in relation to binder content.

Figure 8. The flow of Marshal specimens in relation to binder content.
Table 10. The test results of specimens with optimum binder content (4.3%)

| Properties                              | Results |
|-----------------------------------------|---------|
| Stability of Marshall specimen, KN      | 26.2    |
| The flow of Marshall specimen, mm       | 3.6     |
| The bulk specific gravity of Marshall specimens | 2.348 |
| Theoretical max. the specific gravity of asphalt mixture | 2.458 |
| Air voids in Marshall specimens, %      | 4.5     |
| VMA of Marshall specimens, %            | 14.2    |
| VFA in Marshall specimens, %            | 69      |

4.2 Observation the performance of modified mix after paving

A total of forty asphalt core of 150 mm in diameter and eight asphalt slabs (40 × 40) cm were taken from the site of pavement layers of wearing course. For a better comparison, the location of asphalt cores taken was chosen to be as close as possible to the locations of the asphalt cores taken by the contractor and the consultant, where these samples were tested at site laboratory. All the samples were coded and marked with the correct location and taken to an independent laboratory for testing and
analysis. Figures 12-15 illustrated the extraction of core samples. Cutting of slab samples and investigations of samples were carried out in the site laboratory.

All the tests are within the specification tolerances apart from some of the grading tests that are in a few sieve sizes, outside the envelope and there an expectable correlation between the results that were obtained on-site during construction, as can be seen in Table 11.

The results which recorded in site lab and independent lab showed that the polymer-modified bitumen gives high stability, where they are 20.5 kN, 20.2 kN and 17.5 kN at location 6+400 of R8 section, location 3+850 of R8 section and location 12+294 of R8 section, as shown in Tables 11, 12 and 13, respectively.

![Figure 12. Extraction of core samples.](image1)

![Figure 13. Cutting of slab samples.](image2)

![Figure 14. Extracted of core and slab samples.](image3)

![Figure 15. Lab investigations of samples.](image4)
Table 11. Comparison between properties of polymer modified bitumen pavement in site lab and independent lab at location 6+400 of R8 section

| Location | Lab         | Thickness (cm) | Field density (gm/cm³) | Compaction rate % |
|----------|-------------|----------------|------------------------|-------------------|
| Km: 6+400 – R8-R, inner lane – wearing layer | Site lab | 6.69 | 2.342 | 100.95 |
|          | Independent lab | 6.4 | 2.349 | 99.2 |

| Location | Laboratory test results on asphalt samples taken in site |
|----------|---------------------------------------------------------|
| Km: 6+400 – R8-R, inner lane – wearing layer | Site lab | Stability | Binder content | flow | Air voids | density |
|          | 11.89 | 4.9 | 2.12 | 1.9 | 2.32 |
|          | Independent lab | 20.5 | 4.5 | 3.3 | 3.3 | 2.368 |

Sieve analysis of extracted material

| Sieve open | Cumulative Pass % | Sieve open | Cumulative Pass % | Sieve open | Cumulative Pass % |
|------------|------------------|------------|------------------|------------|------------------|
| 19         | 100              | 19         | 100.0            | 19         | 90               |
| 12.5       | 88.1             | 12.5       | 85.0             | 12.5       | 70               |
| 9.5        | 72.5             | 9.5        | 73.0             | 9.5        | 56               |
| 4.75       | 56.9             | 4.75       | 58.0             | 4.75       | 35               |
| 2.36       | 41.4             | 2.36       | 40.0             | 2.36       | 23               |
| 1          | 31.8             | 1          | 29.0             | 1          | -                |
| 0.6        | 24.8             | 0.6        | 24.0             | 0.6        | -                |
| 0.30       | 18.4             | 0.30       | 16.0             | 0.30       | 5                |
| 0.125      | 10.3             | 0.125      | 10.0             | 0.125      | -                |
| 0.075      | 7.6              | 0.075      | 7                | 0.075      | 3                |
| 0.05       | 4.7              | 0.05       | 4.7              | 0.05       | -                |
Table 12. Properties of polymer modified bitumen pavement in the independent lab at location 3+850 of R8 section

| Location | Test report | Date: 9/2/2019 – Location:3+850-R8-R, outer lane – wearing layer |
|----------|-------------|-----------------------------------------------------------------|
| Laboratory test results on asphalt samples taken in site |
| Km: 3+850, R8-R- outer lane, wearing layer |
| Site lab | Independent lab |
| Thickness (cm) | 8.0 | 8.0 |
| Field density (gm/cm³) | 2.310 | 2.310 |
| Compaction rate % | 97.0 | 97.0 |
| Laboratory test results on asphalt samples taken in site lab |
| Km: 3+850, R8-R- outer lane, wearing layer |
| Site lab | Independent lab |
| Stability | 20.2 | 20.2 |
| Binder content flow | 4.5 | 4.5 |
| Air voids density | 3.3 | 3.3 |
| Technical specification | >10 kn | >10 kn |
| Sieve analysis of extracted material |
| Sieve open | Cumulative Pass % | Sieve open | Cumulative Pass % | Sieve open | Cumulative Pass % |
| 19 | 100 | 19 | 90 | 100 |
| 12.5 | 91.3 | 12.5 | 70 | 90 |
| 9.5 | 79.7 | 9.5 | 56 | 80 |
| 4.75 | 58.7 | 4.75 | 35 | 65 |
| 2.36 | 42.9 | 2.36 | 23 | 49 |
| 1 | 32.8 | 1 | - | - |
| 0.6 | 24.8 | 0.6 | - | - |
| 0.30 | 18.7 | 0.30 | 5 | 19 |
| 0.125 | 10.7 | 0.125 | - | - |
| 0.075 | 8.1 | 0.075 | 3 | 9 |
5. Conclusion

Modification of bituminous mixes using polymers is progressively used in pavement construction. Traditional bituminous mixes are affected by temperature changes. Traditional mixes tend to be brittle material at cold weather resulting in cracks and tend to be ductile material at hot weather resulting rutting. Addition of polymer in bituminous mixes results in a more elastic and durable product with higher temperature stability.

In this present study, using a polymer with ratio 4% and bitumen 40/50 lead to improve the properties of bitumen such as penetration, softening point, flash point, viscosity, etc…

The results of the investigation of samples that were cutting from pavement showed that properties of this pavement have good properties according to results of tests at site lab and independent lab.

The using of polymer in design mixture of asphalt lead to improve pavement properties which lead to successful road and increase the age of pavement and become more resistant to hard conditions such as high temperature in the middle east region.

### Table 13. Properties of polymer modified bitumen pavement in the independent lab at location 12+294 of R8 section

| Location                  | Site lab | Independent lab |
|---------------------------|----------|-----------------|
| Thickness (cm)            | Field density (gm/cm³) | Compaction rate % |
| Km: 12+294, R8-R, outer lane, wearing layer | 6.5       | 2.268           | 95.9       |

**Laboratory test results on asphalt samples taken in site lab**

| Location                  | Stability | Binder content flow | Air voids density |
|---------------------------|-----------|---------------------|-------------------|
| Km: 12+294, R8-R, outer lane, wearing layer | 17.5      | 4.2                 | 2.1               |

**Sieve analysis of extracted material**

| Sieve open | Cumulative Pass % | Sieve open | Cumulative Pass % | Sieve open | Cumulative Pass % |
|------------|-------------------|------------|-------------------|------------|-------------------|
| 19         | 99.7              | 19         | 90                | 100        |
| 12.5       | 78.8              | 12.65      | 70                | 90         |
| 9.5        | 64.1              | 9.5        | 56                | 80         |
| 4.75       | 46.5              | 4.75       | 35                | 65         |
| 2.36       | 34.0              | 2.36       | 23                | 49         |
| 1          | 26.4              | 1          | -                 | -          |
| 0.6        | 20.6              | 0.6        | -                 | -          |
| 0.30       | 15.9              | 0.30       | 5                 | 19         |
| 0.125      | 9.8               | 0.125      | -                 | -          |
| 0.075      | 7.7               | 0.075      | 3                 | 9          |
Recommendations

The main purpose of this study is illustrating the rule of polymers in improving the properties of road pavement and hoping to use improving agents in the pavement of all new road’s construction, especially in the middle east region. The authors recommend using waste polymers that will contribute to sustainability and enhance the environment.

CRediT authorship contribution statement

Mohamed MM. Badry: Resources, Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Investigation, Formal analysis, Validation.

Anmar Dulaimi: Writing - review & editing, Methodology, Writing - original draft, final editing of the study.

Hayder Kamil Shanbara: Writing - review & editing, Methodology, Writing - original draft.

Shakir Al-Busaltan: final editing of the study.

Talaat Abdel-Wahed: Supervision, Project administration, writing - original draft, Writing – review & editing, Investigation, Formal analysis, Validation, Resources, final editing of the study.

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