Studying the Early Cracking Behavior of Asphalt Concrete Base Course

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Abstract. In Iraq, there are some asphalt concrete mixtures suffer from appearing of cracking and deformation immediately after finishing the construction of a base course. In the flexible pavement, the pavement is considered to be degraded after opening to traffic by repeated traffic loading, climatic conditions, aging of asphalt mixture, etc. Crack plays a critical mode in pavement degradation. Several experimental studies have been carried out to gain a deeper understanding of the environment and weak construction monitor the action of pavement fractures. However, one downside of these previous studies was that the majority of them were carried out in a laboratory environment. A trial road section was studied after finishing base course construction by monitoring the early cracking. The major causes of appearing the early cracking have been investigated and debated. In this survey, three trial road sections with defined asphalt layers were considered. These trial sections were constructed with local materials brought from Nasrya refinery and Najaf quarry. On the basis of the findings obtained, two sections have deteriorated, while the third one was made as control for comparison purposes. The observed early cracking could be attributed to the asphalt cement type and poor construction procedure occurring in an asphalt base layer as a result of low underlying sub-base course type and specifications.

Keywords: Asphalt concrete, base course, early cracking, and visual survey

1. Introduction

The first concept of pavement refers to a solid base or covering materials; place in such a way as to be hard and comfortable to use [1]. Flexible pavements are made of many layers of natural granular material covered by one or more layers of waterproof bituminous surface. Under a load of a tire, a flexible pavement can stretch (bend). The aim of designing flexible pavements is to prevent an unnecessary flexing of any layer; which can lead to over-stressing of a layer, which inevitably results in over-stressing and failure. The load distribution pattern varies from one layer to another in flexible pavements, since each layer's intensity is different. In the top layer, the strongest material (least flexible) is used, while in the lowest layer there is the weakest material (most flexible). The explanation for this
is that the wheel load is applied to a small area on the road, the effect is high levels of stress, further down the pavement, the wheel load is applied to a wider area, the result is lower stress levels, allowing weaker materials to be used[2].

Figures (1) Load distribution of flexible pavement

Immediately after the traffic road is opened, the pavement degradation system starts. This phase begins very late, and it speeds up at higher rates over time. In order to reduce the possibility of premature degradation, the best practice approach must be used in road planning, design, construction, and maintenance. This can be done by analyzing pavements that collapsed before due time and concentrating on identifying the causes of failure: so that it can be prevented in the future [3].

2. Cracking In Flexible Pavement(potential reasons)

- Fatigue cracking (Alligator cracking):
  This is a collection of interconnected cracks that produce small pieces of concrete with irregular shapes [4]. It is caused by surface layer or base failure due to repeated loading of traffic. The cracks eventually lead to surface disintegration. Potholes are the outcome. Alligator cracking is commonly associated with problems with the foundation (due to flexible brittle base or inadequate thickness)[1].

- Longitudinal cracking:
  Long cracks run parallel to the roadway’s centerline [4]. This may be caused by reflection cracking, poor paving lane joins, cut/full differential settlement, widening of pavement, or alligator failure, multiple parallel cracks can eventually form [1].

- Transverse cracking:
  It occurs at roughly right angles to the centerline of the pavement. They are spaced periodically [4]. Initially, transverse cracks will be widely spaced (over 20 feet apart). Typically, they start as hairlines or very narrow cracks and widen with age. When not properly sealed and preserved, secondary or multiple cracks are developed parallel to the initial crack. The causes for and repairs to transverse cracking are close to those for longitudinal cracking. Moreover, if the asphalt cement is too strong, thermal problems will contribute to low-temperature cracking.

- Block cracking:
  It is a series of interconnected cracks that split the concrete into irregular pieces [4]. Intersecting transverse and longitudinal cracks are often the cause of this. It can also be attributed to the lack of compaction when it happened during the construction process. Daily temperature cycling and HMA shrinkage. Usually caused by the asphalt binder's inability to expand and contract with temperature cycles as a result of the aging of the asphalt binder and Poor choice of asphalt binder in the mix design

- Slippage cracking:
Cracks in the form of a half-moon with the oncoming vehicles pointing at both ends.[4] They are formed by horizontal traffic forces. They are typically the result of weak bonding between the surface layer of the asphalt and the layer below. In many situations, the absence of a tack coat is the main factor of occurring this type of degradation. The repairing process includes removing and repaving of the slipped patch.

- **Reflective cracking:**
  Usually, reflective cracks appear when the new hot asphalt concrete is laid down and as a result of the presence of cracks in the layers beneath it. This type of failure appears as a reflection of that cracks in the low layer and should be properly fixed to avoid this kind of failure.

3. **Field Survey for Selected Roads**
There are two cases of study in this research which include two roads while the third one was made as a control for comparison purposes.
- The first case was concerted on the annual and service road of storage Karbala highway, which consists of four lanes with a median of 3.0m in width. Each lane has a 4.0m width with a total of 8.0m and 10700km long. It was implemented by Ashur General Contracting Company.
  
  ![Figures (2) storage Karbala road](image1)
  ![Figures (3) storage Karbala road](image2)

- The second road was Al-Ameerat Residential Collection Street in Najaf which has width of 7.0 m.
  
  ![Figure (4) Alameerat Residential collection street](image3)
  ![Figure(5) Alameerat Residential collection street](image4)
While the control road is Al Hawly street /five stage (Al-Mujamaat street). It is two-way highway with 11.5 m width for each side and a 3.0m median, which is implemented by Liemar Al Ghadeer company.

Figure(6) ameerat Residential collection street

A comprehensive visual examination was performed for the three cases under study. Base course defects were diagnosed with an estimate of the severity and intensity of distress of each case.

3.1 Coarse and Fine Aggregate

The Aggregates used in this investigation are obtained from the quarries of Najaf province; these quarries are frequently used in paving work by governmental companies in the southern provinces. Table (1) demonstrates the physical properties of coarse aggregates, while Table (2) shows the properties of fine aggregates.

| Table (1) properties of coarse aggregate |
|-----------------------------------------|
| Property value                         | ASTM Designation No. | Test results | SCRB Specification |
| Bulk specific gravity                  | CI27-88              | 2.618        | -                  |
| Bulk SSD specific gravity              | CI27-88              | 2.644        | -                  |
| Apparent specific gravity              | CI27-88              | 2.688        | -                  |
| Absorption %                           | CI27-88              | 1%           | -                  |
| Percentage of Fractured Particles      | ASTM D5821-3         | 92%          | Min:90%            |
| Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine | ASTM C131/C13M-2014 | 23% | Max:30% for wearing layer |

| Table(2) properties of fine aggregate |
|--------------------------------------|
| Property value                       | ASTM Designation No. | Test results | SCRB Specification |
| Bulk specific gravity                | CI27-88              | 2.618        | -                  |
| Bulk SSD specific gravity            | CI27-88              | 2.644        | -                  |
| Apparent specific gravity            | CI27-88              | 2.688        | -                  |
| Absorption %                         | CI27-88              | 1%           | -                  |
3.2 Collected Soil samples

Seven samples of soil were excavated and gathered from various locations throughout this search alongside the road in both Karbala: and al Amerat Residential. Tables (3) and (4) summarizes the essential physical properties of the collected sub-grade soils.

Table(3) Engineering properties of subgrade soils for Karabala Oil Repository Service Roadway

| Property                      | Test results | Specification |
|-------------------------------|--------------|---------------|
| 1 Soil classification         | A-7-6        | AASHTO M145[5]|
|                               | CL           | ASTM D 2487[6]|
| 2 Optimum moisture content    | 17.5%        | ASTM D 1557[7]|
| 3 Max. Dry unit Wight         | 16.2 KN/m2   | ASTM D 1557[7]|
| 4 Liquid limit                | 48%          | ASTM D 4318[8]|
| 5 Plasticity index            | 26.46%       | ASTM D 4318[8]|
| 6 CBR Soaked                  | 3.6%         | ASTM D 1883[9]|

Table(4) Engineering properties of subgrade soils for Al-Ameerat Residential Streets

| Property                      | Test results | Specification |
|-------------------------------|--------------|---------------|
| 1 Soil classification         | A-6          | AASHTO M145[5]|
| 2 Optimum moisture content    | 15.1%        | ASTM D 1557[7]|
| 3 Max. Dry unit Wight         | 17.6 KN/m2   | ASTM D 1557[7]|
| 4 Liquid limit                | 28%          | ASTM D 4318[8]|
| 5 Plasticity index            | 17%          | ASTM D 4318[8]|
| 6 CBR Soaked                  | 4.2%         | ASTM D 1883[9]|

The general specifications for roads and bridges (R5) have defined a set of requirements for the type of soil used in creating the dictap layers and the final layer of the final soil.

3.3 Sub base Layer

This layer is made of selected materials with a designed thickness placed on a sub-grade to support a base course.

Table(5) Specification requirements of subbase type

| P   | Sieve size(mm) | Grading | Specification |
|-----|----------------|---------|---------------|
| 1   | 75             | 100     | 100           |
| 2   | 50             | 100     | 100           |
| 3   | 25             | 94      | 75-95         |
| 4   | 9.5            | 67      | 40-75         |
| 5   | 4.75           | 61*     | 30-60         |
| 6   | 2.36           | 29      | 21-47         |
| 7   | 0.3            | 17      | 14-28         |
| 8   | 0.075          | 17*     | 5-15          |
Table (6) properties of subbase coarse material

| Property          | Standard method | Volume | Specification |
|-------------------|-----------------|--------|---------------|
| 1 Liquid limit    | AASHTO T 99     | 27     | 25            |
| 2 Plastic limit   | AASHTO T 90     | 11     | 6             |
| 3 CBR Soaked      | ASTM D 1883     | 39     | 35 min        |
| 4 Soluble salts   | -----------------| 2      | 10% min       |
| 5 Content of clay lumps | AASHTO T 112 | 0.1%   | <0.25%        |

3.4 Gradation

One of the most influential aggregate features in deciding how it will work as a pavement material is the particle size distribution or gradation. Gradation helps to determine almost every significant property in HMA including stiffness, resilience, toughness, permeability, workability, fatigue resistance, frictional resistance, and susceptibility to moisture gradation. Also, it helps to determine durability, porosity, workability, strength, and shrinkage. Therefore, gradation is a primary concern in HMA mix design, hence most agencies specify acceptable aggregate gradations[10].

3.5 Asphalt Cement

Asphalt is a visco-elastic substance in which two phases may be considered: a liquid or volatile phase formed by malten and a solid phase formed by asphalt. Theoretically, when a crack occurs, it is closed by itself, but if the liquid component of the bitumen rises, it will do it quicker. This can be accomplished by mixing asphalt with less dense oil namely a rejuvenator, as stated by Gresia[11]. The asphalt cement used in this study has a penetration degree of (40-50), commonly, and its supplied by the Nasiriyah refineries. Tests were done in the construction lab of the Directorate of Roads and Bridges in Al Muthanna, and the results were as shown in Table (7).

Table (7) Physical Properties of Asphalt Cement

| Property               | Test condition       | ASTM,2013 Designation | Test results | SCRBB,2003 Specification |
|------------------------|----------------------|-----------------------|--------------|--------------------------|
| Penetration            | 25C,100gm, 5 sec     | D5-06                 | 44           | 40-50                    |
| Softening point        | D36-95               | D113-99               | 49           | -                        |
| Ductility              | 5 cm|min                | D113-99               | 140          | >100                     |
| Specific gravity       | 25C                  | D70                   | 1.03         | -                        |
| Flash point            | Cleaver land open cup| D92-05                | 302          | >232                     |

After thin film oven test D 1745-97

| Retained penetration of residue | 25C<100gm, 5sec | D5-06 | 81 | >55 |
| Ductility of residue          | 25C,5cm|min| D113-99 | 95 | >25 |

3.6 Mineral Filler

One type of mineral filler (Lime stone dust) was used in all cases. It is a non - plastic material produced in Karbala governorate in lime factory. The gradation and physical properties of the filler are displayed in Table (8).
Table(8) Gradation and Physical Properties Of Mineral Filler

| Sieve Size (mm) | % Passing | SCRB Specification |
|-----------------|-----------|--------------------|
| 0.6             | 100       | 100                |
| 0.3             | 98.2      | 95-100             |
| 0.075           | 92.3      | 70-100             |

**Physical Properties**

| Plasticity Index (PI) | Non-plastic | ≤ 4   |
|-----------------------|-------------|-------|
| Specific gravity, g/cm³| 2.724       | -----|

4. Discussion of Cases Results

The causes that led to the emergence of failure in the first and second cases were determined by comparing the results of their laboratory tests with the third case and studying the effect of their properties according to the laboratory results obtained. Also statistical tests have been performed using SPSS version to test normality and ANOVA to know whether the data are following normal distribution or not.

4.1 Engineering Properties of Pavements Structures

As mentioned before, three trial sections of three different roads are consists of sub-grade, sub-base and base course.
Table (9) shows the Engineering properties of two pavement layers (base and sub-base courses) above sub-grade.

| CASE             | Soil       | Subbase     | Base course |
|------------------|------------|-------------|-------------|
|                  | CBR        | L.L.        | P.I.        | Marshall stability | Air voids | Flow | Asphalt content |
| Karbala Road     | 3.8        | 42          | 8           | 28 29 1            | 5.2       | 4.0  | 3.3            |
|                  | 3.8        | 42          | 8           | 28 29 1            | 5.4       | 3.9  | 3.7            |
|                  | 3.8        | 42          | 8           | 27 29 1            | 5.6       | 4.3  | 3.8            |
|                  | 3.1        | 46          | 5           | 28 30 1            | 5.1       | 4.4  | 3.1            |
|                  | 3.8        | 42          | 8           | 25 33 1            | 5.6       | 4.3  | 3.8            |
|                  | 4.1        | 47          | 6           | 28 29 1            | 5.1       | 4.4  | 3.1            |
|                  | 3.8        | 42          | 8           | 26 31 3            | 5.6       | 4.3  | 3.8            |
| Average          | 3.74       | 45          | 7.2         | 27.14 30 1        | 5.3       | 4.2  | 3.5            |
| Alameerat        | 3          | 46          | 5           | 30% 29 1          | 6.1       | 4.0  | 3.3            |
| Residential      | 4          | 42          | 8           | 28% 30 2          | 6.7       | 3.9  | 3.7            |
|                  | 4          | 47          | 6           | 32% 29 1          | 5.9       | 4.3  | 3.8            |
|                  | 4.2        | 46          | 5           | 33% 30 1          | 6.1       | 4.4  | 3.1            |
|                  | 4.1        | 42          | 8           | 30% 29 1          | 6.1       | 4.3  | 3.8            |
|                  | 5          | 47          | 6           | 36% 29 1          | 4.9       | 4.4  | 3.1            |
|                  | 5          | 46          | 5           | 40% 21 3          | 4.8       | 4.3  | 3.8            |
| Average          | 4.19       | 45.1        | 6.1         | 32.7 28.1 1.42    | 5.1       | 4.2  | 4.3            |
| Control          | 4.5        | 30          | 9           | 37% 6 2           | 6         | 4.1  | 3.4            |
|                  | 5          | 29          | 8           | 40% 7 3           | 7         | 4.2  | 3.8            |
|                  | 5.5        | 28          | 7           | 42% 7 4           | 7         | 4.1  | 3.4            |
|                  | 6          | 26          | 7           | 40% 7.1 3         | 7.1       | 4.3  | 3.1            |
|                  | 4.1        | 21          | 7           | 42% 6.9 3         | 6.9       | 4.2  | 2.9            |
|                  | 4.3        | 30          | 7           | 47% 6.9 3         | 6.9       | 4.1  | 2.8            |
|                  | 4.7        | 21          | 9           | 45% 6.1 3         | 6.1       | 4.1  | 2.8            |
|                  | 4.8        | 22          | 8           | 46% 6.2 4         | 6.2       | 3.9  | 2.8            |
|                  | 4.9        | 21          | 8           | 47% 6.5 4         | 6.5       | 4.2  | 2.9            |
|                  | 4.3        | 19          | 8           | 48% 6.9 4         | 6.9       | 4.1  | 3.9            |
| Average          | 4.81       | 24.7        | 7.8         | 43.4              | 6.6       | 4.31 | 2.93           |

It can be observed from the table above, that there is a significance difference between the three trial sections in terms of Marshall stability. By comparing the properties, the cause of early cracking could
be attributed to: The weak soil and/or sub-base. This is deduced by analyzing the results for CBR, LL and PI for both (subgrade and sub-base).

Figure (7) CBR for soil layer.

Figure (8) CBR For Sub-base Layer

ii) Lack of asphalt content: By observing the results below. It was found that the higher asphalt content resulting in greater interconnection between components and greater self-healing potential of the asphalt mixture, which in turn better performance.

iii) The test results of Marshall Stability, shown in figure (18), showed that the stability increases with increasing the asphalt content.

Figure (9) Asphalt content for the three cases.

Figure (10) Marshal stability for three cases

iv) Also, when the asphalt content increases, the flow value increases, which may also be attributed to the use of hydrated [12].
5. Conclusions and Recommendations

1. To avoid the appearance of cracks of very little width in the surface of asphalt concrete, the following must be adhered to:
   - The temperature of the asphalt mixture from the moment it was removed from the truck and placed in the spreader, should not be less than 120°C or more than 190°C.
   - The nature of the asphalt absorption of aggregate has the effect of reducing the bonding between the grains of aggregate and the surrounding asphalt, which requires increasing the percentage of added asphalt above the minimum limits of the standard when preparing the mixing equation to reduce the appearance of cracks in the future. It should also be noted that the paving of a bonding layer with a thickness of 7 cm and above the current base layer will treat these relatively simple capillary cracks.

2. Attention to directing driver not to exceed The very slow speed the compactor, which is around 5 km/h, should not be exceeded when the hill is started.

It is necessary that a layer under the base coarse (sub-base) be free from cracks and strong.

It is known in asphalt paving work that the edges of the road (the base layer) could not be compacted very well, because there is no pavement or side supported from the sub-. As a result, the movement of the compactor causes a vertical force that turns into a horizontal (lateral) movement within the asphalt mixture where a longitudinal crack is expected to appear.

3. Also, the project of the transverse joints, there is a need to pay attention to cutting the face of the joint in the old meal vertically and spraying it with the adhesive paint (tack-coat) at a rate of (2-1.5) liters per square meter by means of a spray truck corresponding to the standard specifications for roads and bridges.

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