Improving the Properties of Asphalt Concrete Mixtures Using Iron Filling Wastes

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Abstract. The iron filling powder is a byproduct that can be obtained during steel manufacturing. Using iron filling powder in road paving can have many environmental advantages, such as keeping a clean environment and saving natural construction materials. The paper evaluates the impact of utilizing iron filling powder on indirect tensile strength and Marshall Stiffness of hot mix asphalt. Four values of hot mix asphalt with various iron filling contents, namely, 0, 30, 60, and 90% by weight of total mix, were deliberated. The testing showed an improvement in different Marshall Properties and indirect tensile strength of hot mix asphalt modified with iron filling. As the iron filling percent exceeds, Marshall Stability and indirect tensile strength of the studied blends exceeds. This is an indication of mixtures performance improvement and the fact that iron filling powder can be utilized in asphalt paving for ecological features. The research was set up to examine the approval of using iron filling to improve the designing attributes of domestic-made bitumen concrete (A.C.) blends. The examination began by estimating the substance and physical qualities of the iron filling. From that point 0, 30, 60, and 90% of the limestone total in the A.C. blends were snubbed by iron filling. The advancement made the iron exhibition a decision in roundabout elasticity, flexible modulus, rutting obstruction, and weariness life. It was discovered that subbing 90% of the coarse limestone total by iron filling upgraded the mechanistic qualities of A.C. blends.

Keywords: Iron filling aggregate; asphalt concrete; indirect tensile strength; rutting.

1. Introduction

Main characteristics that asphalt paving mixes might have: durability, stability, flexibility, and skid resistance (in surface layers) [1] proper substances (aggregate, bitumen, and additives) and suitable mixture designing step might be utilized to implement perfect characteristics. Trash employment is an attractive substitutional to dump in that dump expense, and possible pollutant troubles are decreased or even eradicated along with the attainment of source maintenance. However, the employment strategy should be combined with environmental and energy considerations to utilize existing substances most effectively. Steel slag, the byproduct of steel and iron manufacturing processes, started to be used in civil engineering projects within the past 12 years [2].

In Iraq, pavements are constructed to superior international standards, for instance, the American Association of State Highway and Transportation Officials [3], bitumen Institute, and the American Society for Testing and Materials [4][5]. And after a shortened interval of serving, several of these pavements are appearance markers of primary distress due to the serve ecological loading and traffic.
conditions. Another element in the soon stress is the utilize of peripheral quality limestone aggregate. Iron filling, a by-product of slug industrialization, is generated through the split of molted iron filling from imperfections in slug-making ovens. Iron filling develops as a melted fluid and is contained in a compound melting of oxides and silicates that consolidate on refrigeration. The iron filling is a converted substance that can be beneficial in the structural factory. For instance, it evaluates that over 7.5x106 t of iron filling is utilized every annual in the U.S. Collins and Ciesielski [6] fundamentally as a granulate pavement foundation or as an aggregate in structural implementations. The iron filling aggregate has adequately been utilized in the Middle East beneath warm climate situations [7]. Some iron filling has altitude proportions of free limestone and magnesium oxides that have not interacted to the silicate constructions and can hydrate and extend in moist ecological [8]; the proper iron filling can be employed as an alteration for nature aggregate in a diversity of civil engineering implementations.

It can be utilized in concrete mixtures, bitumen concrete mixtures (A.C), and soil stability. The iron filling can be treading into fine or coarse aggregate substance for use in intense-gradient and open-gradient hot-mixture A.C pavement and a cool mixture or roof curing implementations [9-12]. Suitable treatment of iron filling and specific goodness-dominance steps is very substantial in adopting iron filling for asphalt paving mixtures. The distention possibility of iron filling is of individual significance due to the loose lime or magnesia in the iron that, if neglected, might consequence in pavement fracturing [9]. The utilize of iron filling in road mixtures might be bounded to the alternative of the coarse or fine aggregate portion. Nevertheless, both, for hot-mixture asphalt including (100%) iron filling is oversensitive to altitude ratio in air voids and bulking trouble due to corner form of iron filling. Blends with an altitude ratio of air voids (e.g., 100% iron filling blends) demand altitude asphalt cement contents through production and will be oversensitive to glittering because of in-servicing traffic compaction. Asphalt mixtures consisting of iron filling may be determined utilizing standard lab steps; the Marshall mix [13] and Superpave mixture [14].

Mixtures consisting of iron filling and traditional aggregate are generally designed volumetrically due to the considerable variance in aggregate bulk relative densities. The demands of ASTM specifications D5106 and D4792 [4] outline concluded features of iron filling for utilizing in hot-mixture bitumen. Japan and Germany have inclusive specifications for the treatment of iron filling. Moreover, senility demands and aggregate expansion testing comprise the hot-mixture asphalt amplification experience consisting of iron filling [8]. Concerning the typical characteristics of asphalt mixes like stability, water sensibility, resilient modulus, or fatigue life, the features are comparatively unaffected and in specific situations amended by the integration of EAFS described by [15]. So, to excess the sensitivity of bituminous mixes to microwave eradation, specific additives have been utilized. For instance, [16] used carbonyl iron powder. Helmand and Saini [17] The compression and splitting tensile strength of concrete made with 100% iron filings is about 26% higher than the concrete made with 100% natural sand. The research's essential goal is to find methods and means of efficiently employing trash substances emanating as by production from slug manufacture by the slug-factory companies in Iraq. To investigation the goal, we concerted to (i) studying the chemical and physical characteristics of produced iron filling to locate them properly for utilizing in asphalt cement mixtures; (ii) attend asphalt cement blends that consisted of iron filling and estimate their characteristics and improve the tensile strength, rutting resistance, resilient modulus, fatigue life of the blends.

2. Materials

In this research, the materials utilized are bitumen cement, aggregate, and limestone filler. The properties of materials were evaluated employing habit kind of experiments, and the gained results were contrasted at the [18] specification requests. In Iraq, all the substances utilized are natively obtainable and vastly appointed for the road structure.

2.1 Asphalt cement

Asphalt cement was used with (40-50) penetration grade gained from Al-Durra's refinery in Baghdad city. The physical characteristics of asphalt are shown in Table 1.
Table 1. Physical characteristics of asphalt cement binder.

| Test                  | Test condition             | ASTM Designation | Asphalt Binder SCRB specification |
|-----------------------|----------------------------|------------------|----------------------------------|
| Penetration           | 100 gm, 25°C, 5 sec., 0.1 mm | D5               | 45                               |
|                       |                            |                  | 40-50                            |
| Specific Gravity      | 25°C/25 °C                 | D70              | 1.02                             |
| Ductility             | 25°C, 5 cm/min.            | D113             | >100                             |
| Flash Point (COC) °C  | ----                       | D92              | 236                              |
| Softening Point       | (4±1) °C/min.              | D36              | 47                               |

2.2 Aggregate
The aggregate utilized in this research is squashed quartz from the quarry of Al-Nibaie that is boundlessly used for black-top blends in the city of Baghdad. The total (coarse and fine) utilize in the test were sieved and integrated in the reasonable ratio to accumulate the surface course degree type III, and as requested by [18] determination, the chose degree with determination ends are shown in Figure 1. The physical features of total utilized appear in Table 2.

![Figure 1. Aggregate gradation curve.](image)

Table 2. Physical features of aggregates.

| No.  | Laboratory Test             | ASTM Designation | Test Results | SCRB Specification |
|------|-----------------------------|------------------|--------------|--------------------|
|      |                             |                  |              |                    |
| Coarse aggregate |                             |                  |              |                    |
| 1    | Apparent specific gravity   | C-127            | 2.678        | -                  |
| 2    | Bulk specific gravity       | C-127            | 2.61         | -                  |
| 3    | Water absorption, %         | C-127            | 0.21         | -                  |
| 4    | Percent wear (Los Angeles abrasion), % | C-131 | 17.5 | 30 Max. |
| Fine aggregate |                             |                  |              |                    |
| 1    | Apparent specific gravity   | C-128            | 2.683        | -                  |
| 2    | Bulk specific gravity       | C-128            | 2.621        | -                  |
| 3    | Water absorption, %         | C-128            | 0.4          | -                  |

2.3 Mineral filler
Mineral filler crossing sieve No.200 (0.075 mm) is a non-plastic material. The filler employed is limestone powder got from the bituminous concrete mix manufacturer of Mayoralty Baghdad of lime in manufacturer from Karbala Governorate. Physical features of filler are shown in Table 3.
2.4 Iron fillings
Iron fillings are such tiny parts of iron that they look like sprightly dust. They are very often utilized in science fields to show the direction of a magnetic domain. Since iron is a ferromagnetic substance, a magnetic domain motivates all molecules to be a tiny bar magnet. The south pole of all particulate then engages the north poles of its neighbors, and the procedure be returned over a vast area creates chains of filings parallel to the tendency of the magnetic domain. Iron Fillings are utilized in many sites, containing schools where they experience the filings’ response to magnets; ironing filling contains about 8.46% SiO₂, 87.46% Fe₂O₃, 0.87% Al₂O₃, and 1.08% CaO. Similar chemical composition was reported by [19]. Iron filling dust was crushed and screened to produce aggregate that fulfills the gradation demands for asphalt concrete mixtures. Table 4 exhibits the mechanical characteristics of the utilized iron filling. The iron filling has suitable physical characteristics for aggregate utilization, containing perfect abrasion resistance, perfect soundness properties, and high bearing strength. Table 5 presents the gradation of the used iron filling.

### Table 3. Physical features of mineral filler.

| Property                                  | Test Result |
|-------------------------------------------|-------------|
| Specific gravity                          | 2.71        |
| % Passing sieve No.200 (0.075 mm)          | 97          |

### Table 4. Properties of iron filling.

| Property                              | Value  |
|---------------------------------------|--------|
| Los Angeles Abrasion (LAA%)           | 25     |
| Percent of soundness loss             | 10     |
| Angle of friction                     | 40     |

### Table 5. Gradation of used iron filling.

| Sieve | Passing, % |
|-------|------------|
| No.50 | 100        |
| No.100| 65         |
| No.200| 40         |

3. Experimental work
The experimental work was started by figuring the optimum asphalt ratio for all the bitumen concrete mixtures using the Marshall method of mixture design. Bituminous concrete blends were made at the optimum bitumen content and tested to estimate the engineering Features that comprise moisture damage, permanent deformation, resilient modulus, and Features of fatigue. The features have been calculated utilizing indirect tensile strength, repeated flexural beam tests, and uniaxial repeated loading.

3.1 Marshall mix design
A perfect mixture design was fulfilled utilizing the Marshall process as a summary in [20] using (75) blows of the automatically Marshall hammer on every face of the sample (the temperature of mixing and compaction is 160°C). Depends on the process, Optimum Asphalt Content (OAC) is specified by mean of three amounts presented hereunder:

1) The ratio of asphalt versus highest unit weight.
2) The ratio of asphalt to the highest value of stability.
3) The ratio of asphalt at 4% air voids.

For every percent of iron filling ratio, six samples were supplied with a fixed raising rate in A.C. ratio of (0.2%). The chose A.C. ratio begins from (4.2%) for the control and established (OAC), then
3.2 Indirect tensile test

Depending on reference [21], the susceptibility of moisture of the bitumen concrete mixtures was estimated. The consequence of the experience is the (ITS), Tensile Strength Rate (TSR). In the experience, a group of samples were destined for every mixture depending on the Marshall step and compressed to 7±1 percent air voids utilizing various numbers of blows per surface that difference from (34 to 49) depending on the iron filling alteration average. The group contains six samples and is split into two subgroups; one group (control) in 25°C and another group (conditional) was exhibited to one cycle of icing and dissolving then examined in 25°C. The experiment included loading the samples with the compressive load at an average of (50.8mm/min) acting parallel to straight perpendicular diagonal level with 0.5 in. broad steel strips that are turned at the face with samples. The samples failed by cleavage along perpendicular diameter. Indirect tensile strength that is counted in accordance with Eq. 1 of the conditional models (ITS$_c$) split by the domination samples (ITS$_d$), which calculates (TSR %) as Eq. 2.

\[
\text{ITS} = \frac{2P}{\pi t D} \quad \text{(1)}
\]

\[
\text{TSR} = \frac{\text{ITS}_c}{\text{ITS}_d} \quad \text{(2)}
\]

where

- ITS = Indirect tensile strength (kPa)
- P = Ultimate applied load (N)
- t = Sample length (mm)
- D = diameter of sample (mm)
- previously define the other parameters

3.3 Uniaxial repeated loading test

The uniaxial repeated loading experiences were behaved for cylindrical samples of 203.2 mm height and 101.6 mm diameter, utilizing the pneumatic repeated load system (appeared in Figure 2). In the experiences, repeated compressive loading with a stress degree of 0.137 MPa was exercised in the shape of a rectangular wave with a fixed loading recurrence of 1 Hz (0.1 sec. load interval and 0.9 sec. repose interval), the permanent axial deformities were scaled beneath the various loading duplications. The uniaxial repeated loading experiments were checked at 40°C. The sample elaboration process for the experiment can exist in [22]. The permanent strain ($\varepsilon_p$) is determined by stratifying the next Eq. 3:

\[
\varepsilon_p = \frac{P_d \times 10^6}{H} \quad \text{(3)}
\]

Where:

- $\varepsilon_p$ = Axial permanent micro strain (in/in)
- $P_d$ = Axial permanent deformities
- H = High of sample (in)

Else, during the experiment, the resilient deflection is calculated at the load duplication of 50 to 100, and the resilient strain ($\varepsilon_r$), resilient modulus ($M_r$) is measured as appears:

\[
\varepsilon_r = \frac{r_d \times 10^6}{H} \quad \text{(4)}
\]

\[
M_r = \frac{\sigma}{\varepsilon_r} \quad \text{(5)}
\]

Where:

- $\varepsilon_r$ = Axial resilient micro strain (in/in)
- $r_d$ = Axial resilient deflection
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\[ h = \text{height of Sample (in)} \]
\[ M_r = \text{Resilient modulus (MPa)} \]
\[ \sigma = \text{Repeated axial stress (psi)} \]

Results of permanent deformation for the research are drawn by the linear log-log relation amidst the number of repeated load, and permanent microstrain with the form appeared in Eq. 6 that is primarily proposed by [23, 24].

\[ \varepsilon_p = aN^b \]  

(6)

Where:
\[ \varepsilon_p = \text{Permanent strain (in/in)} \]
\[ N = \text{Number of stress applications} \]
\[ a = \text{Coefficient of intercept} \]
\[ b = \text{Coefficient of slope} \]

4. Results and discussion

4.1 Effects of iron filling on Marshall properties

The difference of Marshall characteristics with the iron filling ratio is presented in Figure 3, which depends on the results exhibited in Table 6. Tests of the offered results propose which the mixtures with maximum iron filling ratio give maximum optimum asphalt cement ratio, the extreme magnitude of OAC (5.26%) was attained with 90% iron filling, whilst the minimum magnitude (4.71%) was attained with 0% iron filling that is the state which the mineral filler completely contain limestone filler, this indicates that increasing the percent of iron filling leads to an increase in OAC, and this is not economical as large quantities of asphalt must be provided.

| Iron filling content, % | 4.71 | 30 | 60 | 90 |
|------------------------|------|----|----|----|
| Optimum asphalt        | 8.89 | 4.82 | 5.06 | 5.26 |
| Stability, kN          | 3.37 | 10.16 | 11.26 | 11.33 |
| Flow, mm               | 2.327 | 3.71 | 3.62 | 3.47 |
| Density, gm/cm³       | 4.23 | 2.337 | 2.345 | 2.338 |
| Air Voids, %          | 15.65 | 4.13 | 3.96 | 4.36 |
| VMA, %                | 4.71 | 15.50 | 15.21 | 15.86 |

As shown in this study. For the stability, the results signalize that the stability excess with the rising iron filling percent, as well the excessed rate different with iron filling percent, the higher rate acquired
is 1.1 kN/30% of iron filling content between 30% to 60%, while for the iron filling content between 0% to 30% and from 60% to 90% the rate was 1.27 and 0.07 kN/30%, respectively. In the stability figure, it may be potential to discuss that the higher advantage can be acquired with the utilize of 60% iron filling since moreover excess in the content of iron filling connected with just little excesses in stability magnitude and request more bitumen cement ratio in comparison to mixtures with 60% iron filling.

The consequences of flow as a function of different the ratio of iron filling is represented in sketch "c", it's evident that the flow magnitude excesses as the content of iron filling extras from 0% to 60%, and then reduces as the content of iron filling amenities. This is because air voids are too minimum at 30% content of iron filling, the addition of iron filling higher than the magnitude incline to excess air voids because of the deficient compaction effort, so the flow magnitude reduce. The relation between iron filling ratio and density that is represented in the sketch "d" adopt the same direction of that between the iron filling ratio and flow, an optimal iron filling ratio that yields the maximum Marshall density is 60%, moreover excesses in iron filling ratio incline to reduce the density.

As appeared in sketch "e" the direction noticed for the impact of iron filling ratio on air voids magnitudes is accurately inverse to that saw between iron filling ratio and flow, for the iron filling ratio from 0 to 60%, the air voids reduce with an average of -0.125% for every 30% alter in iron filling content, in 90%. The air voids ratio excesses quickly with an average of +0.42% for every 30% change in iron filling ratio. This may be facility described in truth which the iron filling is softer than lime filler so it can efficiency block the air voids enclaves and hardness the mixtures for a definite value behind that will be a waste in the compaction voltage resultant in altitude the voids ratio. Sketch "f" appears the influence of iron filling ratio on (VMA). It's evident from the sketch till a 60% of iron filling ratio; the VMA reduces as the iron filling ratio excesses, the lower VMA magnitude identical to 60% iron filling is 15.21%, which means minimal space to be internalized by asphalt cement, after 60% content of iron filling, an addendum of iron filling causes excessing the VMA magnitudes.

![Graphs](image)

**Figure 3.** Effect of iron filling content on Marshall properties.

### 4.2 Effects of iron filling on moisture susceptibility

The result appeared in Figure 4 and Table 7 it clarifies which the tested contents of iron filling impact the moisture sensitivity of the asphalt concrete mixtures. ITS consequences for every control and conditional mixtures approaching linearly comparative to the iron filling ratio with parameters of comparatively per 30% alter iron filling ratio for the last. It is motivating to note which the development
amends in the ITS for the mixtures with iron filling and a part of asphalt are upper in the state of conditional mixtures than that of control mixtures. These conclusions and the association to the TSR appeared in Figure 4, ensuring that the resistance to moisture caused by damage is consolidated in bitumen concrete pavement improved with iron filling.

**Table 7.** Results of moisture sensitivity test.

| Iron Filling Content, % | ITS, kPa | TSR, % |
|-------------------------|----------|--------|
|                         | Control  | Conditioned |
| 0                       | 1030     | 795    | 77.0 |
| 30                      | 1125     | 915    | 81.3 |
| 60                      | 1355     | 1181   | 87.1 |
| 90                      | 1452     | 1330   | 91.5 |

![Figure 4](image)

*Figure 4. Effect of iron filling content on TSR.*

### 4.3 Effects of iron filling on resilient modulus

Table 8 and Figure 5 exhibit the difference of the resilient modulus magnitudes with the iron filling ratio. The relationship is inverted order up to 30% of the iron filling (i.e., as the iron filling ratio exceeds the resilient modulus reduces), then increment in iron filling content inverts this relationship. The mixtures' resilient modulus with 90% the iron filling (1145 mPa) is 1.45 times the mount for mixtures with 30%. The iron filling that was 790 MPa, these consequences can be demonstrated as follow; since the experience was performed beneath comparatively altitude temperature (40°C). The lower grade of the iron filling content (under 30%) is inadequate to hardening the asphalt concrete mixtures. In comparison, the upper amounts of resilient modulus consequence from the maximum grade of the iron filling ratio (over 30%) indicate that iron filling did exceed the bitumen concrete mixture's strength.

**Table 8.** The results of resilient modulus test.

| Iron filling ratio, % | 0   | 30  | 60  | 90 |
|----------------------|-----|-----|-----|----|
| Resilient Modulus (MR), MPa | 825 | 790 | 985 | 1145 |
4.4 Effects of iron filling on permanent deformation
The consequence of permanent deformation experiences appears in Figure 6, which depends on the data shown in Table 9. Tests of the submitted results propose which the permanent deformation coefficients intercept and slope mostly developed with the utilize of iron filling, for mixtures including 0% iron filling, the slope amount that inverted the cumulating average of permanent deformation is nearly 24% upper than that of mixtures with 90% iron filling. For the intercept, the amount is lightly exceeded as the iron filling content excesses from 0 to 30%, but then the addendum of more iron filling value tends to reduce the intercept magnitude in an average of 20 microstrains per each 30% variate in iron filling ratio. This conclusion assures that the rutting mode of failure in bitumen concrete pavement improved at a temperature of summertime may be decreased in great expansion with the submission of iron filling to bitumen concrete mixes.

Table 9. Results of permanent deformation test.

| Iron filling, % | 0   | 30  | 60  | 90  |
|----------------|-----|-----|-----|-----|
| Intercept      | 129 | 115 | 91  | 73  |
| Slope          | 0.243 | 0.261 | 0.351 | 0.169 |

Figure 5. Effect of iron filling content on M.R.

Figure 6. Effect of iron filling content on permanent deformation.
5. Conclusions and recommendations
The subsequent inferences and proposals depend on the consequents of the lab experiments and details showed in this research:

1) The addendum of various percentages of iron filling has an enormous impact on volumetric mix characteristics; some of them gained consequents can be listed as follows:
   - Mixes give the maximum OAC with higher iron filling content; the maximum magnitude of optimum asphalt content (5.26%) was gained with 9% iron filling, whereas the minimum magnitude (4.71%) was gained with 0% iron filling.
   - The maximum density is 60%, also increases in iron filling content tend to cause a decrease in the density.
2) At a ratio of -0.125 percentage for each 30% alter in the iron filling ratio, an iron filling content changed from 0 to 30%, the air voids reduce. In 60%, the air voids ratio excess with a rate of +0.42% for each 30% alters in iron filling ratio.
3) The resistance to moisture damage and the ITS for control and conditional mixtures improved by adding 90% iron filling.
4) A rate altered from 30% to 90% has shown a rise in resilient modulus for the addition of iron filling. The resilient modulus for mixtures with 90% iron filling was 1.45 times that for mixes with 0% iron filling.
5) The adding of different percentages of iron filling given the significantly effected of permanent deformation parameters, intercept and slope, and iron filling ratio increases, the adjusting mixtures show maximum resistance to permanent deformation.
6) Considerably, to adjust, the asphalt concrete method has taken the percent of iron filling 60 and produces the mixtures more durable, higher resistance to distresses by addendum the local knowledge.

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