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Civil Engineering Journal

Vol. 6, No. 9, September, 2020

Influence of Iron-Filings on Marshall and Volumetric Properties of Asphalt Concrete

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Received 04 June 2020; Accepted 15 August 2020

Abstract

The growth and expansion of road infrastructure had resulted in the continuous use of materials, increased construction costs of flexible pavements and increased environmental impact during the service life of the road. Consequently, many researchers have sought to use methods to maintain these roadways sustain environmental impact and traffic loads. One of these approaches is the use of additives to improve asphalt's volumetric character. In this research, iron filings were used as partial replacement of fine aggregates, and the Marshall and volumetric properties were assessed before and after the implementation of iron filings. Specimens were prepared with iron filings addition of (2, 4, 6 and 8%) by weight of fine aggregates. The Marshall mix design procedure was used to calculate the optimum asphalt content and the volumetric properties, including bulk density, Total voids, voids in mineral aggregates V.M.A., and voids filled with asphalt V.F.A. The Marshall Flow and Stability were calculated. Test results were assessed before and after the inclusion of the iron filings. It was concluded that the addition of iron filings can enhance the Marshall and volumetric properties of asphalt. The stability increased by 15% when replacing fine aggregates by 2%, of iron filings by total weight. Also, the air voids and the VMA decreased by increasing the percentage of iron filings, while VFA was not significantly affected as compared to the conventional specimen. The ideal ratio of iron filings which fulfill the optimal requirements was 5%.

Keywords: Iron Filings; Volumetric Properties; Marshall; Stability; Flow; Mix Design.

1. Introduction

The advancement in material technology to support the sustainability in infrastructure design and construction has brought research work into focus. The major issue is to reserve the materials resources, reuse of reclaimed materials, reduce the need for energy, and improve the quality of the materials. One of the sustainable technologies is the use of iron scrap left in city-scattered iron-workshops. Disposal of iron filings is hazardous to the environment and proper disposal is difficult. Furthermore, iron filings can establish the self-repairing property for concrete due to their temperature conductivity. Many research studies have investigated the impact of incorporating iron waste on the quality of the flexible pavement. Jendia et al. (2016) [1] studied the effect of adding steel wool SW to the asphalt concrete. Steel wool S.W. was added by (3.5 and 7%) by weight of the asphalt to 20 samples. Volumetric, stability, and crawl characteristics of asphalt were calculated, as well as a study of its effect on the conductivity of asphalt and the extent of its effect on the self-healing property of asphalt. It was concluded that the rate of 5% of S.W. had improved the conductivity of the asphalt.

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http://dx.doi.org/10.28991/cej-2020-03091574

In comparison, the ratios 3 and 5% led to a stronger bond between the materials; As for the 4.3 % of S.W., it was the ideal rate for improving the physical properties of asphalt. Alakhrass (2018) [2] investigated the influence of adding iron powder on asphalt concrete properties. The effect of repeated loads and fatigue was studied. (4, 8, 12 and 16%) of iron powder was added to the asphalt concrete specimens. Indirect tensile testing and permanent deformation were performed at (5, 25 and 40°C) temperatures and with the constant stress of 250 and 400 KPa. It was concluded that the performance of the modified asphalt fatigue is better than that of the traditional asphalt, as the life of fatigue increased by 100 and 150% for samples with a ratio of (8 and 12%) of iron powder at a temperature of 5 °C when compared to conventional samples. Yan et al. (2019) [3] used steel slag in the asphalt concrete samples because of its benefits to the performance of the asphalt mixture, as well as to get rid of the costs of landfilling and environmental damage. Physical and mechanical tests were performed on samples with different content of the types of steel slag. A uniaxial compressive test was carried out, as well as an indirect tensile test to assess samples and study crack resistance at low temperatures and fatigue. It was concluded that the addition of furnace slag has increased the adhesion strength as well as improved shear resistance in modified samples compared to control samples. Afaf (2014) [4] added specific percentages of iron slag to asphalt concrete samples and examined the impact of this product on the stability and indirect tensile strength of asphalt samples. The rate of iron slag was (0, 10 and 20%) by the total weight of the mixture. It was concluded that there is an increase in stability when increasing the percentage of iron slag. A small increase was observed in the value of the indirect tensile strength when increasing the rate of iron slag.

Eisa (2018) [5] assessed the use of iron filings as a filler in the asphalt mixture of the wearing surface layer and studied its impact on the volumetric properties of the specimens. The filler weight for iron filings was (15, 20, 25, 35, 50 and 75%) of the mineral filler weight. It was reported that iron filings had changed the values of the volumetric properties of asphalt and the best percentage of iron filings that gave the best results was 25% by the weight of the filler. Arabani and Mirabdolazimi (2011) [6] used iron filings in the asphalt mixture at rates of (2.5, 5, 7.5, 10%) to replace the fine aggregates with this material and studied its impact on self-healing of micro-crack in the pavement. After preparing the specimens, they were cooled to (-20) °C and were fractured with a fracture test device, and the results were recorded. Samples were placed in the microwave for 90 seconds, and the temperatures were recorded. The specimens were fractured again with the fracture test device. The process was repeated, but the times in the microwave were changed to 120 and 140 seconds, and the results were compared. It was concluded that increasing the percentage of iron filings, which are conductive materials, has increased the temperature of the specimens at the fixed time. Also, fracture values were increased by increasing the content of iron filings.

Sarsam and Allamy (2020) [7] examined the effect of silica particles on pavement susceptibility to the fatigue cracking phenomenon. The results show that if the Silica fumes content was 1%, the fatigue life increases by 17%, and if the Silica fumes content increases to 2%, it increases by 46%. Therefore, the resilience of fatigue rises to 34% as Silica fumes rise to 3% relative to the control mixture. Remadevi et al. (2015) [8] studied the use of fibre reinforcement in asphalt concrete and its impact on stability, flow, and volumetric properties and compared the results with conventional asphalt concrete. 10mm polypropylene fibre was implemented at the rate of (4, 6, 8, 10%) by weight of bitumen. It was reported that using the optimum content of fibre of 5.33% by weight of bitumen and 4.41 % optimum asphalt content O.A.C. will increase the stability and decrease flow. Al-Tae et al. (2020) [9] studied the impact of two kinds of additives (Styrene-Butadiene-Rubber (S.B.R.) and carbon black) on the performance of recycled asphalt concrete mixture. It was concluded that the Resilient modulus (Mr) at (0.138 and 0.206) MPa stress level decreases by (14, 22 and 8) % and (22, 34 and 11) for reclaimed and recycle mixtures with (carbon black-asphalt and SBR-asphalt) respectively If compared to that at 0.068 MPa. In the asphalt mixture, Oluwasola et al. [10] added steel slag and copper mine residues by varying proportions and studied the effect of these additives on volumetric properties (air voids, specific gravity, V.M.A., V.F.A., Stability and Flow), Test results were evaluated and the f-test was used to assess the degree of importance of mixtures with both criteria. It was concluded that, the use of steel slag or copper mining residues or either has been shown to create better volumetric properties of asphalt mixtures. Xu et al. (2020) [11] used steel slag, steel fibre and basalt to replace fine and coarse aggregates in modified asphalt mixtures. The effect on mechanical, thermal and healing properties as well as the influence of moisture as a component of durability, and the natural cooling speed in the asphalt mixture was assessed. An infrared camera registered the heating and cooling velocities.

A Scanning Electron Microscope (S.E.M.) has detected the surface texture. Surface area and Porosimetry methods have measured the pore sizes. The percentage of steel fibre was 2%, 4% and 6% (by the volume of asphalt). It was concluded that Steel fibers have improved the moisture damage, high-temperature deformation tolerance and mechanical strength, while steel slag benefits from high-temperature deformation tolerance and mechanical performance, but is not moisture damage tolerant. Also, the healing process is successful in the induction of steel slag and asphalt concrete healing increases with decrease in steel fibres. Gao et al. (2018) [12] measured the heating efficiency of microwave asphalt mixtures comprising steel wool fibre. The effect of the additive was also evaluated in different ratios on the percentage of air voids **.** For the preparation of the asphalt mixtures, three types of low-carbon steel wool with five different diameters were used **.**It was concluded that the air spaces increase with increasing steel wool ratios. Köfteci (2018) [13] used five asphalt samples with ratios (1, 3, 5, 7, 9%) of Low-Cost Iron Wire Fiber. The stability and moisture impact through an ITS and TSR were investigated. The findings of the investigations show an increase of 1%+3% increase in the quality of asphalt mixtures by incorporating low-cost iron fiber. When the rate of fibre increased by more than 3%, stereo-microscope clustering created by fibers was observed. As a result, air vacuums were increased and the interaction between bitumen and aggregates decreased. Especially increased fiber ratio caused compression, durability and stability problems in the mixture at 7-9 percent.

This work aims to assess the influence of partial replacement of fine aggregates with iron filings on the Marshall and volumetric properties of asphalt concrete. (2, 4, 6, 8%) of iron filings replaced fine aggregates of the same size. Seventy-five samples were prepared. The Marshall method of mixture design was used to calculate ideal asphalt content. Volumetric, stability, and flow characteristics of samples were assessed, and it was compared with the results of the conventional samples. Besides, the effect of different iron filings ratios on the behaviours of these properties was evaluated. Finally, it was suggested that the percentage of iron filings that achieve the optimum requirements for these properties will be evaluated. The research flow chart is shown in Figure 1.

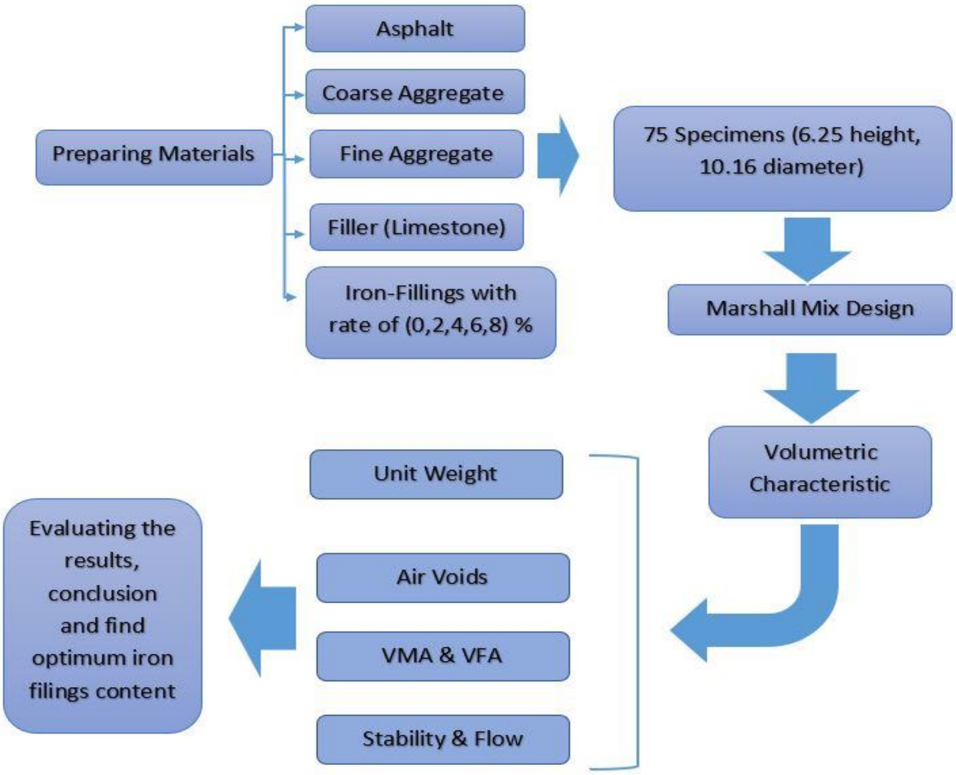

Figure 1. Research methodology flow chart

2. Materials and Methods

2.1. Asphalt cement

Penetration grade asphalt cement (40-50) was obtained from the Al-Nasiriyah refinery. Details of physical properties of asphalt cement are included in Table 1.

Table 1. Physical properties of asphalt cement

Property	Test Conditions	ASTM, 2013 Designation	Test results	SCRB, 2003 Specification
Penetration	25ºc, 100 gr, 5sec	D5-06	44	40-50
Softening Point	-	D36-95	49	-
Ductility	25ºc, 5 cm/min	D113-99	140	>100
Specific Gravity	25˚c	D70	1.03	
Flash Point	Cleave open land cup	D92-05	302	>232
After Thin Film Oven Test D1754-97				
Retained Penetration of Residue (%)	25ºc, 100 gr, 5sec	D5-06	81	>55
Ductility of Residue	25ºc, 5 cm/min	D113-99	95	>25

2.2. Coarse and Fine Aggregates

The fine and coarse aggregates were taken from the stacks of the public Assyria Company of the Ministry of Construction and Housing. The required tests were performed and included in Tables 2 and 3.

Table 2. Properties of Coarse Aggregates

Property Value	ASTM, 2013 Designation No.	Test results
Bulk Specific Gravity of Coarse Aggregate	C127-88	2.619
Apparent Specific Gravity of Coarse Aggregate	C127-88	2.687
Absorption in per cent of Coarse Aggregate	C127-88	1 %
% of Fractured Particles in Coarse Aggregate	ASTM D5821-13	93%
Resistance to Abrasion (Los Angeles)	ASTM C131/C131M-2014	23%

Table 3. Properties of Fine Aggregates

Bulk Specific Gravity of Fine Aggregate	C128-01	2.621
Apparent Specific Gravity of Fine Aggregate	C128-01	2.694
Absorption in per cent of Fine Aggregate	C128-01	1.1%

2.3. Mineral Filler

Limestone dust has been used as filler and was collected from the Karbala factory. Basic testing for physical properties has been carried out. Table 4 illustrates its physical characteristic.

Table 4. Properties of Mineral Filler

Per cent passing sieve No. 200	95
Specific surface area (m^2/Kg)	389
Specific gravity	2.850

2.4. Iron Filings

The iron filings used in this work were obtained from the local iron workshop in Baghdad. Sieve analysis was performed, and only the iron filings were used which passed sieve No. 8 and retained on the sieve number 50. Were implemented. Iron filings were used as a partial substitute for the fine aggregates of the same size as that of the iron filings. The density of the iron filings was 7.15 gr/cm^3. Its calculation is based on CEN EN 1097-6/A1 [14]. Figure 2 illustrates the iron filings used in this work.

2.5. Selection of Combined Gradation

Asphalt concrete was prepared for wearing course type III-B according to the gradation limitations of SCRB [15] listed in Table 5. Figure 2 also shows the limitations used for the fine and coarse aggregate of the surface layer type III B.

Table 5. SCRB, 2003 Limitations of Aggregate Gradation

Sieve size (mm)	% Passing by Weight of Total Aggregate & Filler			
	Asphalt stabilized base course Type I	Binder course Type II	Wearing course Type III-A	Wearing course Type III-B
37.5	100	100	100	100
25.0	90-100	100	100	100
19.0	76-90	90-100	100	100
12.5	56-80	70-90	90-100	100
9.5	48-74	56-80	76-90	90-100
4.75	29-59	35-65	44-74	55-85
2.36	19-45	23-49	28-58	32-67
0.300	5-17	5-19	5-21	7-23
0.075	2-8	3-9	4-10	4-10

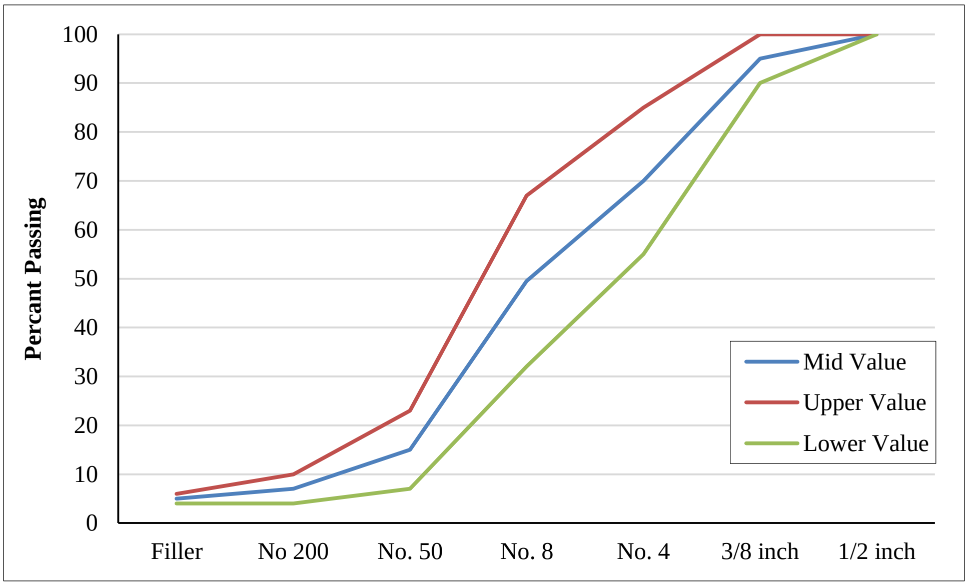

Figure 2. Aggregates Gradation Implemented

2.6. Marshal Mix Design

The Marshall Mixture design method is a critical way to know the optimal asphalt content used for asphalt**.** The design method for Marshall Mixes comprises of six key elements:

1. Choosing the right fine and coarse aggregate
2. Successful selection of asphalt binder with laboratory tests
3. Preparing and compaction of the samples
4. A stability and flow test for samples
5. Calculations of Density and Air Voids
6. Optimum rate of asphalt selection

In this work, fine and coarse aggregates were oven dried at 110 °C and combined with specific weights and proportions. The sums have been combined to satisfy the defined wear rate according to SCRB, [15]. The combined aggregates and bitumen were heated to 150 °C; the required amount of asphalt was added to the sums and mixed for two minutes by hand over the hot plate. The iron filings were added at (0, 2, 4, 6, 8%) of the total weight of the mixture as a partial substitute of fine aggregates. All the materials were mixed at a temperature of 150 °C. Marshall moulds measuring (6.25 height and 10.16 diameters) were prepared, and these moulds were heated to the temperature of 140 °C on the hot plate. The mixture was placed in the moulds and stacked with a spatula, according to ASTM (2013) [16]. Non-absorbable papers were placed on the moulds. A Marshal hammer was used to compact the samples 75 blows on each face of the mould. The temperature limit was taken into consideration, not to fall below 135 °C.

The specimens were left to cool in the laboratory for 24 hours; then, the moulds were removed. In this study seventy-five samples were prepared with different contents of asphalt and iron filings to calculate the optimal content of asphalt in the presence of iron filings and determine the optimal iron filing percentage that meets the specifications of the Marshall Mix design. The volumetric properties of these samples were calculated as follows:

Bulk Specific Gravity (G_{mb}) was determined based on the weight of the samples in the air and their weight in the water from the following equation, as reported by Robert et al. (2009) [17]**.**

$$G_{mb} = A/(B - C) \tag{1}$$

Where:

G_{mb}= bulk specific gravity of the compacted mixture;

A= mass of the dry Specimen in the air (g);

B=mass of the saturated surface dry specimen in the air (g);

C=mass of the Specimen in water (g).

The theoretical maximum specific gravity of bituminous paving mixtures (Gmm) for each Specimen with different content of asphalt and iron filing was calculated using the ASTM D2041 / D2041M-13 and the following equation:

$$G_{mm} = \frac{A}{A-(C-B)} \tag{2}$$

Where:

G_{mm} = maximum specific gravity of the mixture;

A = mass of dry sample in air, g;

B = weight of bowl underwater, g;

C = mass of container and sample underwater, g.

2.7. Air Voids

As stipulated in Al-Tae et al. (2020) [9], the air voids range from 3-5%. A.V value was extracted by changing the content of asphalt in the proportions of (4, 4.5, 5, 5.5, and 6) % of the samples. The content of iron filings in the previously mentioned proportions through the following equation:

$$A.V = \left[1 - \frac{G_{mb}}{G_{mm}}\right] \times 100 \tag{3}$$

Where:

A.V= Percentage of air voids (%);

G_{mm}= Maximum specific gravity of the hot asphalt mix ASTM D 2041 2011;

G_{mb}= Bulk specific gravity of the compacted mixture.

2.8. Void in Mineral Aggregate (V.M.A.)

Lack of V.M.A. can influence the stability of the asphalt mixture [16, 17] was used to calculate voids in the mineral aggregate (V.M.A.) as follow:

$$VMA = 100 - (G_{mb} \times \frac{P_s}{G_{sb}}) \tag{4}$$

Where:

G_{mb} = bulk specific gravity of the compacted mixture;

G_{sb} = bulk specific gravity of the aggregate;

P_s = percentage of the aggregate, by the total mass of mixture (%).

2.9. Void Filled with Asphalt (V.F.A.)

V.F.A. is associated with air spaces filled with asphalt. The V.F.A. is determined using the Equation (5) [16]:

$$VFA = \frac{VMA-A.V}{VMA} \times 100 \tag{5}$$

3. Results and Discussion

3.1. Unit Weight

Figure 3 shows the relationship between the unit weight and the asphalt content of samples with different proportions of iron filings. The value of the unit weight increases by increasing the percentage of asphalt until it reaches the highest value and then begins to descend. Figure 4 shows the relationship between the unit weights with the content of iron-filings in the asphalt. It can be observed that there is an increase in the unit of weight by increasing the content of iron filings. After reaching the highest value, it starts to descend. The reason for the rise in the unit weight is due to the high density of iron filings.

It can be observed that increasing the iron filing percentage will increase the density as long as the specimen can be compacted to a point where compaction is impossible due to protrusion ruggedness and thus density starts to decrease.6 per cent of the iron filings showed the highest unit weight value. Similar findings were reported by Jendia et al. (2016) [1].

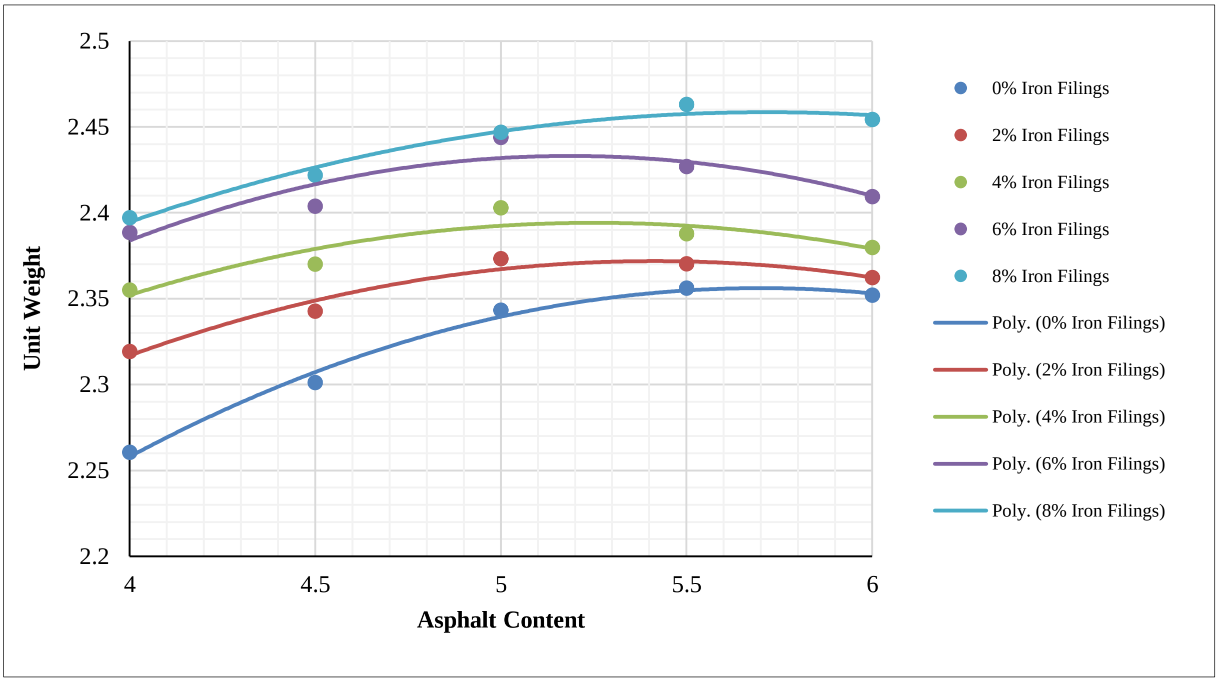

Figure 3. Unit Weight versus Asphalt Content

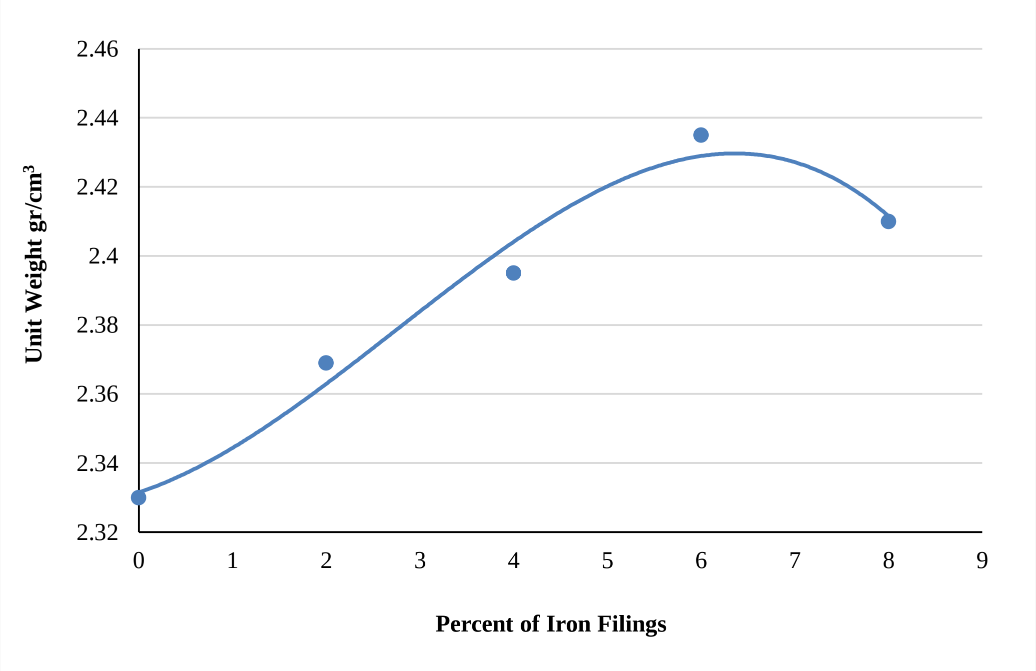

Figure 4. Unit Weight versus Iron Filings

3.2. Air Voids

Figure 5 shows the relationship of the air voids with the asphalt content of samples with different proportions of iron filings. On the other hand, Figure 6 shows the relationship between the iron filings content and the air voids where there is a decrease in the percentage of air spaces with an increase in iron filings. The explanation for the reduction in air voids is the smoothness of iron filings. Low air avoids can lead to bleeding, rutting and loss of stability in the mix [12]. In comparison, high air vacuums can lead to durability and stripping problems. Also Brown et al. (2004) [18] stated that high air vacuums increase the penetration of air and water into the concrete. The required air vacuum quality must, therefore, be achieved during construction by applying compaction pressure. The results were not identical to Gao et al. (2019) and Jendia et al. (2016) findings [1, 12].

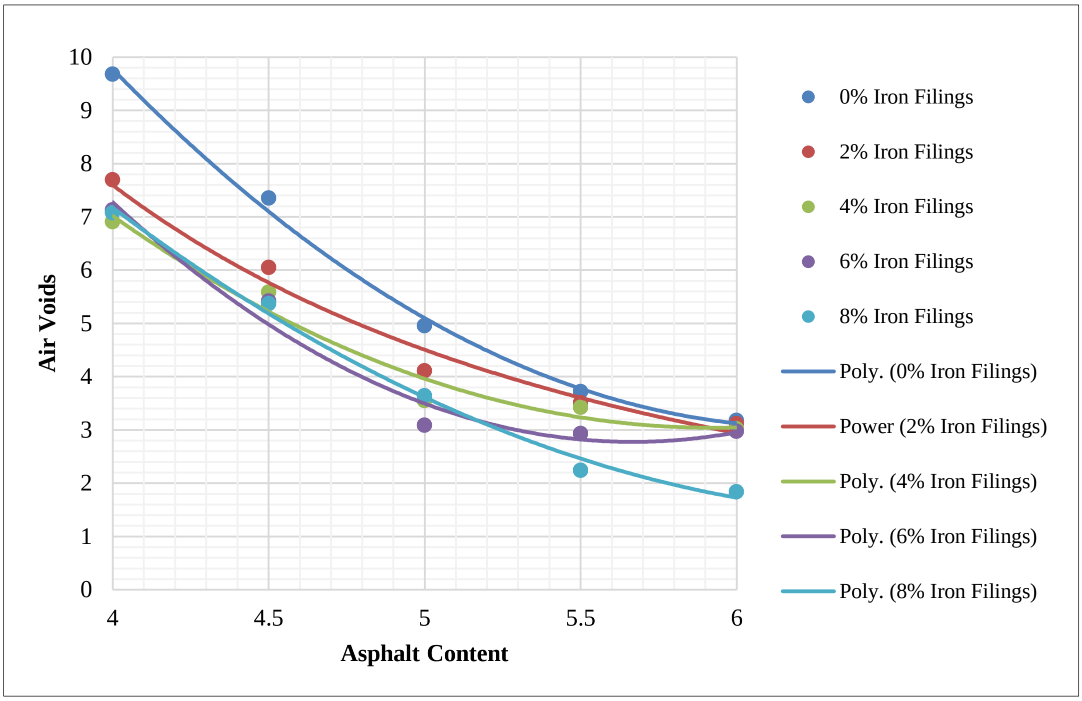

Figure 5. Air Voids versus Asphalt Content

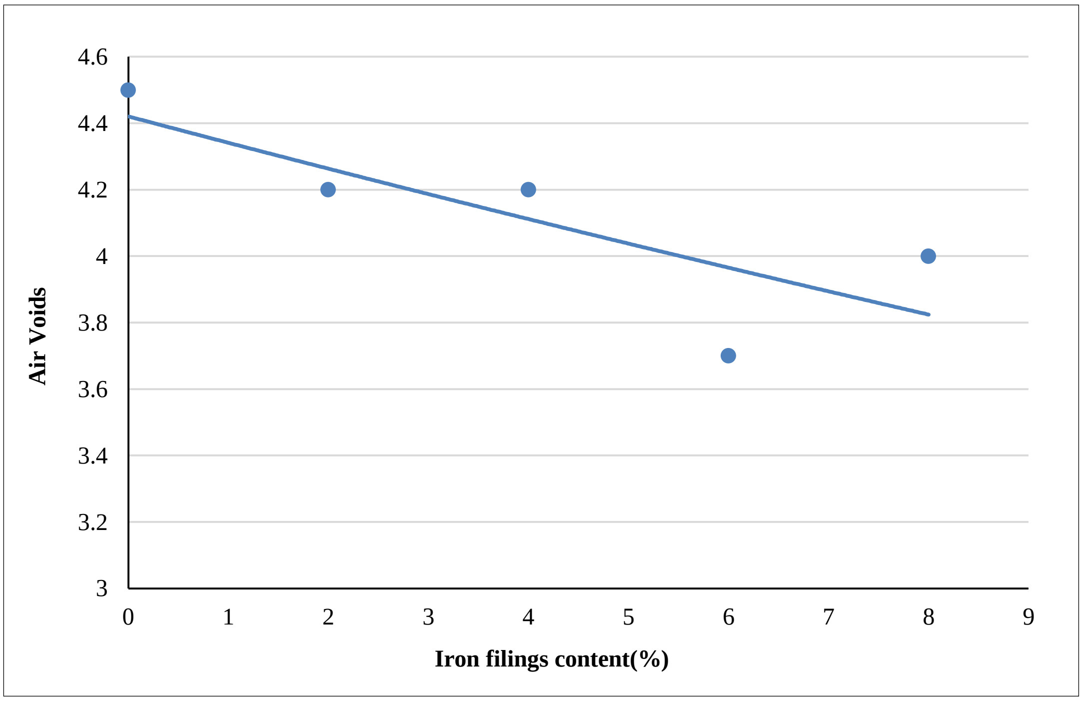

Figure 6. Air Voids versus Iron Filings content

3.3. VMA & V.F.A.

Figures 7 and 8 show the relationship between asphalt content versus V.M.A. and V.F.A., respectively. Figures 9 and 10 show the relationship between the content of iron filings, V.M.A., and V.F.A., respectively. The reason for the lack of VMA when increasing the percentage of iron filings in the asphalt mixture is the increase in bulk specific gravity. The decrease in VMA leads to problems in durability, but the results were within specifications. The variation in VFA is not significant as compared to the traditional mixture sample, where the increase was from 72 to 74 when adding 8% iron filings to the asphalt mixture. The results obtained were different from Jendia et al. (2016) findings [1].

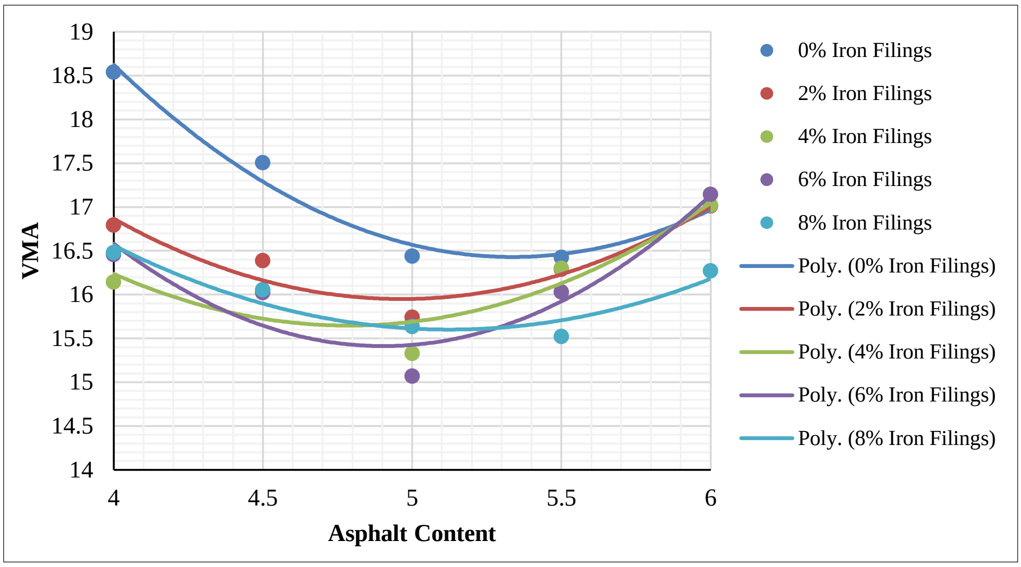

Figure 7. VMA versus Asphalt content

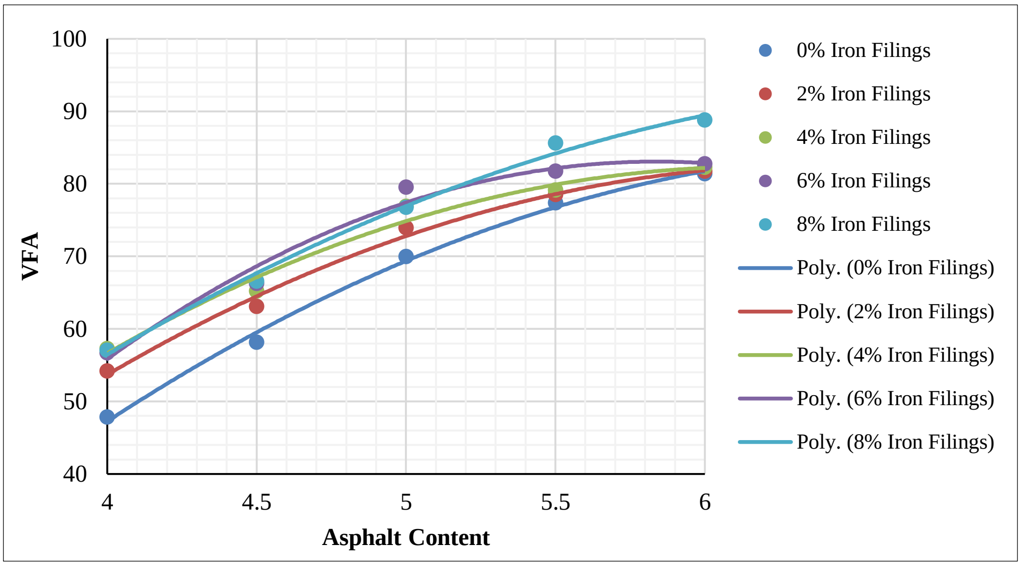

Figure 8. VFA versus Asphalt content

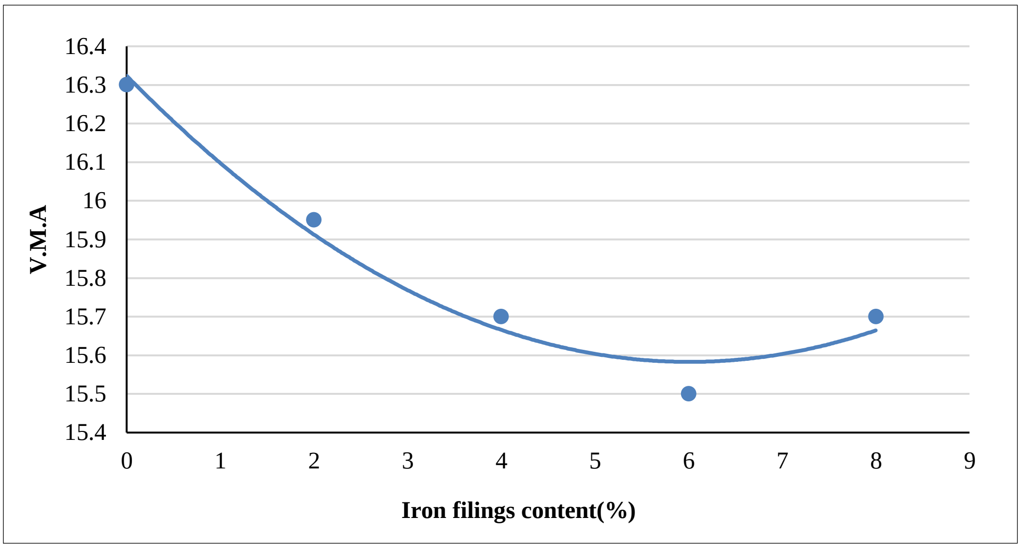

Figure 9. VMA versus Iron Filings Content

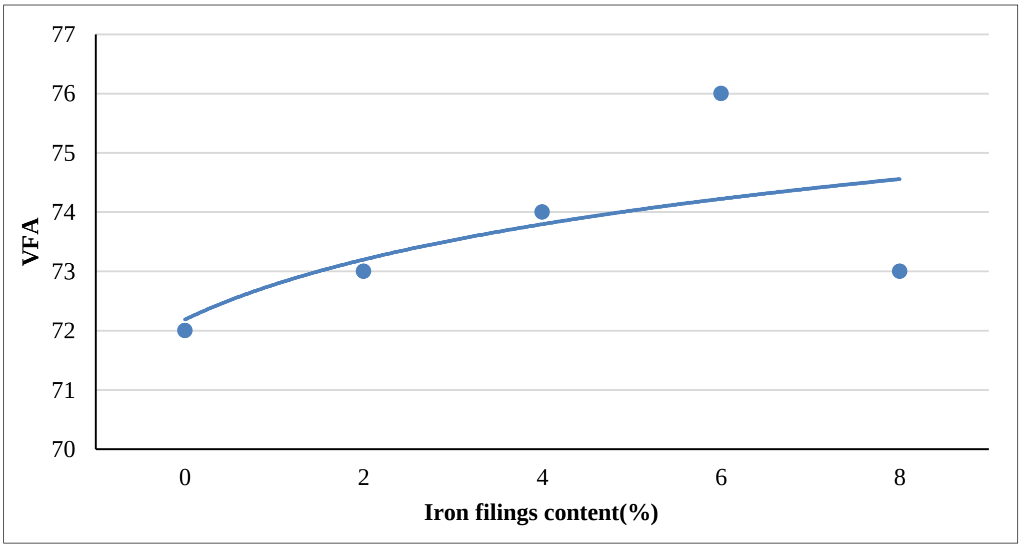

Figure 10. VFA versus Iron Filings Content

3.4. Stability and Flow

Among the most important outputs of the Marshall design of the mixture is the stability and flow of the samples. Figure 11 and Figure 12 illustrates the relationship between the content of asphalt with stability and flow, respectively. In contrast, Figure 13 and Figure 14 shows the relationship between the content of iron filings with stability and flow, respectively. It can be noted that the stability increases with an increase in the content of iron filings until it reaches the maximum value and then begins to descend. At the same time, the flow decreases with an increase in the content of iron filings. The highest stability was in samples with an iron filing content of 2%, while the lowest value of flow was for samples with an iron filing content of 4%. Table 6 shows the rate of increase in the stability of samples with different ratios of iron filings compared to the control sample (without adding iron filings). The improvement in stability with the addition of iron filings can be attributed to the rise in internal friction due to the angular form of the iron filings. Also, the reason for the decrease in stability in samples with the content of iron filings 6% and 8% is the property of non-absorption of binder in iron filings where if it exceeds the ideal percentage, the non-absorbed asphalt will increase and thus stability will decrease. In other words, the reduction in stability after the optimum iron fillings content can be clarified by the trapping of iron filings across the aggregate during mixing, contributing to a slight lack of connection between the blend. Similar results were reported by Jendia et al. (2016) [1].

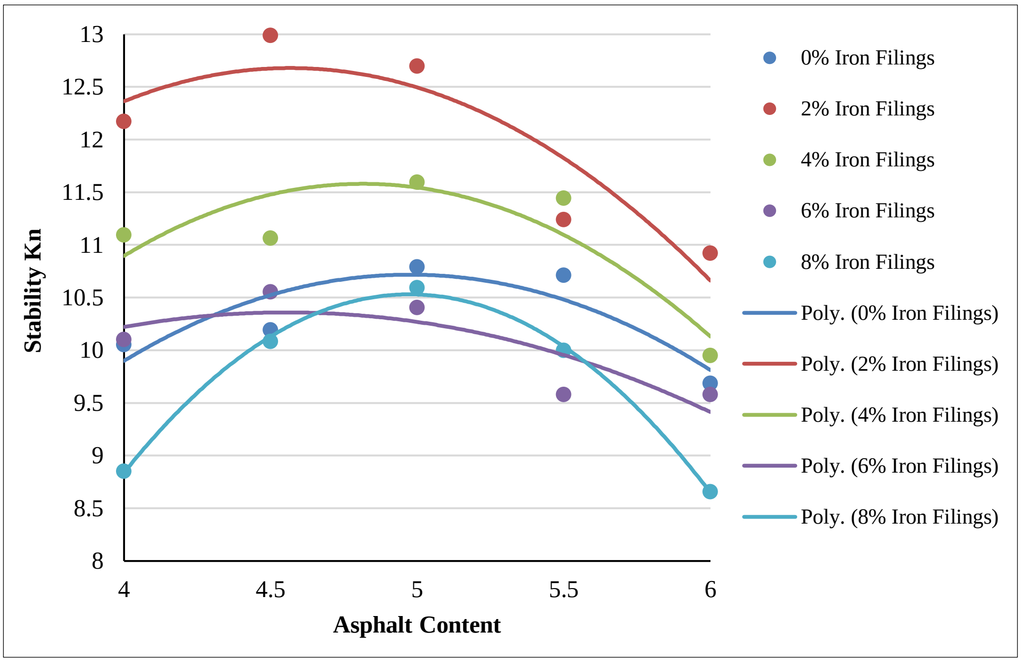

Figure 11. Stability versus Asphalt content

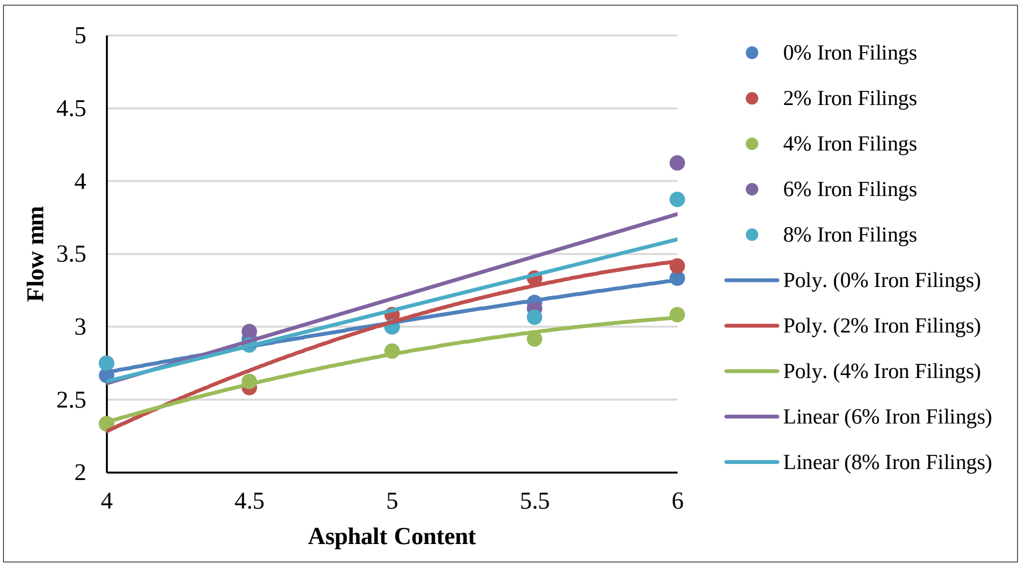

Figure 12. Flow versus Asphalt content

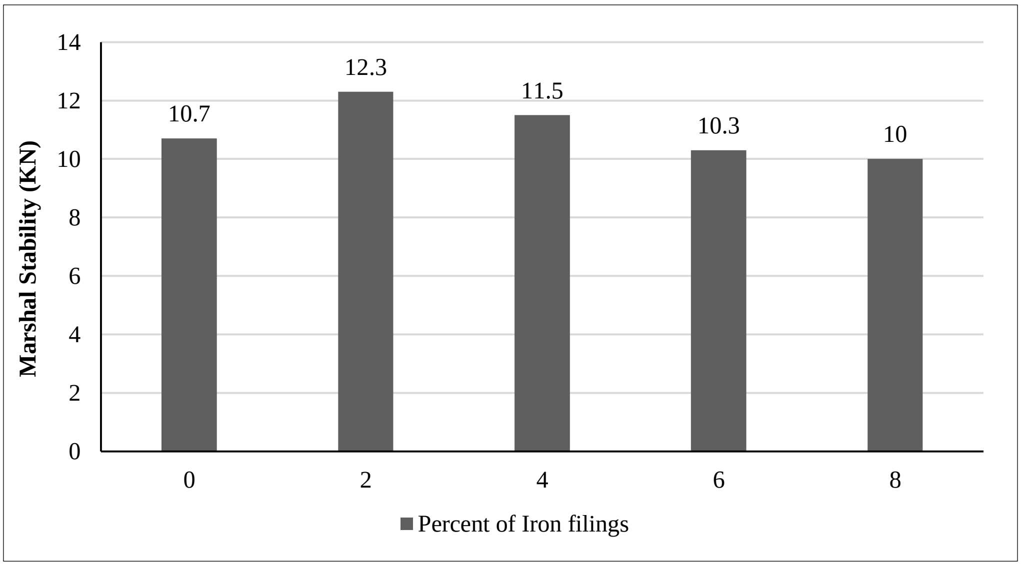

Figure 13. Iron Filings versus Stability

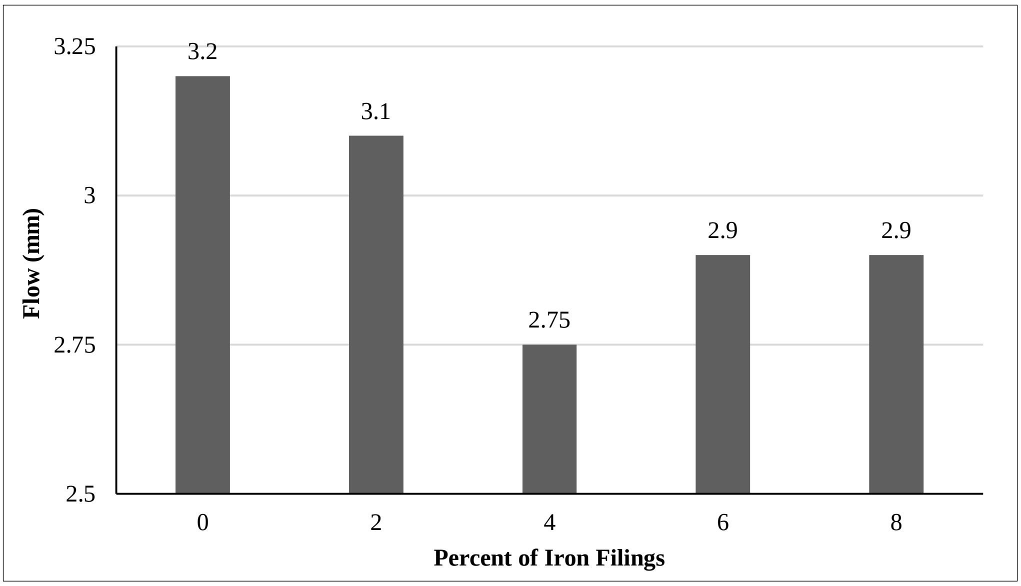

Figure 14. Flow versus Iron Filings

Table 6. Impact of iron filings on Marshall Stability

No.	Percent of Iron filings	Marshal Stability (K.N.)	Percent Increasing
1	Control (0%)	10.7	-
2	2%	12.3	15%
3	4%	11.5	7.5%
4	6%	10.3	-3.74%
5	8%	10	-6.54%

After calculating the average of the maximum values in the tables (unit weight, stability) with the content of asphalt, which achieves 4% of the air voids, the optimum content of the asphalt was obtained. For various concentrations of iron filings, Table 7 indicates the optimum asphalt standard.

Also, an ideal iron filing material that achieves optimum values for Marshall Mix requirements has been established. Table 8 shows the optimum iron filings content with volumetric properties, stability, and flow characteristics. The optimum content of iron filings was calculated by knowing the percentage of iron filings that achieve the highest stability and unit weight values, as well as the content that makes 4% air space and considering the average of the three values.

Table 7. O.A.C with different proportion of Iron Filings

No.	Percent of Iron Filings	O.A.C
1	0%	5.2%
2	2%	5.1%
3	4%	5%
4	6%	4.9%
5	8%	4.8%

Table 8. Volumetric Properties of Optimum asphalt & iron filings Specimen

No.	Volumetric Properties	Value	Specification
1	% Iron Filings	5%	-
2	O.A.C	4.95%	4-6 %
3	% Air Voids	4.1%	3-5 %
4	Unit Weight	2.41	-
5	Marshal Stability	11.4	8 K.N. (min)
6	Flow (mm)	2.8	2-4 mm
7	VMA	15.6	14% (min)
8	V.F.A.	75	-

4. Conclusion

The following conclusions may be may be drawn based on the limitations of materials and testing program.The use of iron filings led to a positive change in the properties of Marshall, as the stability and V.M.A. increased in comparison with the control sample. The value of bulk specific gravity increased, with an increase in the percentage of iron filings. The greatest value was when replacing fine aggregate with 6% iron filings.Also, it was found that there was no clear change in the V.F.A. ratio, with an increase in the iron filing rate as compared to the conventional sample. Air voids decreased with an increase in the percentage of iron filings when compared to the traditional sample, unlike previous studies that used steel wool as an additive. Stability increases with an increase in the percentage of added iron filings compared to the conventional sample, until it reaches its highest value and then begins to descend. The highest increase was seen in the samples with an iron filing content of 2%, with an increase of 15%. While stability decreased when using (6 and 8) % iron filings by (3.4 and 6.54) %, respectively. It was found that as iron filing content increases, The optimum content of Asphalt decreases. The optimum asphalt content of samples with iron filing content of (0, 2, 4, 6 and 8%) was (5.2, 5.1, 4.9, and 4.8%), respectively. The ideal percentage of iron filings that meet the Marshall Design mixture requirements as per SCRB was 5%, where the stability was 11.4 kN, the flow was 2.8 mm, V.M.A. was 15.6%, and V.F.A. was 75%. In addition to what has been mentioned, future studies should assesse the effect of iron filings and other waste on the durability of asphalt during the service life.

5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

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