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UTILZATION OF INDUSTRIAL WASTE MATERIALS ON HOT MIX ASPHALT

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The effect of using industrial waste materials on the mechanical performance of hot mix asphalt was investigated. Two different types of industrial waste materials namely, white cement dust (WCD) and iron slag (IS) were tested. White cement dust was incorporated in the mixture as mineral filler while iron slag was incorporated as fine aggregate. Four waste materials contents were considered, namely; 0%, 10%, 20% and 30% by weight of mineral filler and fine aggregate for the cement dust and iron slag mixtures respectively. The mechanical performance of the studied mixtures was evaluated based on Marshall Properties, indirect tensile strength, and unconfined compressive strength. Laboratory testing has revealed an enhancement in the mechanical performance of asphalt concrete mixtures when cement dust was used. Marshall stability, the unit weight, the indirect tensile strength and the unconfined compressive strength increased with the increase of cement dust content. The flow, voids of total mix (% VTM) and voids of mineral aggregate (% VMA) values decreased as the cement dust content increased. The optimum asphalt content did not change significantly with the change in cement dust content. The mechanical testing has also indicated that, the iron slag has improved the mixture stability, unit weight and the unconfined compressive strength of the mixture. Using iron slag content more than 10% caused a significant reduction on the optimum asphalt content and the indirect tensile strength of the mixture.

Keywords: *Waste Materials; Hot Mix Asphalt; White Cement Dust; Iron Slag; Mechanical Properties.*

1. INTODUCTION

Waste materials can broadly be categorized as industrial wastes such as cement dust, iron slag, bottom ash and fly ash; and municipal/domestic wastes such as incinerator residue, scrap rubber, waste glass and roofing shingles. Waste material recycling into useful products has become a main solution to waste disposal problems. Recently, many environmental and highway agencies are using waste material in highway construction [1]. Asphalt concrete mixture containing a waste material should perform as well or better than conventional asphaltic mixture. It should also be environmentally safe both for the first construction and future recyclability. Within this research, extensive laboratory research was performed on utilization of two different types of waste materials namely, white cement dust (WCD) and iron slag (IS) on hot mix asphalt.

Cement kiln dust is a by-product developed during the calcining process in cement production. Lime (CaO) constitutes more than 60% of CBPD composition. Other compounds include SiO2, Al2O3, Fe2O3, K2O, Na2O, Cl, etc.. In Egypt, cement industry discard about 3 million tons per year of cement dust that are collected from exhaust gases of cement kiln and cooling towers. This huge quantity of dust generates continuous problems for both cement makers and governments. Cement dust causes lung function impairment, chronic obstructive lung disease, restrictive lung disease, pneumoconiosis and affect the humans micro-structure and physiological performance. One of the possible solutions of these environmental pollution problems is to use cement dust as a non-conventional raw material for road construction. Previous studies on utilization of cement dust on asphaltic mixtures indicated that cement dust has a considerable effect on the asphalt cement making it act as a much stiffer grade of asphalt cement compared to the neat asphalt cement grade [2-5]. Other studies have shown that cement dust can improve the HMA pavement performance including its fracture behavior [6-7]. Study made by Taha [8] indicated through Marshall testing that cement dust could be used as a substitution for lime stone mineral filler in asphalt paving mixtures. It was also shown that the components of cement dust can assist in promoting stripping resistance and thus can replace hydrated lime or liquid antistripping agents [9-10].

Blast furnace iron slag is an industrial byproduct of iron produced in a blast furnace. This slag consists primarily of constituent of the iron ore mixed with the silicates and aluminosilicates of lime and other bases [11]. Improper disposal of slag has become a serious environmental problem. Therefore, iron slag has been used extensively around the world as; railway ballast, tricking filter bed media, pipe bedding, water course protection, land reclamation, bulk fill embankments and gabion stone [12]. Recently, many environmental and highway agencies has considered using iron slag in highway construction [13-14]. It is mainly used as a good sub-base material because it is free draining granular material, which has an excellent internal friction as well as good compact ability [15]. Iron slag has also been used in hot mix asphalt wearing surface mixtures because of its affinity for asphalt and its dust-free surface, which aids in asphalt adhesion and resistance to stripping [16]. In general, iron slag was proven to have many advantages over natural aggregates such as having a higher value of soundness, strength and abrasion resistance. It also has a high resistance to crushing and polishing under traffic [17-18]. Very little research work has been done to test the possibility of using iron slag in asphalt concrete mixtures as a replacement of coarse and fine aggregates. Since slag has a good friction resistance property it is believed that it can provide an excellent skid resistance asphalt concrete layer surface.

The current research is performed to study the effect of using white cement dust (WCD) and iron slag (IS) on the mechanical performance of hot mix asphalt. White cement dust was incorporated in the mixture as mineral filler while iron slag was incorporated as fine aggregate. Four waste materials contents were considered, namely; 0%, 10%, 20% and 30% by weight of mineral filler and fine aggregate for the cement dust and iron slag mixtures respectively. Mechanical performance was evaluated based on; Marshall Properties, indirect tensile strength and unconfined compressive strength.

2. MATERIAL CHARACTERIZATION

2.1- Asphalt Binder

Asphalt binder (60/70) supplied by Suez Bitumen Supply Company was used within this research. The used asphalt binder was subjected to a series of standard laboratory tests to determine its physical properties. Results of those tests are shown in **Table (1).**

Table (1): Properties of Used Asphalt Binder

Test	Results
Penetration at 25^o C	67
Kinematics Viscosity (Centistokes at 135^o C)	420
Ring and Ball Softening Point	50.5^o C
Specific Gravity	1.02
Flash Point	265 ^{o} C

2.2 Aggregate

Coarse limestone aggregate and fine aggregate (Bulk specific gravity of 2.72 and 2.67 respectively) that was get from Mankabad quarry were used in the preparation of the asphalt concrete mixtures. Limestone was used as mineral filler. The selected gradation of aggregate incorporated in all asphalt concrete specimens confirms to the mid point of the standard 4-c aggregate gradation specified in the Egyptian highway standard specifications. **Table (2)** presents the selected mix gradation (including Cement dust).

Table (2): Selected Mix Gradation

Sieve	% Passing	
	Used Gradation	Gradation Limits [Egyptian Specs. (4 C)]
1"	100	100
3/4"	100	80-100
3/8"	75	60-80
3/16"	52	48-65
No.10	43	35-50
No. 30	23	19-30
No. 50	20	13-23
No. 100	10	7-15
No. 200	5	3-8

2.3 White Cement Dust

White Cement Dust was obtained as residual (waste) material from El-Minea cement factory. The properties (gradation, unit weight and absorption) of the cement dust used within this research are given in **Table (3).**

Table (3): Physical Properties of Used Cement Dust

% Passing No. 30	100
% Passing No. 50	100
% Passing No. 200	85
Plasticity Index	2
Specific Gravity	2.7
Absorption	1%

2.4 Iron Slag

Blast furnace iron slag was obtained as a residual material (waste) from Hellwan Steel factory. The iron slag was crushed and screened to produce fine aggregate that satisfies the gradation requirements for hot mix asphalt. Table (4) presents the Gradation, physical and mechanical properties of the used iron slag. As seen, iron slag has high specific gravity and low absorption value. The iron slag also has favorable mechanical properties including good abrasion resistance, good soundness characteristics, and high bearing strength.

Table (4): Physical and Mechanical Properties of Used Iron slag

Property	Value
Passing Sieve 3/16	50 %
Passing Sieve N0.10	45 %
Passing Sieve N0.30	24 %
Specific Gravity	3.4
Absorption	2 %
Los Angeles Abrasion (%)	15
Sodium Sulfate Soundness Loss (%)	8
Angle of Internal Friction	45°

1. EXPERIMENTAL PROCEDURE

3.1 Marshall Testing

The Marshall Stability test (ASTM Designation: D 1559-82) is used in highway engineering for both mix design and evaluation. Although Marshall Method is essentially empirical, it is useful in comparing mixtures under specific conditions. Therefore, it was selected within this research to study the effect of adding cement dust as mineral fillers and iron slag as a fine aggregate in the mechanical properties of hot mix asphalt. The optimum asphalt content for the cement dust and iron slag mixtures was determined. The Marshall Properties results for the studied mixtures were found and discussed.

3.2 Indirect Tensile Strength (ITS) Test

A mechanical displacement control testing frame was used to conduct the indirect tensile tests in accordance with (ASTM D4123) to evaluate the tensile strength of asphalt concrete mixtures. Test specimens 2.5 inches thick and 4 inches diameter were compacted and then tested using curved steel loading strips 0.5 inch wide. The load was applied at a vertical deformation rate of 4 mm/min. The indirect tensile strength is the maximum stress developed at the center of the specimen in the radial direction during loading. Two diametrically opposite dial gauges were attached to each specimen at its longitudinal mid-point to measure the diametral (tensile) deformation resulting from the applied loading in an orthogonal direction. This technique can provide an evaluation of the tensile stress-strain characteristics and hence the fracture energy of each mixture can be evaluated. The specimen is loaded until it is failed by splitting along the vertical diameter. Figure (1) presents illustration of the indirect tensile strength test.

The indirect tensile strength is the maximum stress developed at the center of the specimen in the radial direction during loading. Indirect tensile strength testing was made at a room temperature of around 25^{o} C.

3.3 Unconfined Compressive Strength Test

The unconfined compression tests were performed using a 15-ton capacity universal testing machine in a room temperature of around 25^{o} C. Test specimens 2.5 inches thick and 4 inches diameter were placed on the lower fixed plate of the testing machine. Load was applied with a uniform rate of 2 mm/min on the circular face of the testing samples until failure occurred. The maximum load to failure was recorded and hence the compressive strength was calculated.

4. RESULTS AND DISCUSSION

4.1 Marshall Properties

The results of all Marshall Stability are summarized in Table (5) for mixtures with different cement dust content by weight of mineral filler. The results shown for each mixture are the average of three specimens. It is indicated from Table (5) that the optimum asphalt content is not significantly affected with the change in cement dust content. It is also indicated that, the unit weight and Marshall stability at the optimum asphalt content increase as the cement dust content increases. Maximum Marshall stability and unit weight values for cement dust mixture occurred at cement dust content of 30%. The flow, voids in total mix and voids in mineral aggregate values decrease as the cement dust content increases. Thus, it can be concluded that there is a marked improvement in the Marshall properties of the asphalt concrete mixtures when cement dust was used. This improvement can be explained in view of the increase in the adhesive property of the mixture when cement dust is added.

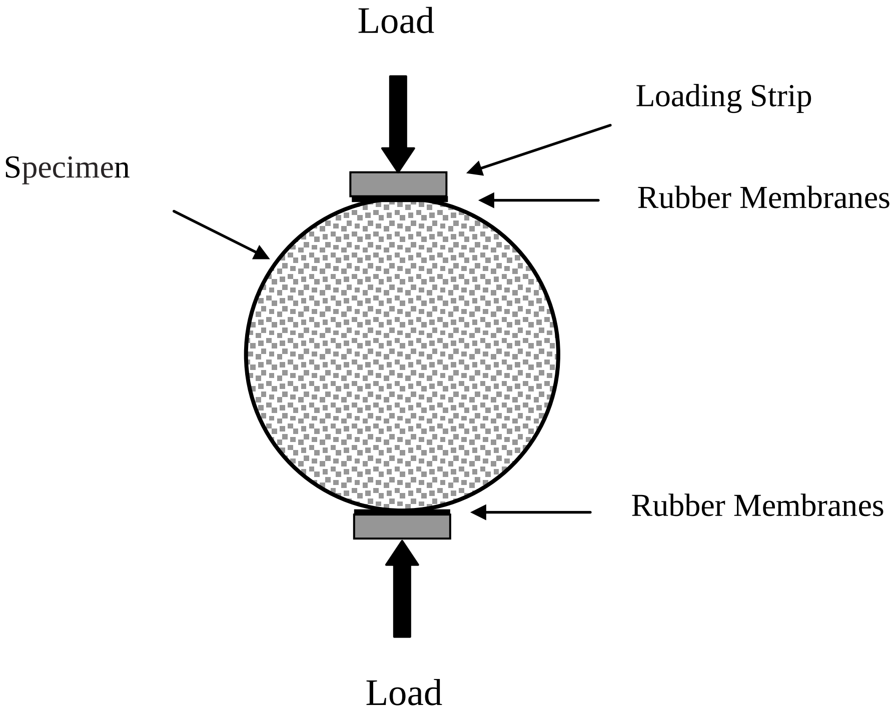

Figure (1): Laboratory Test Setup for (ITS) Strength Test

Table (5): Marshall Properties For Mixtures With Different Cement Dust (WCD) Content

WCD % of Mineral Filler	Optimum Asphalt Content	Unit Weight (gm/cm3)	Stability (KN)	Flow (mm)	% of VMA	% of VTM
0 %	5.0 %	2.27	8.01	3.5	15.1	4.2
10 %	5.0 %	2.31	9.12	3.3	15.0	3.7
20 %	4.9 %	2.40	9.69	2.5	14.8	3.7
30 %	4.9 %	2.43	9.78	2.2	14.8	3.4

The results of Marshall Stability tests for mixtures with different iron slag content by weight of fine aggregate are given in Table (6). It can be seen from Table (6) that, for iron slag content more than 10%, the optimum asphalt content decreases as the iron slag content increases. This can be related to low asphalt absorption value of iron slag. Also, it is evident that, iron slag has improved the mixture stability. This may be attributed to the angular and rough textured particles of iron slag that would increase the interlocking friction between the mixture aggregates. The angular shape and high friction angle (40° to 45°) of iron slag contributes to good lateral stability when it is incorporated into paving mixes. This is particularly beneficial where hard braking and acceleration are considerations. It is also indicated from Table (6) that, the unit weight and voids in mineral aggregate (VMA %) at the optimum asphalt content increases as the iron content increases. The increase in the unit weight of the iron slag mixture is due to the higher specific gravity of the iron slag particles. The flow value decreases as the iron slag content increases. The difference in voids in total mix (VTM) between the iron slag mixtures and the control mixture is very small.

Table (6): Marshall Properties For Mixtures With Different Iron Slag (IS) Content

IS % of Fine Agg.	Optimum Asphalt Content	Unit Weight (gm/cm^3)	Stability (KN)	Flow (mm)	% of VMA	% of VTM
0 %	5.0 %	2.27	8.01	3.5	15.1	4.2
10 %	5.0 %	2.41	8.12	3.3	15.2	4.2
20 %	4.8 %	2.53	8.40	3.1	15.5	4.3
30 %	4.5 %	2.64	8.60	2.7	15.8	4.3

A comparison between the two tested mixtures regarding Marshall testing results is presented in Figures (2-6). It is indicated from Figures (2-3), the Marshall stability and unit weight values that for both mixtures increase as the waste material content increases. However, the Marshall stability and unit weight values for the cement dust mixture are much higher as compared to the iron slag mixture at the complete range of waste material content. This indicates an obvious enhancement in the mixture stability and unit weight when cement dust was added.

Figure (4) presents the flow values for the two mixtures. It can be seen that the flow values for both mixtures decreases with the increase of the waste material content. The rate of decrease in the flow value for the cement dust mixture is higher as compared to the iron slag mixture.

Relationships between voids in mineral aggregates and voids in total mix for the two studied mixtures are given in Figures (5) and (6) respectively. It is indicated from Figure (5) that, the voids in mineral aggregates percent for the cement dust mixtures decreases with the increase of cement dust content up to a content of 20%. The voids in mineral aggregates percent almost remain constant for higher cement dust content. The iron slag mixture displays an opposite trend. The voids in mineral aggregates percent increases (almost in a linear fashion) as the iron slag content increases. This can be explained in view of the fact that the iron slag mixtures contain more coarse particles than in the cement dust mixture. This results in producing a much porous mixture.

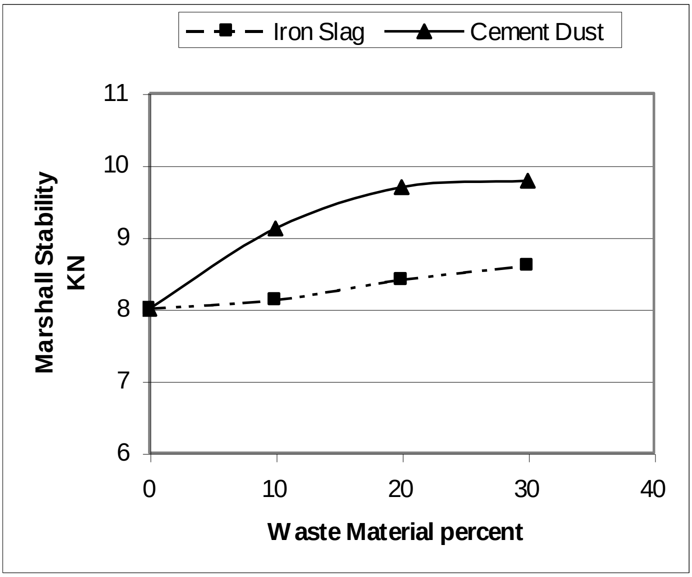

Figure (2): Variation of Marshall Stability with Waste Material Content

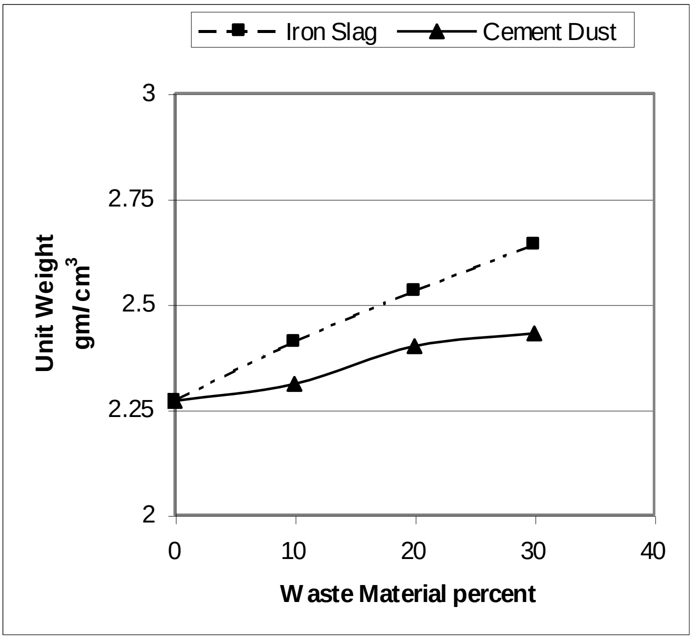

Figure (3): Variation of Unit Weight with Waste Material Content

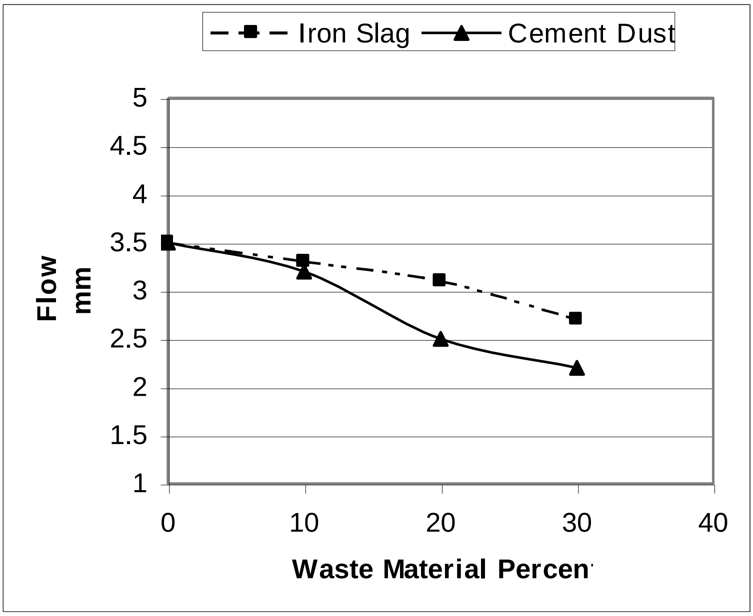

Figure (4): Variation of Marshall Flow with Waste Material Content

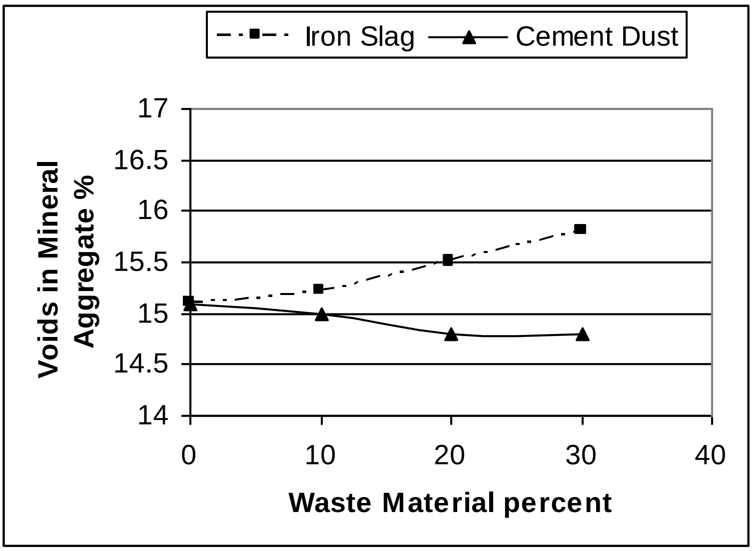

Figure (5): Variation of VMA with Waste Material Content

In Figure (6), it can be seen that, the percent of voids in total mix for the cement dust mixture decreases with the increase of cement dust content up to a content of 10%, then it remains constant up to a content of 20%. After that, the percent of voids in total mix decreases as the cement dust content increases. For, the iron slag mixture the percent of voids in total mix almost remains constant and is not affect by the increase in the iron slag constant. In general, Marshall testing results indicates the superiority of cement dust in improving Marshall Properties.

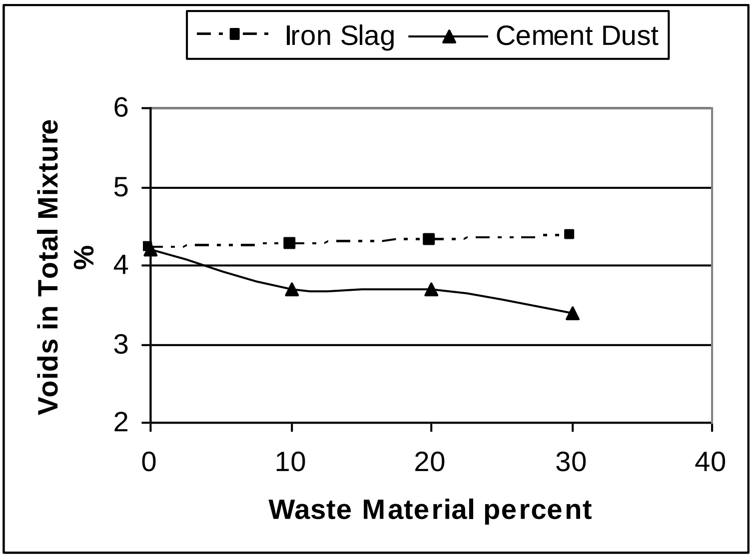

Figure (6): Variation of VTM with Waste Material Content

4.2 Indirect Tensile Strength

The indirect tensile test on asphalt concrete mixes is a used procedure for assessing likely pavement performance. The indirect tensile test was developed to determine the tensile properties of cylindrical concrete and asphalt concrete specimens through the application of a compression load along a diametrical plane through two opposite loading heads. It was shown [10] that this type of loading produces a relatively uniform stress acting perpendicular to the applied load plane, causing the specimen to fail by splitting along the loaded plane. The expression for the maximum tensile strength can be stated as;

$$\sigma_t = \frac{2\,P_{\max}}{\pi DH} \qquad (1)$$

Where σ_t is the indirect tensile strength, Pmax is the maximum applied load and H, D is the thickness and the diameter of the specimen respectively. The indirect tensile strength test was performed on three samples from each mixture. Values of indirect tensile strength are calculated based on Equation (1) at the optimum asphalt content for each mixture and presented on Table (7).

Table (7): Indirect Tensile Strength (MPa) of Mixtures with Different Waste Materials Content

Waste Materials Content	Cement Dust	Iron Slag
0 %	0.59	0.59
10%	0.65	0.58
20%	0.74	0.53
30%	0.81	0.48

Values of indirect tensile strength are also presented in Figure (7). It is evident from Figure (7) that the indirect tensile strength for the cement dust mixture increases as the cement dust content increases. The enhancement in the tensile strength in the case of cement dust mixtures can be related to the modification of the surface chemistry at the aggregate-asphalt interface to promote better adhesion. It is also indicated from Figure (7) that, the indirect tensile strength for the iron slag mixture decreases as the percent of iron slag increases.

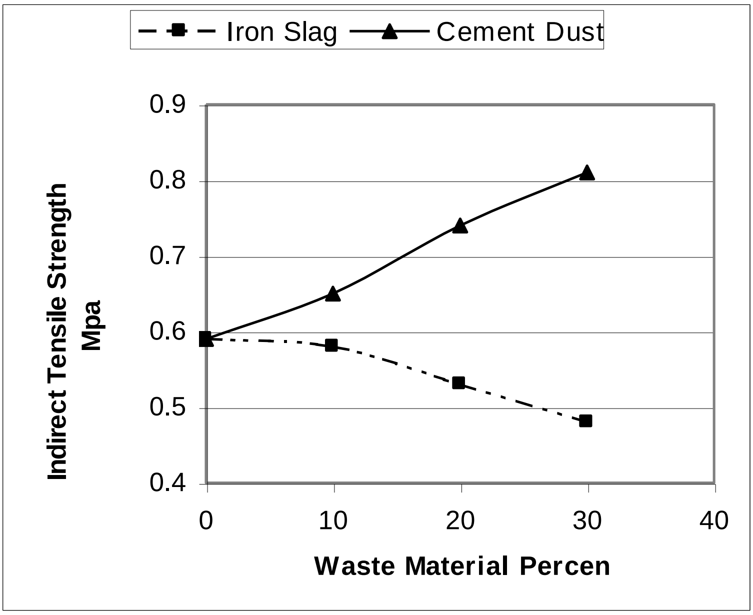

Figure (7): Variation of ITS with Waste Material Content

4.3 Unconfined Compressive Strength

The unconfined compressive strength test was performed to determine the compressive properties of the four studied mixtures. A compression load is applied on the circular face of the circular specimens. The load is increased until failure occurs. The compressive strength can be calculated using the following expression;

$$\sigma_c = \frac{4P_{\max}}{\pi D^2} \qquad (2)$$

where σ_c is the Unconfined Compressive Strength, Pmax is the maximum applied compressive load and, D is the diameter of the specimen. The average unconfined compressive strength for various mixtures is calculated based on Equation (2) at the optimum asphalt content for each mixture and presented on Table and listed in Table (8).

Table (10): Unconfined Compressive Strength (MPa) of Mixtures with Different Waste Materials Content

Waste Materials Content	Cement Dust	Iron Slag
0 %	2.39	2.39
10%	2.45	2.42
20%	2.60	2.50
30%	2.82	2.58

Figure (8) also presents the relation between compressive strength and waste materials content for the two tested mixtures. The figure indicates that for the cement dust and iron slag mixtures, the compressive strength increases as the waste material content increases. A comparison between the two mixtures indicated that the cement dust mixture has a higher compressive strength than the iron slag mixture. This indicates the positive role of cement dust in the improvement of the compressive strength of asphaltic mixtures.

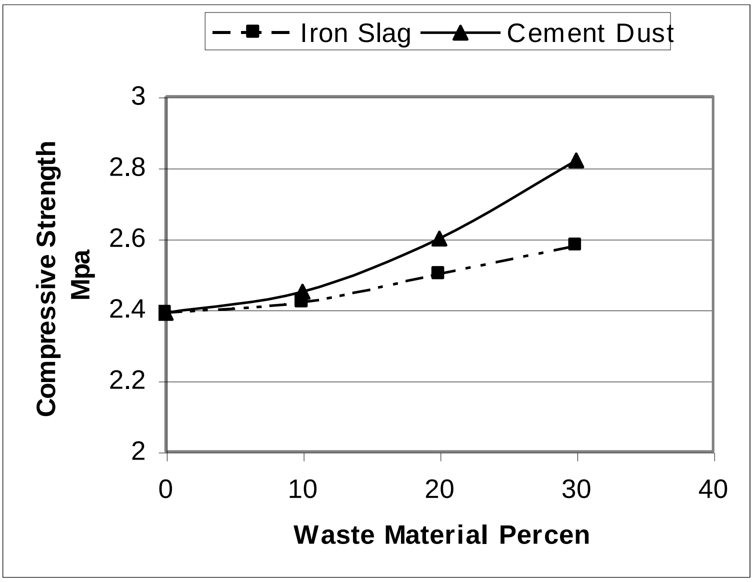

Figure (8): Variation of Compressive Strength with Waste Material Content

5. CONCLUSIONS AND RECOMMENDATIONS

The effect of using white cement dust as mineral filler and iron slag as fine aggregate on the mechanical properties of hot mix asphalt was investigated. It was shown that, the effect of the cement dust content on the mechanical performance of hot mix asphalt is clearly distinguishable. Increasing the cement dust content leads to an increase on Marshall stability and the unit weight of the mixture. Flow values, void in total mix and voids in mineral aggregates decrease as the cement dust content increases. There was no significant change in the optimum asphalt content when the cement dust content was changed. The cement dust mixture also demonstrated higher resistance to fracture as verified by indirect tensile strength and unconfined compressive strength, which both increase as the cement dust content increases.

Results of mechanical testing have indicated a slight improvement on Marshall stability, unit weight and compressive strength of the mixture when iron slag was added. However, the results did not indicate an improvement on the flow, void in total mix and voids in mineral aggregates. Using iron slag content more than 10% causes a significant reduction on the optimum asphalt content and the indirect tensile strength of the mixture. Hence, it can be concluded that, using blast furnace iron slag is not recommended on asphaltic mixtures on main roads, while it still can be used on secondary roads that accommodates low volume traffic. Cement dust mixtures has displayed an encouraging results, therefore one can safely conclude that cement dust can be used as a part of the mineral filler in asphalt concrete mixtures. In general, it can be stated that the successful utilization of waste materials in pavement construction can provide a new and more cost effective approach for aggregate resources, and decrease the threats of industrial solid wastes to environment. However, more studies including making trial sections and establishing adequate provisions should be initiated.

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استخدام المخلفات الصناعية فى الخلطات الأسفلتية على الساخن

تم إجراء هذا البحث بهدف دراسة إمكانية استخدام نوعين مختلفين من مخلفات المصانع وهما غبار الأسمنت الأبيض وخبث حديد الأفران في الخلطات الأسفلتية التي يتم خلطها على الساخن، وكذلك دراسة مدى تأثير استخدام هذه المخلفات على الخواص الميكانيكية للخلطات الأسفلتية. وقد تم استخدام غبار الأسمنت الأبيض كنسبة من بودرة الحجر الجيري بينما تم استخدام خبث حديد الأفران كنسبة من الرمل في الخلطات الإسفلتية ، وتمت الدراسة على نسب مختلفة وهى 0%, 10%, 20%, 30% ، وبعد تحديد القيم المثلى لمحتوى البيتومين لكل نسبة من هذه النسب تم دراسة مدى تأثير هذه الإضافات وبتلك النسب على خواص مارشال وعلى مقاومتي الشد غير المباشر والضغط للخلطات الاسفلتية.

وقد أظهرت النتائج وجود تحسن ملحوظ في خواص مارشال وقيم الشد الغير مباشر والضغط للخلطات التي تحتوي على بودرة غبار الأسمنت الأبيض ويزداد هذا التحسن كلما زادت نسبة البودرة في الخلطة، مما يؤكد أن إستخدام بودرة غبار الأسمنت الأبيض له تأثير إيجابي في تحسين خواص الخلطات الأسفلتية. كما أظهرت الاختبارات المعملية أن استخدام خبث الحديد يحسن نسبيا من قيم معامل الثبات لمارشال والوزن النوعي ومقاومة الضغط للخلطات بينما لم تظهر النتائج وجود تحسن ملموس في معامل ألانسياب ونسبة الفراغات ومقاومة الشد غير المباشر لهذه الخلطات.

وعليه فأنه يوصى من خلال هذا البحث بإمكانية استخدام غبار الأسمنت الأبيض في الخلطات الإسفلتية كجزء من البودرة لما له من اثر ايجابي في تحسين الخواص الميكانيكية للخلطات الأسفلتية بالاضافة إلى المزايا البيئية الناجمة من هذا الاستخدام ٍ، كما انه يمكن استخدام خبث الحديد في الخلطات الإسفلتية كجزء من الرمل في الطرق الثانوية التي تستوعب أحجام واحمال مرورية خفيفة.