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Evaluation and Remedy of Asphalt Concrete Quality Using an Expert System

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Abstract

A significant amount of engineering judgment is required in the decision of whether to accept the deviation in the quality of asphalt concrete from job mix formula or specification requirements and the remedy to be taken regarding the measures and penalty to be decided. Such measurements and decisions are difficult to confine. In this paper, attention is directed toward the quality of asphalt concrete mix constituents (aggregate gradation, asphalt content & voids) and their physical properties (Marshall Stability & flow).

The acceptable quality of the constituents depends on general requirements of the material. The development of an advisory expert system in the domain of flexible pavement quality is presented. The developed system is called ACQAES (Asphalt Concrete Quality Advisory Expert System).

The knowledge base of the system contains heuristic rules extracted from literature survey and a consultant's report from Ministry of Housing and Construction. It was felt that such system could meet the practical demand of road construction & quality control.

الخلاصـــــة

جهدا تحكيميا وهندسيا واضحا يتطلبه اتخاذ القرار الصائب حول قبول الانحراف في مزيج الخرسانة الإسفلتية عن حدود معادلة المزج أو متطلبات المواصفات، وكذلك إجراء المعالجة المناسبة أو الخصم من الكلفة. إن مثل هذه القرارات لايسهل اتخاذها.تم في هذه الدراسة توجيه الانتباه إلى تأثير نوعية محتويات مزيج الخرسانة الإسفلتية (تدرج الركام، نسبة الإسفلت، والفراغات الهوائية) والخواص الفيزياوية للمزيج (ثبات وزحف مارشال) على حصول الانحراف

حيث إن النوعية المقبولة لهذه المكونات تعتمد على متطلبات الخواص العامة للمواد. تم استنباط نظام توجيهي خبير في مجال نوعية الرصفة المرنة في هذه الدراسة وتقديمه بعد تسميته (نظام خبير توجيهي للخرسانة الإسفلتية).

إن قاعدة المعلومات الخاصة بالنظام تتكون من مجموعة من القوانين المساعدة التي تم اعتمادها من خلال الأدبيات المتوفرة وتقارير الاستشاريين. نعتقد إن هذا النظام يمكن أن يناسب المتطلبات العملية لتنفيذ الطرق والرقابة النوعية عليها.

1. Introduction

Flexible pavement is widely used for road construction in Iraq. It is constructed by either government companies or by local private contractors. The quality of the final Asphalt Concrete pavement is expected to be variable and depends mainly on the experience in mix design, operation of Asphalt Concrete plant, maintenance of the weight gages of the plant and uniformity of the raw materials quality supplied to the plant.

Due to the lack of such experience and the nature of the product, some variation in the quality is unavoidable. The three Asphalt Concrete pavement layers (Asphalt stabilized base, binder and wearing courses) consist of a dense graded Asphalt Concrete mix as per (SORB 1983). Such gradation will provide a uniform pavement surface and develops fewer distressed areas and thereby increases pavement service life.

Once a job mix formula is selected, there should be as little deviation as possible from the aggregate gradation and Asphalt content. The decision taking of how much such inherent variation is associated with the production, and identifying the variations which exceed the permissible tolerance amount as a change in product which is unacceptable will need an expert.

2. Background

Since 1971, most highway departments had statistical rating methods to assess pavement quality. The application of such statistical quality control to the production of Asphalt Concrete pavement has been the subject of recent studies [1,2,3]. Such studies had concluded that it should be introduced in the acceptance-rejection procedure. Such approach needs time and much Engineering experience.

The application of expert system concept to quality control will enable the Engineer to produce an economically feasible, better quality materials and to evaluate more reliably the finished product [4, 5].

This new approach may possibly lead to better understanding of the variability in construction materials which will render possible the correlation of expected performance and actual behavior [6, 7].

3. Development of the Expert System

The developed system was designed to minimize subjective judgment. It incorporates computer processing and has a variety of outputs with priorities for remedial treatment [8]. Three main concepts are involved in the development of ACQAES. These are routine laboratory test results of Asphalt Concrete quality (gradation of aggregate, voids and Asphalt content), Physical properties (Marshall Stability and flow) and expert system technique.

3-1 Knowledge Acquisition

It includes finding domain knowledge from literature and public knowledge source such as those of consultant reports [9,10] and then merged with heuristic knowledge obtained from experts [11].

3-2 Knowledge Representation

The most common form used is (if-then) rule; a sample of such rule can be shown in the next paragraph.

3-3 System Logic

The typical system describes what to do in particular circumstances. There are five major variables, which should be considered in the evaluation of Asphalt Concrete quality as illustrated in **Fig.(1)**:

1. Marshall stability
2. Marshall flow
3. Voids content (Vv %)
4. Asphalt content (As %)
5. Gradation G (j), where J=1, 2, 3,…….. N and N are sieve size.

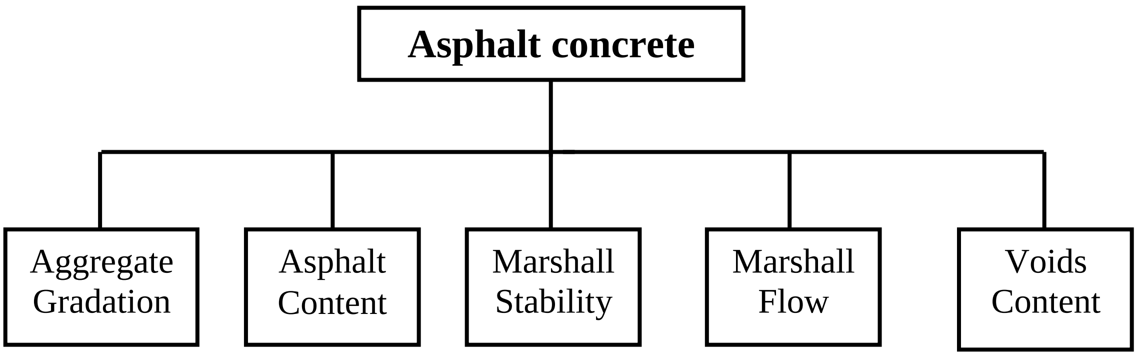

Figure (1) Asphalt concrete major quality variables

The deviation of any of the above variables from the specification or from job mix tolerance will lead to one of the following action processes:

1. Accept the work with cost reduction or discount RD (K).
2. Addition of extra layer AL (K)
3. Removing the layer material RM (K)

For example, if the system shows RD (5) =50, it means a discount in the cost of contract by 50% which is attributed to the deviation in gradation. Also if it shows RM (4) =1, it means removing the layer due to failure in Asphalt content.

The variables AL (K), RM (K) takes values of either zero or one when zero means taking no action and one means layer addition or layer removal. For final decision, the system will execute the followings:

1. Addition of all RD (K) values

$$\mathbf{RD} = \sum_{k=1}^{5} \mathbf{RD(K)}$$

$$= \mathbf{RD\ (1) + RD\ (2) + RD\ (3) + RD\ (4) + RD\ (5)} \quad \ldots\ldots (1)$$

2. Execute the (logic OR) operation using all the values of AL (K) and RM (K)

AL=AL (1) U AL (2) U AL (3) U AL (4) U AL (5) ………………………….. (2)

RM=RM (1) U RM (2) U RM (3) U RM (4) U RM (5) ……………………… (3)

If the value of any of AL (K) is equal to one, then AL value will have the same value of one and the same is for the variable RM.

3. If RM=1, the system will ask to remove the layer. If RM=0 and AL=1, then the system will ask to add an extra layer of 2 cm thickness if the failed layer was either base or binder courses. On the other hand, if the failed layer was the wearing course, then the system will ask to add an extra layer of 3-cm thickness.

If RM=0, AL=0, the system will ask for discount RD.

If RD > 100%, then it is considered as 100%.

RD (K), AL (K), RM (K) is calculated when going through the five test variables as follows:

a) Marshall stability test Sm; If Sm value is lower than the minimum specification requirement, the deviation in Sm is calculated using the mathematical expression:

$$\mathbf{P} = \frac{\mathbf{Ss - Sm}}{\mathbf{Ss}} * \mathbf{100} \quad \ldots\ldots (4)$$

where:

Sm = Marshall Stability of the mix

Ss = Minimum Marshall Stability requirement in the specifications.

If $P \leq 15$, then RD (1) = P

$15 < P \leq 30$, then AL (1)=1

$P > 30$, then RM (1) =1

b) Marshall Flow Fm: The value of Fm is compared with the maximum and minimum requirements of the specification (F1 & F2).

If Fm <F1, the deviation p from F1 is calculated using the formula:

$$P = \frac{F1 - Fm}{F1} * 100 \quad \text{.......... (5)}$$

If Fm > F2, the deviation p from F2 is calculated using the formula:

$$P = \frac{Fm - F2}{F2} * 100 \quad \text{.......... (6)}$$

If P $\leq$ 30, then RD (2) = P/ 2
If P > 30, then AL (2) =1

c) Voids content Vv: The system compares Vv with minimum and maximum void requirements in specification (V1, V2)

If Vv <V1, then the deviation (p) from V1 is calculated as below:

$$P = \frac{V1 - V}{V1} * 100 \quad \text{.......... (7)}$$

If P $\leq$ 2, then RD (3) = P*8
If P > 2, then AL (3) = 1

If V > V2, then the deviation (p) from V2 is calculated as below:

$$P = \frac{V - V2}{V2} * 100 \quad \text{.......... (8)}$$

If P $\leq$ 6, then RD (3) = P * 3
If P > 6, then AL (3) = 1

d) Asphalt content As: The system compares As with minimum and maximum Asphalt content requirements as per the job mix tolerance G1 (N+1), G2 (N+1)

If As < G1 (N+1), then $$P = \frac{C1(N+1) - As}{G1(N+1)} * 100 \quad \text{.......... (9)}$$

If As > G2 (N+1), then $$P = \frac{As2 - G2(N+1)}{G2(N+1)} * 100 \quad \text{.......... (10)}$$

If P$\leq$ 1.2 then RD (4) = 15* P
P$\leq$ 2.2 then AL (4) = 1
O > 2.2 then RM (4) = 1

e) Mix gradation G (J), [J= 1, 2, 3, …N]: The deviation is taken as an absolute value and not as a percentage. The value of G (J) is compared with the minimum and maximum values of % finer by weight G1 (J), G2 (J) as per job mix tolerance. Also the value of G (J) is compared with minimum and maximum % finer by weight requirements M (J), Z (J) of specification limits.

If M (J) ≤ G (J) < G1 (3), then PJ = G 1(J) – G (J)

If G (J) < M (J), then PJ = G1 (J) – M (J) + [M (J) – G (J)] / 2

If G2 (J) < G (J) ≤ Z (J), then PJ = G (J) – G2 (J)

If G (J) > Z (J), then PJ = Z (J) – G2 (J) + [G (J) – Z (J)] / 2

The value of RD (S) is calculated as below:

$$\mathbf{RD\ (5)} = \sum_{J=1}^{n} \mathbf{PJ} \quad \ldots\ldots \quad \mathbf{(11)}$$

Appendix (A) shows typical output of the system.

4. Conclusions

It was felt that the developed system would permit the development of a practical quality control procedure for Asphalt Concrete Plant production. The system will also help site engineers in decision taking of acceptance or rejection of Asphalt Concrete pavement.

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Appendex (A)
Typical Output of the System

Sample No. 1
Layer: Wearing Course

Sieve size (mm)	%finer by weight		Job mix tolerance	specifications (SCRB)
19	99.04	*#	100	100
12.5	90.42		83.3-95	75 - 95
9.5	73.1	*	79-88	65-88
4.75	55.01	*	64.1-75	50-75
2	38.24	*	43.9-51.9	32-55
1	29.83	*	31.2-39.2	24-42
0.6	25.3		23.5-31.5	18-35
0.25	14.71		12.3-20.3	10-25
0.125	9.75		8-16	8-20
0.075	7.04	*	8.9-11.9	6-12
Asphalt (%)	6.09	*	5.4-5.95	
Marshall stability (Kg)	1763			815 MIN.
Marshall flow (mm)	3.81			2-4
Specific gravity	2.414			
Maximum Sp. Gravity	2.487			
Voids (%)	2.9	#	3-5	
Fractured faces (%)	95		90 MIN.	

(*) Out of Tolerance

(#) Out of Specifications

ACQAES: Not accepted …Remove the layer

Sample No. 2
Layer: Asphalt Stabilized Base Course

Sieve size (mm)	%finer by weight	Job mix tolerance	specifications (SCRB)
37.5	100	100	100
25	95.96	89.9-100	87-100
19	88.6	83.0-95	80-95
12.5	76.9	73.3-86.3	70-90
9.5	67.6	65.7-77.7	65-85
4.75	56.7	53.9-65.9	50-75
2	47.0	39.9-47.9	33-65
0.425	28.15 *	17.6-25.6	17-40
0.18	12.75	10-15.6	10-25
0.075	8.63	6.0-9.0	3-10
Asphalt (%)	4.80 *	4.1-4.65	
Marshall stability (Kg)	892		
Marshall flow (mm)	2.7		2-5
Specific gravity	2.422		
Maximum sp. Gravity	2.504		
Voids (%)	3.3		3-7

(*) Out of Tolerance

ACQAES: Addition of extra 3 cm layer thickness of Binder course is required.

Sample No. 3
Layer: Binder Course

Sieve size (mm)	%finer by weight		Job mix tolerance	Specifications (SCRB)
25	100		100	100
19	92.6		90-100	88-100
12.5	80.4		70- 83	65-87
9.5	68.3		60-70	55-80
4.75	47.9		45-63	37-64
2	31.8		27-40	23-45
1	24.97		20-30	17-34
0.6	20.74		16-23	13-27
0.25	12.82		9-15	8-20
0.125	9.38		6-12	6-15
0.075	7.53		6-9	5-10
Asphalt (%)	5.37		5-5.5	3.8-5.8
Marshall Stability (Kg)	1482			700 Min.
Marshall Flow (mm)	4.15	*		2-4
Specific gravity	2.415			
Maximum sp. Gravity	2.495			
Voids (%)	3.2			3-7
VFB. (%)	79	*		60-70
Fractured faces (%)	91			90 Min.

(*) Out of Specifications

ACQAES: Apply cost reduction of 2%