ASPHALTIC CONCRETE ON ROADS IN MALAYSIA: IS QUALITY UNDER CONTROL?

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ABSTRACT
The introduction of asphaltic concrete in Malaysia has brought with it the problem of a through design process of the mixture composition and subsequent extensive control testing that are required to produce and lay the mixture to the required tolerances. However, it is unfortunate to note that many elements of the design, production and construction of the delicate mixture have been either blatantly ignored or manipulated by the contractors and the supervising consultants. While it is clearly stated in PWD guidelines that the initiation and execution of quality control testing must be not left to the contractor, it is a common practice in Malaysia to let the contractor carry out most or all the testing as a means to control the quality of the materials and construction works. Verification of test results by the supervising consultants is usually done on the basis of more or less effective surveillance, often by site staff with little or no training and experience. As such, PWD is invariably presented with inferior quality of materials and constructed works which include asphaltic concrete as road surfacing material. A total of 21 work sites were surveyed to identify the problems at each site. This paper looks into the problems and suggests ways how they could be mitigated.

1 INTRODUCTION
Many contractors tend to believe that design, production and laying of asphaltic concrete mixture are a straight forward task. Consequently, the quality of the mixture produced and subsequent laying of the road surfacing material at the construction sites are often taken for granted without realizing that such practices are bound to create undesirable premature failure to the road surfacing.

Based on a study carried out jointly by Public Works Department (PWD) Malaysia and Transport Research Laboratory of United Kingdom on the performance of asphaltic concrete overlays in Malaysia that were designed and constructed to the specification of PWD, it was found that the performance had been dominated by the properties of the road surfacing material rather than the overall strength of the road pavement.

A similar study carried out on some experimental bituminous overlays in Kenya had also shown that the performance of the overlays was primarily dependant on the properties of the overlay material itself.

It was the concern over by poor quality asphaltic concrete on the road pavements in this country that this study was initiated PWD which the primary aim was to investigate the current level of quality of asphaltic concrete that were being produced and supplied for the on-going road construction and rehabilitation projects of PWD throughout the country with respect to the current standard specification for road works of PWD.

2 OBJECTIVES

The main objectives of this study were:

i. To review asphaltic concrete quality framework within the current PWD Standard Specifications and Guidelines.

ii. To review current practices in on-going road construction and rehabilitation projects of PWD in assuring acceptable standards in the production of asphaltic concrete as actually produced in the projects.

iii. A member of on-going road construction and rehabilitation projects which were being undertaken by PWD had been identified throughout the country. Samples of asphaltic concrete produced by respective hot mixing plants were obtained from randomly selected tip-trucks and tested in the laboratory. These results were compared with more recent quality control test results obtained from the various sites visited.

iv. To recommend improvements to handling and acceptance procedures of asphaltic concrete at mixing plants and laying sites.

3 BACKGROUND

In Malaysia, there is a total of 137,219kilometers of roads which make up the whole road network of the country, 81.1% of which are paved.

In the 1940s, paved roads in this country were mainly semi-grout and double surface dressing. Bitumen macadam was only introduced in the 1960s.Subsequently based on recommendations in the Malaysian Highway Maintenance Study in 1967, asphaltic concrete was adopted by PWD. Since then, asphaltic concrete has been widely used throughout the country on both Federal Roads and State Roads while the usage of bitumen macadam has been in general limited to State Roads only.

3.1Bitumen Macadam

Bitumen macadam is composed of three (3) fractions of aggregate which are continuously graded, and bitumen. Its strength is primarily achieved through friction and mechanical interlock of the coarse aggregate. Air void contents in bitumen macadam are generally higher than asphaltic concrete and it is thus relatively permeable to air and water, and consequently not as durable as asphaltic concrete. The higher level of air voids ensures the proportions of the mixture are not as critical as for asphaltic concrete, thus easier to produce.

As a wearing course material, specification for road work provides two recipes of bitumen macadam viz. nominal size 14mm with allowable binder content 5.0 +/- 0.5% (BMW14) and nominal size 20mm with allowable binder content 4.9 +/- 0.5% (BMW 20) whereas the Malaysian Standard (MS 512) offers two nominal sizes (¾ " and 1") each for open textured and dense mixtures.

3.2 Asphaltic Concrete

Like dense bitumen macadam, asphaltic concrete is continuously graded but contains less coarse aggregate, fine aggregate and mineral filler, coated with a higher quantity of bitumen. Differ from the recipe method of bitumen macadam, the composition of asphaltic concrete is determined by a thorough standard design procedure the aim of which is to carefully proportion the mixture of coarse aggregate, fine aggregate and mineral filler, and to arrive at optimum bitumen content to coat the aggregate particles for maximum stability and density, and adequate air voids. This results in an economical blend of aggregate and bitumen having high stability under traffic and good durability in service. During laying, the compaction of the material, which is governed by among others the type and size of rollers used, number of roller passes, rolling pattern and rolling temperatures, has to be carefully monitored to ensure that the compacted density achieved exceeds the minimum requirements so as to ensure that the air voids in the field are within the permissible limits.

4 PROBLEM STATEMENTS

The introduction of asphaltic concrete in Malaysia has brought with it the problem of a thorough design process of the mixture composition and subsequent extensive control testing that are required to produce and lay the mixture to the required tolerances in the among others, aggregate gradation, bitumen content and air voids.

However, from authors' past observations while doing few rounds of auditing on site, it is unfortunate to note that many elements of the design, production and construction of the delicate asphaltic concrete mixture have been blatantly ignored or manipulated by the contractors and the supervising consultants.

PWD Guidelines for Inspection and Testing of Road Works states that as far as practicable, all quality control testing of materials and workmanship should be directed and carried out by the staff of the PWD Superintending Officer (S.O.), or the Engineer responsible for supervision of construction. As a general rule, the initiation and execution of quality control testing must not be left to the Contractor.

The Guidelines also states that a project laboratory for the exclusive use of PWD S.O or the Engineer responsible for supervision of construction will be provided for each road works contract.

In contrast, it is a common practice in Malaysia to let the contractor carry out most or all the testing as a means to control the quality of materials and construction works. Verification of test results by the supervising consultants is usually done on the basis of more or less effective surveillance, often by site staff with little or no training and experience. With this kind of practice in place, it usually tends to bring the contractor's focus on obtaining the signature of approval from PWD or supervising consultants rather than on actually controlling the quality of materials produced and the works constructed. This verification procedure is certainly not effective in controlling without fully supervising the conduct of tests. Serious errors made during production and construction will often not be detected or reported. Until premature failure prevails, even quality audits would not be able to detect the discrepancies as the test records indicate compliance and appear 'verified' by the consultant. When premature failure does prevail, a contractor's typical reply is 'the consultant approved it'.

As such, PWD is variably presented with inferior quality of materials and constructed works which include asphaltic concrete for use as road surfacing material.

The most common non-compliances that are the results of poor control on the quality during the production of asphaltic concrete which subsequently contribute to poor performance of the road surfacing material in service are:

i. Too much or little quantity of bitumen
ii. Too coarse or too fine aggregate gradation
iii. Too low or too high air voids in the compacted mixture.

These are some of the parameters that were being looked into this study in order to determine the level of asphaltic concrete that were being produced and supplied to some on-going PWD road construction and rehabilitation projects throughout the country with respect to the current standard specification of road works adopted by PWD.

5 MIX DESIGN CONCEPTS

Asphaltic concrete as specified in PWD specification is of type continuously graded aggregate mixture. The gradation of the combined coarse aggregate, fine aggregate and mineral filler shall produce a smooth continuous curve within and essentially parallel to the gradation limits as specified in PWD specification. The aggregates are evenly graded from coarse to fine sizes so as to produce a dense mixture with controlled air void content.

In designing a good asphaltic concrete mixture, the aim is to produce a blend of aggregate with a controlled air void content and not necessarily the one with the lowest possible air voids. If the air void content in the blended aggregate is too low, the mixture will be able to carry sufficient bitumen and, therefore, will be difficult to compact due to insufficient lubrication, and will not be sufficiently durable as the bitumen film on the aggregate particles will be too thin. On the other hand, if the air void content is too high, it is probable that the mixture will be lacking in stability as each aggregate particle will receive less support from those surrounding it.

5.1 A Unique Mix Design for the Whole Country?

Questions have been raised as to why there could not be a mix design which can be readily adopted throughout the country, and why need to carry out mix design every time there is a new road project. In order to answer these questions, one needs to look at the nature of the aggregates.

Aggregates vary from place to place in their geological origins (granite, limestone, basalt, etc.) surface texture, shape etc. As such, two (2) sets of aggregates having identical grading but of different surface texture and shape will under the same compactive effort, produce different air void contents. Even if the compactive efforts are not the same, the air voids produced will have different systems. Hence, although one particular grading may give the best mixture with one (1) set of aggregates, a variation in the grading and/or bitumen content may be required if a different set of aggregates is used.

Thus for any given aggregate grading and type, there is an optimum bitumen content whereby non-compliance can lead to premature failure. An excess of bitumen will lead to a surfacing material that readily deforms under traffic loading while a deficiency can cause a rapid hardening of the relatively thin film of bitumen coating the aggregates.

Even for any specific project, there is a need to revise the mix design if the source of aggregates keeps changing especially for mixing plants which do not have their own quarry face and are dependent on the supply of aggregates from various external sources.

However, National Asphalt Specification of Australia allows previously designed mix to be used subject to the following conditions;

i. The project is undertaken within a two–year period of mix design work for previous approval of the job mix formula.
ii. The type, quality and sources of all constituent materials remain unchanged.
iii. The proportions of the constituents are not varied by more than 20% from the original job mix formula.
iv. The in-service performance of the previous job mix formula materials has been satisfactory.

6 SPECIFICATION CONCEPTS

The effectiveness of construction surveillance in controlling the quality of asphaltic concrete that is actually produced and supplied to road construction and rehabilitation projects is dependent on the type of specifications and acceptance procedures used. There are in general four types of specification concept as described below.

6.1 Material and Method Specifications

This is the traditional construction specifications whereby the desired end product is often described in terms of materials to be delivered and construction methods to be used. Recipe or prescriptive specifications given will request the contractor to use specific materials and construction processes. These specifications may include quantifiable material properties such as modulus values as well as qualitative descriptions such as the number of passes with an approved roller. Acceptance is based on inspection and limited testing.

6.2 Traditional QC Specifications

In traditional QC specifications, it is the responsibility of the contractor to select materials and to use construction procedures which ensure that empirical or performance related properties stated in the specifications are met. The contractor prepares method statements, sometimes based on test section construction, for review and acceptance by the consultant and client. The consultant monitors field work based on the method statement, or if the method statement is inadequate, surveillance may be poor. Proof of compliance with specifications is typically based on quality control (QC) plan administered by both the contractor and consultant/client, and subsequently supervised by consultant/client.

6.3 Performance Based QC/QA Specifications

Performance based QA/QC specifications comprise a technically sound integration of engineering design, specifications and evaluation of constructed works. The desired level of performance is described in terms of fundamental properties of materials and constructed works. Quality characteristics used in the specifications must be amenable to accurate and timely based on widely accepted standards. Precision and bias inherent to the test methods used are taken into consideration. Test results must be obtained on randomly selected and representative samples, and they are analyzed using proven statistical methods.

6.4 Performance Specifications

Performance specifications describe in clear quantifiable terms the desired product and how the finished product should perform over time. Specifications contain warranty or guarantee clauses covering periods of 4 to 8 years. With this specification concept, the risk of poor performance lies clearly with the contractor. However, the contractor can choose materials and work methods, and may use know-how and innovative approaches as a competitive advantage.

7 DATA COLLECTION

For the purpose of the study, data of qualitative and quantitative natures were collected from the selected on-going road construction and rehabilitation projects undertaken by PWD throughout the country.

7.1 Qualitative Data

Qualitative data were obtained through response given by the respective supervising consultants of the projects visited to a standard questionnaire. This was done by personally interviewing the representative of the consultant, mostly the senior resident engineer at the site office. In the survey form, information's regarding mix design, trial lay, Marshall and field density tests were requested from the consultants.

7.2 Quantitative Data

Quantitative data include samples of asphaltic concrete which was either the binder course or wearing course depending on the current progress of the project, collected randomly from selected tip-trucks and compilation of some recent results of routine control tests carried out at site by the contractors, consultants or independent laboratory operators, as well as results of tests conducted by PWD on the collected samples.

In collecting the samples, it was so planned that each selected site was visited three times and at each time, sufficient samples were collected from three different tip-trucks which were randomly selected. Thus, a total of nine samples were collected from each site.

Each sample was kept in air tight plastic container and was labeled accordingly to include among others the project name, sampling date and type of asphaltic concrete before being sent to PWD laboratory.

Samples were collected in accordance with BS 598 Part 3. In brief, a minimum quantity of 24kg was extracted for materials of nominal size larger than 20mm such as the binder course ACB28 whereas not less than 16kg was sampled for materials of nominal size 20mm and smaller like the wearing course ACW20. For each tip-truck selected, samples were taken from three different spots which were widely spaced but not more than 30mm from the edge of the tip-truck. Samples were scooped by using a shovel from at least 100mm below the surface to avoid segregated materials.

A total of 21 sites throughout the country were visited in this study out of 30 initially targeted as summarized in Table 1. This is because some projects had not reached to the stage of producing asphaltic concrete during the site visit while some including the paving sub-contractors for the Federal Roads maintenance concessionaire had already completed their paving works. A few additional sites were also included as last minute substitutes.

Table 1: List of Projects and Quarries

Item	Name of Projects/Quarries
1	FT 001 Jalan Sultan Azlan Shah-Gopeng, Perak
2	FT 001, Jalan Tanjung Malim-Bidor, Perak
3	FT 001, Jalan Tapah-Gopeng, Perak
4	FT 005 Jalan Lumut-Sitiawan, Perak
5	FT 58, Jalan Teluk Intan-Bidor, Perak

6	FT 001 – A117, Jalan Baru Gopeng-Siputeh, Perak
7	Jalan Temerloh-Mentakab, Pahang
8	Jalan Pintas Gebeng, Kuantan, Pahang
9	Jalan Masuk ke Bukit Tinggi Resort, Pahang
10	Segmen 6 – Benta Bypass to Kuala Lipis, Pahang
11	FT 008 Bentong – Kuala Lipis, Pahang
12	Penggorak Quarry of PWD, Pahang
13	Kampung Awah Quarry, Pahang
14	FT 50, Batu Pahat – Air Hitam-Kluang, Johor
15	Jalan Muar-Melaka-Alor Gajah-Simpang Ampat, Melaka
16	Jalan Durian Tunggal-Paya Rumput-Sungai Udang, Melaka
17	FT 68 Jalan Gombak- UIA, Selangor
18	FT 005 Kapar-Sabak Bernam, Selangor
19	Jalan Kelang Lama, Selangor
20	FT 136 Jalan Bandar Baharu-Kulim, Kedah
21	Overhead Bridge at Bayan Baru Roundabout, Pulau Pinang

All together, there were 189 samples collected which consisted of 9 samples from each 21 sites. These samples were subjected to a series of laboratory testing as listed below;-

i. Bitumen content
ii. Aggregate gradation
iii. Preparation of Marshall samples
iv. Bulk specific gravity
v. Theoretical maximum specific gravity
vi. Volumetric analysis
vii. Marshall stability and flow

8 RESULTS AND DISCUSSION

8.1 Qualitative Data

8.1.1 Plant Type

Out of 21 quarries surveyed, 57% were batch plants and 43% were continuous drum mix plants. The control of quality was better in the batch plant than drum mix plant whereby, in the former, aggregates from a dryer were screened into different sizes and kept in various hot bins before they were being fed into a pug mill in fixed proportions and mixed with a known quantity of bitumen as a batch whereas in the latter, aggregates were continuously fed into the drum from cold bins with adjustable gate openings and bitumen was sprayed continuously and mixed with the aggregates by the rotary motion of the drum.

8.1.2 Mix Design

A total of 18 out of 21 quarries surveyed did carry out laboratory mix design on the asphaltic concrete mix manufactured and produced by them. Out of three (3) quarries which did not, two (2) were PWD quarries as shown in Figure 1. Without mix design, quality control simply would not exist as there would be no reference to gauge the quality level of the mix being produced.

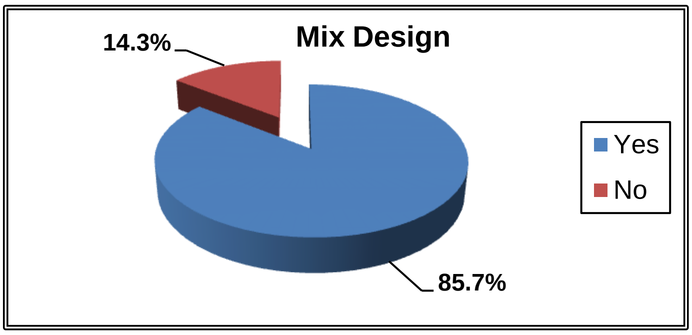


Figure 1: Percentages of sites having mix design

8.1.3 Trial Lay

There were 14% and 10% of 21 quarries which did not carry out trial lay and were uncertain whether they had really carried out one respectively as shown in **Figure 2**. Trial lay is meant to demonstrate that the mixing, laying and compacting equipment conform to the requirements of the specifications and the proposed mix which has undergone laboratory mix design satisfactorily does comply with the design. Without trial lay, one would not know that the initial few batches of mix produced and laid at site are satisfactory or otherwise.

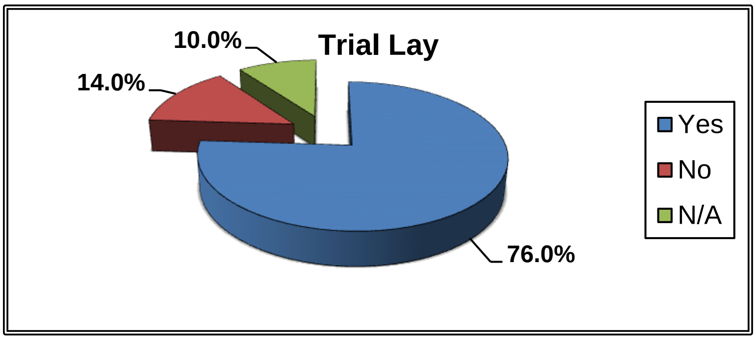


Figure 2: Percentage of sites having trial lay records

8.1.4 Rejection Experience

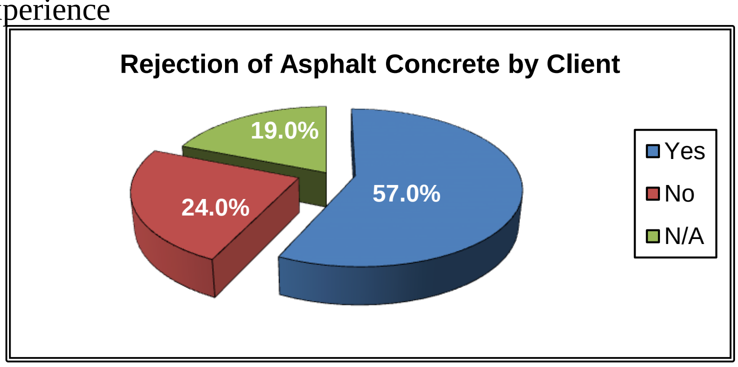


Figure 3: Percentage of Rejection Asphaltic Concrete by Client

From Figure 3 only five (5) out of 21 contractors/quarries surveyed had past experiences in rejecting the mix for the following reasons:-

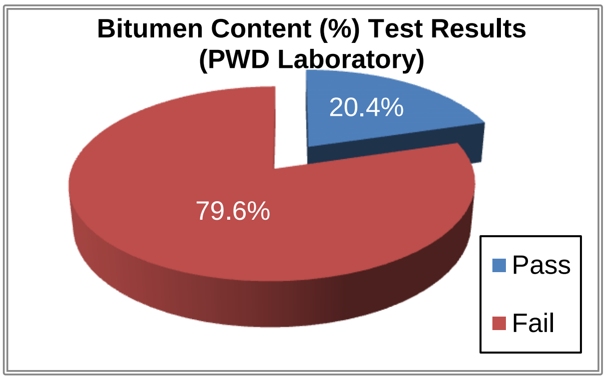
i. Temperature of mix too low (2 cases)
ii. Paving in the rain (1 case)
iii. Bitumen content too high (1 case)
iv. Road surface cracks after open to traffic (1 case)

Note that there was only one (1) case of rejection due to too high bitumen content which could be related to routine laboratory testing which verify the compliance of materials with mix design.

8.2 Quantitative Data

8.2.1 Bitumen Content

Comparing bitumen contents test results obtained from the laboratory center with those from sites, only 20.4% complied with respective job mix formulae as compared to 56.0% obtained from various sites as shown in Figure 4a and 4b. In any case, the figures contradict with the fact that only one site have past experience in rejecting the mixture due to non-complied bitumen content.



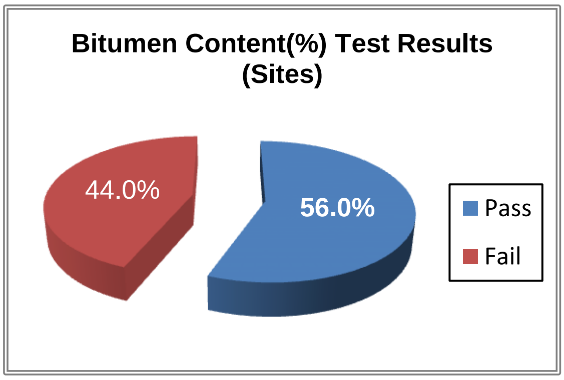


Figure 4: Bitumen Content tested by PWD Laboratory and contractors

There appears a considerable difference in the variation in bitumen content between PWD laboratory and some project sites. Even the variation in bitumen content for some of these sites, based on the test results obtained from respective sites, is considered too small, taking into consideration the variation in testing and sampling procedures and normal variation in the materials and production process.

Even though test results obtained from the laboratory and various sites were not from duplicate samples, the considerable difference that exist over a relatively short period of time (between one to three weeks) raise some doubts on the integrity of the test results obtained from respective sites.

Nevertheless, there were two (2) sites from which the test results showed variation in bitumen content which were similar to laboratory despite testing not being done on duplicate samples. These sites were Pekan Awah Quarry, Temerloh, Pahang (Project No.13) and FT 005 Sabak Bernam-Tanjung Karang (Project No.18).

8.2.2 Aggregate Gradation

Aggregate gradation test results obtained from laboratory and sites both indicated relatively low percentage of compliance with job mix formula (permissible variation from design aggregate gradation ranging ± 5.0% to ± 2.0%). Compliance with job mix formula means the percentage passing through the test sieves as listed in Table 4.8 PWD Specification (Table 2) are all within the permissible variation for the various fractions of aggregate size as given in Table 4.11 of PWD Specification (Table3).

Table 2: Gradation Limits for Asphaltic Concrete

Mix Type	Wearing Course	Binder Course
Mix Designation	ACW 20	ACB 28
B.S. Sieve	% Passing by Weight	
37.5 mm		100
28.0 mm	100	80 - 100
20.0 mm	76 - 100	72 -93
14.0 mm	64 -89	58 -82
10.0 mm	56 -81	50 -75
5.0 mm	46 -71	36 -58
3.35 mm	32 -58	30 -52
1.18 mm	20 -42	18 -38
425 um	12 -28	11 -25
150 um	6 -16	5 -14
75 um	4 -8	3 -8

Table 3: Tolerances for Asphaltic Concrete Mixes

Mix Type	Wearing Course
Bitumen	± 0.2%
Fractions of combined aggregate passing 5.0mm and larger sieves.	± 5.0 %
Fractions of combined aggregate passing 3.35mm and 1.18mm sieves.	± 4.0 %
Fractions of combined aggregate passing 425µm and 150µm sieves.	± 3.0 %
Fractions of combined aggregate passing 75µm and sieve.	± 2.0 %

8.2.3 Air Voids

There was a substantial difference in percentage air voids which were within the limits as stipulated in the PWD specification between the laboratory and sites test results: the figures were 18% and 94% respectively. It was observed, as expected, that low bitumen contents tend to yield high air voids from laboratory test results: the percentage that pass the bitumen content (20.4%) was almost identical to the percentage that pass the air voids requirement (18.0%). However, this trend was not reflected from site laboratories test results.

8.2.4 Marshall Stability and Flow

Test results from the PWD laboratory and sites indicated that the Marshall stability of all samples exceed the minimum requirements (ie. 4500N for binder course and 5000N for wearing course) despite the fact that a substantial number of samples did not comply with job mix formulae with respect to bitumen content, aggregate gradation and air voids. At the same time, a relatively large number of test results from both laboratory and sites indicated compliance with Marshall Flow requirements (ie. 2.0-4.0mm).

9 CONCLUSIONS

The type of specification and acceptance procedure widely used in this country is the Traditional QC Specifications whereby the contractor prepares method statements for review and acceptance by the consultant and the consultant monitors field work based on the method statements. Proof of compliance with specifications is based on quality control plan administered by both the contractor and consultant, and subsequently supervised by the consultant. However, the supervision is usually done on the basis of more or less effective surveillance and often so by site staff with less or no training and experience. As a result, the client is bound to be presented with materials and constructed work of inferior quality even though test results indicate otherwise.

In this study, out of a total 21 construction sites being surveyed, only one (1) site consistently complied with mix design and showed a trend of test results similar to those obtained independently from the PWD laboratory. Even though the test results obtained from laboratory were not from duplicate samples as tested at the various sites, the considerable difference in the test figures that exist over a relatively short period between time of samples were taken and tested at laboratory and purportedly tested by the contractor/consultant at sites one to three weeks earlier raise some doubts on the genuineness of the test results obtained from respective sites.

In summary, the following conclusions can be deduced from this study:

1. Out of 21 construction sites surveyed, and based on nine samples taken at random from each site and tested at the PWD laboratory:
    i. Only one site consistently complied with job mix formula.
    ii. Only one site consistently showed a trend of test results similar to the PWD laboratory.
2. Three (3) sites do not have mix design; two (2) of them involve PWD quarries.
3. Marshall samples which comply with design binder content and aggregate grading will also comply with Marshall stability and flow requirements.
4. Marshall samples which do not comply with design binder content and aggregate grading may still comply with Marshall stability and flow requirements.
5. Marshall samples which comply with design binder content and aggregate grading may have air voids exceeding the allowable limits. However, these samples may still comply with Marshall stability and flow requirements.

10 RECOMMENDATIONS

1. As a means to control the quality of asphaltic concrete, compliance with the design binder content and aggregate grading is adequate. If the production of asphaltic concrete is controlled within the allowable tolerances or job mix formula, it is not necessary to perform further testing for conformity to mix design criteria as a routine measure of quality. In fact, the variability inherent in such sampling and testing may lead to misleading interpretation of quality variation where no such variation really exists.

2. A true dual system of evaluation ie. QC by the contractor and QA by the consultant or PWD shall be adopted in PWD projects. Acceptance or rejection decision shall be based on QA test results.

3. In the event QA and QC testing does arrive at different test results which need reconciliation; the involvement of independent third party QA shall be solicited.

4. In the event only one laboratory is provided (as in normal cases), a supervisory staff shall be based full time in the laboratory. The respective personnel shall be competent with the testing procedures and shall actively participate in conducting the tests like for example in jotting down readings from test apparatus, filling up the test forms and carrying out the necessary calculations. The personnel in charge shall then immediately sign the test forms upon completion of the tests and shall retain the original copy for verification by the engineer.

5. Performance specifications shall be introduced whereby the description on how the finished product should perform over time shall be given. In the case of a road pavement, performance is normally described in terms of allowable changes in physical condition of the road surfacing (functional) and its response to load over time (structural). Specifications should contain warranty/guarantee clauses.

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