Effect of Coal-Contaminated Aggregate on Asphaltic Concrete Pavement Performance

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Crushed aggregate containing approximately 8 percent by weight of soft coal was used in the construction of asphaltic concrete pavements on 23 km of secondary and primary roadways. Within 5 months after construction, surface distress in the form of raveling, pitting, and localized potholing occurred along and outside the wheelpaths. The presence of coal in the aggregate had been identified during the quarrying and crushing stages. Normal and 24-hr soaked Marshall stability tests were undertaken to evaluate the quality of the crushed aggregate. Retained stabilities of 20 percent to 69 percent were obtained using samples obtained from the crushing plant and dryer of the asphalt plant, respectively. On the basis of the higher stability obtained from the asphalt plant-processed material, it was decided to use the aggregate. This decision was also influenced by a contract deficiency pertaining to the "acceptable" amount of deleterious material. For production asphaltic concrete, a 70 percent retained stability was chosen as a minimum requirement for an acceptable mix. During the first 6 km of paving, retained stability lower than the target resulted in the contaminated aggregate being blended with 20 percent of clean aggregate. This blend resulted in 80 to 90 percent retained stability. Despite this, all roadways suffered pavement distress. To stop the progressive pavement deterioration, a fog seal was applied to the secondary roadways, with a subsequent single-surface seal applied to all roadways in 1985. Since then, no further pavement distresses have been reported and the roadways are performing well.

Mineral aggregates constitute 88 percent to 96 percent by weight, or approximately 80 percent by volume, of an asphaltic concrete pavement. As a major component, therefore, aggregates directly influence the structural integrity and durability of the pavement structure. To ensure that performance and service life of a pavement are not affected prematurely, high-quality aggregates are generally preferred in the manufacture of asphaltic concrete mixes. Gradation, shape, strength, toughness, durability, hydrophobic characteristics, and cleanliness are the quality attributes of aggregates that govern their behavior and, hence, ultimate pavement performance under load- and non-load-associated environments. It is generally recognized by highway agencies worldwide that aggregates for asphaltic concrete mixes should be clean. Cleanliness of an aggregate is determined, in general, by the presence or absence of deleterious or harmful materials. The overall quality ranking of an aggregate is often influenced by the types and amounts of deleterious material within the aggregate matrix, with high-quality aggregates having none to negligible amounts of deleterious materials.

Materials considered deleterious include clay, clay lumps, soft shale, lignite, coal, mica, shells, organic matter, vegetable matter, and roots. Some highway agencies provide percentage limitations on the amounts of these materials. Others state their objection to deleterious materials qualitatively, whereas others consider that their requirements for the quality attributes of strength, toughness, and durability would limit the amount of deleterious material. The types of deleterious materials and their percentage limitations in coarse and fine aggregates considered by 50 highway agencies in North America are reported by Chastain and Burke (*1*). In Alberta, the majority of the aggregates used in asphaltic mixes in the Provincial highway system is obtained from naturally occurring gravel and sand sources. In addition to the impurities such as clay, clay lumps, and organic matter, coal is frequently encountered within gravel aggregate sources.

When coal is encountered during the gravel prospecting stage, the source is considered unsuitable if the amount of coal is significant and if its disposition is such that quarrying of the deposit would not eliminate this material.

In a situation where coal is discovered during quarrying, the coal is stripped and removed or the deposit is worked in such a manner as to avoid aggregate contamination. This situation is generally not the norm because most sources are pretested prior to large-scale use. Where selective quarrying is undertaken, it is generally impossible to eliminate all coal from any known contaminated deposit. In such cases, the amount of coal acceptable is based on visual observations of the color of the total aggregate rather than by actual testing. Generally, the percentage acceptable from visual observation may not exceed about 1 percent by weight of the total aggregates. Although it is well established that coal is highly undesirable in aggregates for portland cement concrete, coal in asphaltic concrete aggregates is not treated with the same degree of concern. According to Woods (*2*), the ASTM specifications, by excluding a section on deleterious materials, recognize that small amounts of deleterious materials are not as harmful to bituminous concrete as they are to portland cement concrete.

Very little work is reported in the literature on the influence of coal on asphaltic concrete behavior. One of the reasons for the scarcity of information on this topic is that this material is restricted to a trace in aggregate production and, hence, may not have created a situation warranting any special study.

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The purpose of this paper is to present a case study of the performance of asphaltic concrete pavements along two secondary roadways and one primary highway constructed with coal-contaminated aggregate containing a significant percentage of coal.

PROJECT BACKGROUND

Under an Alberta Transportation (now known as Alberta Transportation and Utilities) contract, the scope of work included the construction of approximately 23 km of asphaltic concrete pavement construction along three designated roadways consisting of one primary (Hwy. 28:04) and two secondary (SR 827:02 and SR 644:02) roadways. The location of these roadways is shown on Figure 1.

Structural pavement design of the three roadways was based, with slight modifications, on the Asphalt Institute Method of Design (*3*). A California Bearing Ratio of 4 percent for the subgrade soil and a 20-yr roadway design life were common to the design of the roadways. Other design parameters consisted of an Average Annual Daily Traffic (AADT) of 3,300 vehicles per day and Design Traffic Number (DTN) of 334 for Hwy 28:04, with AADT of 700 and DTN of 56 for the SR 827 overlay and AADT of 250 and DTN of 23 for SR 644:02.

Hwy. 28:04

This project was a realignment of Hwy. 28:04 in the vicinity of Junction Hwy. 28:04 and SR 827:02 to facilitate the construction of an at-grade railroad separation. The length of the realignment was approximately 1.4 km and required embankment, base, and surfacing constructions.

This roadway, designed to accommodate two-way traffic, consisted of a 13.8-m finished pavement width and a 400-mm-thick structural pavement. The pavement thickness consisted of 300 mm granular base course and 100 mm asphaltic concrete pavement.

SR 827:02

This project involved new construction (embankment, base, and surfacing), embankment only, and asphaltic concrete pavement overlay.

As a two-lane secondary roadway, this road was designed with a 9-m finished pavement width and a 330-mm structural pavement thickness consisting of 230 mm granular base and 100 mm asphaltic concrete pavement.

The asphaltic concrete overlay construction covered a distance of about 15 km beyond the limit of the new construction and extended into the Town of Thorhild. The existing pavement was constructed in 1980-1981 and consisted of 175 mm soil cement base and 50 mm asphaltic stabilized base course. The designed overlay consisted of 60 mm asphaltic concrete pavement.

SR 644:02

Construction of this project roadway consisted of subgrade preparation and base course and asphaltic concrete pavement construction over a total project length of approximately 4 km. Designed to accommodate two-way traffic, this roadway was constructed with a finished width of 9 m and a 350-mm structural pavement thickness. This pavement thickness consisted of 230 mm granular base and 120 mm asphaltic concrete pavement.

CONSTRUCTION AGGREGATES

The aggregates used in granular base and asphaltic concrete pavement constructions were obtained from a naturally occurring gravel aggregate source. This source, situated along the North Saskatchewan River, was located approximately 38 km from the Jct. SR827 and Hwy. 28:04. The pit location in relation to the project roadways is shown on Figure 1.

Prior to the gravel crushing operations, an inspection was made of the pit site. At the time of the inspection, preparation of the crushing plants and stockpile sites was in progress. The following observations were made:

1. The pit site had been extensively worked and appeared to be depleted.
2. Pit rehabilitation had not been performed following excavation and crushing. A number of waste stockpiles had been randomly left, creating the appearance of an abandoned pit.
3. The area identified for quarrying was a narrow bank of high ground at the east fringe of the pit area. The workable gravel seam was 2 to 4 m thick and was located below 6 to 8 m

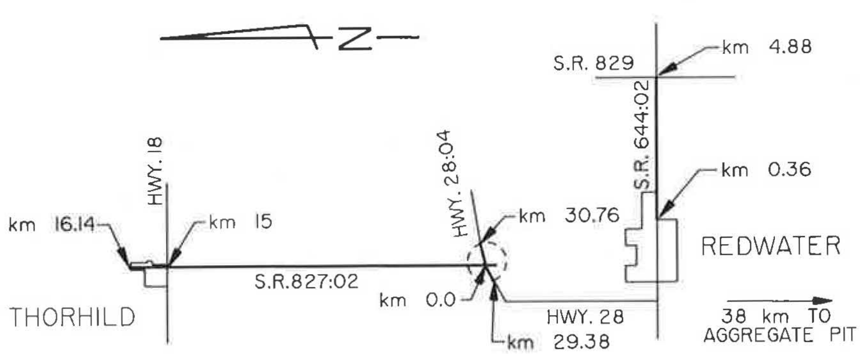

FIGURE 1 Location of project roadways.

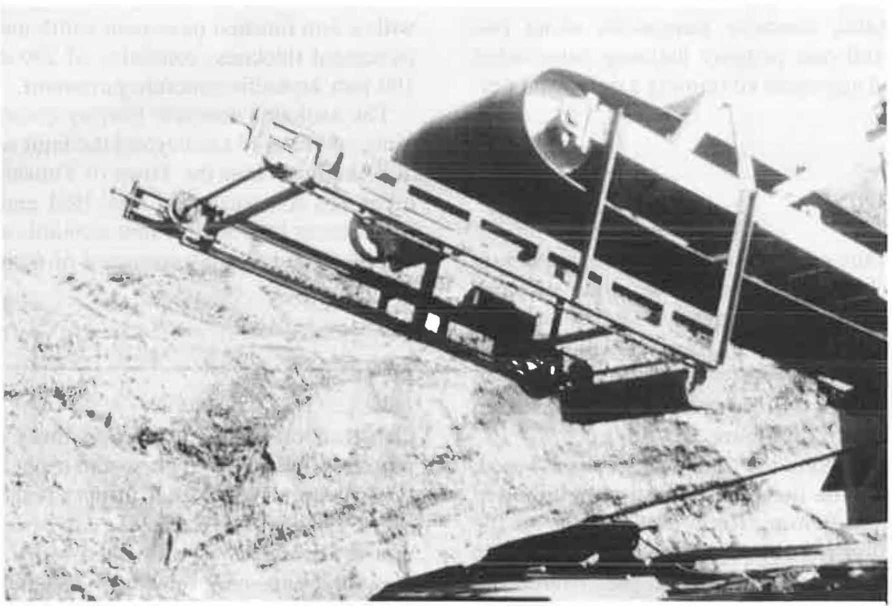

FIGURE 2 Section of workable pit area.

of clay overburden. Medium to coarse sand existed below the gravel. Figure 2 shows a section of the workable pit area.

GEOLOGICAL CONSIDERATIONS

Briefly, the aggregate source forms part of the Saskatchewan sands and gravels, sand and gravel deposited in preglacial valleys (as valley till in terraces) before the onset of the Quaternary glaciation. Generally, the composition of the Saskatchewan gravels is primarily quartzitic rock with minor amounts of chert, clay ironstone, and coal. Coal is derived from the local bedrock (Edmonton Formation) through bedrock incision by the preglacial rivers. Additional information about the geological setting and characteristics of the Saskatchewan sands and gravels can be obtained from work by Shaw and Kellerhals (*4*), Kathol and McPherson (*5*), and Edwards et al. (*6*).

SUPPLY

The supplemental provisions of the contract required the aggregates to be supplied from a source of the contractor's choice. The materials supplied were to satisfy the gradation specifications for Designation 1 Class 16 and Designation 2 Class 40 materials (Figure 3). The Designation 1 Class 16 material was to be used in both granular base course and asphaltic concrete pavement constructions.

In terms of the quality attributes of strength, durability, and soundness, the General and Construction Specifications required under Specification 5.1, Subclause 5.1.02.2—Gradation Requirements, the following:

"The crushed aggregate shall be composed of sound, hard and durable particles of sand, gravel and rock with all material up to and including 300 mm crushed, and shall be free from elongated particles, injurious quantities of flaky particles, soft shales, organic matter, clay lumps, and other foreign matter."

PRETESTING

Because the aggregate source was to be the contractor's choice, no pretesting of the source was done by the department. Information regarding the characteristics of the source was therefore unavailable until actual quarrying and crushing had commenced. According to postconstruction information, however, this source had been tested by the department some 20 yr ago. At that time, it was noted that the source consisted of fine to coarse gravel deposits with numerous sand seams. Testing had also been undertaken by an independent testing laboratory. According to a departmental appraisal of the testing laboratory's report, it appeared that the quality attributes of the aggregate had not been well addressed, leaving some reservations about its quality. The appraisal, nevertheless, considered that the source material might be suitable for use in highway construction. No mention was made by either the department or the independent laboratory of the presence of coal within the source.

CRUSHING

Crushing of pitrun gravel to produce Designation 1 Class 16 material for asphaltic concrete and top lift granular base course constructions began on September 17, 1983. Approximately 2,000 tons of material had been crushed and stockpiled by the supplier on September 20, 1983, when quality control monitoring was officially initiated on site. The material was produced as an "all-in" aggregate. The production of an "all-in" aggregate was chosen by the supplier instead of splitting and recombining the coarse and fine fractions.

The stockpiled aggregate was inspected on September 20, 1983, following a request by the contractor and supplier for gradation checks to determine whether the crusher settings were satisfactory for producing the desired crushed aggregate.

The inspection of the aggregate stockpile revealed the presence of finely divided particles of coal that gave the stockpile

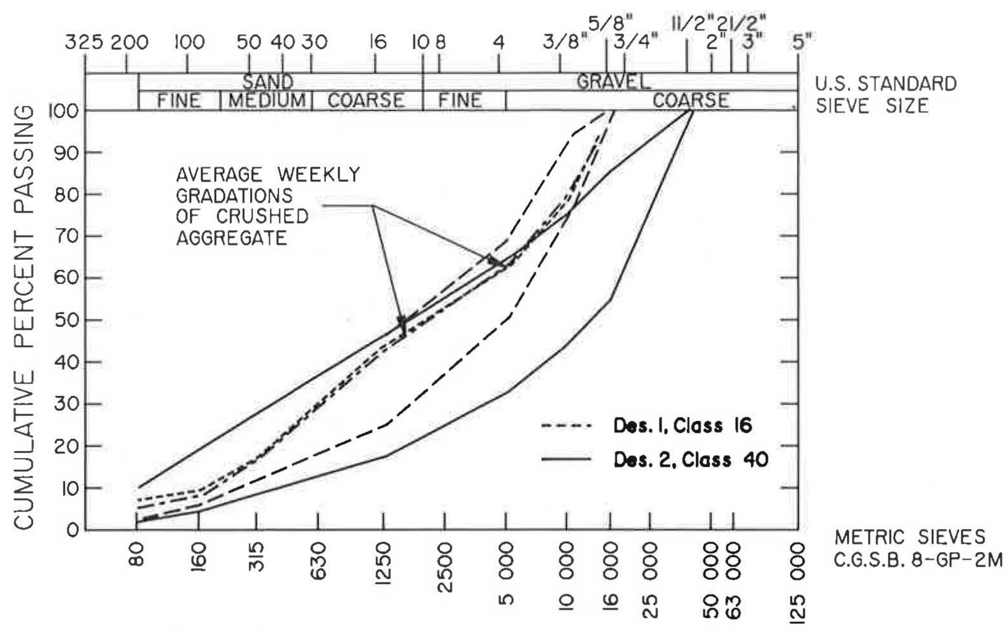

FIGURE 3 Aggregate gradation specifications.

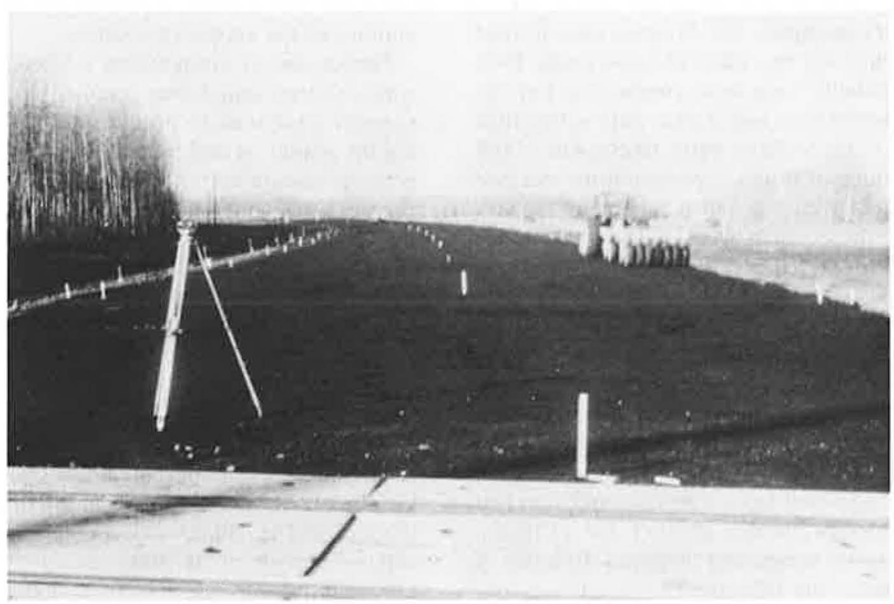

FIGURE 4 Appearance of Designation 1 Class 16 material as base course.

a very dark appearance resembling, from a distance, an oil-bound aggregate stockpile. Figure 4 shows the appearance of the Designation 1 Class 16 material when laid as base course on the roadway.

Following the inspection of the aggregate stockpile, an examination of the pit was made. Five thin coal seams 75 to 150 mm thick were observed to be interspersed within the 2 to 4 m of workable gravel face. On close examination, the coal was soft and could readily be disintegrated between the fingers to dust-size particles. One seam in particular was brown and contained leafy vegetative matter. It was assumed that this seam was in a transitionary stage of coalification. The disposition of the five coal seams made it practically impossible to avoid contamination of the pitrun gravel during excavation. On-site discussions were held immediately, with the contractor and supplier expressing the unsuitability of the pit to produce asphaltic concrete aggregate.

A sample of material was taken from the stockpile and tested for gradation and percent fractures. The presence of coal within aggregate was also confirmed during washing of the aggregate. Both the gradation and percent fractures failed to meet the specification requirements.

Six additional samples were taken from the crusher discharge during production on September 21, 1983. These samples also failed to meet the gradation specification requirements and were stockpiled separately. The crusher was finally adjusted to produce the desired aggregate at around 7:30 *p.m.* that day. Two samples were taken during the night shift, and both satisfied the specification requirements in terms of gradation and fractures. Between September 22 and 25, when operations were temporarily halted, the material produced was slightly coarser than the specification requirements between the 315 and 80 (metric) sieves. This deviation from the specifications was consistent and was not considered critical.

Because coals were present in the aggregate, the material crushed between September 20 and 21 had to be submitted to the Transportation Laboratory for analysis to determine the aggregate's suitability for use in asphaltic concrete pavement construction. The suitability of the aggregate was assessed from Marshall stability tests done on both normal (30- to 40-min-soaked) and 24-hr-soaked specimens. The criterion used to assess the suitability of the mix and hence the aggregate suitability was that the retained stability (percentage of soaked to normal stability) should be at least 70 percent. The soaked stability test, also known as the Marshall Immersion Test, measures the change in stability resulting from the action of water on compacted bituminous mixes. The test is done on samples prepared with the same asphalt content, gradation, and number of blows as the Marshall specimen tested in the normal manner.

Using a batch split (aggregate tested as submitted), two sets of three Marshall briquets were made with 6.0 and 6.6 percent asphalt by weight of dry aggregate. The briquets were formed using 50 blows on each of the two faces of a specimen. Both normal and soaked stability tests were conducted. For the soaked tests, the specimens were tested after 18 hr rather than 24 hr. This was done to facilitate an early assessment of test results. Retained stabilities of 20 and 28 percent were obtained for the specimens made with 6.0 and 6.6 percent asphalt, respectively. Because these values were considerably lower than the 70 percent considered acceptable for high-quality asphaltic concrete, the mix was considered unacceptable. According to the Materials Testing Laboratory, the low retained stability might have been influenced by the gradation of the aggregate. This gradation was slightly finer than that contained in the specification requirements. In addition to the stability testing, testing was performed to determine the percentage of coal in the aggregate. Using a flotation method, the percentage was determined to be 0.89 percent by weight of total aggregate. Through burning at 800°F for 14 hours, however, 8 percent coal by weight was obtained. In terms of the physical appearance of the aggregate, 8 percent was considered a far more realistic value.

As a result of the low retained stability, a meeting was held with the contractor and supplier on September 25 during the night shift crushing. It was agreed at that time that further crushing would be halted pending the results of further laboratory investigation. Further testing was undertaken on samples taken from the crusher discharge between September 21 and 25, 1983. A 3-point Marshall mix design was carried out on aggregate batch samples. The retained stability was 34 percent despite the gradation of the material satisfying the specification requirements.

On account of these low results, it was decided that the aggregate was unacceptable for use in asphaltic concrete pavement construction. Both the contractor and supplier were advised of the decision. At a later meeting between the contractor and representatives of the department, however, it was agreed to assess further the mix characteristics of aggregate processed through the dryer drum at normal operating temperature. This was done to verify the contractor's opinion that the coals would burn off from the aggregate once heated to mixing temperature.

For the stability tests on plant-processed aggregate, it was decided to investigate the suitability of Designation 1 Class 12.5 aggregate in addition to the Designation 1 Class 16 aggregate.

Two sets of 12 briquets of the Designation 1 Class 12.5 and Designation 1 Class 16 aggregate were tested for normal and soaked stabilities. Retained stabilities of 55 and 69 percent, respectively, were obtained. Although these values were less than the 70 percent criterion, it was decided to allow the use of Designation 1 Class 16 aggregate. It is of interest that coal was still observed in the aggregate after processing through the dryer drum. No checks were made on this percentage of coal.

To ensure that the stabilities were consistently high during actual production, it was decided to continue Marshall stability testing on field-formed briquets. The contractor and supplier were both notified that should the retained stabilities drop significantly lower than 70 percent, the use of the contaminated aggregate would be stopped. This decision was agreeable to both the contractor and supplier. In fact, before the plant trials they had suggested an alternative plan that involved the use of a percentage of clean aggregate from another of the supplier's sources.

Production of Designation 1 Class 16 material from the contaminated source was resumed on October 7, 1983. The supplier continued to produce an "all-in" aggregate satisfying the gradation and fracture specifications. The weekly average gradation up to the completion of crushing is shown in Figure 3.

ASPHALTIC CONCRETE PAVEMENT CONSTRUCTION: QUALITY CONTROL CHARACTERISTICS

SR 827:02

Asphaltic concrete pavement construction commenced on October 12, 1983, starting from km 0.937 toward km 16.137 (Figure 1). The "all-in" coal-contaminated aggregate was used with 6.6 percent of 200-300 penetration grade asphalt cement to initiate paving. The 200-300 asphalt cement grade was also used in the paving of SR 644:02. Asphaltic concrete mixes for both of these roadways were based on the characteristics of a 50-blow Marshall stability design satisfying, in general, the Asphalt Institute Marshall Stability Design Criteria.

During plant production on October 12, 1983, eight field-formed briquets were made for stability evaluation. An average retained stability of 55 percent was obtained, with the normal stability averaging 5,201 N and the gradation satisfying the specification requirements.

On the basis of the low retained stability, it was decided to pursue the option of blending the contaminated aggregate with aggregate from the supplier's alternate source. A mix of 20 percent by weight of clean aggregate and 80 percent of contaminated aggregate was found to satisfy the aggregate gradation requirements.

The use of this blended aggregate to continue paving this project from km 6.6 was resumed on October 31, following the completion of paving Hwy. 28:04 and SR 644:02. These latter projects were given priority because subgrade and base course constructions had been completed while paving was in progress on SR 827:02. The paving of SR 827:02 was finally completed on November 6, 1983.

Quality control monitoring of the mix characteristics and field compaction resulted in 25 field-formed Marshall briquets and 65 field cores. The percentage compaction achieved varied from 91 to 98 percent of the field-formed Marshall density, with an overall average compaction of 95 percent. Field air voids ranged from 8 to 11 percent with an overall average of 10 percent, whereas mix asphalt content averaged 6.2 percent with a range from 5.7 to 6.8 percent determined by the nuclear gauge. A similar range of asphalt content was determined from bulk and totalizer plant checks. Aggregate gradations were found generally to satisfy the job mix formula.

Hwy. 28:04

The asphaltic concrete mix used in paving this project roadway consisted of the blended aggregate and 5.7 percent of 150-200 asphalt cement. This design was based on a 75-blow Marshall stability simulating the heavy traffic category criteria. Characteristics of the design mix were as follows:

Characteristic	*Amount*
Stability (N)	8,200
Asphalt content (%)	5.7
Density (kg/m³)	2,329
Air voids (%)	4.0
Voids in mineral aggregate (%)	15.3
Voids filled with asphalt (%)	73
Flow (mm)	2
Retained stability (%)	79

Mix reaction to kneading compaction was medium.

Pavement construction commenced on October 17 and was completed on October 20, 1983. During this period 20 briquets were made for stability evaluation. Six of these made on October 17, 1983, gave an average retained stability of 82 percent with an average normal stability of 9,154 N. The remaining 14 briquets were made on October 19, 1983. Three gave an average retained stability of 74 percent and an average normal stability of 8,725 N, with stability values ranging from 7,562 to 10,231 N.

Because the retained stabilities consistently exceeded the minimum criterion, the mix was considered acceptable for use from a laboratory analysis viewpoint, and further testing was discontinued.

A summary of the quality control monitoring information from 30 field-formed Marshall briquets and 27 field cores showed the field compaction to range from 91 to 97 percent with an overall average of 93 percent. Field air voids ranged from 6 to 13 percent with an overall average of 10 percent, whereas mix asphalt content varied from 5.5 to 6.1 percent with an average of 5.6 percent. A similar range of asphalt content was determined from bulk and totalizer plant checks.

SR 644:02

Paving of this 4-km stretch of roadway was undertaken following completion of Hwy. 28:04. The mix contained the same aggregate combination as that used on Hwy. 28:04 except that 200-300 asphalt cement was used with an optimum asphalt content of 6 percent. Roadway paving commenced on October 22 and was completed on October 28, 1983.

No retained stability checks were done; rather, field-formed briquets were made for reference density and air voids determinations for compliance with mix design characteristics, and for evaluation and comparison of field compaction control characteristics. A summary of the mix characteristics and field compaction determined from 15 field-formed briquets and 36 field cores showed the following:

1. Percentage compaction ranged from 91 to 97 percent of field-formed Marshall briquet density with an overall average of 95 percent.
2. Field voids ranged from 8 to 13 percent with an overall average of 9 percent.
3. Mix asphalt content ranged from 5.6 to 6.3 percent with an overall average of 5.9 percent. A similar range of asphalt content was determined from bulk and totalizer plant checks.

MIX LAYDOWN CHARACTERISTICS

During mix placement and rolling a few observations were made that appeared to be somewhat unusual when compared with observations of mixes made with uncontaminated aggregates.

1. Difficulty in obtaining consistently high densities despite adequate compaction equipment and varying techniques used in mix rolling. Both vibratory and pneumatic tire rollers were employed on the project. The best combination for achieving reasonably good compaction on all projects consisted of two breakdown passes with vibratory on the forward roll and static on the return roll for each pass using a Dynapac CC 50A roller. Three breakdown passes with vibratory on both the forward and return rolls were found to be too severe and resulted in fracturing the mat. Although several factors can influence compaction, it appeared, on the basis of visual observations, that mix material characteristics were a major influencing factor because asphalt content and aggregate gradation were in compliance with specification requirements. In consideration of the influence of ambient air temperature during mix laydown, a mean maximum of 10°C and a mean low of 0.4°C with an overall mean of 4.7°C were recorded over the duration of construction. Temperature was not considered an influencing factor because late fall paving is usually undertaken at temperatures up to about -5°C without pavement performance being influenced. Because the asphaltic concrete specifications do not stipulate a cutoff temperature, construction during the fall is often undertaken at the discretion of the project and district engineers. The guidelines often used for late fall construction are that paving is not undertaken during snowfall and that an acceptable level of compaction is achieved. It is the writer's experience that 95 percent compaction is readily achieved during paving in ambient air temperature of -5°C.
2. "Picking-up" and excessive steaming of mix during breakdown rolling. Frequent mix pickup by the rollers occurred despite clean and properly wetted wheels. This was also observed to a lesser extent during pneumatic tire intermediate rolling.

3. Tendency of mix to hairline crack during breakdown rolling. Intermediate rolling by a pneumatic tire roller was found to seal these cracks.
4. Quick "setup" of mix under breakdown rolling.

POSTCONSTRUCTION ROADWAY EVALUATION: ROADWAY OBSERVATIONS

On April 6, 1984, approximately 5 months after the completion of roadway paving, the area maintenance foreman reported the observation of cracks within the pavement surface along Hwy. 28:04. An inspection of this roadway undertaken the same day revealed crescent-shaped tearing and slippage cracks within the asphaltic concrete top lift at one location and impending pavement slippage at other locations west of the at-grade railway crossing. The slippage and potential pavement slippage cracks were concentrated on the high side of the horizontal curve and covered a distance of about 200 m. It was later reasoned that these cracks occurred because a tack coat was not applied between lifts during asphaltic concrete pavement laydown.

Pavement cracks were also noticeable east of the railroad tracks where the roadway was along tangent or normal crown pavement sections. These cracks bore some resemblance to fracture cracks in brittle materials and can perhaps best be classified as random cracks. These cracks were associated with high-porosity areas as evidenced from the moist and open texture of the pavement surface at these locations. No pavement slippage had occurred on this side of the tracks, nor were there any signs that this type of pavement distress was pending. It is of interest that no tack coat was used between asphaltic pavement lifts.

In addition to the cracking and pavement slippage phenomena, other surface distress manifestations became readily apparent during the site inspection. These consisted of loss of fine aggregates, raveling, and pitting of the pavement surface.

The loss of fine aggregate was evident throughout the entire roadway length. This loss gave the pavement a very coarsely textured appearance, which was very pronounced along wheelpaths and at the intersection of Hwy. 28:04 and SR 827:02. The appearance of the pavement resulting from this loss of fine aggregate is illustrated by Figure 5.

Raveling of the mix was evident at the tapers at the beginning and end of the paved section of roadway. At these locations where the new roadway adjoins the existing one, the mat is generally very thin. Although the loss of aggregate at these locations was anticipated, the extent to which this occurred was found to be unusual when comparisons were made with similarly paved roadways with varying pavement lives. It was concluded, on the basis of visual observations, that the loss of aggregate was definitely too severe within the short period of pavement life.

The loss of coarse aggregate particles from the pavement surface, giving the mat a pitted or pock-marked appearance, was also quite evident. This distress manifestation was distinct from the loss of fine aggregate and from the raveling that occurred at the tapers. On close visual and surface examination of the pavement, it was found that some of the coarse aggregate particles could readily be removed with a penknife using moderate pressure. Some of these particles were associated with poor aggregates, such as chert and clay ironstone, typically found within the Saskatchewan gravels. Figure 6 depicts the pitted or pock-marked appearance of the pavement surface.

SR 827:02

This roadway was also found to exhibit the same surface distress manifestations that occurred on Hwy. 28:04 except that pavement tearing and slippage cracks were absent. In contrast to Hwy. 28:04, the pavement overlay was constructed in one lift and on an existing pavement surface that was tacked prior to asphalt laydown.

FIGURE 5 Pavement surface texture due to loss of fine aggregate.

In addition to raveling at the tapers, there was raveling to the full depth of the new mat at several locations, resulting in the formation of potholes within the pavement. Longitudinal streaking of the surface was also observed within the 0.8-km stretch north of Jct. Hwy. 28:04 and SR 827:02.

In the Town of Thorhild the loss of fine aggregate was extremely severe, resulting in a very rough textured pavement surface as shown by Figure 7. Random pavement cracks, similar to those observed on Hwy. 28:04, were also observed at isolated sections.

FIGURE 6 Pitted or pock-marked appearance due to coarse aggregate loss.

FIGURE 7 Severe raveling.

SR 644:02

Except for tearing and slippage cracks, potholing, and streaking, all other surface distress manifestations that occurred on Hwy. 28:04 and SR 827:02 were readily noticeable along the entire paved length of SR 644:02. The severity of the distresses, however, was not as pronounced and may have been retarded owing to the lower volume of traffic on this roadway. It is also of interest that no tack coat was used between lifts of asphaltic concrete pavement.

REMEDIAL MEASURES

On May 7, 1984, a further inspection of the roadway was undertaken by the department's surfacing consultant. On the basis of his observations, it was recommended that SR 827:02 and SR 644:02 be fog-sealed immediately with an SS-1 emulsion at an effluent rate of 0.5 kg/sq m. Further, it was recommended that all roadways be scheduled for seal coating in the 1985 construction program.

Fog-sealing of the secondary roadways was done in June 1984 with the application of the single surface treatment to all roadways during May-June 1985. Before the application of the surface seal coat to Hwy. 28:04, the slipped areas were removed and repaved. Since the application of the seal coat, no further surface distress has been reported.

AGGREGATE EVALUATION

In comparing the performance of the project roadways over the 5-month period with similarly paved roadways in service from 1 to 10 yr and constructed with coal-free aggregate, it was obvious that the surface distress manifestations that occurred on the project roadways resulted from mix aggregate characteristics.

Considering the variables that could have contributed to the types of distress observed, it was felt that the presence of the coal impurity was a significant contributor to, if not the primary cause of, poor pavement durability.

As a first step in this evaluation an X-ray diffraction analysis of the contaminated aggregate was undertaken. This analysis was even done prior to the reported distresses and site inspection, because the presence of this impurity aroused curiosity during the crushing and preconstruction evaluation stages. Later, a coal petrographic analysis was done to determine the ranking of the coal because it was felt that the soft nature of the coal was influenced by a high percentage of organic matter content.

X-ray Diffraction Analysis

X-ray diffraction analysis was conducted on the -125-micron and -2-micron particle sizes of the coal-contaminated Designation 1 Class 16 aggregate. This analysis reported on April 4, 1984, showed the -125-micron particles to consist mainly of silt sizes, with quartz being the dominant mineral along with some feldspar, illite, and christobalite. The -2-micron size showed clay sizes to constitute a small part of the total sample. The minerals present were mainly montmorillonite with some illite, kaolinite, and quartz. As an overall assessment, it was determined that there was nothing unusual about the presence of the minerals noted. The presence of bentonite, presumed prior to the analysis, was not indicated. Bentonite was presumed possibly to account for the low retained stabilities that were obtained from laboratory testing before and during pavement construction.

Coal Petrography

A petrographic analysis of the coal containment was undertaken to ascertain its ranking. Briefly, the petrographic composition of coal can be expressed in terms of macerals and microlithotypes. Macerals are the basic constituents of coal and are analogous to the minerals of organic rocks. Microlithotypes are distinct assemblages of macerals and may be considered equivalent to rock types in inorganic petrology (7).

Ranking the coal is achieved by measuring the reflectance. The technique is based on the fact that as the rank of the coal increases, so does its reflectance. It is a precise method of determining rank and has the advantage that it can be done on one component, namely vitrinite. Vitrinite is the coalified remains of a variety of plant tissues with a large contribution from wood and bark. It is normally the most abundant constituent of coal (7).

The results of the petrographic analysis are summarized in Figure 8 as a plot of frequency versus reflectance. These data were obtained from a 35-point vitrinite analysis. As shown, the reflectance ranges from a minimum of 0.135 to a maximum of 0.475, with a mean of 0.239. On the basis of these results the coal can be ranked as "peat," according to the German and North American (ASTM) classifications. A characteristic feature of the rank of this coal is its bed moisture, which is about 75 percent.

DISCUSSION

In an asphalt-aggregate mix containing coal, the coal will tend to coat the asphalt film first and hence result in reduced bonding between the asphalt and aggregate. Poor aggregate-asphalt bonding would directly influence mix strength and durability. Hence, the mix would be more susceptible to the influence of moisture and disintegration by weathering.

Further field evidence of the influence of coals on mix behavior was obtained from research aimed at exploring the possibility of making an improved binder for bituminous pavements by dispersing coal in distilled coal tars and oils (*8*).

Thirteen test sections covering a distance of 16 km and a similar number of control sections covering a distance of 18 km were constructed using coal-modified, coal tar binder and standard asphaltic binder, respectively. The control sections were constructed near or adjacent to the test sections.

The following is a summary of some of the observations made from six test sections during the first 2 yr of pavement construction.

1. About 3 months after construction excessive raveling and wearing away of the surface course were occurring in two of the test sections. The wear was progressive, and patching had to be done at an early stage. At several places in urban sections the entire mix thickness was worn through along wheelpaths.
2. Raveling and loss of fine aggregate resulted in a rough-textured pavement surface.
3. The experimental mix lacked flexibility. Edge cracking developed rapidly, and old surface and base failures soon reflected through the mix.
4. The degree of pavement deterioration was less on roadways that were subjected to low volumes of traffic (less than 100 vehicles per day).

CONCLUSIONS

On the basis of observations made during and after construction of the project roadways, it would seem appropriate to conclude the following:

1. Surface deterioration in the form of raveling, loss of fine and coarse aggregates, and cracking can be expected from mixes containing coal.

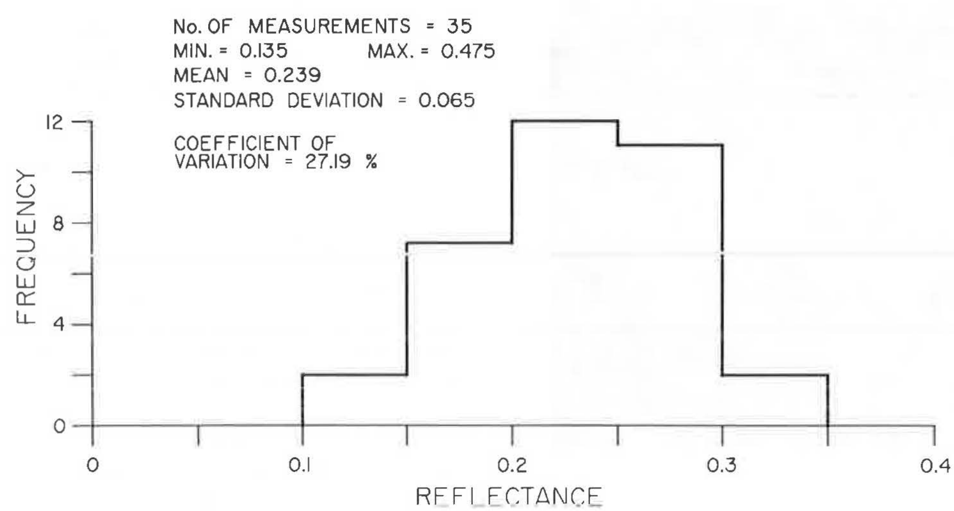

FIGURE 8 Reflectance diagram, coal petrography.

2. The severity of deterioration of the pavement surface depends on the type and amount of coal, and on the volume of traffic.

3. The application of a surface seal coat immediately after paving would aid considerably in preventing deterioration of the pavement surface.

RECOMMENDATIONS

Further research is necessary to determine the amount of coal that would be acceptable in an asphaltic concrete mix without resulting in serious pavement deterioration. This work would also provide some guidelines for the acceptance and rejection of source materials. At the moment it appears that the decision on whether or not to use a coal-contaminated source is subjective or based on the results of the Marshall Immersion Test. Although the Marshall test can give some indication of the presence of deleterious material, this test does not provide information on the likely performance of the pavement structure due to weathering. Freeze-thaw and some form of abrasion testing would seem to be warranted for judging long-term performance.

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